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Programme Area: Marine

Project: Tidal Modelling

Title: The CSM Functional Summary & Testing Report

Abstract:

This document describes the development of the Coarse and Detailed Continental Shelf Models. It explains the design methodology, the various model outputs and discusses the results of the models calibration and validation.

Context:

Launched in October 2011 this project involved Black & Veatch, in collaboration with HR Wallingford and the University of Edinburgh to develop a model of the UK Continental Shelf and North European Waters, 100 times more accurate than existing marine data. This has been used to assess the tidal energy potential around the UK (tidal range and tidal streams), to inform the design of energy harnessing schemes, to assess their interactions, and to evaluate their impact on European coasts. It can also be used to renew and inform flood defences, coastal erosion and aggregate extraction. Now completed, the project has been launched to market under the brand of SMARTtide. This is available to the marine industry under licence from HR Wallingford.

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Energy Technologies Institute

MA1009

Tidal Modelling
(Modelling Tidal Resource Interactions around the UK)

PM02.06 B
Technical Documentation for the UK Continental Shelf Model

Part B – The CSM Functional Summary and Testing Report

15th June 2012

Version 2.0

Participant Lead – HR Wallingford
Other Participants – Black & Veatch and The University of Edinburgh

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1 EXECUTIVE SUMMARY

The *Energy Technologies Institute* (ETI) is developing a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes, to understand the interaction between different tidal range and tidal stream energy schemes, and to evaluate their impact on European coasts. *Black & Veatch* (B&V), in collaboration with *HR Wallingford* (HRW) and the *University of Edinburgh* (UoE), is providing support with regard to the development of this model and subsequent use by the tidal power industry. This report has been led by HRW and is part of the *Tidal Resource Modelling* (TRM) scope of work delivered by B&V as prime contractor.

B&V has been consulting on tidal energy since 1975 (B&V was previously Binnie & Partners in the UK until 1995). B&V has a very broad and in-depth experience of both tidal range and tidal current projects, including resource assessment and project development, technology development, due diligence, cost of energy and policy development. Through working on these projects, it has gained a deep technical and commercial understanding of tidal energy projects in addition to simply resource assessment.

HRW has vast experience of numerical modelling of free surface flows using the TELEMAC system and has been instrumental in its continued development. The TELEMAC system is a state-of-the-art free surface flow suite of solvers developed by a kernel of European organisations including HRW and other partners such as *Electricité de France* (EDF) and the Federal Waterways Engineering and Research Institute of Germany (information related to the TELEMAC system is provided in a separate document, see Section 3). HRW's expertise is acknowledged within the UK tidal modelling community as the only entity with an in-depth experience of TELEMAC and its tailoring to specific problems.

The UoE is one of the largest and most successful universities in the UK with an international reputation as a centre of academic and research excellence. The *Institute for Energy Systems* (IES) is one of five multi-disciplinary research groupings within the School of Engineering at the University. In the most recent UK-wide *Research Assessment Exercise* (RAE 2008), the School was ranked third in the UK for combined research quality and quantity.

The aim of the TRM scope of work is to address the following fundamental questions:

- How will the impacts of tidal range and tidal current energy schemes positioned around the UK combine to form an overall effect?
- Will the extraction of tidal energy resources in one area affect the tidal energy resources at distant sites around the UK and Europe?
- What constraints might these interactions place on the design, development and location of future systems?

This is achieved through a series of work packages and, ultimately, 10 deliverables outlined below.

D01 – Tidal resource characterisation
D02 – Continental Shelf Model (CSM) requirements specification document
D03 – Scenarios modelling
D04 – Cost of Energy Model and supporting documentation
D05 – Interface specification for detailed tidal current model with CSM
D06 – CSM (coarse and detailed versions) with supporting documentation
D07 – Interactions (analysis and conclusions report)
D08 – Interface specification for detailed tidal range model and the CSM
D09 – Tidal Range model and supporting documentation

D10 – Project dissemination

This report forms part of the D06 deliverables; specifically Part B. D06 is comprised of 3 parts:

- Part A – The TELEMAC system: Installation Guide,
- Part B – The CSM Functional and Testing Report,
- Part C – The CSM Web User Interface: User Guide.

As such this report contains information about the development and testing of the *coarse*- and *detailed*-resolution versions of the *Continental Shelf Model* (CCSM and DCSM respectively), which either followed or improved the approach and specifications established in deliverable D02 (document PM01.02 – CSM Requirements Specification). In particular for the setup of the CSM (Section 3.1):

- The open source, industry driven TELEMAC system, and more specifically its two dimensional module, TELEMAC-2D, forms the underlying methodology of both the CCSM and the DCSM.

- The geographical coverage of the CSM extends offshore slightly beyond the Northern European Continental Shelf and includes the coastlines of the United Kingdom, Ireland, the Channel Islands, France, Belgium, the Netherlands, Germany, Denmark, Sweden and Norway. It includes, amongst others, the Malin Sea, Irish Sea, Celtic Sea, English Channel and the North Sea, but does not include the Baltic Sea.

- Significant effort was invested by *SeaZone, a fully owned subsidiary of HRW* (SeaZone of HRW), in the pre-processing of the digitised bathymetric charts to ensure consistency across all regions as many of the charts overlap. In addition to the anticipated charts, detailed local charts were sourced to increase resolution in areas of interest, such as Liverpool Bay and the Thames Estuary. SeaZone maintains bi-lateral agreements with many hydrographic offices worldwide (including those covering the Northern European waters) with the right to use and distribute charted products.

- Significant effort was invested by HRW in identifying and grouping clusters of small islands together into larger land masses. While it was initially planned that individual islands smaller than the resolution of the CSM would not be represented in the model, it was later deemed preferable to consider them as clusters for a better representation.

- It was initially proposed that the minimum resolution of the CSM be of 1 km around key areas, with a growth ratio of 10% from there, out to open water. Instead, a resolution of 1 km was employed at all the coastlines, with a growth ratio of 8%. This more than triples the total number of computational points, making the CCSM more accurate. Despite this refinement, the CCSM computes a 15-day period within 3 hours on a standard multi-core desktop computer, below the 4 hour target. If used in parallel on one 12-core workstation, the CCSM only takes 15 minutes for the same predicted period.

- Similarly, although it was initially proposed that the minimum resolution of the DCSM be of 200 m around key areas, with a growth ratio of 10%, a resolution of 200 m was eventually retained for all the coastlines, with a growth ratio of 8%. While this makes the DCSM more accurate than anticipated, the total number of computational points remains well below the targeted maximum of 5 million, with just over 1.6 million points. Therefore, the DCSM computes a 15-day period within 15 hours on one 12-core workstation and in less than 2 hours on one 8-blade 12-core high performance computer. It is noted that these times do not include pre- and post-processing of data and transfer of files to and from the targeted computers.

- The unstructured mesh used by TELEMAC-2D was fitted to predefined internal lines and refined locally to facilitate the inclusion of *Sites of Interest* (SoI), or the geographical locations of anticipated tidal range and tidal current energy schemes. The CSM is, however, capable of modelling unforeseen energy schemes as long as the user provides the appropriate input tidal energy scheme parameters and geographical locations. While the SoI will be more accurately represented, other site locations will be automatically mapped to the nearest series of edges in the unstructured mesh, a process that only depends on the local mesh resolution.

- The open water boundaries of the CSM are driven by imposed water levels combined with a relaxation algorithm that allows internal waves to leave the domain with little or no reflection. Time histories of water levels were synthesised at every computational point directly from TELEMAC, based on the 13 constituents available from the Northern European TPXO dataset (8 primary, 2 long-period and 3 non-linear constituents), which is itself derived from harmonic analyses of TOPEX/POSEIDON satellite remote sensing measurements.

The CSM was first calibrated, then validated and verified. Calibration of the CSM is detailed in Section 4.1. Validation and verification of the CSM is reported in Section 4.2. The main conclusions are:

- Following the specifications laid out in D02, calibration was carried out over a complete 15-day tidal cycle: March 1st to March 16th 2010. This 15-day period features above average spring conditions and below average neap conditions, to ensure that the CSM performs well for the entire range of expected tidal conditions.

- Considerable effort was invested by HRW in identifying, obtaining and analysing suitable data from various organisations, metocean and hydrographic offices for the CSM calibration and validation. Observed data were obtained for approximately one hundred in-situ tidal gauges. The calibration and validation exercise was performed against 35 tidal gauges or pressure recorders (24 data points for calibration and 11 for validation), both coastal and offshore, located throughout Northern European waters and in particular near the sites of interest highlighted in D03 – Scenarios modelling. This is significantly more data points than in the initially proposed methodology (20 gauges), and increases confidence in the CSM for predictions - if it can be shown that the CSM performs well.

- It is noted that some of the observed datasets were not concurrent with the calibration / validation period. This required that the time histories of site-specific observed data be analysed to extract the tidal constituents and reconstruct the signal for the period from March 1st to March 16th 2010. This analysis was performed using the T_TIDE software introduced in Section 4.1.2.2.

- Calibration was achieved by tuning the CSM bottom friction parameter at a global level. A number of different approaches were followed to determine the most appropriate bottom friction for both versions of the CSM (Section 4.1.3). Several maps of friction values varying with depths, and eventually varying with depths and geographical locations, were investigated. This resulted in a significant improvement over the methodology initially proposed in D02 (use of constant friction maps).

- Performance of the CSM was then principally assessed against a stringent criterion, whereby it was expected that the N-RMSE values (see glossary for definition) at all the calibration sites globally fall within 10% of observed tidal levels. Overall, the performance of the CCSM is very good, demonstrating favourable agreement with observations in the St George’s Channel, Bristol Channel, Irish Sea and North Channel area (N-RMSE values generally well below the target of 10%). The agreement is also strong around the Orkney and Shetland Islands although the calibration locations are not directly located in areas of significant tidal energy potential (due to lack of data). The CCSM compares very favourably with observations in the English Channel and around the Channel Islands, with a weaker agreement at Bournemouth near the amphidromic point. On the eastern coast of England, however, the CCSM predictions are consistently c.45 minutes early compared to coastal tidal gauge data. Even then, the tidal amplitudes are also in good agreement featuring N-RMSE values well below 10%.

It is clear that the CCSM represents well the spatial variations in both the shape and amplitude of the tide from locations close to amphidromic points to locations with markedly high tidal ranges (e.g. the Severn estuary and the Mont St-Michel Bay). This is important to sites where either tidal current or tidal range energy schemes are envisaged. In most cases, the discrepancies observed with measurements can largely be explained by a slight difference in the time of arrival of the tide, which is generally unimportant. The difference is, however, c.45 minutes on the East Coast for reasons so far unclear. It is noted that, given the regional consistency of this difference on the East coast, the use of the CCSM for the study of the SoI is not deemed compromised.

- The overall conclusions regarding the performance of the DCSM in the calibration exercise are similar to those drawn for the CCSM. The CCSM and DCSM have comparable performances, that is to say that the two versions of the CSM can be regarded as identical to within 1-2% (in terms of N-RMSE output) for all intents and purposes (Appendix D). No one version stands out as being superior to the other for tidal level predictions, although the DCSM obviously provides far superior resolution everywhere, which is most apparent on current velocity maps. It is noted that, overall, the predicted tidal ranges are higher with the DCSM than with the CCSM. Such differences were not unexpected.

- The data used to validate the CSM comprised observed offshore tidal gauge and bottom pressure data. Comparison against these independent data sets confirmed the suitability of the CSM in high energy key areas. As was noted during the calibration exercise, the CCSM and the DCSM have similar levels of performance, with the DCSM, generally, only marginally more accurate than the CCSM in terms of RMSE output (the principal measure chosen to evaluate performance). This gives confidence in the resolution selected for the models. Therefore, both versions of the CSM can be expected to give similar predictions for future scenarios. It is generally recommended that the CCSM be used for high level tidal range and broad tidal current investigations, and the DCSM for tidal current schemes, as the greater resolution predicts tidal currents (and spatial variability thereof) more accurately, and detailed site investigations into tidal range schemes, as more detailed bathymetry can be incorporated in the model.

- The data used to verify the CSM comprised velocity data and atlases of tidal range and peak current speed. Although the agreement of the CCSM with velocity data is mixed (principally because of its coarse resolution), the DCSM velocity predictions compare very favourably with measurements. Verification against the MAFF Atlas (1981) was successful with the amphidromic points (e.g. off Wexford) and the areas of high tidal range (e.g. Morecambe Bay) are reproduced very well in both versions of the CSM. Verification against peak current atlases was also favourable for known energetic areas identified in the models. It is noted that the finer resolution of the CSM (compared to that used in the UK Marine Renewable Energy Resources Atlas, 2007) allows a far better discretisation of the velocity field in key areas.

A sensitivity analysis was subsequently performed in an effort to assess the response of the CSM to tuneable parameters such as bottom friction, turbulence and numerical parameters to name a few. The results of this analysis are presented in Section 4.3. The main conclusions are:

- Based on HRW's extensive project experience with hydrodynamic models, the parameter with the most impact on model results is the bathymetry.

- The bottom friction parameter is also demonstrated here to have a major effect on the CSM predictions. Although it has been shown that the formulation employed is not of particular importance (the CSM could be satisfactorily calibrated with a Chézy law or a Nikuradse roughness length law indifferently), the selection of the bottom friction parameter has a significant effect on the model results (water levels and current speeds), and hence performance against observations. This makes it a parameter of choice to calibrate hydrodynamic models. In general terms, the highest impact in terms of levels is observed in the English Channel, in the Severn Estuary, and in the Irish Sea east of the Isle of Man.

- In general terms, the numerical scheme ("free surface gradient compatibility criteria" tested), turbulence model employed (constant viscosity, Elder or Smagorinski models), discharge rate applied in the Thames and/or the Baltic Sea, and tidal force (calculating the astronomical terms required in the tidal forcing terms) all have a limited impact on the CSM water level and velocity predictions. It is noted that turbulence has a noticeable effect on the predicted current speeds in some specific areas. In the absence of observed velocity data in many sites of interest to calibrate the CSM against, it is difficult to discard (or favour) one turbulence formulation over the other.

- It is noted that the time step selected in the CSM is appropriate for the model resolution and the predicted current / tidal wave speeds (physical speeds). It is well below the performance criteria routinely used in the TELEMAC system.

- The good level of agreement between the CCSM and the DCSM (obtained with very different model resolutions) is demonstrative of grid insensitivity, although the DCSM results will be more resolved for both tidal current and tidal range schemes.

Overall, it is considered that the Continental Shelf Model of the UK waters developed in this study is robust and will fulfil the objectives set by the ETI, which aim to answer the following questions:

1. How will the interactions between tidal range and tidal stream systems positioned around the UK's waters combine to form an overall effect?
2. Will the extraction of tidal energy resource in one site impact the tidal energy resource at distant sites around the UK and Europe?
3. What constraints might these interactions place on the design, development and location of future systems?

It is noted that the D08 and D09 scope of work is to provide a *Detailed Tidal Range Model* (DTRM). The correlation of the DTRM with the CSM is dependent on the final extent of the DTRM selected during scoping of D08. The extent of the DTRM is dependent upon the end use of the model. For simple technology checks, a small extent out to the mouth of an estuary would be sufficient to provide a tool for looking at technology behaviour, where tidal behaviour within the estuary did not have to be representative. For site specific consideration and optimisation of a location, the DTRM should be as large as possible to consider the water movements entering the sea, channel and finally the estuary in question as well as to consider the regional / international extent of the impact of the tidal energy schemes tested. In the latter case, the deciding factor with regard to the extent of the DTRM will be the available computing capacity for users. The larger the DTRM the closer the alignment to / duplication with the DCSM. In addition, should a range of estuaries be , ideally, looked at in detail by the user it may be most sensible to refine the DCSM in these estuaries rather than limiting the user to a single estuary in the DTRM. During Project Review meeting 1, it was planned that discussions with principal interested parties (Rolls Royce in particular) would be organised to define the requirements of the primary users of the DTRM. This could potentially lead to a change in scope for D08 and D09 and an associated variation request.

2 INTRODUCTION

2.1 Background

The *Energy Technologies Institute* (ETI) is developing a *Continental Shelf Model* (CSM) of the UK waters to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes, to understand the interaction between different tidal range and tidal stream energy schemes, and to evaluate their impact on European coasts. *Black & Veatch* (B&V), in collaboration with *HR Wallingford* (HRW) and the *University of Edinburgh* (UoE), is providing support with regard to the development of this model and subsequent use by the tidal power industry. This report has been led by HRW and is part of the *Tidal Resource Modelling* (TRM) scope of work delivered by B&V as prime contractor.

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D07 – Interactions (analysis and conclusions report)

D08 – Interface specification for detailed tidal range model and the CSM
D09 – Tidal Range model and supporting documentation
D10 – Project dissemination

This report is the second of three accompanying reports for D06:

- D06 Part A – The TELEMAC system, is primarily intended for users of the TELEMAC system beyond those using solely the CSM, and presents a comprehensive source of references with respect to TELEMAC-2D. It includes the information required by an experienced modeller to get acquainted with the TELEMAC-2D solver, in particular a general description of the solver and instructions to download, install and run the available test cases.

- D06 Part B – Functional Summary and Testing Report, focuses on the development of the CSM (both the coarse and detailed versions).

- D06 Part C – The Web User Interface, is primarily intended for users of the CSM, and introduces the CSM access via the web user interface. It also briefly touches on the energy scenario parameterisations - for the implementation of one or multiple tidal range or tidal current scenarios, together or individually, in either the coarse or detailed resolution of the CSM.

2.2 Modelling stages' terminology

In accordance with D02, the development of the CSM was carried out in several stages, as described in this document and summarised below:

- The CSM setup (Section 3.1). This stage includes the definition of the CSM methodology, the model extent and resolution, as well as supporting datasets such as bathymetric charts and boundary conditions.

- The CSM calibration (Section 4.1). This stage is characterised by the tuning of model parameters (such as friction), to optimise the model agreement against a set of observations, covering an appropriate period. Performance of the CSM during the calibration stage was measured against a set of coastal tidal gauge data.

- The CSM validation (Section 4.2.1). This stage evaluates model performance, by comparing the model results obtained with the calibrated parameters against an independent set of observations, covering an appropriate period. Performance of the CSM during the validation stage was measured against a set of offshore tidal gauge and bottom pressure data.

- The CSM verification (Sections 4.2.2 to 4.2.6). This stage assesses model performance against an additional set of observations, including quantitative and qualitative information such as atlases, known model results and spot velocity measurements.

- The CSM sensitivity testing (Section 4.3). This stage quantifies the sensitivity of the model results to some of the numerical and physical parameters defining it.

3 PROJECT DESIGN/METHODOLOGY

3.1 Summary of the CSM specifications

A CSM of the UK waters was developed in this study, with the principal aims of assessing the tidal energy potential around the UK, informing the design of energy harnessing schemes, understanding the interaction between different tidal range and tidal stream energy schemes, and evaluating their impact on Northern European coasts.

This section summarises the approach followed and confirms that all elements of the requirements previously established and reviewed in D02 have been delivered or exceeded.

3.1.1 Underlying CSM methodology

In accordance with D02, the open source, industry driven TELEMAC system, and more specifically its two dimensional hydrodynamics module, TELEMAC-2D, forms the underlying methodology of the CSM.

Sections 3.2 and 3.3 of D02 present a short overview of the TELEMAC system and TELEMAC-2D. They also provide pertinent details in the context of the CSM, in particular:

- How the unstructured mesh of triangles can be fitted to follow natural lines (e.g. coastlines and islands) and artificial lines (e.g. future barriers and tidal energy schemes) alike;

- How the forces and the sink and source terms in its mathematical formulation can be adapted to represent both tidal range and tidal current energy schemes.

3.1.2 Additional information about the TELEMAC system

The TELEMAC system is a state-of-the-art free surface flow suite of solvers developed by a kernel of European organisations including Electricité de France and HR Wallingford but also other partners such as the Federal Waterways Engineering and Research Institute of Germany, the French consultant ARTELIA and the Science and Technical Facility Council, Daresbury Laboratories, in the UK.

For completeness, a document referenced D06 Part A has been compiled by HRW to provide a comprehensive source of references for TELEMAC-2D. This document is intended as general guidance for users of the TELEMAC system and, as such, contains the following:

- Information required by an experienced modeller to get acquainted with the TELEMAC-2D solver, in particular a general description of the solver and instructions to download, install and run the available test cases;

- Appendices that include copies of the TELEMAC-2D user manual, validation document and other theoretical, scientific and technical documentation, which can also be found on the TELEMAC official website hosted by HRW: http://www.opentelemac.org/.

It should be emphasised that users of the CSM are not required to be familiar with TELEMAC. A separate document referenced D06 Part C has also been compiled by HRW, as part of the deliverables for D06, focusing on the use of and remote access to either versions of the CSM.

3.1.3 Geographical coverage of the CSM

As demonstrated in Sections 3.1.1 and 3.1.2 of D02, the CSM requirements specification, a Continental Shelf Model of the UK waters cannot be confined to the immediate vicinity of the sites under investigation to cater for long-range impacts and interactions between energy schemes, but must extend further to include the coastlines of neighbouring countries.

In keeping with D02, the geographical coverage of the CSM is, therefore, such that it extends slightly beyond the Northern European Continental Shelf and includes the coastlines of the United Kingdom, Ireland, the Channel Islands, France, Belgium, the Netherlands, Germany, Denmark, Sweden and Norway, as indicated in Figure 1 at the end of this document. It includes, amongst others, the Malin Sea, Irish Sea, Celtic Sea, English Channel and the North Sea.

The CSM extent is illustrated in Figure 1 (thick purple line) superimposed on an impression of the bathymetry and country boundaries derived from the *General Bathymetric Chart of the Oceans* (GEBCO) database. It is noted that GEBCO data were used for visualisation purposes. In this figure the land above mean sea level is indicated in grey.

In accordance with the specifications laid out in D02:

- The Baltic Sea is not included in the CSM. The tidal range there is very limited and the peak current velocities of a mean spring tide, through the Kattegat east of Denmark, for example, are weak (Carlsson, 1997), and hence have only a very limited impact on the Northern European Continental Shelf physics.

- The offshore boundary, identified in red in Figure 1, principally follows the 300 m depth contour between France and Norway, around Ireland and the UK, along the Northern European Continental Shelf, except at the Norwegian Trench where the CSM offshore boundary cuts across this deep channel[1]. In France (north-western coast) and Norway (western coast) the boundary follows the steepest slope up to the coastline.

- The CSM coastline consists of the coastlines of the United Kingdom, Ireland, France (from Concarneau to Dunkerque), Belgium, the Netherlands, Germany, Denmark (to Aalborg), Sweden (across the Kattegat, from Goteborg) and Norway (to Måløy); it was developed from *Mean High Water Spring* (MHWS) contours extracted from the navigation charts by SeaZone of HRW. It is noted that the interpretation of the MHWS contours is dependent on the resolution of the model and is consequently different in both versions of the CSM.

The CSM was developed in a bespoke spherical coordinate system due to its large extent, true to distances in metres. All the CSM outputs (e.g. tabulated values, plots) are, however, displayed in the latitude-longitude geographic coordinate system, WGS84, to be compatible with the methodologies adopted by other organisations such as The Crown Estate. As stated in D02, the directions are quoted with respect to True North, the vertical reference datum used in this study is *Mean Sea Level* (MSL), and all times are relative to *Coordinated Universal Time* (UTC).

3.1.4 Discretisation(s) of the CSM

In accordance with the specifications laid out in D02, coarse- and detailed-resolution versions of the CSM were developed in this project. The aim of the CCSM is to provide predictions within a relatively short period on a standard desktop computer; the aim of the DCSM is to provide more detailed predictions at the expense of computational time and/or access to a high performance cluster of computers to deliver results within a similar relatively short period.

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[1] The suitability of the positioning of the offshore boundary close to the shelf edge will be assessed during the work package for D07 (the scenario testing phase). If it is shown, then, that the impact of some of the larger tidal energy extraction schemes can reach the CSM offshore boundary, extension of the model and relocation of the offshore boundary will be considered, although the type of boundary setting applied here (see Section 3.1.6) should prevent any reflections from entering the model area.

3.1.4.1 Resolution of the CSM

As detailed in Section 3.1.3 of D02, the resolution of a model is defined herein as the distance between two computational points. This distance typically varies across the model's geographical coverage. In simplistic terms, the finer the resolution, the smaller the distance between computational points, the higher the number of computational points overall, and the longer it takes to complete a prediction. Following preliminary testing, the resolution of both the CCSM and the DCSM was refined beyond that of the specifications laid out in D02 to allow a better representation of the tidal flows than first anticipated, and therefore of the interactions between tidal energy schemes:

- It was initially proposed that the minimum resolution of the CSM be of 1 km around key areas, with a growth ratio of 10% from there, out to open water. Instead, a resolution of 1 km was employed at all the coastlines, with a growth ratio of 8%. This more than triples the anticipated total number of computational points, making the CCSM more accurate. Despite this additional refinement, the CCSM computes a 15-day period within 3 hours on a standard desktop computer, below the 4 hour target. If used in parallel on one 12-core workstation, the CCSM only takes 15 minutes for the same predicted period.

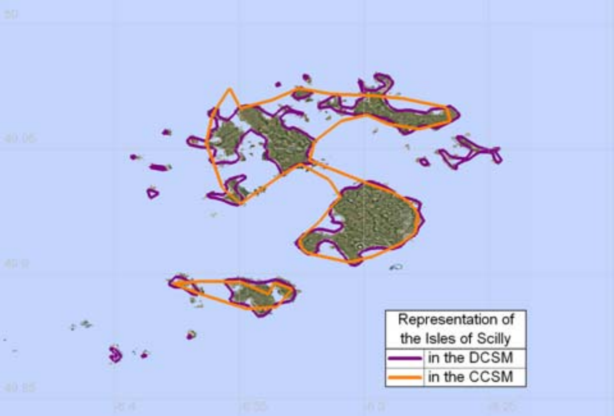
- Similarly, although it was initially proposed that the minimum resolution of the DCSM be of 200 m around key areas, with a growth ratio of 10%, a resolution of 200 m was retained for all the coastlines, with a growth ratio is 8%. While this makes the DCSM more accurate than anticipated, the total number of computational points remains well below the targeted maximum of 5 million, with just over 1.6 million points. Therefore, the DCSM computes a 15-day period within 15 hours on one 12-core workstation and in less than 2 hours on one 8-blade 12-core high performance computer. It is noted that these times do not include pre- and post-processing of data and transfer of files to and from the remote computer.

It should be noted that, while the resolution of the DCSM will yield more detailed predictions than that of the CCSM, its purpose, like the CCSM, is primarily to provide preliminary impact assessment results for the entire Northern European Continental Shelf. It should not be used in place of a refined local model when considering resources / impacts in specific areas.

3.1.4.2 Exclusions from the CSM

As explained in Section 3.1.2 of D02, the level of detail with which the coastlines and islands are represented in the CSM depends largely on the local resolution. For instance, the interpretation of the MHWS contours in the CSM is dependent on the resolution of the model and is consequently different in both versions of the CSM. As such, details of complex coastlines have been smoothed out by the resolution of the CSM. This is particularly relevant to the numerous fjords in Norway and the detached coastline of The Netherlands and is particularly true of the CCSM.

In the case of islands, it was originally proposed that their perimeter be at least 5 times the local resolution of the CSM for them to be explicitly included in the coastline. In the development of both the CCSM and the DCSM, this criterion was only applied to remote islands far from other islands and from the mainland; a new strategy was put in place for the remainder whereby a cluster of small islands, or a small island close to the mainland, would be contoured up as a bigger landmass.



Examples of the resolution threshold for islands include some of the smaller islands in the cluster of the Isles of Scilly, the islands between Ile d'Ouessant and Ile de Molène off the coast of Brittany, or islands along the rugged coastline of Norway to name a few.

In the example illustrated opposite, the Isles of Scilly are individually contoured in the DCSM (purple contours) but are clustered, to some extent, in the CCSM (orange contours). It is noted that these clusters confirm the resolution threshold defined for passages and reiterated below.

In a similar way to islands, and in accordance with the specifications laid out in D02, a resolution threshold was defined for passages between islands, or between islands and the mainland, and for estuaries, inlets, channels and bays. A passage or a channel is characterised by an opening of more than 2 times the local resolution of the CSM.

For example, the CCSM does not include the Solent between the Isle of Wight and mainland England, the Sound of Islay, located between the Isles of Islay and Jura in Scotland, or the Mersey Estuary[2]. Each of these locations: the Solent, the Sound of Islay, the Mersey Estuary, are all fully incorporated in the DCSM as the model resolution is suitable to do so. Both models include the Churchill Barriers, although the DCSM provides higher resolution.

3.1.4.3 *CSM flexibility in potential Sites of Interest*

In keeping with Section 3.3 of D02, the unstructured mesh used by TELEMAC-2D has been fitted to predefined internal lines and refined locally to facilitate the inclusion of anticipated tidal range and tidal current energy schemes, hereafter referred to as *Sites of Interest* (SoI).

The CSM resolution is at its finest within the following tidal current site areas:

- Around the Orkney Islands: north of the North Ronaldsay Firth and the North Ronaldsay Firth itself, the Westray Firth and the deeps and shallows of the Pentland Firth;
- Within the North Channel: west and south of Islay and the Mull of Oa, Rathlin Island, the Mull of Kintyre and the Mull of Galloway;
- In the Irish Sea: west of Carmel Head and west of Ramsey Island;
- In the Bristol Channel: Minehead;
- On the south coast of England: south of the Isle of Wight;
- Around Alderney: east and west of Casquets and the Race of Alderney;

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[2] It is noted that a feature of the CSM is the ability for the user to define tidal range schemes using a parameterisation of the scheme if the resolution of the CSM is not sufficient to represent the impoundment explicitly. In that case, the tidal range scheme is modelled using a 0-d model. This methodology could be applied to model a Mersey Estuary barrage in the CCSM.

- Around Jersey: north-east and south of Jersey and south of Minquiers.

The CSM resolution is at its finest around the following tidal range barrier sites:

- In the Irish Sea: Wigtown Bay, the outer and inner the Solway Firth, the Cumbria Lagoon south of St Bees, the Duddon Estuary, Morecambe Bay, the Dee Estuary and around the Wirral and the Mersey Estuaries;
- In the Bristol Channel: Oxwich Bay, Morte Bay, the outer and inner Severn Estuary, the Cardiff-Weston alignment, Bridgewater Bay, south of Rhoose and south-west of Aberthaw;
- Around Dover: Dymchurch Bay and Rye Bay;
- In the Thames Estuary, the inner and outer Thames Estuary;
- On the east coast of England: the Wash and the inner and outer Humber Estuary.

It should be emphasised, however, that the CSM has been developed to model any energy scheme as long as the user provides the appropriate input parameters and geographical locations. While the SoI would be more accurately represented, energy schemes at other site locations will be automatically mapped to the nearest series of edges in the unstructured mesh, a process that only depends on the local mesh resolution. Input parameter requirements and a description of how to access the CSM through its Internet interface are described in a separate document D06C.

3.1.5 Seabed map in the CSM

In accordance with the specifications laid out in Section 3.1.4 of D02, the CSM seabed maps were developed from digitised versions of Level 1 and Level 2 navigation charts, complemented by Level 3 charts as appropriate. It was also deemed necessary to use some Level 4 charts to complete the original set and provide further details in key areas of interest, such as in the Mersey Estuary, the Thames Estuary and some of the estuaries in The Netherlands.

The extents of the various charts, or tiles, are identified as black polylines in Figure 1 (at the end of this document). The references are listed below. The bathymetry data for these tiles were all obtained from SeaZone of HRW. SeaZone was granted the right to re-distribute these tiles, at a cost, under agreements reached with the relevant national hydrographic institutions.

- UK and Ireland:
  GB100001; GB100002; GB100004; GB100005; GB100006; GB100007; GB100008; GB100010; GB100011; GB100012; GB100013; GB100014; GB100016; GB104011; GB104102;
  GB201600; GB201800; GB202000; GB202200; GB202400; GB202600; GB202800; GB202900; GB203000; GB203200; GB203400; GB203500; GB203600; GB203700; GB203800; GB204000; GB204400; GB204600; GB204800; GB205000; GB205200; GB205600; GB205800; GB206000; GB206100; GB206200; GB206300; GB206400; GB206500; GB206600; GB206800; GB207000; GB207200; GB207400; GB207600; GB207800; GB208000; GB208200; GB208400; GB208600;
  GB301149; GB301152; GB301156; GB301164; GB301178; GB301478; GB301620; GB308620;
  GB40284C; GB40344A; GB40344B; GB40344E; GB40484B; GB40484C; GB40484H; GB40584A; GB40584B; GB40584C; GB40826D; GB40863A; GB40864A; GB40864B;
  GB501834; GB50284J; GB50284K; GB50826E

- France:
  FR166230; FR200010; FR301010; FR301040; FR366800; FR368240; FR368570; FR369300; FR369400; FR369410; FR369660; FR370660; FR401050; FR401080

- Belgium:
  BE3VLBNK; BE5ANTWN; BE5ANTWZ; BE5KGETE

- Holland:

NL21037P; NL301505; NL301507; NL301630; NL302593; NL32322P; NL400116; NL400120; NL40121E; NL40121W; NL50120D; NL50132B; NL50133A; NL50133B; NL50133C; NL5120FH

- Germany:
  DE110000; DE221000; DE321002

- Denmark:
  DK1NORSO; DK2BORNH; DK2FEMON; DK2KATGN; DK2KATGS; DK2LILBL; DK2NORSO; DK2SKARK; DK2STOBL; DK2SUNDT

- Norway:
  NO2A0404; NO2B0400; NO2B0404; NO2B0408; NO2B0412; NO2B0416; NO2B0420; NO2B0800; NO2B0804; NO2B0808; NO2B0816; NO2B0820; NO2B1200; NO2B1204; NO2B1208; NO2B1212

Significant effort was invested by SeaZone of HRW in the pre-processing of the digitised data from the above sources to ensure consistency across regions, as many of the charts overlap. All data were then reduced to MSL.

In accordance with Section 3.1.4 of D02, a digital elevation model of the seabed throughout the CSM modelled domain was subsequently constructed by combining these data, including both soundings (points), isobaths (contours) and MHWS contours. A thin-plate-spline method (Harder and Desmarais, 1972) was used to generate a realistic seabed surface.

Those users of the CSM who wish to install and run the model themselves on their system (i.e. not through the Fee-For-Service arrangement) would be supplied this processed seabed map, provided the licenses for the underlying source bathymetry (references given above) were in place with SeaZone.

3.1.6 Tidal forcing at the CSM open boundary

In keeping with the specifications laid out in Section 3.1.7 of D02, the open water boundaries of the CSM were forced boundaries (identified as red lines in the figures, example: Figure 1, at the end of this document, includes the Baltic Sea boundary). Along these boundaries, spatially varying time histories of water levels were specified, combined with a Thompson boundary setting (Thompson, 1987; and Hervouet, 2007 and 2011) to allow waves to leave the domain with little or no reflection. The time histories were derived from tidal synthesis based on the 13 constituents (M2, S2, N2, K2, K1, O1, P1, Q1, Mf, Mm, M4, MS4, MN4) available from the Northern European TPXO dataset and derived from harmonic analyses of TOPEX/POSEIDON satellite remote sensing measurements (OSU, 2008 and Egbert, 2010).

For the purpose of model calibration and verification, time histories covering the period between March 1st and March 16th 2010 were synthesised (see Section 4.1.1).

It is noted that the TPXO dataset can be interrogated directly within the TELEMAC system, making use of the Fortran code available from http://volkov.oce.orst.edu/tides/otps.html, yielding a seamless definition of the boundary conditions.

An extra term (a numerical filter on the water level values) was also introduced along a relatively small stretch of offshore boundary next to the French coast, off the Shetland Islands, and in the Baltic Sea, which limits local instabilities.

3.1.7 Initial conditions and spin-up period

The Northern European TPXO dataset (OSU, 2008, Egbert, 2010 and D02) was also used to determine suitable initial conditions everywhere in the model area, therefore minimising initial transients. In addition, a 2-day spin-up period was applied to all simulations.

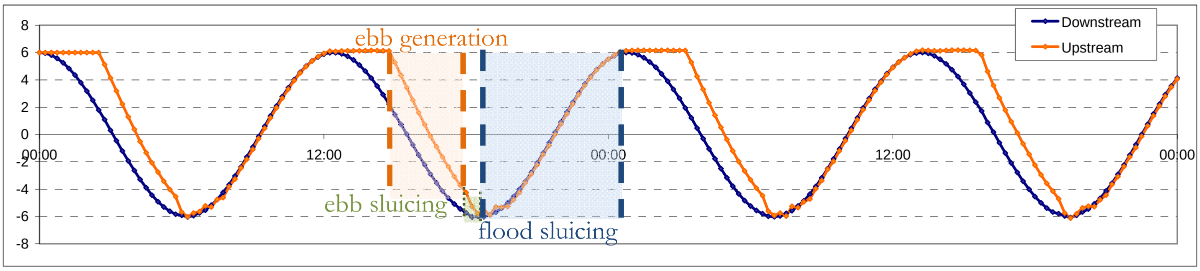
3.1.8 Representation of La Rance tidal power plant

As agreed in D02, the base case configuration of the CSM represents the existing environment and, therefore, includes the La Rance tidal power plant.

In the absence of detailed information, it was assumed that conventional turbines can represent the scheme, for an ebb-only generation (as is the dominant case for La Rance). The following parameters, developed by B&V, were implemented in the CSM for the La Rance tidal power plant. This parameterisation was used as an example application from which the code specific to the CSM was developed in TELEMAC-2D in preparation of the work to be carried out in WP6. As such, final fine-tuning of the operational rules between devices and modes of the La Rance scheme will be the object of WP6.

Site: La Rance – Mode: Ebb									
Tstart	5			F1	-0.5387				
Nsluice	6			F2	0.2685				
A1sluice	150			F3	0.4552				
A0sluice	274	B1	8.8009	F4	-0.0306				
CWsluice	19	B2	114.6330						
αebb	1.6	B3	-21.3395	L1	-7.36	H1	3.50		
αflood	1.6	B4	1.8536	L2	-5.89	H2	4.25		
Nturbine	24			L3	-4.42	H3	5.00		
D	5.35	C1	338.4373	L4	-3.68	H4	5.25		
A0turbine	80.6	C2	-61.2289	L5	-2.94	H5	4.50		
CWturbine	13.9	C3	14.0552	L6	-1.47	H6	2.75		
βebb	1.62	C4	-1.0082	L7	1.47	H7	2.75		
βflood	1.62			L8	2.94	H8	4.50		
Hrated	5.65	E1	944.0334	L9	3.68	H9	5.25		
Pmax	10	E2	-205.0735	L10	4.42	H10	5.00		
Hmin	1.20	E3	17.6662	L11	5.89	H11	4.25		
Hint	4.33	E4	-0.5285	L12	7.36	H12	3.50		

Tests were carried out in a numerical flume prior to a prototype implementation in the DCSM (the CCSM being too coarse at this location). The following figure depicts the water levels upstream and downstream of the structure predicted by the model and highlights the generation time for an arbitrary tide of similar amplitude to that observed near La Rance, France.



3.2 Confidence in the CSM performance

3.2.1 Data set selection for model comparisons

It is essential that calibration and validation be performed on independent data sets, which should be comprised of observed data where possible to enhance the confidence in the model predictions.

Further, they should be selected such that (a) they cover the entire model area (this is particularly relevant here since one of the principal aims of the CSM is to inform the impact of the implementation of tidal energy schemes on neighbouring energy schemes/shorelines); (b) they represent the possible range of expected spatial variations (in tidal amplitude for tidal gauges) throughout the model area; and (c) they are located close to key areas of interest.

The data used to calibrate the CSM comprised observed coastal tidal gauge data. The CSM was then validated against an independent set of offshore data comprising tidal gauges and bottom pressure gauges. It was further verified at discrete locations against available velocity data, and as a whole against recognised atlases of the Northern European waters.

It is noted that the choice of location and data type was deliberate to strengthen the quality / reliability of the CSM calibration / validation exercise. It is important to remember that a global friction map was used in this study (see Section 4.1.3). As such, the calibration / validation is global. Had local adjustments been made to the friction map to reach better agreement with the observed data locally, then verification of the CSM against additional local data would have been necessary to confirm the refinement. Local adjustments were not undertaken here.

3.2.2 Observed data vs. simulated data vs. re-synthesised data

Observed tidal levels are in part the result of atmospheric pressure variations, winds and other events, which cannot be included in the CSM without a complete incorporation of spatially varying atmospheric conditions for the simulated period. Besides, observed tidal levels are not always reliable, particularly where quality checks and controls are not performed on a regular basis.

In order to make the comparison with simulated tidal levels possible, a harmonic analysis is carried out on the observed tidal levels to correct mean sea level variations (due to seasonal weather, storms and surges for example) and to re-synthesise a tidal signal using only known astronomical periods (or tidal constituents). This analysis is highly dependent on the length of the selected period and the quality of the original observed tidal levels, resulting in a different number of harmonic constituents at each site. In particular, tidal harmonic analysis is less reliable near amphidromic points where the amplitude of the tide alone is of the same order as the variations due to atmospheric conditions or surges.

As a result, it is understood that neither the observed tidal levels nor the re-synthesised tidal levels are exact representations of the tidal-alone level variations. Therefore, it is anticipated that comparisons with simulated tidal levels cannot be precise, but that the overall quality of the comparison of the CSM at as many sites as possible distributed over the whole domain will enable users to be confident in the CSM results.

Finally, in semi-diurnal conditions, the M2 and S2 constituents extracted from tidal harmonic analysis can often be used to estimate the average spring range (2×(M2+S2)) and the average neap range (2×|M2-S2|). It should be emphasised that this is only an approximation, which is itself relying on estimates of M2 and S2. The error on M2 and S2 is a function of the period selected to perform the tidal analysis and its duration.

3.2.3 15-day vs. 90-day CSM predictions

Calibration / validation of a hydrodynamic model is best achieved by comparison of the model predictions against observed data for a full tidal cycle (15 days) including spring and neap conditions. In this study, a 15-day cycle representative of above average spring conditions and below average neap conditions (March 1st to March 16th 2010, Section 4.1.1) was considered for the CSM calibration / validation / verification exercise to ensure that the CSM was being validated for the full range of conditions expected to be run in model scenarios and beyond.

Longer periods of 90 days (March 1st to May 30th 2010) were considered for the harmonic analysis of model predictions in an effort to improve the analysis results. As described in D02, the number of harmonic constituents that can sensibly be extracted from a time record, and the reliability of those constituents, largely depends on its length. As a guide, five constituents can be obtained from a one-day record; 15 from 15 days; 26 from 29 days; 54 from 6 months and 60 from one year of data (Vassie, 1986). 90 day simulations were therefore considered more appropriate for the purpose of tidal harmonic analysis than the 15 day strictly sufficient for the purpose of model calibration / validation.

3.2.4 Measure of the CSM performance

Various measures of validation performance are targeted to be met by the CSM, to ensure its accuracy/robustness against a standard recognised by the industry. In particular, the development of the CSM has followed the most stringent of recent guidance from either the *European Marine Energy Centre* (EMEC) on resource assessment, published in 2009 (EMEC, 2009), or the IEC TC114 August 2011 draft technical specification (IEC, 2011). These recommendations largely depend on the resource assessment phase for which the numerical model is developed.

Even at the 'feasibility stage' of projects (which is considered to be beyond the scope of the CSM development), it is noted that there are no clear performance criteria to be met in terms of predicted velocities (IEC, 2011) as it is recognised that there is considerable spatial variability in this type of data, which could result in a significant difference between a spot measurement and a c.1 km cell-averaged prediction. Nonetheless, the EMEC guidance considers a 20% error in peak velocities acceptable at feasibility stage. This criterion is used in this document to assess the model performance where current data are available, bearing in mind that rapid spatial variation in currents are possible.

Similarly, it is noted that there are no clear performance criteria to be met in terms of predicted levels, by either the EMEC guidance or the IEC technical specification. As such, the following points aim at defining the standards against which the CSM will be evaluated in terms of level differences between observed and predicted data, and in the context of the CSM objectives:

- The speed at which the water rises and falls is important to sites where either or both tidal current and tidal range energy schemes are envisaged. Therefore, it is important that the CSM be able to predict accurately the shape of the tidal wave (or asymmetry between flood and ebb). A measure such as the root mean square error, accounting for the differences between observed and predicted water levels at all timestamps, over the entire period considered, is therefore an appropriate performance measure for the CSM.

- The slope in the water surface relates to the currents between two sites and, as such, is important where tidal current energy schemes are envisaged. Therefore, it is important that the CSM be able to predict consistently the arrival time of the tidal wave in the vicinity of tidal current energy schemes. It is also important that the CSM be able to predict accurately the spatial variations in tidal range. An appropriate performance measure for the application of the CSM to tidal current energy schemes is the consistency in predicted vs. observed phase over the region and more locally to the site. Another measure is the comparison of the spatial variations in predicted maximum tidal range against published tidal atlases. Accurate prediction (of the location) of amphidromic points and equally of tidal range amplification are particularly relevant in that context.

- The amplitude of the tide is important to sites where tidal range energy schemes are envisaged. Therefore, it is important that the CSM be able to predict accurately the maximum tidal range. A measure, such as the difference between observed and predicted tidal ranges during high spring cycles, is therefore an appropriate performance measure for the CSM at those sites.

For the reasons detailed above, the performance of the CSM was measured consistently throughout the model domain. Thus, the root mean square error values were computed for each calibration / validation site, and normalised with respect to the maximum tidal range at that site (N-RMSE). *Mean absolute error* (MAE) values were also used as a useful statistic when the tidal range was relatively small, in the vicinity of amphidromic points, for example. While the current IEC technical specifications do not offer a modelling target to be reached, HRW routinely uses a target N-RMSE value of 10% in their studies. In this context, values below 10% are deemed to reflect a good calibration of the model at a particular site. This target was subsequently considered as the standard for the CSM calibration and validation.

Furthermore, spot checks of the error in maximum tidal range for a high spring cycle (more than 4 m) were performed at sites where tidal range energy schemes are envisaged.

Finally, qualitative information, extracted from published atlases, was compared to that obtained from the CSM.

4 RESULTS, PRESENTATION OF THE CSM OUTPUTS

4.1 Calibration of the CSM

The CSM was first calibrated, then validated and verified in order that it can then be exploited more widely to represent the implementation of tidal scheme scenarios (refer to D03 – Scenarios modelling and D07 – Interactions (analysis and conclusions report)). It is important for any tidal model to be able to predict accurately the attenuation or amplification of water level fluctuations throughout the model area and particularly in areas of interest. A good agreement between the observed tidal levels and the simulated tidal levels shows that the dynamics of the tide are well represented in the model.

4.1.1 Period selection

Following the specifications laid out in D02, calibration was carried out over a complete 15-day tidal cycle using observed water level data obtained from a network of coastal tidal gauges. Calibration against a complete 15-day cycle, as opposed to calibration against one tide event alone, enhances the accuracy of the exercise. The selected period was March 1st to March 16th 2010.

This 15-day period features high spring conditions and low neap conditions, to ensure that the CSM performs well for a wide range of tidal conditions. It was also selected in the recent past (March 2010) to maximise the chances of obtaining suitable observed data to calibrate the CSM against.

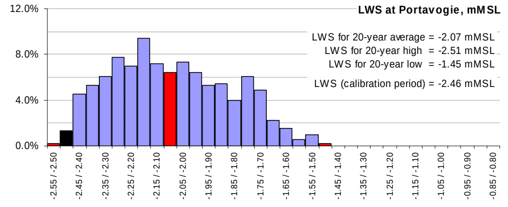
In order to put the selected period in context with respect to average, high and low conditions, synthesised time records published in the C-Map database (MIKE C-MAP, 2009) were obtained for Portavogie, County Down, Northern Ireland, and Portmore, Slievebawn, Ireland, (an energetic area of the CSM) for a 20-year period spanning from 1991 to 2010. These records were analysed to identify the high and low waters and consequently the spring and neap cycles. The method described in Table V of the Admiralty Tide Tables (Admiralty Tide Tables, 2010) was used to compute *High Water Springs* (HWS), *Low Water Springs* (LWS), *High Water Neaps* (HWN) and *Low Water Neaps* (LWN) from the published data, i.e. the height of HWS was computed as the “average of the heights of two successive high waters during the period when the range of the tide is greatest”, and the height of LWS was computed as the “average height obtained by the two successive low waters during the same period”. The same approach was used for the neap tides.

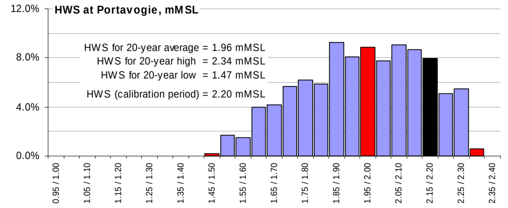
Once all the high and low waters were determined for spring and neap cycles and for the 20-year period, the average / maximum / minimum values were computed, as reported in the table below.

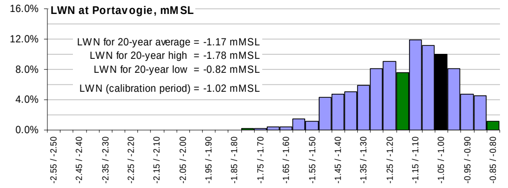
	Locations:	Portavogie	Portmore
Average conditions	HWS	1.96	1.62
	LWS	-2.07	-1.60
	Spring range	4.03	3.22
	HWN	1.30	0.62
	LWN	-1.17	-0.67
	Neap range	2.47	1.30
High conditions	HWS	2.34	2.04
	LWS	-2.51	-2.08
	Spring range	4.85	4.12
	HWN	1.73	1.02
	LWN	-1.78	-1.10
	Neap range	3.51	2.12
Low conditions	HWS	1.47	1.11
	LWS	-1.45	-0.97
	Spring range	2.92	2.08
	HWN	0.97	0.23
	LWN	-0.82	-0.29
	Neap range	1.79	0.52

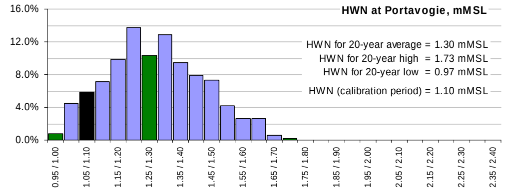
The time records obtained at Portavogie and Portmore between March 1st to March 16th 2010 were subsequently compared to the above table to put the selected period in context with respect to average, high and low conditions. This analysis is presented in the figures below in the form of HWS, HWN, LWS, LWN distribution plots (based on the full 20 years of data). In these figures, the average, high and low spring tides are marked in red, the average, high and low neap conditions in green. HWS, HWN, LWN and LWS computed from the same dataset for the CSM calibration period are marked in black.

Portavogie, Northern Ireland:

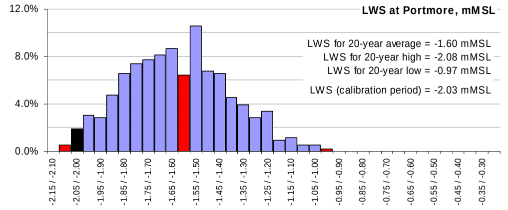


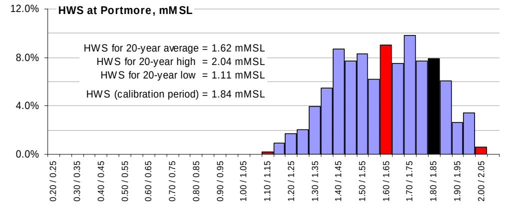


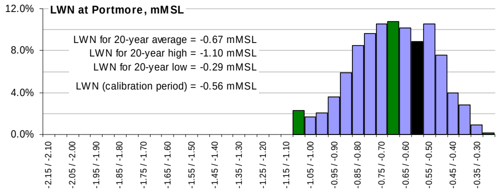


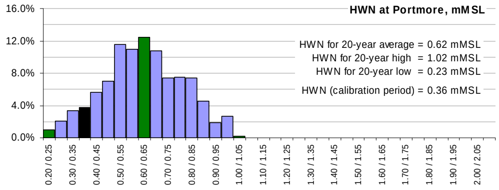


Portmore, Ireland:









Although it is recognised that the characterisation of the 15-day period in relation to a 20-year mean depends on the location considered, this analysis demonstrated that the period between March 1st to March 16th 2010 features an above average spring tide (+20% at Portmore, +16% at Portavogie) and a below average neap tide (-28% at Portmore, -14% at Portavogie). As mentioned earlier, this ensures that the CSM will perform well for a wide range of tidal conditions.

4.1.2 Observed coastal (tidal gauge) data

4.1.2.1 Data sources

The data used to calibrate the CSM comprised observed coastal tidal gauge data. Significant effort was invested by HRW in identifying and obtaining suitable data from national authorities or from international institutes acting as repositories for such data. Considerable effort was also invested in examining the data, and correcting for gaps, noise and inconsistencies where appropriate before tidal harmonic analysis (Section 4.1.2.2). In some instances, the data were eventually discarded for the purpose of the CSM calibration on the grounds that the tidal gauge was sheltered in a natural bay or a harbour, or that it ran dry at low water, for example.

Calibration of the CSM has to date been performed against 24 coastal tidal gauges throughout Northern European waters, out of the 83 gauges for which data were obtained. It is noted that these 24 gauges were selected in accordance with the methodology set out in Section 3.2.1.

The observation stations retained in the CSM calibration exercise are highlighted by white circles in Figure 4, at the end of this document. In this figure, the colours identify different data sources. For example, blue filled circles correspond to data obtained from the British Oceanographic Data Centre portal. The websites from which data can be obtained are given in the reference section at the end of this document.

It is noted in Figure 4 that some of the observation stations are close to the open boundary of the CSM (e.g. Goteborg Torshamnen in Sweden or Brest in France). This was a deliberate choice to ensure that the tidal forcing (derived from the TPXO global model of ocean tides, see Section 3.1.6) is in agreement with observations.

A summary of the observation stations, with exact coordinates, is also given in the tables below. Appendix A reports on the analysis performed for each gauge (one per page). In the tables below, the value in the right column refers to the relevant page in Appendix A for those finally retained.

<u>Source: The Marine Institute in Ireland</u>

> The Marine Institute in Ireland distributes under license tidal level data from the Irish National Tide Gauge Network. Observations are made every 6 minutes with only very limited interruptions in the records. The data were subsequently sub-sampled to only retain every 5th data point (every 30 minutes). This allows a direct comparison with the CSM output (output frequency of 15 minutes).
>
> Tidal levels are said to be reported in metres relative to Ordinance Datum Malin Head. The mean sea level, computed as the average of the tidal levels observed in 2010, is close to 0 at

all the stations where data were obtained. No further corrections were, therefore, applied to the levels to reduce them to MSL (the vertical datum used in the CSM).

It is noted that the stations are calibrated and serviced annually but no post-collection quality checks are performed by the Marine Institute. In this project, data were obtained at 14 observation stations around Ireland for the year 2010 (although the time histories were incomplete at Ballyglass, Inishmore, Ballycotton, Skerries and Dundalk). Upon careful examination of the data, it was decided to discard the level time history observed at Dundalk on the basis that no tidal harmonic analysis could be performed on the data since the gauge appears to dry out at low water.

The time reference of all Marine Institute data is UTC.

Marine Institute	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
Malin Head – Ireland	55.37170	-7.33440	(A 1)
Aranmore – Ireland	54.99050	-8.49550	
Killybegs – Ireland	54.63640	-8.39490	
Sligo – Ireland	54.30990	-8.58200	
Ballyglass – Ireland	54.25360	-9.89280	
Galway – Ireland	53.26900	-9.04800	
Inishmore – Ireland	53.11780	-9.66690	
Castletownbere – Ireland	51.64960	-9.90340	(A 2)
Ballycotton – Ireland	51.82780	-8.00070	
Wexford – Ireland	52.33850	-6.45890	(A 3)
Dublin Port – Ireland	53.34570	-6.22170	
Howth – Ireland	53.39150	-6.06830	
Skerries – Ireland	53.58500	-6.10810	

Out of the 13 stations listed above, only 3 were retained for the calibration of the CSM based on their proximity to the SoI and their unique characteristics (tidal amplitude and flood/ebb asymmetry) (Section 3.2.1). A specific reference to Appendix A is indicated on the right of the table.

Source: The Global Sea Level Observing System

The *Global Sea Level Observing System* (GLOSS) is a programme of the *Joint Technical Commission for Oceanography and Marine Meteorology* (JCOMM) of the *Intergovernmental Oceanographic Commission* (IOC) and the *World Meteorological Organisation* (WMO) for the establishment of global and regional sea level networks. In that context, individual countries and organisations contribute sea level data to the GLOSS database. The data are made available through the *University of Hawaii Sea Level Centre* (UHSLC) at http://ilikai.soest.hawaii.edu/uhslc/woce.html.

In this project, data were obtained at hourly intervals at Castletownsend for the year 2010, with virtually no interruptions in the record. The time reference is not specified, thought to be UTC from comparison of the GLOSS records with observations at other locations.

Global Sea Level Observing System	**Coordinates (WGS84)**	
	Latitude (°N)	**Longitude (°E)**
Castletownsend – Ireland	51.53333	-9.18333

This station was eventually not selected for the calibration of the CSM because of its relative proximity to Castletownbere, which is already incorporated through the Marine Institute data discussed above.

<u>Source: The British Oceanographic Data Centre</u>

The *British Oceanographic Data Centre* (BODC) distributes quality-controlled tidal level data from the UK Tidal Gauge Network. Tidal level observations are recorded routinely every 15 minutes throughout England, Wales, Scotland and Northern Ireland, with some interruptions in the records. These interruptions can be significant in some cases (e.g. Sheerness in England or Portpatrick in Scotland) making some of the data of limited value for this calibration exercise.

Whilst the levels were originally supplied relative to local Chart Datum, they were subsequently reduced to MSL (the vertical datum used in the CSM) using relationships inferred from the UK Admiralty Tide Tables for each station individually (Admiralty Tide Tables, 2010). Records identified as suspicious by BODC (improbable or null values) have been discarded to only retain those records of good quality or interpolated (BODC) between records of good quality.

In this project, data were obtained at 44 observation stations around the UK for the year 2010 (although the time histories were incomplete at a number of stations, refer to Appendix A).

The time reference is GMT, which is equivalent to UTC for all intents and purposes.

British Oceanographic Data Centre	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
Bangor – Northern Ireland	54.66480	-5.66950	
Portrush – Northern Ireland	55.20678	-6.65683	
Stornoway – Hebrides	58.20772	-6.38889	
Kinlochbervie – Scotland	58.45669	-5.05022	
Ullapool – Scotland	57.89525	-5.15806	
Tobermory – Scotland	56.62311	-6.06422	
Millport – Scotland	55.74981	-4.90633	
Port Ellen – Scotland	55.62758	-6.18992	(A 4)
Portpatrick – Scotland	54.84256	-5.12003	(A 5)
Port Erin – Isle of Man	54.08522	-4.76806	
Workington – England	54.65072	-3.56717	(A 6)
Heysham – England	54.03183	-2.92025	
Liverpool – England	53.44969	-3.01814	(A 7)
Llandudno – Wales	53.33167	-3.82522	
Holyhead – Wales	53.31394	-4.62042	(A 8)
Barmouth – Wales	52.71933	-4.04503	
Fishguard – Wales	52.01322	-4.98375	
Milford Haven – Wales	51.70739	-5.05178	(A 9)
Mumbles – Wales	51.57000	-3.97547	
Newport – Wales	51.55000	-2.98744	
Hinkley Point – England	51.21525	-3.13447	(A 10)
Avonmouth – England	51.51080	-2.71510	(A 11)
Ilfracombe – England	51.21114	-4.11239	
St. Mary's – Isles of Scilly	49.91783	-6.31714	
Newlyn – England	50.10300	-5.54275	(A 12)
Devonport – England	50.36839	-4.18525	
Weymouth – England	50.60850	-2.44794	
St. Helier, Jersey - Channel Islands	49.18333	-2.11667	(A 13)

Bournemouth – England	50.71433	-1.87486	(A 14)
Portsmouth – England	50.80219	-1.11125	
Newhaven – England	50.78178	0.05703	
Dover – England	51.11439	1.32253	(A 15)
Harwich – England	51.94800	1.29206	
Felixstowe – England	51.95769	1.34656	
Lowestoft – England	52.47308	1.75025	
Cromer – England	52.93419	1.30164	(A 16)
Immingham – England	53.63042	-0.18753	(A 17)
Whitby – England	54.49000	-0.61469	
North Shields – England	55.00744	-1.43978	
Leith – Scotland	55.98983	-3.18169	
Aberdeen – Scotland	57.14400	-2.08030	
Wick – Scotland	58.44097	-3.08639	(A 18)
Lerwick – Shetland Isles	60.15403	-1.14031	(A 19)

Out of the 44 stations listed above, only 16 were used in the calibration of the CSM. The selection was based on proximity to the SoI and the tidal curve features (amplitude and flood/ebb asymmetry) (Section 3.2.1). A specific reference to Appendix A is indicated on the right of the table.

Source: The Service Hydrographique et Océanographique de la Marine

The *Service Hydrographique et Océanographique de la Marine* (SHOM) distributes validated tidal level data collected as part of the REFMAR programme in France and in the French Territories. The levels are recorded at 10 minute intervals in France with few interruptions in the records. They were subsequently sub-sampled to only keep every 3rd data point (every 30 minutes). This allows a direct comparison with the CSM output (output frequency of 15 minutes).

Tidal levels are supplied relative to a local datum, assumed to be Chart Datum. This was verified by computing the long-term mean sea level from the tidal levels obtained in 2010, and the data were corrected to MSL based on relationships inferred from the UK Admiralty Tide Tables for each station individually (Admiralty Tide Tables, 2010).

In this project, data along the northern French coast (a total of 11 observation stations) were obtained for the year 2010 (although the time histories were incomplete at a number of stations, refer to Appendix A).

The time reference is UTC.

Service Hydrographique et Océanographique de la Marine	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
Concarneau – France	47.87355	-3.90721	
Brest – France	48.38290	-4.49504	(A 20)
Le Conquet – France	48.35910	-4.78075	
Roscoff – France	48.71838	-3.96574	
Saint-Malo – France	48.64081	-2.02810	
Cherbourg – France	49.65145	-1.63551	
Le Havre – France	49.48202	0.10607	
Dieppe – France	49.92917	1.08449	
Boulogne-sur-Mer – France	50.72750	1.57746	(A 21)
Calais – France	50.96940	1.86772	
Dunkerque – France	51.04809	2.36670	

Out of the 11 stations listed above, only 2 were retained for the calibration of the CSM based on their proximity to the SoI and their unique characteristics (tidal amplitude and flood/ebb asymmetry) (Section 3.2.1). A specific reference to Appendix A is indicated on the right of the table.

Source: Rijkwaterstaat

Rijkwaterstaat distributes level data recorded at coastal stations and within its river network. There is no indication that the records have been quality-checked or otherwise processed prior to being made available. Only data collected along the coast of Holland are of interest in this project, and data were obtained at 10 minute intervals at the Amelander-Westgat Platform for the year 2010 (January to August 28th), with virtually no interruptions in the record. They were subsequently sub-sampled to only retain every 3rd data point (every 30 minutes) to allow direct comparison with the CSM output (output frequency of 15 minutes).

No corrections were applied to the observed water levels since the data were supplied to MSL.

The time reference was originally GMT+1, later converted to GMT, which is equivalent to UTC for all intents and purposes.

Rijkwaterstaat	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
Amelander-Westgat Platform – Holland	53.49091	5.93989	(A 22)

This station was selected for the calibration of the CSM. A reference to Appendix A is shown on the right of the table.

Source: Intergovernmental Oceanographic Commission

The IOC presents sea level data at just under 500 stations around the world. Although the initial focus was on operational monitoring in Africa, the scope developed to include a global station monitoring service for real time sea level measuring stations that are part of IOC programmes such as the GLOSS Core Network, and the networks under the regional tsunami warning systems in the Indian Ocean (IOTWS), North East Atlantic & Mediterranean (NEAMTWS), Pacific (PTWS) and the Caribbean (CARIBE-EWS). It is noted that provision of quality sea level data is not the aim of this service; the primary objective is to provide a fast status assessment of station availability and performance, and it is recommended on the website that such data be requested from the data originators. As such the data distributed by the IOC have not undergone any quality control and are provided as received.

In this project, data were obtained at 7 stations in Germany, Denmark and Sweden for (part of) the year 2010, with very limited interruptions in the record. The data are available at variable time intervals depending on location, and are supplied to an arbitrary datum. They were subsequently reduced to MSL based on the tidal harmonic analysis performed on the data.

The time reference is UTC.

Intergovernmental Oceanographic Commission	**Coordinates (WGS84)**	
	Latitude (°N)	**Longitude (°E)**
Borkum Fischerbalje – Germany	53.55750	6.74944
Cuxhaven – Germany	53.86667	8.71667
Helgoland Binnenhafen – Germany	54.17583	7.89139
Hörnum – Germany	54.75806	8.29750

Hirtshals – Denmark	57.60000	9.97000	
Goteborg Torshamnen – Sweden	57.68000	11.78000	(A 23)
Smogen – Sweden	58.35000	11.21667	

Out of the 7 stations listed above, only 1 was selected for the calibration of the CSM, such that the tidal forcing at the CSM boundary with the Baltic Sea (derived from the TPXO global model of ocean tides) could be compared to observations (Section 3.2.1). A specific reference to Appendix A is indicated on the right of the table.

The other stations listed above were not considered on the basis that the eastern North Sea is not an area of interest for energy extraction in the context of this project. It is, however, understood that suitable reproduction of tidal dynamics in the North Sea may be crucial to broader motions and changes to these arising from major energy extractions in later scenario tests. As such, open water gauges throughout the North Sea were selected as part of the CSM validation to corroborate the reproduction of tidal dynamics in the North Sea in the CSM.

The Norwegian Hydrographic Service, Vannstand

The Norwegian Hydrographic Service, Vannstand, holds tidal level observations (and tidal harmonics) for the 23 tide gauges operated by the service in Norway. Data are available from 1992 up to the current year at 10 minute intervals, with virtually no interruptions in the record. It is noted that the data were sub-sampled to only retain every 3rd data point (every 30 minutes). This allows a direct comparison with the CSM output (output frequency of 15 minutes).

Tidal levels are reported in metres relative to a local datum, assumed to be Chart Datum. This was verified by computing the long-term mean sea level from the tidal levels obtained in 2010. The data were subsequently corrected to MSL based on relationships inferred from the UK Admiralty Tide Tables for each station individually (Admiralty Tide Tables, 2010).

In this project, data were obtained at 5 observation stations within the model area for the year 2010 (although the time histories were incomplete at Tregde). It is not known whether the data have been subject to any quality control.

The time reference is local time, later corrected to GMT, which is equivalent to UTC for all intents and purposes.

Intergovernmental Oceanographic Commission	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
Helgeroa – Norway	59.00000	9.86667	
Tregde – Norway	58.00000	7.56667	
Stavanger – Norway	58.96667	5.73333	(A 24)
Bergen – Norway	60.40000	5.30000	
Måløy – Norway	61.93333	5.11667	

The only station retained for the calibration of the CSM was Stavanger. The other stations listed above were not considered on the basis that the eastern North Sea is not an area of interest for energy extraction in the context of this project (Section 3.2.1). Open water gauges throughout the North Sea were, however, selected as part of the CSM validation to corroborate the reproduction of tidal dynamics in the North Sea in the CSM.

4.1.2.2 Data re-analysis

The quality of the tidal gauge data varies depending on the national authority maintaining the network, as identified in Section 4.1.2.1. Some data have been validated before they were released to the public, in which case some basic sanity checks are performed (e.g. consistency of the datum throughout the observation period) and anomalies removed from the data set. This is true of the data obtained from the BODC for example. Some other data are supplied directly from the instrument to the user, without quality checks, although in many cases the stations are calibrated and serviced annually. This is true of the data obtained from the Marine Institute (Ireland) for example.

In this study basic quality checks have been carried out on the “non-validated” data before they were used in the calibration of the CSM. These checks included the identification of gaps in the data, the derivation of a suitable reference elevation for the data and removal of outliers.

Tidal harmonic analysis was subsequently performed on all the observed sea level time records in an effort to remove meteorological and other effects, which are not accounted for in the modelled scenarios of the CSM. Tidal harmonic analysis seeks to break the overall tide into the summation of a number of simple and quasi-independent oscillations of varying periods, each corresponding to the tractive cycle of an astronomical disturbing force, called tidal harmonic constituents.

The amplitude and phase of a tidal constituent are defined by harmonic constants; they are unique for every location. Combined with the fixed rotational speed of that constituent, the harmonic constants allow the prediction of the contribution of that constituent to the overall tide in time. Adding up the effects of all the constituents at a given location enables prediction of the overall tide at any time in the future or past (Foreman, 1977 and 1978).

In keeping with D02, the harmonics analysis software used in this study was T_TIDE (Pawlowicz et al., 2002) which is written in the Matlab programming environment. The T_TIDE software is based upon original Fortran program developed by M.G.G. Foreman (1977 and 1978). T_TIDE was developed further by S. Lentz and R. Beardsley from the Woods Hole Oceanographic Institution, and R. Pawlowicz from University of British Columbia, Canada.

The results of the harmonic analysis for each gauge is shown in Appendix A. In particular, the figure produced by T_TIDE is included, for which the observed data are displayed as a blue line, the re-synthesised data as a green line. The residual, or difference between the two traces, is shown as a red line. Spikes in the residual are often attributed to missing data in the original observed dataset. The amplitude and phase of the significant constituents (in blue) are also indicated. This gives a visual impression of the quality of the analysis.

It is noted that not all observed tidal gauge data had been reduced by the originator organisation to a consistent (let alone specified) datum. When inconsistent with that published in the Admiralty Tide Tables, the mean sea level determined by tidal analysis of the observed sea level trace was used to correct the synthesised data and reduce them to MSL, the vertical datum used in the CSM.

4.1.2.3 Further considerations

There are five known amphidromic points within the model area: in Scottish waters between Islay and the Mull of Kintrye, in Irish waters off St George’s Channel, off Dorset, off East Anglia, and off the south-western coast of Norway. An amphidromic point, or tidal node, is a point where the amplitude of the vertical tide is close to zero (or zero for one or more of the major constituents). The tidal range increases with distance from that point.

The tidal range observed at the coastal tide gauges is minimal (under 2.5 m) in England at Weymouth and Bournemouth, in Scotland at Port Ellen, in Ireland at Wexford and Portrush, in Germany at

Borkum and Cuxhaven, in Denmark, Sweden and Norway in general. Being relatively close to Norway, Lerwick also falls in that category.

Tidal range is generally between 4 and 5 m in Scotland, with the highest tidal ranges found in the Solway Firth (the mean spring tidal range there can reach between 7 and 8 m). It is markedly higher in Wales, 8 m at Llandudno, 4 to 5 m along the western coast and up to 12 m in the Bristol Channel at Newport. Tidal range is high (between 9 and 16 m) along the western coast of England (eastern Irish Sea and Bristol Channel); other areas of high tidal range include the English Channel between Newhaven and Dover (8 m), and the Channel Islands with 11 m at St Helier; tidal range is noticeably lower (3 to 7 m) along the eastern coast, especially between Cromer and Harwich due to the presence of the East Anglia amphidromic point. In Ireland, tidal range is generally between 3 and 5 m. These observations are in agreement with maps of tidal range published in the Atlas of the Seas around the British Isles (Ministry of Agriculture, Fisheries and Food, 1981) for example.

In Europe, high tidal range regions include the French coast between Boulogne-sur-Mer and Dieppe (in excess of 8 m) and Saint-Malo (10 m). Tidal range is relatively low (around 3 m) in Germany and The Netherlands, and even lower (below 2 m) in Scandinavia. Combined with the rather poor resolution of the bathymetry in these regions (particularly in fjords along the coasts of Sweden and Norway) and the features of the detached coastlines, it is anticipated that re-synthesis of tidal harmonic constituents and comparison against model predictions may not be appropriate there.

4.1.3 Calibration parameter

The principal calibration parameter of the CSM is bottom friction. Bottom friction is a physical force, which is not precisely known in the natural environment and is, therefore, one of the few parameters available to modellers to fine-tune model performance against observed data. TELEMAC-2D allows bottom friction to be set at every computational point of the CSM and represents:

- The local seabed roughness, which is often unknown as it relates to seabed characteristics (sand, gravel, rocks, vegetation, etc.) and is influenced by larger bed forms such as dunes and banks;

- Local bathymetric changes, which are often affected by the resolution of the model and of the quality of the bathymetric data obtained.

Further, TELEMAC-2D allows bottom friction to be derived from several laws, whether a linear formulation, a Chézy formulation, a Strickler / Manning formulation, or using a Nikuradse roughness length formulation. Users of TELEMAC-2D often choose the law they are most comfortable with and tune its principal parameter within physically realistic values until calibration of the model is achieved. Depending on the characteristics of the model area, spatial variations in the friction parameter can be justified, for instance where seabed material is known to vary across the region of interest, or where bigger bed forms are present, or as a depth-dependent variable.

A Chézy formulation was used in this study. The Chézy parameter relates to friction drag, often referred to as the C_D coefficient, where $C_D = 2g / \text{Chézy}^2$ and where g is the gravitational constant. The use of different parameters (friction drag between 0.0015 and 0.005) and different formulations (Chézy and Nikuradse roughness length) were investigated as part of the model sensitivity testing, the results of which are presented in Section 4.3.3.

It should be emphasised that although friction parameters can be defined for individual computational points, refining bottom friction parameters very locally around a tidal gauge (thus achieving calibration at individual sites) may not provide a satisfactory calibration nor validation for the whole domain. Therefore, it is often preferable to limit the spatial variations where little is known about the seabed. Besides, the quality and accuracy of bathymetric data remain the primary inputs to a model, which bottom friction can only partly compensate for.

In the context of the CSM, bathymetric data were sourced from various regional and national organisations (see Section 3.1.5). Having started the calibration with a constant Chézy, spatial adjustments to the bottom friction were investigated according to regional coverage, with the aim still being to limit the variety in spatial variations.

4.1.3.1 Constant Chézy parameter

A constant friction parameter was first defined throughout the modelled domain, to keep model calibration manageable. The parameter yielding the closest agreement to observed levels throughout the model area was retained: a value of 80 $m^{1/2}/s$ (friction drag of 0.003) for the CCSM and a value of 65 $m^{1/2}/s$ (friction drag of 0.0046) for the DCSM. These values are within the range of accepted bottom roughness for natural beds.

The difference between the values used for the CCSM and the DCSM can be explained by differences in their respective mesh resolutions. While friction should not depend on mesh resolution, it competes or combines with model diffusion (numerical diffusion in this case), which is also a source of energy dissipation and often strongly depends on mesh resolution. It is acknowledged that the current release of TELEMAC-2D still includes some numerical diffusion. This is a ubiquitous characteristic of tidal hydrodynamic models due to the representation of a continuous system using a discretised equation set. Research work is being carried out by HR Wallingford to continually improve this inherent aspect of TELEMAC-2D.

The conclusions drawn from this first calibration exercise are presented in the sensitivity analysis in Section 4.1.4, and this version of the CSM is considered as the reference for sensitivity analysis.

4.1.3.2 Depth-varying Chézy parameter

The earlier calibration exercise resulted in comparable performance of the CCSM and the DCSM (in terms of amplitude and shape of the tidal curve throughout the calibration period). In particular, calibration was deemed strong at all but a few specific sites in the vicinity of some amphidromic points.

An additional calibration exercise was, therefore, undertaken, for the CCSM only, by varying the Chézy parameter with water depth. It is noted that some friction formulations such as Manning / Strickler or the Nikuradse length formulations implicitly calculate the friction drag as a function of depth, in addition to variations in the seabed types and materials. The Chézy formulation (see introduction to Section 4.1.3) does not implicitly calculate the friction drag as a function of depth, but the user can define the friction parameter such that it varies with depth, to control this dependency.

In that context, three distinct bands were defined to keep model calibration manageable: (a) the “deeps” of the CSM; (b) the “shallows” of the CSM; and (c) an intermediate band between the two. Calibration was achieved by fine-tuning the upper and lower cut-off depths forming the three bands, as well as the associated friction parameters in the deeps and shallows. A linear function of depth was used in the intermediate band yielding a continuous transition. It should be remembered that all depths are referred to MSL in this study.

The friction parameters yielding the closest agreement with observed levels were found to refine the constant Chézy parameter of the earlier calibration exercise (value of 80 $m^{1/2}/s$ for the CCSM), in that smoother values between 85 and 120 $m^{1/2}/s$ were retained in the deeps of the CCSM (friction drag between 0.0014 and 0.0027) and rougher values between 40 and 65 $m^{1/2}/s$ were used in the shallows (friction drag between 0.005 and 0.012). Sensitivity testing with respect to depth identified the upper and lower cut-off depths as 20-40 m and 60-70 m depth respectively.

However, despite efforts to optimise the additional parameters, the overall performance of the CCSM could not be improved. Obtaining better agreement against observed levels on the east and south coasts of England, for instance, was detrimental to the agreement in the rest of the domain. This was confirmed during the CSM sensitivity testing to friction, where calibrating the CCSM based on the Nikuradse length formulation (with inherent dependency to depth) yielded no significant improvement around amphidromic points compared to the first calibration exercise, which was based on a constant Chézy parameter.

The results of this second calibration exercise are not presented in this document as these have been supplanted by those presented in the following section.

4.1.3.3 Spatially- and depth-varying Chézy

Based on the previous calibration exercises and the observed sensitivity of the CSM to friction parameters, but also informed by HRW's previous experience from national and regional models, a final calibration exercise was undertaken where the Chézy parameter was varied according to depth, for depths lesser than 60 m, in 4 different regions of the CSM:

- Zone 1: The Celtic Sea, including the Severn Estuary, the English Channel and the North Sea;
- Zone 2: The Atlantic region of the CSM and the Irish Sea;
- Zone 3: The region immediately off the south coast of England; and
- Zone 4: The region immediately off the east coast of England.

This partitioning into zones 1-4 followed an iterative process based on model performance against observations. The starting point was only one zone. Additional zones, treated as separate friction entities, were introduced in turn to further improve model performance (for instance, the phase difference on the east coast, the amphidromic point at Bournemouth, etc.), until satisfactory agreement was reached throughout. The principal aim was to define the least number of friction zones since it is important that the model as a whole performs well. Locally fitting friction zones to one or two gauges would not guarantee good performance globally, which is critical for the CSM.

The same approach was followed for both the CCSM and the DCSM, based on the same zones. The values finally retained, and reported below, resulted from a trial and error approach (some 50 trials overall), where the improvement in the CSM calibration was measured by the improvement to the N-RMSE values globally, at calibration locations across the model area. In line with the conclusions presented in Section 4.1.3.2, the friction parameters yielding the closest agreement with observed levels refine the constant Chézy parameter initially obtained. The values used in the two versions of the CSM are relatively close and are within the range of accepted bottom roughness values for natural beds and bed forms.

In summary, in the CCSM, Zones 1 and 2 are the smoothest with constant friction parameters of 68 and 70 $m^{1/2}/s$, below cut-off depths of 40 and 35 m respectively. Zone 3 is defined by a cut-off depth of 50 m and a constant friction parameter of 42 $m^{1/2}/s$ below this depth. Zone 4 is defined by a cut-off depth of 20 m and a constant friction parameter of 35 $m^{1/2}/s$, which is the roughest value used in the CCSM, below this depth. Beyond water depths of 60 m (lower cut-off value), a single friction parameter (85 $m^{1/2}/s$) was employed across zones. In all cases, the Chézy parameter varied linearly in the intermediate depths between lower (60 m) and upper cut-off values.

In the DCSM, Zones 1 and 2 are the smoothest, as was the case in the CCSM, with constant friction parameters of 70 and 60 $m^{1/2}/s$, below cut-off depths of 40 and 35 m respectively. Zone 3 is characterised by a cut-off depth of 50 m and a constant friction parameter of 40 $m^{1/2}/s$ below this depth. Zone 4 is defined by a cut-off depth of 30 m and a constant friction parameter of 33 $m^{1/2}/s$, which also is the roughest value used in the DCSM, below this depth. Beyond water depths of 60 m (lower cut-off value), similar friction parameters (between 70 and 80 $m^{1/2}/s$) were employed across zones. In all cases, the Chézy parameter varied linearly in the intermediate depths between lower (60 m) and upper cut-off values.

Overall, as discussed in Section 4.1.5 and 4.1.6, the region nearest the East Anglia amphidromic point, in Zone 4, has proven to be the most challenging for the calibration of the CSM. Results from this calibration exercise are presented in the next section and in more detail in Appendices B and C for the CCSM and the DCSM respectively.

4.1.4 Presentation of the CSM performance against observed coastal (tidal gauge) data

Although direct comparisons were drawn against observed water levels, calibration of the CSM was primarily achieved through a comparison of predicted water levels against water levels re-synthesised by tidal harmonic analysis from observed levels at a number of coastal tidal gauges in Northern Europe (refer Sections 4.1.2.1 and 4.1.2.2, and Figure 4 at the end of this document). As explained earlier, the use of re-synthesised water levels is deemed more appropriate in the context of model calibration since meteorological effects are not included in the CSM, and re-synthesised levels are in theory clean of atmospheric and surge variations. It is noted that comparison of predicted water levels is also shown against direct observations to give an appreciation of the shape of the tidal curve, as the harmonic analysis is not always accurate, particularly in areas of low tidal amplitude (see Section 4.1.2.3) and when the record is corrupted and/or the record length is insufficient to capture all the relevant harmonics.

The CSM comparison against coastal tidal gauge data is displayed in several different ways, described in the following subsection. All the figures are presented in Appendices B and C (CCSM and DCSM respectively) for clarity of this document. As illustrated below, each page (one per observation station) is set out to include:

- A map inset indicating the geographical location of the observation station. The map is a reduced and combined version of Figures 6 and 8 for the CCSM and of Figures 7 and 9 for the DCSM;
- Time history plots comparing the observed data, and the re-synthesised observed data to the CSM data over the 15-day calibration period;
- MAE and N-RMSE statistics (it is noted that the N-RMSE are also displayed as a coloured filled circle in the map inset); and
- Some tables presenting the main harmonic constituents (amplitude, phase and *signal to noise ratio* (SNR)) extracted from the observed tidal levels and from tidal levels predicted by the CSM over the same 90-day period (see Section 3.2.3).

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.0846	178.1	430000
S2	12.00	0.4221	206.5	79000
N2	12.66	0.2274	155.4	24000
K2	11.97	0.1184	204.3	6100
K1	23.93	0.0938	158.7	3900
O1	25.82	0.0809	15.7	3000
MU2	12.87	0.0541	105.7	1200
MSM	763.48	0.0479	278.4	980

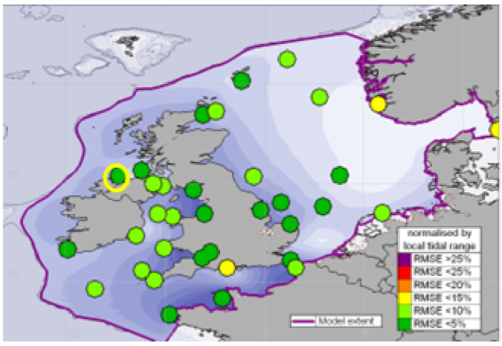
[1] Only the first 8 constituents are listed

Number of days: 365
Number of constituents: 59
MSL = 0.01 m

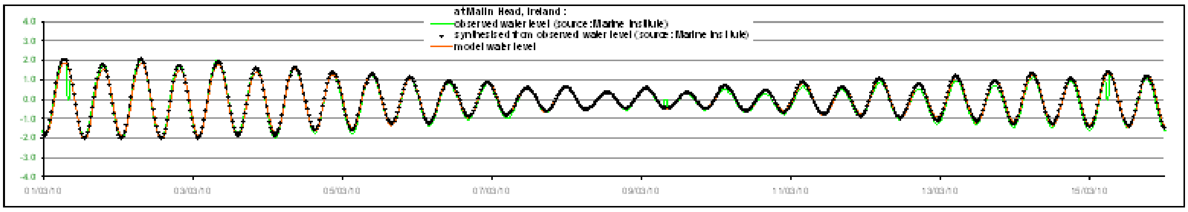
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.0732	183.2	190000
S2	12.00	0.4640	202.0	39000
N2	12.66	0.2355	160.3	11000
K1	23.93	0.1108	121.6	2100
O1	25.82	0.0847	358.9	2000
M4	6.21	0.0351	159.1	220
Q1	26.87	0.0312	301.1	200
L2	12.19	0.0312	30.7	170

Number of days: 90
Number of constituents: 35
MSL = -0.04 m



MAE = 0.08 m (3% of tidal range in calibration period)



B 1. CCSM comparison against observed data at Malin Head, Ireland

4.1.4.1 *Time histories*

Agreement of the CSM results with observed data is primarily illustrated by comparison of the predicted and observed water level traces at specific sites over the full 15-day tidal cycle. In these plots, the horizontal axis is time; the vertical axis is free surface elevation in metres. To aid visualisation of the results, the vertical axis was coloured according to range (dark green for ±4 m, bright blue for ±8 m, and red for ±12 m). The tidal levels predicted by the CSM are indicated as a thick orange line, the levels obtained by tidal re-synthesis of observed levels are shown as black crosses for the same period. When available concurrently to the calibration period, the observations are represented by a thick light green line.

4.1.4.2 *Statistics*

The time histories give an immediate visual impression of the agreement. The quality of the CSM calibration was assessed by computing the difference in tidal levels between the model predictions and the re-synthesised data at each time step throughout the 15-day tidal cycle. The result of this assessment is presented in terms of N-RMSE and MAE values for all the calibration locations identified in Section 4.1.2. The N-RMSE values at each observation station were obtained by normalising the root mean square error using the higher of the maximum tidal range at that location over the calibration period and 1 m. While the current IEC technical specifications do not offer a modelling target to be reached, HRW routinely uses a target N-RMSE value of 10% in their studies. Values below 10% are deemed to reflect a good calibration of the model at a particular site. The MAE values will give an indication of the absolute errors over the entire 15-day period. This may prove a useful statistic when the tidal range is relatively small in the vicinity of amphidromic points.

It should be noted that, where the predicted tidal signal was ahead or behind the observed signal by more than ±15 minutes (only a few sites), the N-RMSE and the MAE calculations were carried out based on the phase-corrected signal (to the nearest 15 minutes). The CSM performance can then be evaluated in terms of tidal amplitude and phase independently. The sites where such corrections were performed are common to both versions of the CSM, and located along the east coast of the UK, as discussed above.

At the remaining 22 sites, the predicted signal was not corrected for phase (error lesser than 15 minutes); the N-RMSE and the MAE values thus combine both amplitude and time differences.

The results of this analysis are reported in Section 4.1.5 for the CCSM and in Section 4.1.6 for the DCSM. They are also summarised as spatial maps of N-RMSE, where the coloured background is the tidal amplitude (Figure 6 and Figure 7 respectively for the CCSM and DCSM).

4.1.4.3 Harmonic constituents

The primary (first 8) constituents resulting from tidal harmonic analysis of the observed data and of the CSM data are also presented at each site. In this analysis, the calibrated CSM was re-run for a longer period (90 days) more suitable to harmonic analysis. The selected period starts with and extends beyond the 15-day period selected for the calibration exercise. It is noted that the results of the tidal harmonic analysis is only weakly dependent on the 90 day period selected.

4.1.5 Discussion of the CCSM performance against coastal (tidal gauge) data

Comparison of the CCSM predicted levels against observed and re-synthesised coastal tidal gauge data is presented in Appendix B in the form of time histories and principal tidal constituents, at all the calibration locations. The agreement was quantified by individually calculating the N-RMSE and the MAE values. These results are summarised by region in the tables below, where the value in the right column refers to the relevant page in Appendix B.

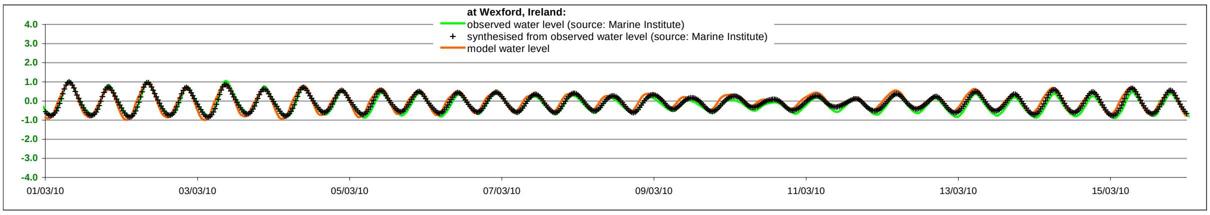
4.1.5.1 Celtic Sea, St George's Channel and Severn Estuary

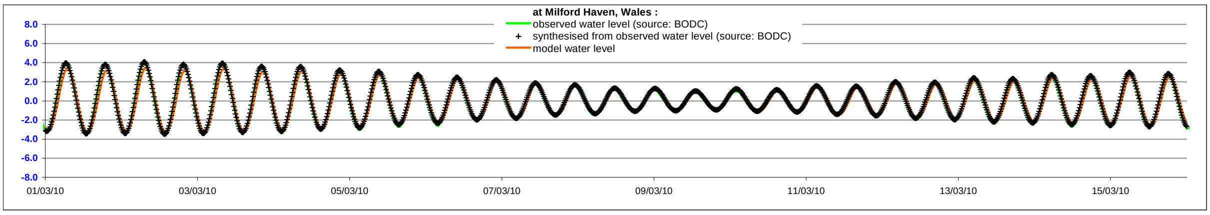
The CCSM performs favourably against observed coastal tidal gauge data in the Celtic Sea, St George's Channel and the Severn Estuary. As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) are between 5 and 8% on either side of the Celtic Sea and St George's Channel (first 3 stations in the table below). The CCSM performs gradually better up the Severn Estuary with N-RMSE values below 5%, well within the generally accepted 10% error.

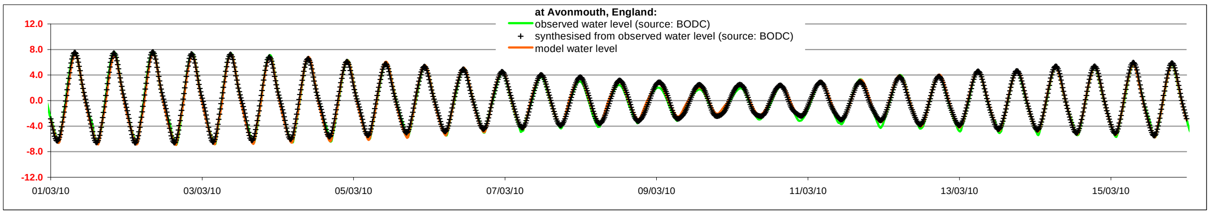
	Sites	**N-RMSE**	**MAE (m)**	
Celtic Sea and Severn Estuary	Castletownbere – Ireland	5%	0.12	(B 2)
	Wexford – Ireland	8%	0.12	(B 3)
	Milford Haven – Wales	7%	0.33	(B 9)
	Hinkley Point – England	4%	0.42	(B 10)
	Avonmouth – England	2%	0.25	(B 11)

The MAE values at Milford Haven and Hinkley Point are greater than 30 cm. This can mainly be attributed to a slight delay (under 15 minutes) in the predicted tidal phase.

The performance of the CCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix B). For illustrative purposes, the time histories at Wexford (spring tide amplitude of c.2 m), Hinkley Point (spring tide amplitude of c.8 m) and Avonmouth (spring tide amplitude of c.15 m) have been reproduced below (from B 3, B 10 and B 11 respectively). It is also clear from these figures that the CCSM adapts to variations in amplitude and asymmetry between flood and ebb both in time and in space. At Hinkley Point, the spring tidal range is predicted within -0.21 m (2%) of that derived from harmonic analysis of the observed data. At Avonmouth, further up the Severn Estuary it is predicted within 0.14 m (1%). These results, in key regions for tidal range energy schemes, are considered very good compared to the targeted accuracy.







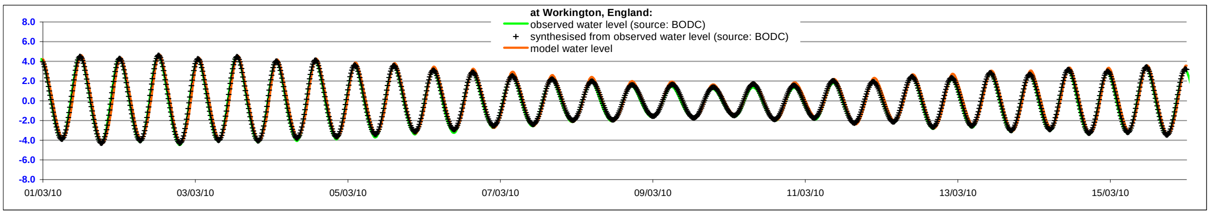
The St George's Channel and Severn Estuary area is of interest in this project. It is noted that, overall, the CCSM performs well there.

4.1.5.2 Irish Sea, North Channel and Malin Sea

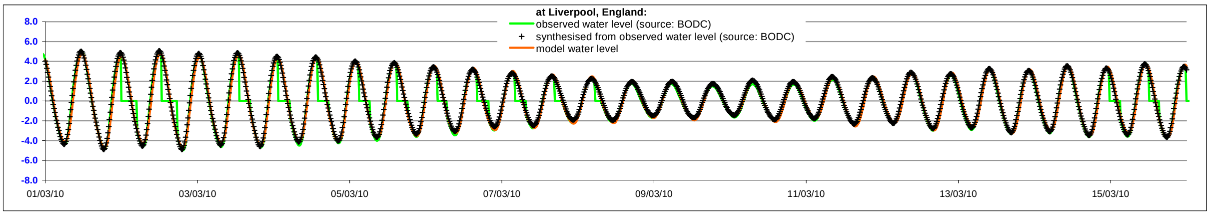
The CCSM also performs well against observed coastal tidal gauge data obtained in the Malin Sea through the North Channel into and around the Irish Sea down to the St George's Channel. As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) are 3% at Malin Head, 5% at Port Ellen and 6% at Portpatrick at the other end of the North Channel, and between 4 and 6% throughout the Irish Sea. This is notable given the presence of an amphidromic point rendering model predictions challenging in the North Channel.

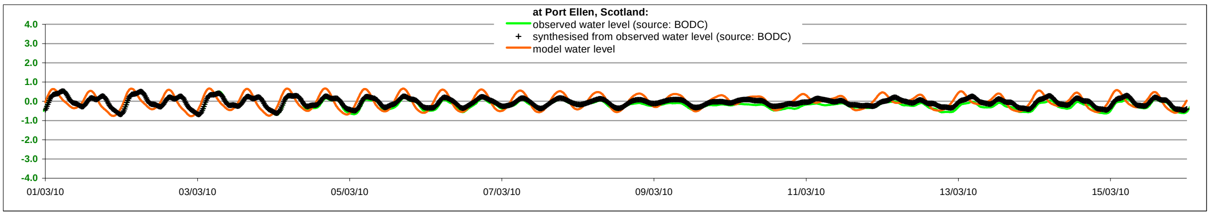
	Sites	**N-RMSE**	**MAE (m)**	
Irish Sea, North Channel, Malin Sea	Malin Head – Ireland	3%	0.08	(B 1)
	Port Ellen – Scotland	5%	0.24	(B 4)
	Portpatrick – Scotland	6%	0.22	(B 5)
	Workington – England	5%	0.35	(B 6)
	Liverpool – England	4%	0.29	(B 7)
	Holyhead – Wales	6%	0.27	(B 8)

The MAE values are below 30 cm for all gauges but Workington. For illustrative purposes, the time histories at Workington (spring tide amplitude of c.8 m) have been reproduced below from B 6. The discrepancies can be attributed in part to a slight delay (under 15 minutes) in the predicted tidal phase. The spring tidal range at Workington is predicted within 0.10 m (1%) of that derived from harmonic analysis of the observed data. It is predicted within -0.44 m (4%) at Liverpool. Again, these results are very good.



The performance of the CCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix B). It is clear from these figures that the CCSM adapts to variations in shape of the tidal curves both in time and in space. For illustrative purposes, the time histories at Liverpool (spring tide amplitude of c.9 m) and Port Ellen (spring tide amplitude of c.1 m) have been reproduced below from B 7 and B 4 respectively. The N-RMSE value at these two locations is 5%.





It is noted that the water levels predicted by the CCSM are relatively high compared to those observed at times of HW at Port Ellen. This can be explained by a slight mis-location of the North Channel amphidromic point which is relatively unimportant in the context of the model's intended usage.

It is noted that the Irish Sea, North Channel and Malin Sea area is of interest in this project and, overall, the CCSM performs well there.

4.1.5.3 The northern Firths of Scotland

The CCSM performs very satisfactorily against observed coastal tidal gauge data in northern Scotland, around the Orkney and Shetlands Islands. As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) are between 3 and 5%, well within the generally accepted 10% error. The MAE values remain below 15 cm throughout the region.

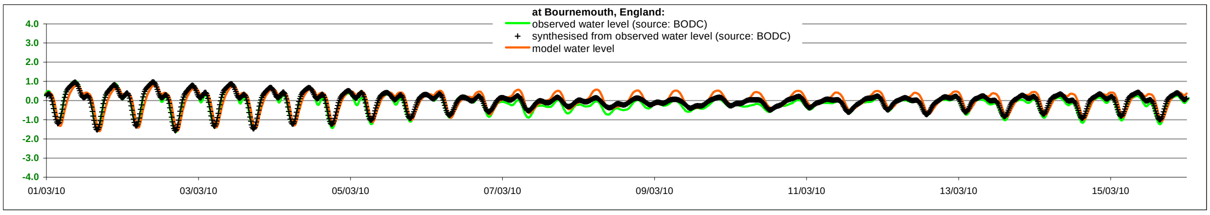
	Sites	N-RMSE	MAE (m)	
Firths of Scotland	Wick – Scotland	5%	0.13	(B 18)
	Lerwick – Shetland Isles	3%	0.05	(B 19)

The performance of the CCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix B).

Northern Scotland (Orkney / Shetland Islands in particular) is an area of interest in this project. It is noted that, overall, the CCSM performs well there.

4.1.5.4 English Channel and Channel Islands

The CCSM performs favourably against observed coastal tidal gauge data obtained in the English Channel and around the Channel Islands, except in the vicinity of the south coast amphidromic point, around Bournemouth where the N-RMSE value (giving an indication of the error on the amplitude and phase combined) is 11%. For illustrative purposes, the time histories at Bournemouth (spring tide amplitude of c.2 m) have been reproduced below from B 14. It is noted that the error at Bournemouth is considered relatively unimportant in the context of the model's intended use, since Bournemouth is not a particularly attractive site and the primary error appears to be at neaps.

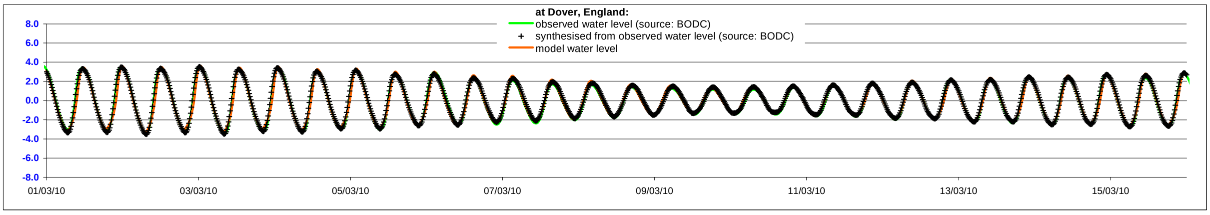


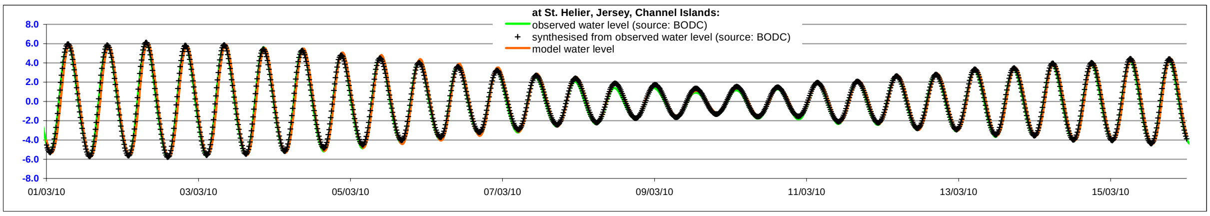
As summarised in the table below, the N-RMSE values range between 2% and 8% everywhere else from Dover, England to Brest, France.

	Sites	N-RMSE	MAE (m)	
English Channel and Channel Islands	Newlyn – England	8%	0.32	(B 12)
	Bournemouth – England	11%	0.22	(B 14)
	Dover – England	4%	0.19	(B 15)
	Boulogne-sur-Mer – France	6%	0.33	(B 21)
	St. Helier, Jersey - Channel Islands	5%	0.41	(B 13)
	Brest – France	2%	0.10	(B 20)

The MAE values are larger than 30 cm at a number of locations, principally because of differences in the shape of the re-synthesised and predicted tidal signals.

The performance of the CCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix B).The CCSM adapts to spring to neap variations and asymmetry between flood and ebb both in time and in space, including at Bournemouth (see illustrations above). For illustrative purposes, the time histories at Dover (spring tide amplitude of c.7 m) and St. Helier (spring tide amplitude of c.12 m) have been reproduced below (B 15 and B 13 respectively). At Dover, the spring tidal range is predicted within -0.19 m (3%) of that derived from harmonic analysis of the observed data.



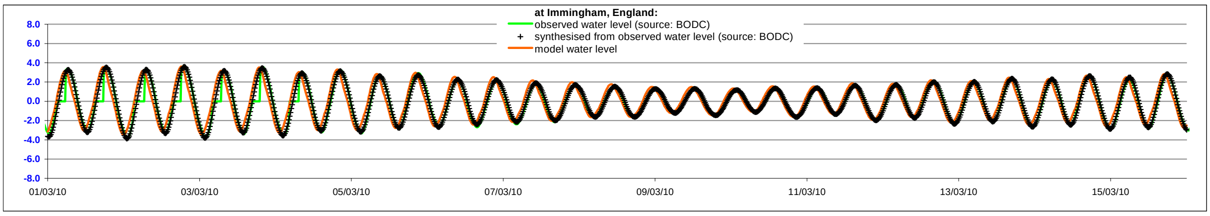


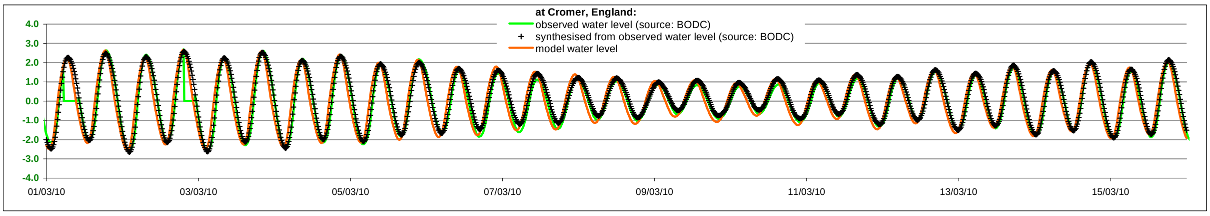
The English Channel and Channel Islands are an area of interest in this project, and it is noted that the CCSM performs well there.

4.1.5.5 North Sea

The CCSM performance is generally poorest along the east coast of the UK and near the East Anglia amphidromic point in particular. As summarised in the table below (last column), the predicted tidal wave rises (and falls) c.45 minutes earlier than the observed tidal wave at Cromer and Immingham, England.

While the tidal wave is accurately predicted through the Dover Strait (refer Section 4.1.5.4), its propagation along the east coast of the UK is not as well predicted with a noticeable discrepancy in the time of arrival. This discrepancy means that the tide turns too soon (south of the line) between Cromer, England and Amelander-Westgat, Holland, compared to coastal observations. For illustrative purposes, the time histories at Immingham (spring tide amplitude of c.8 m) and Cromer (spring tide amplitude of c.5m) have been reproduced below from B 17 and B 16 respectively. Discarding the time differences, the CCSM is still capable of adapting to variations in shape of the tidal curves both in time and in space. At Immingham, the spring tidal range is predicted within -0.35 m (5%) of that derived from harmonic analysis of the observed data. At Cromer, it is predicted within -0.01 m (0%).



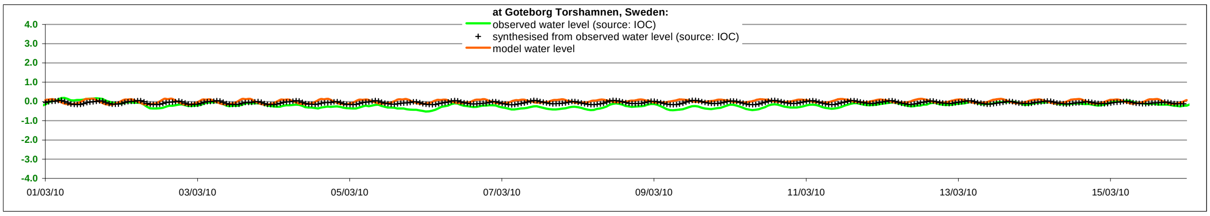


Despite efforts to optimise the calibration parameters within their physical range along the east coast of the UK, the performance of the CCSM in this area could not be improved. It is expected that the observed differences in time of arrival are primarily caused by the presence of underwater sand banks in that region increasing in-situ friction on the flow, thus slowing down the observed tidal wave as it approaches the coast. The resolution of the bathymetric charts used and / or that of the model may have to be improved to represent this additional friction process. However, the N-RMSE values are acceptable, with 4% and 3% respectively at Cromer and Immingham, having corrected for phase differences (which is considered appropriate since tidal range projects will not be affected to a significant extent by this consistent phase error). The error is of 9% at Amelander-Westgat, Holland, by the North Sea amphidromic point, without correction on phase.

It is noted that, in the table below, the N-RMSE values where no time difference is reported give an indication of the error on the amplitude and phase combined, whereas the N-RMSE values with time difference only report the error on the amplitude (in the calculation, the tidal trace was artificially offset to compensate for the time difference).

	Sites	**N-RMSE**	**MAE (m)**		
North Sea	Amelander-Westgat– Holland	9%	0.19	(B 22)	
	Cromer – England	4%	0.16	(B 16)	*(45min)*
	Immingham – England	3%	0.18	(B 17)	*(45min)*
	Goteborg Torshamnen – Sweden	12%	0.10	(B 23)	
	Stavanger – Norway	13%	0.10	(B 24)	

On the other side of the North Sea, along the Scandinavian coast, the CCSM does not perform well against observed coastal tidal gauge data with N-RMSE values between 12 and 13%, despite MAE values being consistently below 30 cm. This is explained by the relatively limited tidal range in the eastern North Sea. For illustrative purposes, the time histories at Goteborg Torshamnen (spring tide amplitude of c.0.2 m) have been reproduced below from B 23.



In addition to the relatively small tidal range (hence the difficulty to differentiate astronomical components from meteorological components in the tidal harmonic analysis), the poor performance of the CCSM in this area can be explained by the location of the Scandinavian gauges, within fjords along a very detached coastline, the details of which may not be well represented by the bathymetric charts obtained and the resolution of the model. However, this result is less critical as this is not an area of interest in the project. The bathymetry of the CCSM could be updated as and when reliable information becomes available.

4.1.5.6 Overall conclusions for the CCSM

Overall the performance of the CCSM is good, demonstrating favourable agreement with observations in the St George's Channel, Bristol Channel, Irish Sea and North Channel area. The N-RMSE values there are generally well below 10%, the generally accepted error. The agreement is also strong around the Orkney and Shetland Islands although the calibration locations are not directly located in areas of significant tidal energy potential.

The CCSM compares very favourably in the English Channel and around the Channel Islands, with a weaker agreement at Bournemouth near the amphidromic point. On the eastern coast of England the CCSM predictions are consistently c.45 minutes early compared to coastal tidal gauge data. This is, however, not cause for concern in the context of the model's intended use, as noted in Section 3.2.4[3]. Even then, the shape and main features of the tidal curve can be well predicted by the CCSM, as is the case in Cromer and Bournemouth for example. The tidal amplitudes are also in good agreement featuring N-RMSE values well below 10%.

Overall, the MAE values are generally smaller than 30 cm and the result of a slight discrepancy in the time of arrival of the tide. It is clear that the CCSM represents well the spatial variations in both the shape and amplitude of the tide from locations close to amphidromic points to locations with markedly high tidal ranges (e.g. the Severn estuary and the Mont St-Michel Bay).

It is noted that the spring tidal range is generally predicted within 5% in key regions for tidal range energy schemes.

4.1.6 Discussion of the DCSM performance against coastal (tidal gauge) data

As with the CCSM (refer Section 4.1.5) the agreement between observed tidal levels and those predicted by the DCSM was quantified by calculating the N-RMSE and MAE values at all the coastal tidal gauge stations selected for calibration individually. This analysis is presented in Appendix C (one page per site) together with comparisons of tidal level time histories and of tidal constituents.

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[3] The extent of the impact of each scenario will be measured during WP6. If that extent should cross over the area where a discrepancy in the phase is observed, then further sensitivity tests will be performed, by introducing artificial changes to the model, in an effort to eliminate the phase shift (and identify potential differences in the predicted impact footprint). It is reasonable to think that, should the impact footprint be limited to the phase shift zone, then the model predictions are reliable.

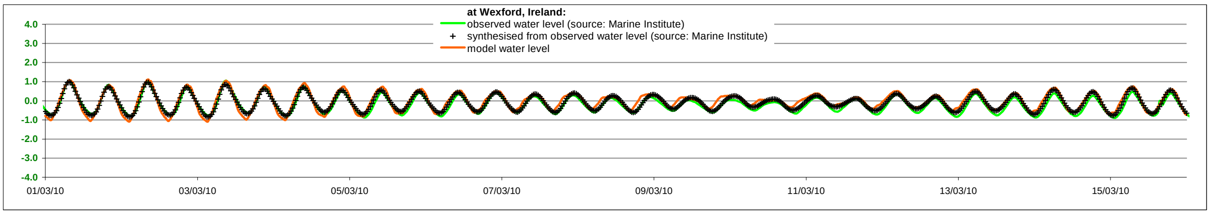
The errors are summarised in the tables below by region. A reference is made to the relevant page in Appendix C (right column) for more details.

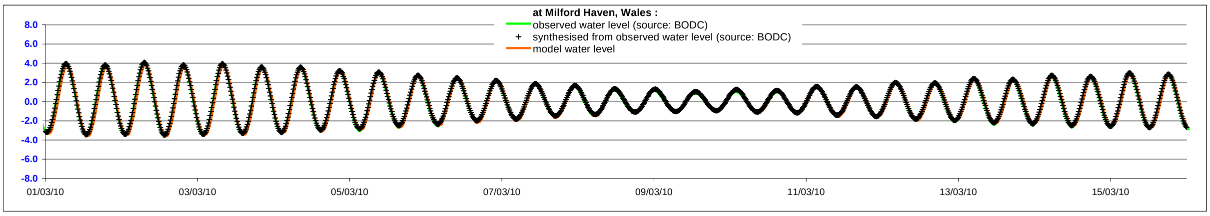
4.1.6.1 Celtic Sea, St George's Channel and Severn Estuary

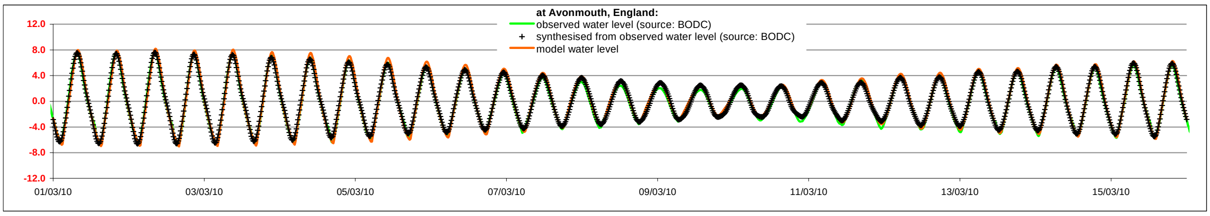
As was the case for the CCSM, the DCSM performs well against observed coastal tidal gauge data in the Celtic Sea, St George's Channel and the Severn Estuary. As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) are between 3 and 7%. As with the CCSM, the DCSM performs gradually better up the Severn Estuary with N-RMSE values below 5%, well within the generally accepted 10% error.

	Sites	N-RMSE	MAE (m)	
Celtic Sea and Severn Estuary	Castletownbere – Ireland	3%	0.07	(C 2)
	Wexford – Ireland	7%	0.13	(C 3)
	Milford Haven – Wales	6%	0.27	(C 9)
	Hinkley Point – England	4%	0.44	(C 10)
	Avonmouth – England	3%	0.37	(C 11)

The performance of the DCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix C). Similarly to the CCSM, the DCSM adapts to spring to neap variations and asymmetry between flood and ebb, both in time and in space. For illustrative purposes, the time histories at Wexford (spring tide amplitude of c.2 m), Hinkley Point (spring tide amplitude of c.8 m), and Avonmouth (spring tide amplitude of c.15 m) have been reproduced below (from C 3, C 10 and C 11 respectively). At Hinkley Point, the spring tidal range is predicted within 0.77 m (6%) of that derived from harmonic analysis of the observed data. At Avonmouth, further up the Severn Estuary, it is predicted within 1.01 m (7%).







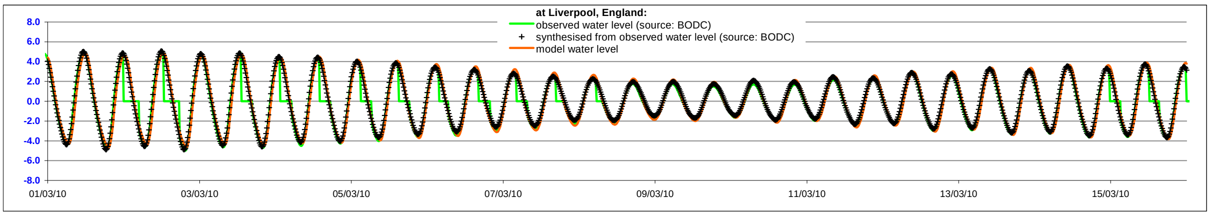
The St Georde's Channel and Severn Estuary area is of interest in this project. It is noted that, overall, the DCSM performs well there.

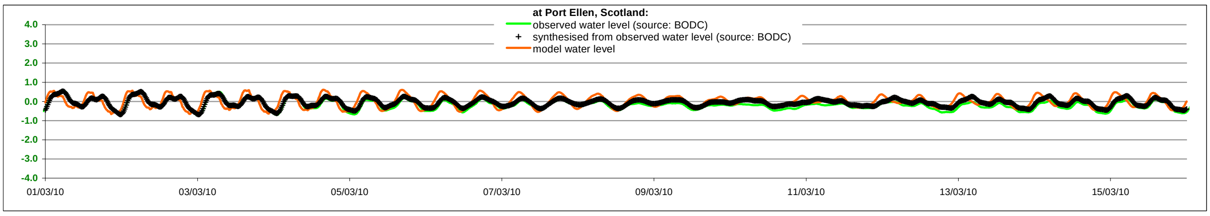
4.1.6.2 Irish Sea, North Channel and Malin Sea

The DCSM performs favourably against observed coastal tidal gauge data from the Malin Sea through the North Channel into and around the Irish Sea down to the St George's Channel. As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) are 3% at Malin Head, 4% at Port Ellen and 4% at Portpatrick at the other end of the North Channel, and between 3 and 5% throughout the Irish Sea.

	Sites	N-RMSE	MAE (m)	
Irish Sea, North Channel, Malin Sea	Malin Head – Ireland	3%	0.08	(C 1)
	Port Ellen – Scotland	4%	0.19	(C 4)
	Portpatrick – Scotland	4%	0.14	(C 5)
	Workington – England	4%	0.27	(C 6)
	Liverpool – England	5%	0.42	(C 7)
	Holyhead – Wales	5%	0.23	(C 8)

The performance of the DCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix C). Similarly to the CCSM, the DCSM adapts to variations in amplitude and shape of the tidal curves both in time and in space. For illustrative purposes, the time histories for Liverpool (spring tide amplitude of c.9 m) and Port Ellen (spring tide amplitude of c.1 m) have been reproduced below (C 7 and C 4 respectively). The comparatively high MAE value at Liverpool (above 30 cm) can be attributed in part to a slight delay (under 15 minutes) in the predicted tidal phase. The spring tidal range at Workington is predicted within 0.29 m (3%) of that derived from harmonic analysis of the observed data. It is predicted within -0.38 m (4%) at Liverpool.





It is noted that the Irish Sea, North Channel and Malin Sea area is of interest in this project, and the DCSM performs well there overall.

4.1.6.3 The northern Firths of Scotland

As for the CCSM, the DCSM performs very satisfactorily against observed coastal tidal gauge data in northern Scotland, around the Orkney and Shetlands Islands. As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) are between 4 and 6%. The MAE values are well below30 cm.

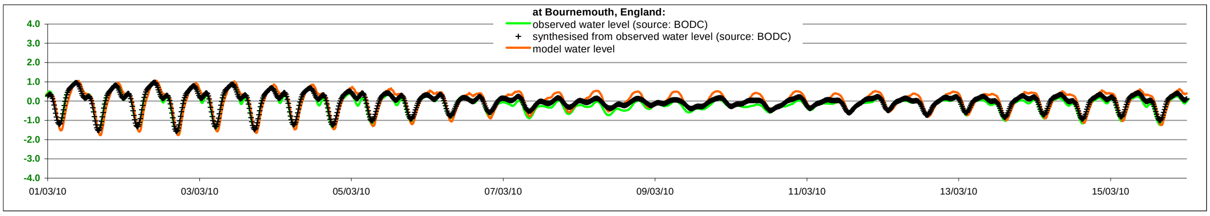
	Sites	N-RMSE	MAE (m)	
Firths of Scotland	Wick – Scotland	6%	0.17	(C 18)
	Lerwick – Shetland Isles	4%	0.06	(C 19)

The performance of the DCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix C).

Northern Scotland (Orkney / Shetland Islands in particular) is an area of interest in this project. It is noted that the DCSM performs well there. Comparison of the DCSM velocity data with observations (in the Pentland Firth or the Fall of Warness, for example) would, however, be desirable to confirm the suitability of the DCSM for tidal current energy schemes.

4.1.6.4 English Channel and Channel Islands

The DCSM performs well against observed coastal tidal gauge data in the English Channel and around the Channel Islands. Comparably to the CCSM, the poorest agreement is noted near the south coast amphidromic point around Bournemouth (with N-RMSE values of the order of 8%, still below the generally accepted 10% error). For illustrative purposes, the time histories at Bournemouth (spring tide amplitude of c.2 m) have been reproduced below from C 14.

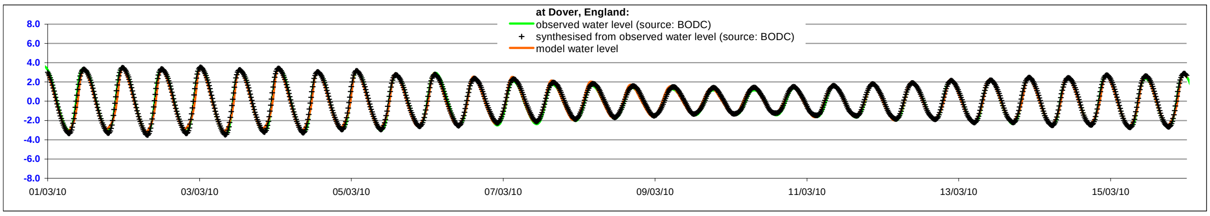


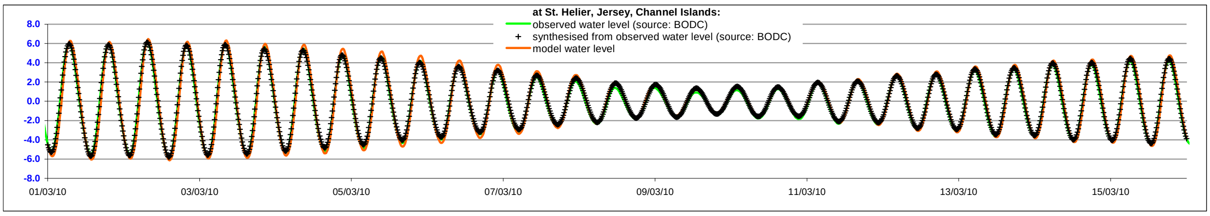
As summarised in the table below, the N-RMSE values (giving an indication of the error on the amplitude and phase combined) range between 3 and 6% at the other locations considered within the English Channel and Channel Islands.

	Sites	N-RMSE	MAE (m)	
English Channel and Channel Islands	Newlyn – England	6%	0.27	(C 12)
	Bournemouth – England	8%	0.20	(C 14)
	Dover – England	4%	0.21	(C 15)
	Boulogne-sur-Mer – France	4%	0.24	(C 21)
	St. Helier, Jersey - Channel Islands	4%	0.36	(C 13)
	Brest – France	3%	0.14	(C 20)

The MAE values are below or slightly over 30 cm throughout. Again, the discrepancies can largely be attributed to slight differences in the shape of the re-synthesised and predicted tidal signals.

The performance of the DCSM is confirmed visually by comparison of the predicted and observed time histories over the 15-day spring-neap-spring period (see relevant pages in Appendix C). The DCSM adapts to spring to neap variations and asymmetry between flood and ebb, both in time and in space, including at Bournemouth (see illustration above). For illustrative purposes, the time histories at Dover (spring tide amplitude of c.7 m) and St. Helier (spring tide amplitude of c.12 m) have been reproduced below (C 15 and C 13 respectively). At Dover, the spring tidal range is predicted within -0.38 m (5%) of that derived from harmonic analysis of the observed data.



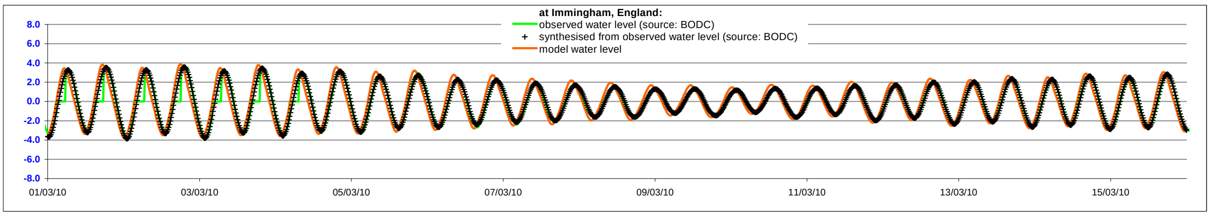


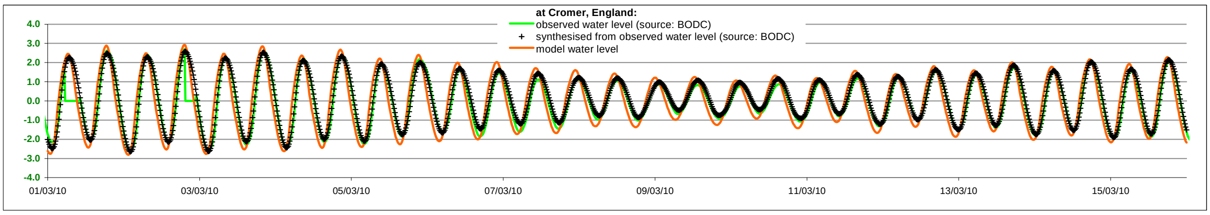
The English Channel and Channel Islands are an area of interest in this project, and it is noted that the DCSM performs well there.

4.1.6.5 North Sea

Similarly to the CCSM, the DCSM does not perform as satisfactorily against observed coastal tidal gauge data along the east coast of the UK, and near the East Anglia amphidromic point in particular. As summarised in the table below (last column), the predicted tidal wave rises (and falls) earlier than the observed tidal wave by c.45 minutes at Cromer and Immingham, England.

For illustrative purposes, the time histories at Immingham (spring tide amplitude of c.8 m) and Cromer (spring tide amplitude of c.5 m) have been reproduced below from C 17 and C 16 respectively. It is noted in these figures that, although the time of arrival may not be accurately predicted, the shape of the tidal curves, both in time and in space, are reasonably well predicted by the DCSM. At Immingham, the spring tidal range is predicted within 0.21 m (3%) of that derived from harmonic analysis of the observed data. At Cromer, it is predicted within 0.51 m (10%).



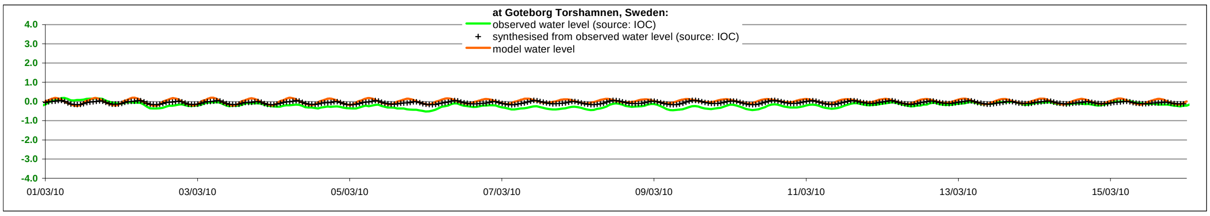


Despite efforts to optimise the calibration parameters within their physical range along the east coast of the UK, the performance of the DCSM in this area could not be improved. As suggested previously (Section 4.1.5.5), it is expected that the observed differences in time of arrival are primarily caused by the presence of underwater sand banks increasing in-situ friction on the flow, thus slowing down the observed tidal wave as it approaches the coast compared to the DCSM representation. Still the N-RMSE values are acceptable with 5% and 4% respectively at Cromer and Immingham. The error is of 9% at Amelander-Westgat, Holland, by the North Sea amphidromic point, as was the case in the CCSM.

It is noted that, in the table below, the RMSE values where no time difference is reported give an indication of the error on the amplitude and phase combined, whereas the RMSE values with time difference only report the error on the amplitude (in the calculation, the tidal trace was artificially offset to compensate the time difference).

	Sites	N-RMSE	MAE (m)		
North Sea	Amelander-Westgat– Holland	9%	0.18	(C 22)	
	Cromer – England	5%	0.26	(C 16)	*(45min)*
	Immingham – England	4%	0.25	(C 17)	*(45min)*
	Goteborg Torshamnen – Sweden	10%	0.08	(C 23)	
	Stavanger – Norway	10%	0.09	(C 24)	

On the other side of the North Sea, on the Scandinavian coast, the DCSM performs slightly better than the CCSM against observed coastal tidal gauge data, with N-RMSE values of 10% (between 12% and 13% in the CCSM). The MAE values are well below 30 cm due to the relatively limited tidal range in the eastern North Sea. For illustrative purposes, the time histories at Goteborg Torshamnen (spring tide amplitude of c.0.2 m) have been reproduced below from C 23.



As was mentioned previously for the CCSM, the weaker performance of the DCSM in Scandinavia can be explained by the location of the gauges, within fjords along a very detached coastline, the details of which may not be well represented by bathymetric charts obtained for the study. However, this result is not deemed critical as this is not an area of interest in the project. The bathymetry of the DCSM could be updated as and when reliable information becomes available.

4.1.6.6 Overall conclusions for the DCSM

The overall conclusions regarding the DCSM calibration exercise are similar to those drawn for the CCSM (Section 4.1.5.6) and will not be repeated here. The next section summarises and compares the performances of the two versions of the CSM.

4.1.7 Performance comparison between the CCSM and the DCSM

Around the Celtic Sea and in the Severn Estuary, the CCSM and the DCSM have similar levels of performance against the same observed coastal tidal gauge data. The DCSM is generally only 1% to 2% more accurate than the CCSM in terms of changes to N-RMSE when compared to observed. Further, the two versions have the same behaviour in the Severn Estuary in that performance gradually improves up the estuary to reach N-RMSE values of 2% to 3% N-RMSE.

From the Malin Sea, through the North Channel, around the Irish Sea and down to St George's Channel, the CCSM and DCSM also have similar levels of performance against observed coastal tidal gauge data, although it is noted that the DCSM is generally 1% to 3% more accurate in terms of N-RMSE when compared to the observed than the CCSM. The two versions have similar behaviour at Malin Head (3% RMSE for both the CCSM and the DCSM), which is mainly explained by their reaction to the Atlantic boundary forcing.

Similarly around the Orkney and Shetlands Islands, the CCSM and DCSM have comparable performances. The DCSM is 1% less accurate than the CCSM in terms of N-RMSE, that is to say that the two versions of the CSM can be regarded as identical to within 1-2% for all intents and purposes. No one version stands out as being superior to the other for tidal level predictions, with both versions of the CSM expected to give similar predictions for future scenarios (although of course the DCSM should be used for tidal current schemes wherever possible, as the greater resolution is useful to predict tidal currents more accurately - due to their spatial variability).

In the English Channel and around the Channel Islands, the CCSM and DCSM also have similar levels of performance against observed coastal tidal gauge data (to within 1% in terms of N-RMSE, except at Bournemouth where the DCSM is 3% more accurate than the CCSM) and the same weaker link at Bournemouth, near the amphidromic point.

Finally in the North Sea, this analysis highlights the same weakness in both the CCSM and the DCSM, in that the tide is consistently predicted c.45 minutes early compared to observed coastal tidal gauge data along the east coast of England. Still, the predicted RMSE values on the amplitude alone are well within the generally accepted 10%. As a result, and because the tide is accurately predicted through the Dover Strait, it is deemed that the accuracy of the CSM east of Dover and south of the line between Cromer and Amelander-Westgat will be appropriate for tidal range energy schemes, even if less so for tidal current energy schemes. It should be emphasised that this remains acceptable since the area is not generally considered to be a site of interest for tidal current energy schemes.

The main conclusion that can be drawn from this analysis is that the tidal levels predicted by the CCSM are very comparable to those predicted by the DCSM with similar levels of performance and the same problem areas. Overall the DCSM performs only marginally better than the CCSM (1 to 3% on the N-RMSE values), although there is a tendency for the DCSM to exaggerate the spring tidal range compared to the CCSM, and observations. As discussed above, the DCSM should be used for tidal current schemes wherever possible, as the greater resolution is useful to predict tidal currents more accurately - due to their spatial variability.

It should be remembered that the purpose of the CCSM is primarily to provide preliminary impact assessment results for the entire Northern Europe continental shelf while remaining practical to use on a standard desktop computer; that of the DCSM is to provide more detail in areas of interest, at the expense of computational time. The DCSM, like the CCSM, however, remains a model of the entire Northern European continental shelf and should not be used in place of a refined local model when considering resources / impacts in specific areas.

4.2 Validation and verification of the CSM

Significant effort was invested by HRW and B&V in identifying and obtaining suitable data to validate and verify the CSM against. The CSM was first validated against an independent set of offshore data comprising tidal gauges and bottom pressure gauges. The CSM was then further verified at discrete locations against available velocity data, and as a whole against recognised atlases of the Northern European waters, giving in particular an indication of the tidal range and peak current speed.

The sources of data and the CSM performance are detailed in the following subsections. It is noted that basic quality checks have been carried out on the data before they were used in the validation and verification of the CSM. These checks included the identification of gaps in the data, the derivation of a suitable reference elevation for the data and removal of outliers. The information associated with the bottom pressure observations and ADCP data were also inspected to identify unreliable data (e.g. presence of large sandwaves next to a deployment location).

4.2.1 Validation against observed offshore (tidal gauge and bottom pressure) data

4.2.1.1 Period selection

Given the variety of data sources used in the validation exercise and the period originally selected for the calibration exercise (full tidal cycle including spring and neap tides), the same period as that of the calibration was used to validate and verify the CSM. This required that the time histories of site-specific observed data be analysed to extract the tidal constituents and reconstruct the signal for the period from March 1st to March 16th 2010. This analysis was performed using the T_TIDE software introduced in Section 4.1.2.2.

4.2.1.2 Data sources

The data used to validate the CSM comprised observed offshore tidal gauge and bottom pressure data. A summary of the 33 available observation stations is given in the tables below. Their locations are marked by filled diamonds in Figure 5. In this figure the colours identify the data sources: green for the Rijkwaterstaat and brown for the BODC. The websites from which data can be obtained are given in the reference section at the end of this document. It is noted that not all stations were finally retained, as noted in the following sections. The locations used in the validation exercise (11) are identified by white diamonds in Figure 5.

It is noted in Figure 5 that some of the observation stations are close to the open boundary of the CSM (e.g. North Cormorant in the North Sea). As with the CSM calibration, this was a deliberate choice to confirm that the tidal forcing is consistent with observations.

Appendix A includes the tidal harmonic analysis performed for each data point (one per page); Appendices B and C the comparison between predicted and observed tidal characteristics (time histories, tidal constituents, statistical measures of error) for the CCSM and the DCSM respectively.

Source: Rijkwaterstaat

Refer Section 4.1.2.1, where details about the type of data available from Rijkwaterstaat are provided in the context of the CSM calibration.

For validation purposes, data were obtained at 10 minute intervals at 7 additional stations set up on platforms in the North Sea for the year 2010, with virtually no interruptions in the records.

Rijkwaterstaat	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
North Cormorant	61.23949	1.14769	(A 25)
Platform A12	55.38264	3.79858	(A 26)
Platform D15-A	54.32493	2.93434	
Platform F16-A	54.11593	4.01085	
Platform J6	53.81663	2.95001	(A 27)
K13a platform	53.21701	3.21892	
Platform Hoorn Q1-A	52.92535	4.15029	

Out of the 7 stations listed above, only 3 were retained for the validation of the CSM. Specific references to Appendix A are indicated on the right of the table.

Source: The British Oceanographic Data Centre

The BODC holds historical bottom pressure recorder data collected around the UK, either in the open ocean (water depth greater than 200 m) or in the shelf seas (water depth less than 200 m), in the seventies and early eighties. Only data collected in the shelf seas are of interest in this project. Because these are not contemporary data, they have to undergo tidal harmonic analysis before they can be used to validate the CSM. It was therefore decided to restrict the observation stations to those where bottom pressure data had been collected for 20 days or more (32 locations). The data and metadata for these were subsequently scrutinised and the data obtained for 26 stations, as listed below.

British Oceanographic Data Centre	**Coordinates (WGS84)**		
	Latitude (°N)	**Longitude (°E)**	
RG1,M5	61.5000	0.0216	
R5	59.9981	-2.9624	
PJONSDAP,R56	59.3251	2.7779	(A 28)
PJONSDAP,R55	59.3196	0.2509	
RE	59.2966	-0.0499	
PJONSDAP,R54	58.9329	-1.2500	
PJONSDAP,R53	58.6166	-2.4375	(A 29)
NLOWER LOCH	56.5666	-5.3116	
NUPPER LOCH	56.5666	-5.2949	
RP	56.2666	-1.1999	
R8(14)	56.0071	-8.5843	
RD	55.8599	-5.7416	
RE	55.4633	-6.1633	
RL	55.3266	-0.5449	(A 30)
RB	54.9616	-5.5949	(A 31)
RH	54.7999	0.2500	
RE	54.0099	0.8399	(A 32)
RGE	53.4416	-5.3666	(A 33)
RB	53.2399	2.0999	
RB	51.7500	-6.5999	
RE	51.3549	-8.5166	
RM	51.1399	-9.7966	
RD	50.5833	-6.1666	(A 34)
RF	50.5283	-7.6116	
RG	49.6599	-8.5283	(A 35)
RL	48.7949	-7.0233	

At these locations bottom pressure observations, that is pressure observations from instruments located on or near the seabed, or the pressure exerted by the water body on the fixed in-situ pressure sensor, have generally been recorded every 15 minutes (with the exception of RG1,M5 at hourly intervals), without major interruptions in the records, for periods ranging between 22 and 162 days. It is expected that the tidal harmonic analysis will be less accurate for the shorter record lengths.

In some cases the bottom pressure data had been corrected for *Mean Sea Level Pressure* (MSLP) using co-located air pressure data. In most cases, however, the pressure data were supplied as measured by the instrument. A constant reference pressure was therefore used to correct the pressure observations prior to the tidal analysis being performed.

Using a concurrent time varying record of atmospheric pressure would have been desirable as variations in atmospheric pressure translate directly in MSL variations, but such data were not immediately available. Although the approximation of a constant reference atmospheric pressure throughout the observation period is rather simplistic, it is expected that the tidal harmonic analysis will smooth out the meteorological effects to yield a water level trace comparable with that predicted in the model. The transformed levels were reduced to MSL for consistency with the vertical datum used in the CSM for each station individually.

The time reference was assumed to be GMT, which is equivalent to UTC for all intents and purposes, given the nature and extent of the observation campaign.

Out of the 26 stations listed above, 8 were retained for the validation of the CSM in an effort to provide good coverage in the Celtic and Irish Seas and in the North Sea. Specific references to Appendix A are indicated on the right of the table.

4.2.1.3 Presentation of the CSM performance against observed offshore data

The results of the CSM validation exercise were presented in the same way as those of the calibration exercise, i.e.:

- A map inset indicating the geographical location of the observation station. The map is a reduced version of Figure 6 and 8 for the CCSM and of Figure 7 and 9 for the DCSM;
- Time history plots comparing the observed data (where applicable), and the re-synthesised observed data to the CSM data over the 15-day validation period;
- MAE and N-RMSE statistics (it is noted that the N-RMSE values, obtained by normalising the root mean square error values using the higher of the corresponding maximum tidal range over the calibration period and 1 m, are also displayed as a coloured filled circle in the map inset); and
- Some tables presenting the main harmonic constituents (amplitude, phase and *signal to noise ratio* (SNR)) extracted from the observed tidal levels and from tidal levels predicted by the CSM over a 90-day period.

A detailed description of each type of output is given in Section 4.1.4.

4.2.1.4 Discussion of the CSM performance against observed offshore data

Comparison of the CSM predicted levels against observed and re-synthesised offshore data is included in Appendices B and C for the CCSM and DCSM respectively in the form of time histories and principal tidal constituents, at all the validation locations. The agreement was quantified by individually calculating the N-RMSE and the MAE values. These results are summarised by region in the tables below, where the value in the right column refers to the relevant page in Appendix B and in Appendix C as appropriate.

Celtic and Irish Seas

The CSM performs well against observed offshore tidal gauge and bottom pressure data in the Celtic and Irish Seas, with N-RMSE values below 8% throughout.

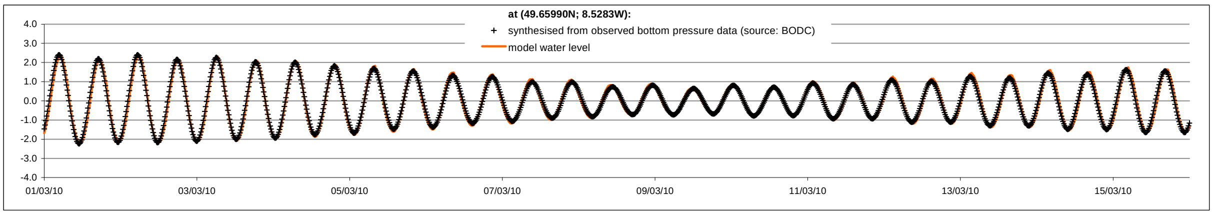
	CCSM **Sites**	**N-RMSE**	**MAE (m)**	
Celtic and Irish Seas	RG	6%	0.15	(B 35)
	RD	8%	0.31	(B 34)
	RB	8%	0.23	(B 31)
	RGE	7%	0.25	(B 33)

	DCSM **Sites**	**N-RMSE**	**MAE (m)**	
Celtic and Irish Seas	RG	4%	0.12	(C 35)
	RD	7%	0.28	(C 34)
	RB	7%	0.18	(C 31)

	RGE	6%	0.22	(C 33)

As was the case in the calibration exercise, the CCSM and the DCSM have similar levels of performance for all intents and purposes, with the DCSM generally only 1% to 2% more accurate than the CCSM.

For illustrative purposes, the time histories at RG (spring tide amplitude of c.5 m) have been reproduced below from C 35 for the DCSM. It is noted that the strong agreement illustrated in this figure can be attributed, for the most part, to a direct reaction to the Atlantic boundary forcing.



North Sea

The CSM does not perform as satisfactorily against offshore tidal gauge and bottom pressure data along the east coast of the UK. As summarised in the tables below, the predicted tidal wave rises (and falls) earlier than the observed tidal wave in both versions of the CSM (c.45 minutes at RL and RE and c.30 minutes at Platforms A12 and J6). This analysis confirms that presented for the calibration exercise (Sections 4.1.5.5 and 4.1.6.5), with RE and RL located closer to the coast than Platforms A12 and J6, farther offshore in the southern North Sea and above the line between Cromer, England and Amelander-Westgat, Holland.

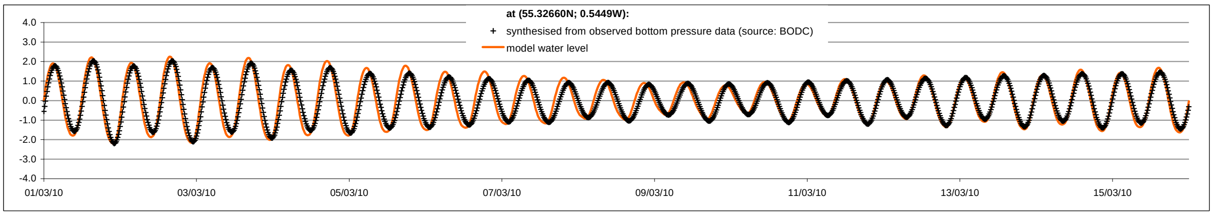
The N-RMSE values quoted in the tables below where no time difference is reported give an indication of the error on the amplitude and phase combined, whereas the N-RMSE values with time difference only report the error on the amplitude (in the calculation, the tidal trace was artificially offset to compensate the time difference).

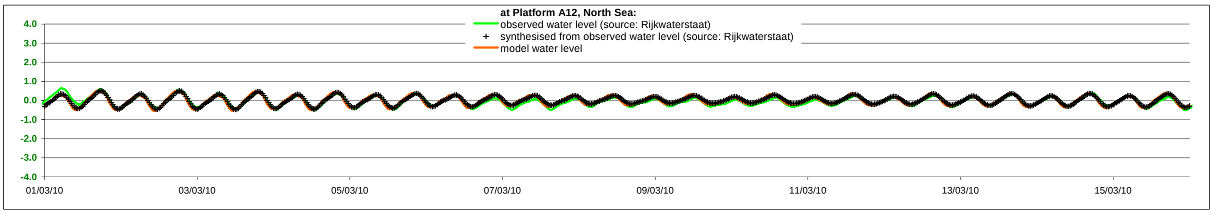
	CCSM **Sites**	**N-RMSE**	**MAE (m)**		
North Sea	Platform A12	4%	0.04	(B 26)	*(30min)*
	North Cormorant	7%	0.09	(B 25)	
	Platform J6	4%	0.07	(B 27)	*(30min)*
	PJONSDAP,R53	6%	0.15	(B 29)	
	RL	6%	0.16	(B 30)	*(45min)*
	RE	5%	0.19	(B 32)	*(45min)*
	PJONSDAP,R56	7%	0.06	(B 28)	

	DCSM **Sites**	**N-RMSE**	**MAE (m)**		
North Sea	Platform A12	5%	0.04	(C 26)	*(30min)*
	North Cormorant	5%	0.07	(C 25)	
	Platform J6	5%	0.11	(C 27)	*(30min)*
	PJONSDAP,R53	7%	0.19	(C 29)	
	RL	6%	0.18	(C 30)	*(45min)*
	RE	6%	0.22	(C 32)	*(45min)*
	PJONSDAP,R56	6%	0.05	(C 28)	

It is noted that the N-RMSE values are in close agreement between the two versions of the CSM, to within 1-2% depending on location.

For illustrative purposes, the time histories at RL (spring tide amplitude of c.4 m) and Platform A12 (spring tide amplitude of c.1 m) have been reproduced below for the DCSM from C 30 and C 26 respectively. It is noted in these figures that, although the time of arrival may not be accurately predicted, the shape of the tidal curves (spring to neap variations and flood/ebb asymmetry) is reasonably well predicted by the DCSM, both in time and in space. This is also true of the CCSM.





4.2.1.5 Overall conclusions for the validation of the CSM

The main conclusion that can be drawn from this analysis is that it substantiates that developed for the calibration exercise. In particular, the tidal levels predicted by the CCSM are very comparable to those predicted by the DCSM with similar levels of performance and problem areas.

Overall the DCSM performs only marginally better than the CCSM. This gives confidence in the resolution selected for the models. Therefore, both versions of the CSM can be expected to give similar predictions for future scenarios(although of course the DCSM should be used for tidal current schemes wherever possible, as the greater resolution is useful to predict tidal currents more accurately - due to their spatial variability).

It should be remembered that the purpose of the CCSM is primarily to provide preliminary impact assessment results for the entire Northern Europe continental shelf while remaining practical to use on a standard desktop computer; that of the DCSM is to provide more detail in areas of interest, at the expense of computational time. The DCSM, like the CCSM, however, remains a model of the entire Northern European continental shelf and should not be used in place of a refined local model when considering resources / impacts in specific areas.

Even though the phasing of the tidal wave through the Strait of Dover is accurately predicted, tidal variations along the East Anglian coast consistently occur about 45 minutes sooner than observed. Because the phase lag is consistent, the CSM remains valid for applications to both tidal current and tidal range energy schemes along the East Anglian coast. However, in the relatively small region between East Anglia and Belgium, the CSM may not model tidal current energy schemes as well as throughout the remainder of the model domain. Based on the current list of SoI (see Section 3.1.4.3), this is not a concern in this project[4].

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[4] As noted in Section 4.1.5.6, the extent of the impact of each scenario will be measured during WP6. If that extent should cross over the area where a discrepancy in the phase is observed, then further sensitivity tests will be performed.

4.2.2 Verification against velocity data from Marine Current Turbine Ltd

4.2.2.1 Data sources

In 2008 Partrac Ltd collected *Acoustic Doppler Current Profiler* (ADCP) and *Acoustic Wave and Current* (AWAC) mooring data on behalf of *Marine Current Turbines Ltd* (MCT) at four sites off the coast of Anglesey, North Wales. Three of the instruments were deployed relatively close to each other (locations 1, 2, and 4), and the other (location 3) approximately 4km south-west.

Although MCT has agreed to share these data with HRW in the context of the CSM verification, the exact deployment locations and periods of the data presented in this section remain confidential and the property of MCT. It is understood that the instruments were deployed such that they would capture the characteristics of the flow at the site of interest.

The moorings were deployed for periods ranging from 30 days (location 2) to 72 days (location 4). There were no interruptions in the records at locations 1, 2 and 3, and only a minor interruption at location 4, during which time the mooring was recovered to extract the initial data and check the mooring.

It is noted that all the instruments were set to measure the current characteristics every metre throughout the water column. Typically, however, surface flows are not measured by ADCP and AWAC devices. The measured current speeds and directions were subsequently analysed by HRW to yield depth-averaged values at locations 2 to 4 (the data at location 1 were omitted being of lesser resolution and collected within metres of location 4).

The accepted accuracy of ADCP and AWAC devices in measuring current speeds is of the order of 0.02m/s for a single measurement. In the case of the ADCP deployment, for which HRW had access to the raw data, it was calculated that the error on the measurements was between 7% and 25% of the peak current speeds (depending on location and tidal state) because the record included natural turbulence attributed to rough sea conditions.

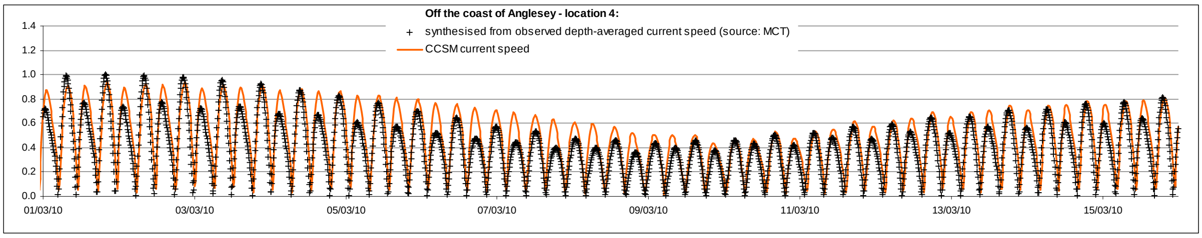
4.2.2.2 Presentation of the CSM performance against MCT velocity data

The velocity data obtained from MCT were not concurrent with the CSM verification period (March 1st to March 16th 2010). For that reason, comparisons could not be drawn against tidal velocity measurements directly. Instead the tidal signal was reconstructed by harmonic analysis of the velocity (T_TIDE) and compared to the CSM data for the verification period. It is noted that the results of the harmonic analysis cannot be presented in this document to protect the intellectual property of the data owner.

For the same reasons, the analysis discussed in the following sections is always presented in terms of normalised values in an effort not to disclose absolute values. This was done by normalising the current speeds (or velocity components as appropriate) at each location with respect to the corresponding spring peak current speed synthesised for the verification period.

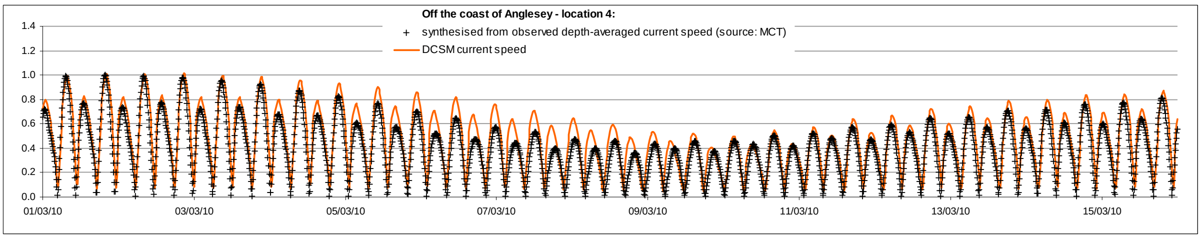
4.2.2.3 Discussion of the CSM performance against MCT velocity data

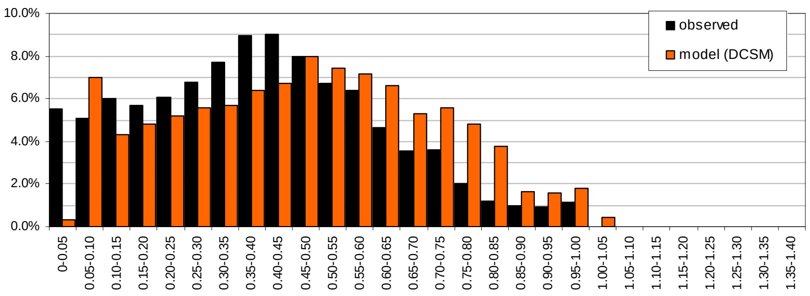
Verification of the CSM was achieved through a comparison of predicted current speeds against those synthesised from the in-situ measurements in 2008. The results of this analysis are presented in Figure 10 (for the CCSM) and in Figures 11 to 13 (for the DCSM) where the CSM predictions are shown as a thick orange line, while the measured values are shown as dark crosses. The time histories at location 4 are reproduced below from the CCSM for illustrative purposes.

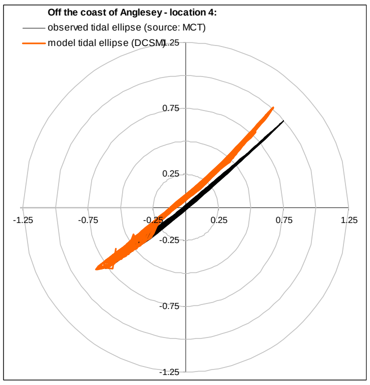


It is evident from Figure 10 that the resolution of the CCSM (c.1 km along the coasts) is too coarse to adequately resolve the peak velocities at the first and third locations (under-predict the ebb in one case and over-predict the flood in the other). This results in relatively poor current predictions at these two locations. Nonetheless, the resolution seems adequate at the second site (location 3), featuring smaller velocities and located outside of the turbulent region.

The agreement is much stronger at all three locations in the DCSM (Figures 11 to 13), where the model resolution (c.200 m at the coasts) allows a finer representation of the complex phenomena occurring in this region. The phase, amplitude and the asymmetry ebb / flood are all well represented in the DCSM, with the exception of the transitional period between spring and neap tides (approximately March 5th to March 9th 2010) when the ebb and flood peak velocities are generally over-predicted by a factor 1.3 at locations 2 and 4, and a factor of 1.1 at location 3. The time histories synthesised and predicted at location 4 are reproduced below for illustrative purposes. Given the overall agreement, it is reasonable to assume that the discrepancy noted at the transition from spring to neap tide can be attributed to unresolved harmonic constituents rather than to a model weakness.







The performance of the DCSM was also assessed in terms of current speed distribution and tidal ellipses, as illustrated above and shown in Figures 11 to 13. In these figures, the DCSM predictions are shown in orange and the observations in black. As concluded earlier from comparison of the tidal level time histories, the DCSM performance is very satisfactory at location 3, where the distribution of the currents is favourably reproduced and where their strength and direction are well predicted by the DCSM. The agreement is a little less positive at the other two locations where comparisons were performed. The over-estimation of the peak currents manifests as a skewing of the speed distributions toward higher speeds. However, the shape of the distributions are similar to the synthesised distribution, indicating that the DCSM has captured the correct flow behaviour in this highly energetic area. It is noted that the current directions are predicted to within 10°, which is generally considered acceptable.

4.2.3 Verification against velocity data from Thetis Energy Ltd

4.2.3.1 Data sources

In 2009 Titan Environmental Surveys Ltd carried out an extensive survey on behalf of *Thetis Energy Ltd* (Thetis) at a location within the Northern Ireland Strategic Zone 2. In particular, three bottom-mounted ADCP devices were deployed at pre-selected high energy sites (referred to as Sites 3, 4 and 5 following the survey specifications). The Site 3 ADCP mooring was deployed in shallow water for a little over 15 days. This is not considered suitable for tidal harmonic analysis. The Site 4 and Site 5 ADCP moorings, however, were installed in deeper water for approximately a month and a half, without interruptions in the records.

Although Thetis has agreed to share these data with HRW in the context of the CSM verification, the exact deployment locations and periods of the data presented in this section remain confidential and the property of Thetis. It is understood that the instruments were deployed such that they would capture the characteristics of the flow at the site of interest.

The ADCP devices were set to measure the current characteristics throughout the water column. The raw data were subsequently processed by HRW, shortly following the survey, to yield current speeds and directions at given elevations throughout the water column. The near-surface observations, readily available from previous analysis, were used to verify the CSM predictions. It is, however, noted that the close proximity of the deployment locations with respect to the coastline (approximately 1 km for Site 4, and 2 km for Site 5) may prove challenging to the CCSM because of the model resolution (1 km at best) and even to the DCSM because the complex bathymetry may not have been captured (200 m resolution at best).

4.2.3.2 Presentation of the CSM performance against Thetis velocity data

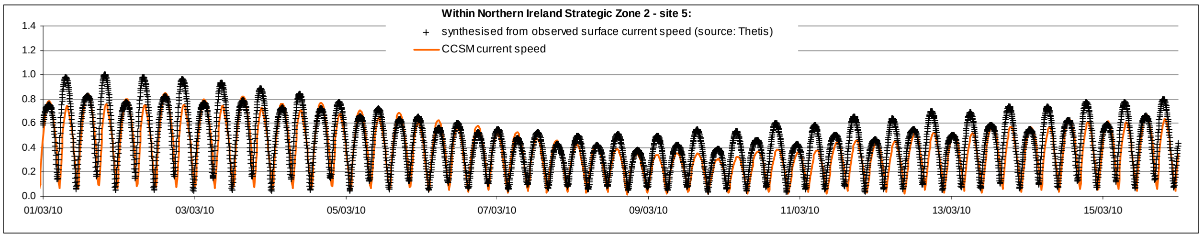
As with the velocity data obtained from MCT, those obtained from Thetis were not concurrent with the CSM verification period. Harmonic analysis was, therefore, performed (T_TIDE) to generate an extrapolated inferred record for the period adopted for the CSM verification exercise: March 1st to March 16th 2010. The re-constructed signal was then compared to the CSM velocity data for the same period.

It is noted that the results of the harmonic analysis cannot be presented in this document to preserve the intellectual property of the data owner.

For the same reasons, the analysis discussed in the following sections is always presented in terms of normalised values in an effort not to disclose absolute values. This was done by normalising the current speeds (or velocity components as appropriate) at each location with respect to the corresponding spring peak current speed synthesised for the verification period.

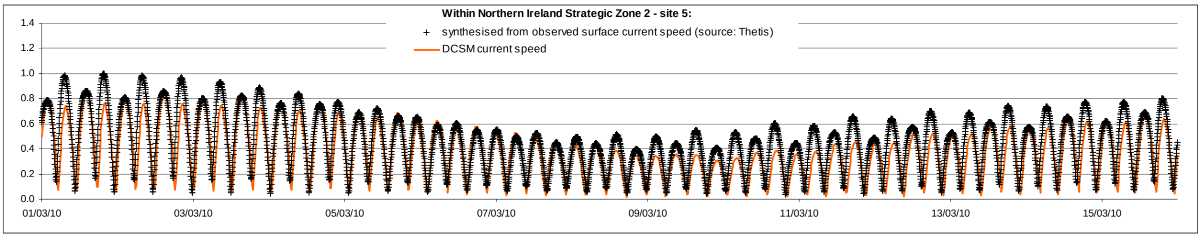
4.2.3.3 Discussion of the DCSM performance against Thetis velocity data

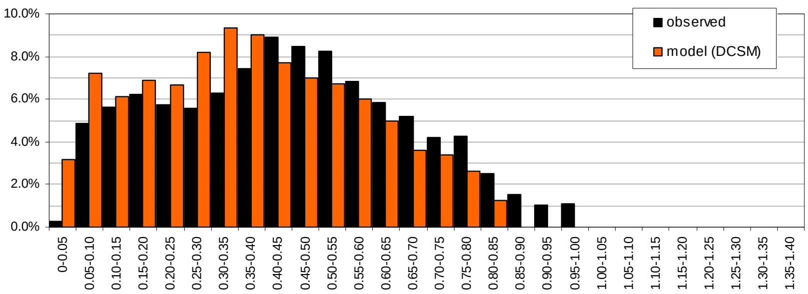
Verification of the CSM was achieved through a comparison of predicted current speeds against those synthesised from the in-situ measurements in 2009. The results of this analysis are presented in Figure 14 (for the CCSM) and in Figures 15 and 16 (for the DCSM) where the CSM predictions are shown as a thick orange line, while the measured values are shown as dark crosses. The time histories at the deeper location, Site 5, are reproduced below from the CCSM for illustrative purposes.

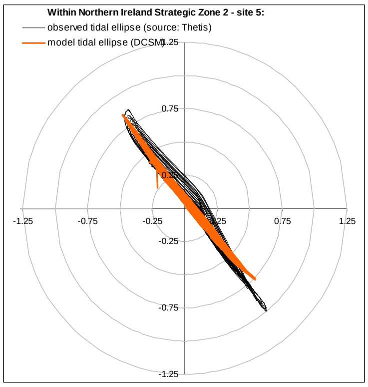


As was the case at the MCT locations, it appears as though the resolution of the CCSM (c.1 km along the coasts) is too coarse to adequately resolve the peak velocities: the model consistently under-predicts the current speeds both on the spring and neap cycles (Figure 14).

The agreement is better in the DCSM (Figures 15 and 16), where the model resolution (c.200 m at the coasts) should allow a finer representation of the complex processes in the region. Although the phase is reasonably well predicted, the asymmetry ebb / flood in the DCSM is not as pronounced as that observed in-situ, resulting in an under-prediction of the flood current speeds throughout the verification period, and particularly for springs. The time histories synthesised and predicted at Site 5 are reproduced below for illustrative purposes.







The performance of the DCSM was also assessed in terms of current speed distribution and tidal ellipses, as illustrated above and shown in Figures 15 and 16. In these figures the DCSM predictions are shown in orange and the observations in black. This analysis indicates that the overall distribution of the currents is satisfactorily reproduced at Site 5, as is the general direction of the currents. The under-prediction of the flood currents manifests there as a slight shift of the distribution towards lower values. The agreement is not as good at Site 4, where the distribution is generally skewed toward lower speeds (albeit of a similar shape) and the ebb direction is predicted to within approximately 10°. It may be that the Site 4 location is still too close to the shore and in too shallow water to be predicted accurately by either version of the CSM.

4.2.4 Verification against velocity data from the Coastal Observatory, Liverpool Bay

The Coastal Observatory, Liverpool Bay, holds *High Frequency Radar* (HF Radar) data for the Irish Sea, east of the Isle of Anglesey and the Isle of Man, south of Barrow-in-Furness (an area of approximately 1600 km^2). HF Radar uses radio-wave backscatter to map surface currents over wide swaths of coastal waters, up to 200 km off the shores.

The Irish Sea setup measured currents and waves for a period of 8 minutes and 52 s, every 20 minutes, from August 1st 2005 to December 6th 2011 when the experiment ended. Data were sent to the National Oceanographic Centre hourly, and processed monthly. Time history data are now available and can be downloaded from the Coastal Observatory website (Coastal Observatory, 2012). It is noted that from March 2007 onward, some cells were no longer processed as the beam angle was deemed too wide. No data exist for these cells after this date. The time reference for the data is not known.

In this project, data were first obtained at (53.927979°N, 4.035000°W) in approximately 40 m of water. These data cover the period from November 1st 2005 through to February 14th 2007.

Unfortunately there were frequent interruptions in the record, rendering tidal harmonic analysis impractical at this site (and others later investigated from the same source). The data source was therefore deemed not suitable and subsequently discarded for the purpose of the CSM verification exercise.

4.2.5 Verification against maximum tidal range atlases

The Atlas of the Seas around the British Isles (MAFF, 1981) gives a map of tidal range (in m) for a mean spring tide. The Atlas suggests that several amphidromic points exist within the area modelled in the CSM. Amphidromic points are shown to exist between Islay and Kintyre Peninsula in Scotland, off Wexford in the St George's Channel, between Weymouth and Portsmouth on the south coast of England, off East Anglia, and in the North Sea in general. It should be remembered that an amphidromic point is a point within a tidal system where the tidal range is close to zero (or zero for one or more of the major constituents).

It is apparent from Figure 21, showing the maximum (spring) tidal range predicted by the CCSM, that the model replicates these phenomena and the amphidromic points are located at the expected places. The regions with high tidal range (Morecambe Bay, the Severn Estuary, Mont St-Michel Bay and the Somme Estuary in France, and to a lesser extent The Wash and Humber Estuaries) are also well predicted by the CCSM, although the range is generally over-predicted by approximately 20%. This can be attributed to the fact that the CCSM was run for a period featuring a spring tide estimated to be approximately 20% above average (refer Section 4.1.1) when the Atlas is said to be representative of average spring tides.

It is also noted in Figure 21 that the general features are respected in the CCSM, such as the tidal range variations in the Irish Sea, or the tidal range differential in the Pentland Firth. This suggests that the CCSM should be able to predict velocities relatively accurately as well.

Despite this good result, slight differences are noted, notably in the patterns in the North Sea (which is not an area of interest in this project), north of the Orkney Islands, and in the Atlantic, west of Scotland. Some of these differences are not cause for concern in this project as these regions are far from potential tidal energy schemes, and could be explained by the fact that the Atlas relies on 30 year old data.

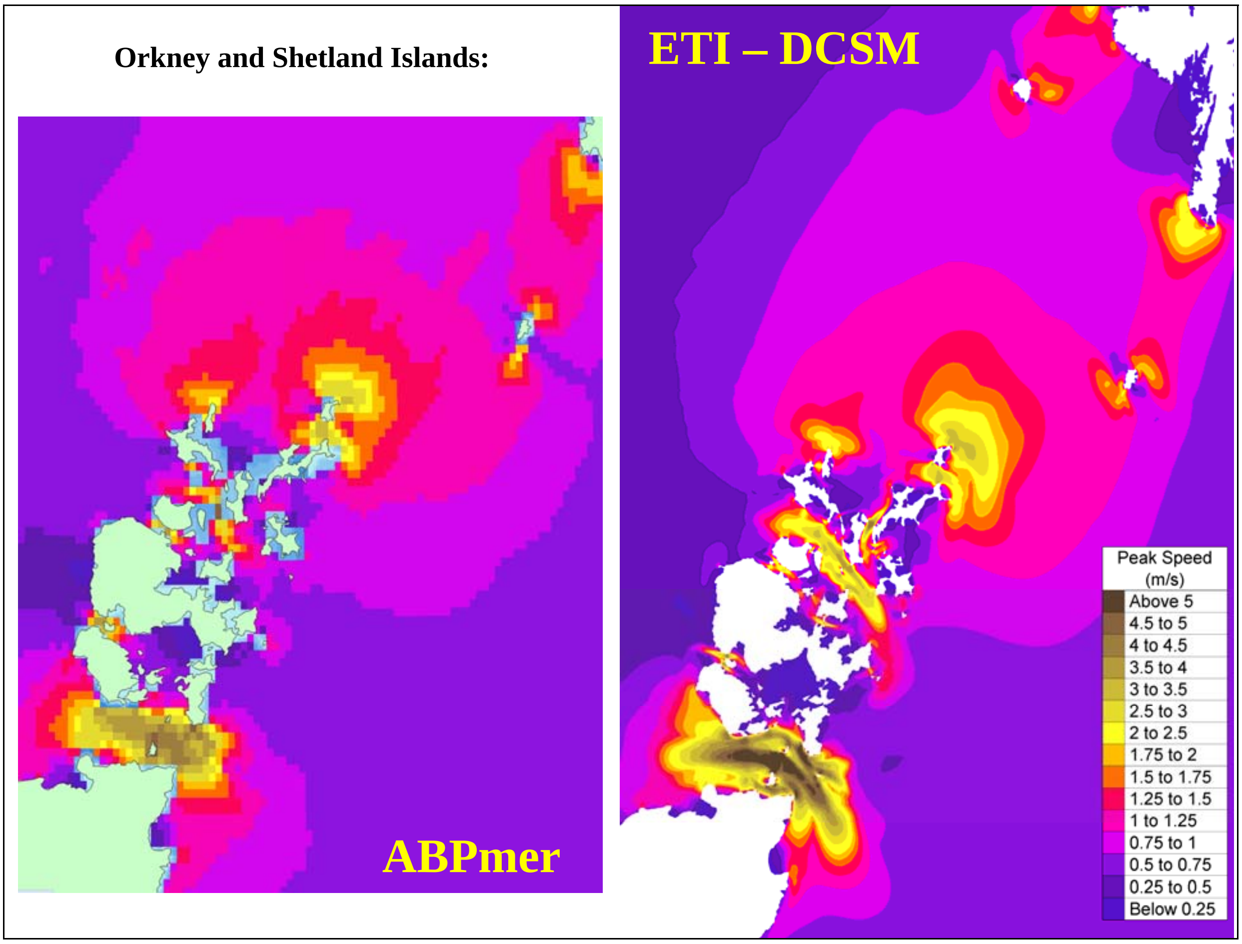
The results of the DCSM (Figure 22) are quantitatively similar to those of the CCSM, but it is noted that the tidal range of the above average peak spring tide is generally higher than that predicted by the CCSM (between 15% and 20% at Workington, Liverpool, Avonmouth, Dover and Immingham). Differences between the two resolutions of the CSM are not unexpected since the calibration parameter (friction map) differs as a result of differences in the resolution, and subsequently the definition of the bathymetry. Still, both versions of the CSM conform with the performance criterion (10% on N-RMSE) set out in Section 3.2.4.

4.2.6 Verification against peak current speed atlases

The Atlas of the Seas around the British Isles (MAFF, 1981) also gives a map of peak current speeds (in knots) for a mean spring tide. The CCSM and DCSM are able to predict most of the highly energetic areas, from the Pentland Firth, to the North Channel, the Skerries off Anglesey (Figures 21 and 22). It is, however, noted that the resolution of the Atlas does not allow a good discretisation of high energy areas where the current velocity varies rapidly with local bathymetry and position of the coastline.

A second Atlas (ABPMer, 2007) was therefore used to assess the performance of the CSM in terms of peak current speed predictions. This Atlas was developed from the existing UK Marine Renewable Energy Resources Atlas by a team led by *ABP Marine Environmental Research* (ABPMer). The charts in the Atlas represent the most detailed regional description of potential marine energy resources in UK waters to date at a national scale and are therefore a good dataset to compare the CSM performance against, even though the resolution of the Atlas is quite coarse compared to that of the CSM (and the DCSM in particular). It is noted that no reference is made, on the Atlas website, to the characterisation of the spring tide used in the analysis.

The results of this analysis are presented for the DCSM in the figures below with emphasis on two regions of interest: Orkney and Shetland Islands, and North Channel. In these figures the colour scheme used in the ABPMer Atlas was reproduced as closely as possible, by colour-picking individual codes from the Atlas website, to facilitate the comparison.

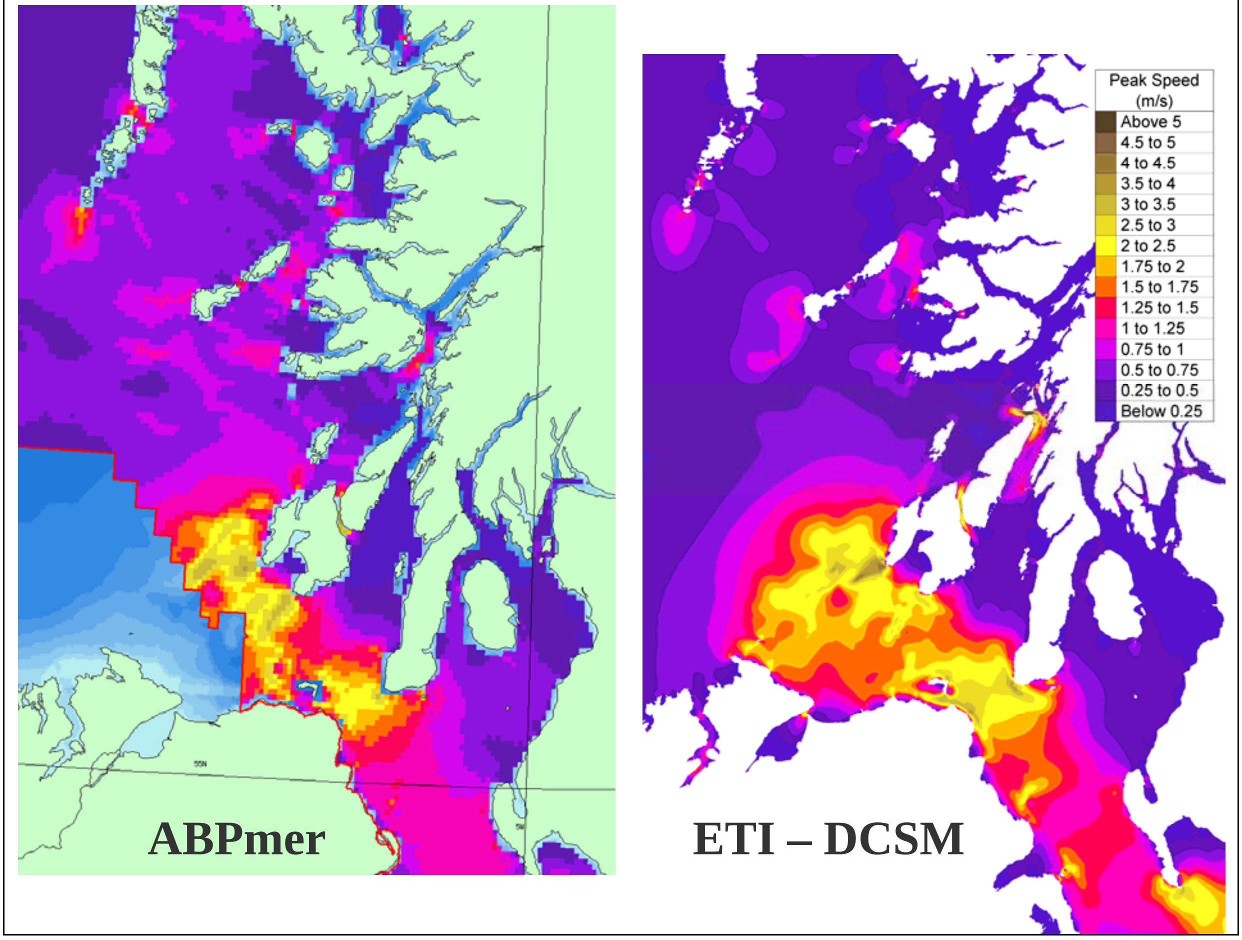


It is clear from the figures above that the DCSM and the Atlas are in broad agreement. As previously noted, however, the Atlas has a coarser resolution than the CSM, which does not allow a good representation of the Fall of Warness (Orkney Islands) for example. As a result the Atlas shows limited tidal resource in this area of known high current speeds.

Another area where the Atlas does not appear to perform as well as the CSM is the Outer Hebrides, around Barra Head, for which the current speeds appear to be over-predicted by the Atlas. This could be attributed to the absence of flow through the Southern Hebrides Islands, as a result of a coarse model resolution.

In the North Channel region, it is noted that the finer resolution of the DCSM yields better representation of the energetic area around and offshore the Copeland Islands, east of Bangor for instance. The Atlas appears to be poorer in these regions.

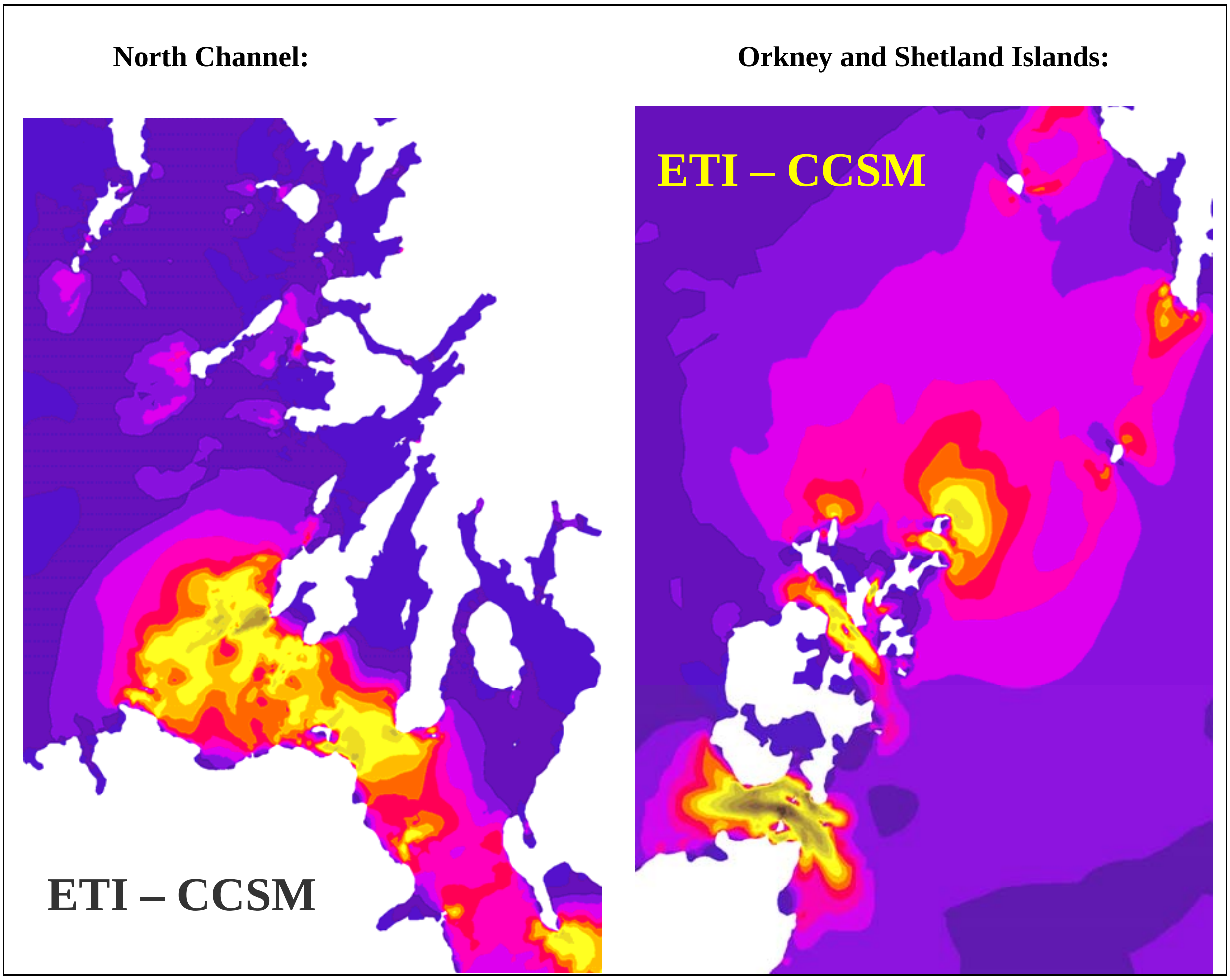
North Channel:



In general terms it is expected that the CSM provides a more refined definition of energetic areas and therefore predicts more well defined areas with higher velocities than the Atlas.

For comparison purpose, a capture of the peak current speeds for the same two regions above are provided below for the CCSM. In comparison to the ABPmer Atlas, results from the CCSM are closer to those of the DCSM, while highlighting only a marginally better resolution. However, just like the

ABPmer Atlas, the results from the CCSM shows that some of the narrow passages have not been resolved by the CCSM.



4.2.7 Verification against tidal phase atlases

The Atlas of the Seas around the British Isles (MAFF, 1981) also gives a map of contours, where each contour represents the time (in hours) at which the peak of the tide occurs. In agreement with the maps on tidal ranges, the Atlas highlights several amphidromic points.

It is apparent from Figure 19 and 20, that the CSM (CCSM and DCSM respectively) replicate relatively well the arrival times throughout the model area. This is particularly true of the St George's Channel (and to some extent of the Irish Sea), the English Channel including the Isle of Wight, and Orkney / the Shetland Islands (see 8, 9, 10 hr cotidal lines). The agreement is less satisfactory in Northern Ireland and in the North Sea but the location of the main amphidromic points there are reasonably predicted. The phase shift mentioned in previous sections is also apparent against this atlas along the eastern coast of England (shown as slightly over 1 hour in places, but it is expected that comparison against tidal gauge data, Sections 4.1.5.6 and 4.2.1.5, is more accurate).

It is noted that the values on the cotidal lines are relative to where the zero-time reference is chosen and that it may vary depending on sources. The lines themselves are, however, independent of the strength of the tide (high spring tide in this case).

The results of the DCSM are quantitatively similar to those of the CCSM although, generally speaking, the DCSM offers a better reproduction of the details of the cotidal lines.

4.3 Sensitivity analyses on the CSM

4.3.1 Sensitivity to model time stepping

As part of the CSM sensitivity analysis the use of different values for the time step was investigated until optimised values were reached. An optimised value is defined as the largest possible value that allows good convergence of the model for the resolution considered. For the CCSM, a value of 180 s was retained; 30 s for the DCSM.

These time steps are appropriate for the model resolution and the predicted current / tidal wave speeds (physical speeds). They are well below the performance criteria routinely used in the TELEMAC system (in particular with the use of the wave equation formulation, refer to Hervouet, 2007).

It is noted that the optimisation of the time step contributes to good performance of the CSM in terms of run times but that it is highly dependent on the size and the quality of the elements in the mesh.

4.3.2 Sensitivity to model resolution

In keeping with the specifications laid out in the CSM specification document, D02, sensitivity to model resolution is demonstrated through the comparison of the CCSM and DCSM predictions. As identified in the previous sections, the tidal levels predicted by the CCSM are very comparable to those predicted by the DCSM, with similar levels of performance and problem areas. However, the velocities predicted by the CCSM tend to be smoothed out (smaller) in comparison to those predicted by the DCSM. This is merely the result of differences in the models' resolutions.

Therefore, this gives confidence in the resolutions selected for the models. Both versions of the CSM can be expected to give similar predictions for future scenarios, ignoring the inevitable smoothing related to respective mesh resolutions.

It should be remembered that the purpose of the CCSM is primarily to provide preliminary impact assessment results for the entire Northern Europe continental shelf while remaining practical to use on a standard desktop computer; that of the DCSM is to provide more detail in areas of interest, at the expense of computational time. The DCSM, like the CCSM, however, remains a model of the entire Northern European continental shelf and should not be used in place of a refined local model when considering resources / impacts in specific areas.

4.3.3 Sensitivity to friction parameter

Tests were also performed to assess the sensitivity of the CCSM to the friction formulation and friction parameter. The results of the sensitivity analysis to the friction parameter are presented in this section; those for the friction formulation in Section 4.3.4.

It should be remembered that TELEMAC-2D allows bottom friction to be derived from several laws, whether a linear formulation, a Chézy formulation, a Strickler / Manning formulation, or using a Nikuradse roughness length formulation. A Chézy formulation was retained in this study, and so the use of different constant parameters (between 70 $m^{1/2}/s$ and 120 $m^{1/2}/s$) was investigated and compared to a reference value of 80 $m^{1/2}/s$.

Sensitivity of the CCSM to the friction parameter in the Chézy formulation is illustrated in Figures 17 and 18 in the form of difference plots showing the effect on the maximum tidal range predicted throughout the model area. Results are not reported for all the friction parameters, e.g. the 120 $m^{1/2}/s$

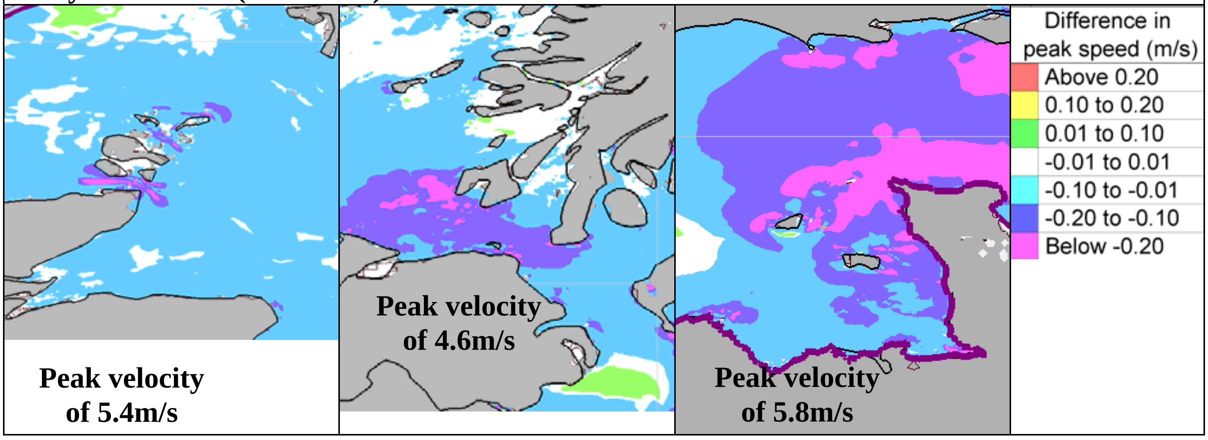
parameter, but it is noted that they were in line with observations drawn from the use of the other parameters.

Strikingly, the response is qualitatively similar for all the Chézy considered in this study. As anticipated a reduction in the Chézy (indicative of a rougher seabed, hence increased energy dissipation by friction) generally results in a reduction of the maximum tidal range. Likewise, an increase in the Chézy generally results in an increase in the maximum predicted tidal range. It is noted that the tidal range is modified throughout the model area as a consequence of the change in Chézy. Broadly speaking, however, the highest impact is felt in the English Channel (between the Isle of Wight and Harwich in England; Cherbourg and Brugge in Europe), in the Severn Estuary, and in the Irish Sea east of the Isle of Man.

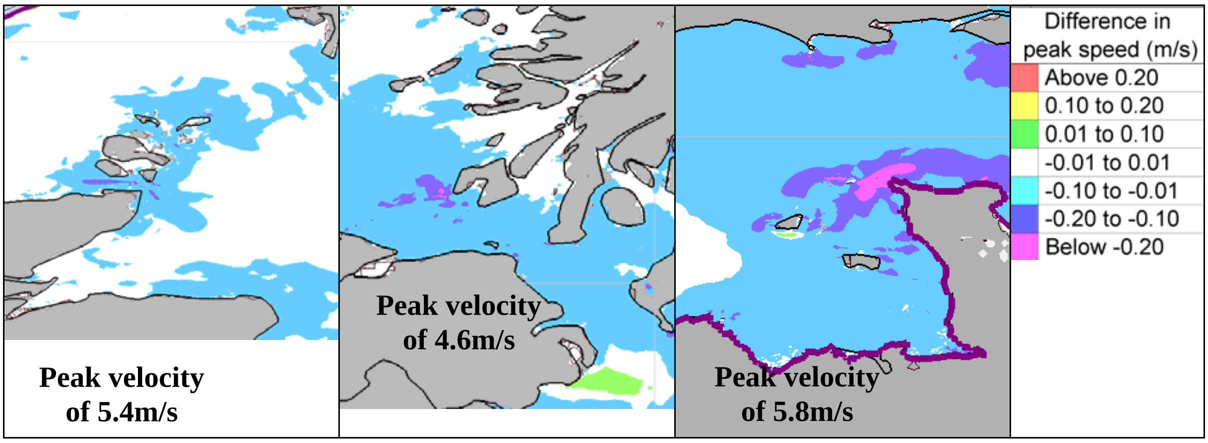
The tidal phase was also modified with the use of different friction parameters, as expected, but only marginally (not illustrated here). As such, there was no indication that friction alone could resolve the 45 min phase lag experienced along the east coast.

The results of the sensitivity analysis to friction parameter are also reported below for 3 highly energetic areas (Orkney, Islay and the Channel Islands from left to right) in terms of changes to the predicted peak current speed. As expected, it is shown that the friction parameter has a noticeable effect on the current speeds within the model area. In general terms, this makes it a parameter of choice to calibrate hydrodynamic models. It is, however, noted that these regions correspond to high energy areas and, as such, the relative effect on velocity is minimal.

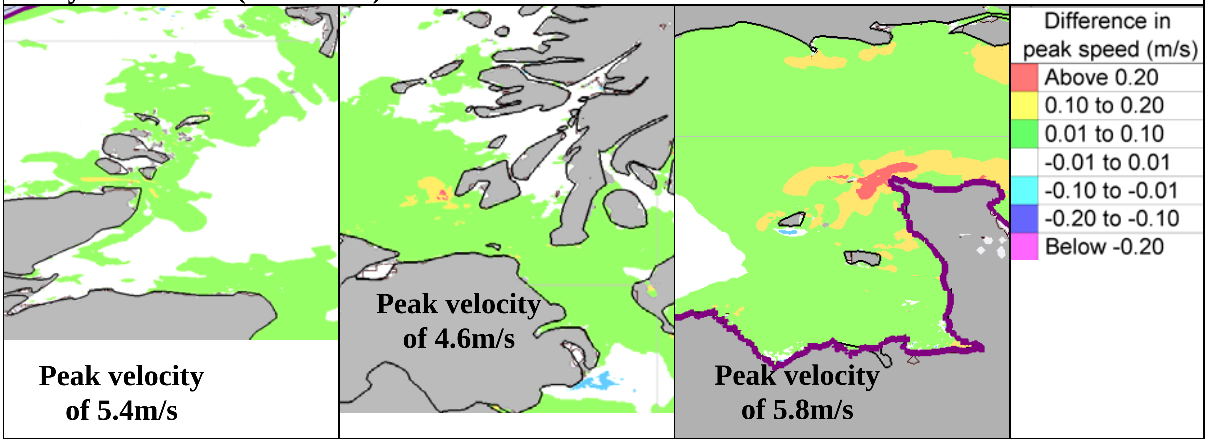
Chézy of 70 vs. 80 (calibrated):



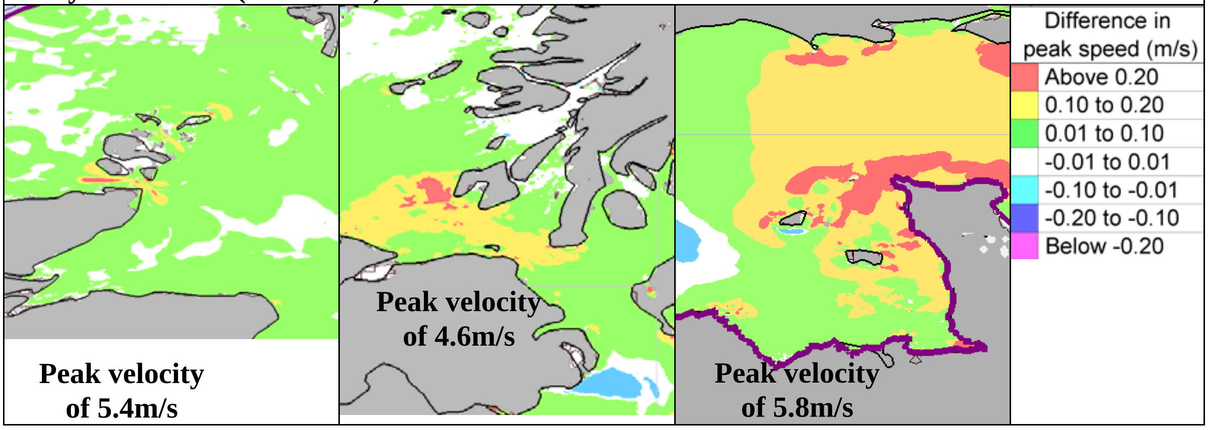
Chézy of 75 vs. 80 (calibrated):



Chézy of 85 vs. 80 (calibrated):



Chézy of 90 vs. 80 (calibrated):



4.3.4 Sensitivity to friction formulation

As part of the CSM sensitivity to friction, the use of a different formulation than that used to calibrate the CSM against was investigated. The Nikuradse formulation was considered for this purpose, with roughness lengths (a measure of the roughness of the seabed) ranging between 0.001 m and 0.1 m. The results of this analysis are presented in the table below for some of the parameters tested, for all the calibration and validation locations, in terms of the N-RMSE values for the water levels, and compared to a reference Chézy parameter of 80 m$^{1/2}$/s.

	Sites	Chézy (80 m$^{1/2}$/s)	Nikuradse (0.001 m)	Nikuradse (0.01 m)	Nikuradse (0.05 m)	Nikuradse (0.1 m)
Celtic Sea and Severn Estuary	RG, Celtic Sea	6%	6%	6%	6%	6%
	RD, Celtic Sea	8%	8%	8%	9%	9%
	Castletownbere – Ireland	6%	6%	6%	6%	6%
	Wexford – Ireland	8%	14%	10%	6%	6%
	Milford Haven – Wales	7%	6%	6%	7%	8%
	Hinkley Point – England	4%	5%	4%	5%	6%
	Avonmouth – England	2%	7%	4%	3%	5%
Irish Sea to Malin Sea	Malin Head – Ireland	3%	4%	3%	3%	2%
	Port Ellen – Scotland	6%	8%	7%	5%	5%
	RB, North Channel	8%	13%	11%	9%	8%
	Portpatrick – Scotland	7%	10%	8%	6%	6%
	Workington – England	5%	6%	5%	5%	5%
	Liverpool – England	4%	5%	4%	4%	4%
	Holyhead – Wales	6%	8%	7%	6%	6%
	RGE, Irish Sea	7%	9%	8%	7%	6%
English Channel	Newlyn – England	8%	7%	7%	7%	7%
	Bournemouth – England	11%	19%	18%	17%	16%
	Dover – England	4%	7%	5%	4%	4%
	Boulogne-sur-Mer – France	4%	6%	4%	5%	6%
	St. Helier, Jersey - Channel Islands	5%	3%	2%	4%	5%
	Brest – France	2%	2%	2%	2%	2%
Firths of Scotland and North Sea	Amelander-Westgat– Holland	10%	12%	10%	10%	11%
	Platform A12, North Sea	5%	9%	6%	5%	5%
	Platform J6, North Sea	5%	8%	6%	4%	4%
	Cromer – England	4%	6%	5%	5%	4%
	Immingham – England	3%	6%	5%	5%	4%
	RE, Western North Sea	5%	6%	6%	5%	5%
	RL, Western North Sea	6%	7%	6%	6%	5%
	Goteborg Torshamnen – Sweden	12%	14%	13%	12%	12%
	Stavanger – Norway	14%	17%	15%	14%	14%
	PJONSDAP,R56, North Sea	7%	10%	9%	8%	8%
	North Cormorant, North Sea	7%	8%	7%	7%	7%
	PJONSDAP,R53, North Sea	6%	7%	6%	6%	6%
	Wick – Scotland	5%	6%	5%	5%	5%
	Lerwick – Shetland Isles	3%	4%	4%	3%	3%

It can be seen from this table that a Nikuradse parameter value of 0.05 m yields the best overall agreement with observations across the model area. There are occasions (e.g. Hinkley Point) where a the use of other values is superior, but these are limited. The similarities in the N-RMSE values between a Chézy of 80 m$^{1/2}$/s and a Nikuradse of 0.05 m (generally within 0-2%, except at Bournemouth: 6% where the use of the Chézy formulation is superior) indicates that the choice of the friction law is not as important in TELEMAC-2D as the fine-tuning of the associated parameters.

4.3.5 Sensitivity to a parameter of the numerical scheme employed

One of the numerical parameters in the TELEMAC system which can be tuned is the so-called “free surface gradient compatibility criteria”. This parameter can be varied from 0 to 1 and sets the amount of filtering introduced to remove water surface wiggles where they occur (Hervouet, 2011). It is noted that this filtering can result in an artificial smoothing of the model predictions. The default value for the "free surface gradient compatibility criteria" is 1: no numerical filter.

In the case of the CCSM, this parameter was set to 0.9, which was found to be sufficient to render the CCSM more stable while avoiding significant artificial smoothing of the results. Nonetheless, a sensitivity to this parameter was carried out with higher values, 0.95 and 0.97 to verify that the value chosen does not introduce excessive smoothing.

This analysis demonstrates that, although the extent of the area where differences are noted is relatively large (generalised to the Celtic Sea, English Channel, Inner Seas off the west coast of Scotland and Atlantic north of Scotland), the tidal range is generally predicted to within 0.1 m of that in the base case scenario (parameter value of 0.9). Understandably, the extent is larger, the further the "free surface gradient compatibility criteria" parameter value departs from the base case value of 0.9. With a value of 0.97, the highest discrepancies are observed at Alderney and off Fishguard in Wales (up to +0.5 m and -0.5 m respectively at discrete locations).

The results of the sensitivity analysis to the numerical scheme are also reported in the table below, for all the calibration and validation locations, in terms of the N-RMSE values, and compared to a reference value of 0.9.

	Sites	**0.9**	**0.95**	**0.97**
Celtic Sea and Severn Estuary	RG, Celtic Sea	6%	6%	6%
	RD, Celtic Sea	8%	9%	9%
	Castletownbere – Ireland	6%	6%	6%
	Wexford – Ireland	8%	8%	8%
	Milford Haven – Wales	7%	7%	7%
	Hinkley Point – England	4%	4%	4%
	Avonmouth – England	2%	4%	4%
Irish Sea to Malin Sea	Malin Head – Ireland	3%	3%	3%
	Port Ellen – Scotland	6%	5%	6%
	RB, North Channel	8%	10%	10%
	Portpatrick – Scotland	7%	6%	7%
	Workington – England	5%	5%	5%
	Liverpool – England	4%	4%	4%
	Holyhead – Wales	6%	6%	6%
	RGE, Irish Sea	7%	7%	7%
English Channel	Newlyn – England	8%	7%	7%
	Bournemouth – England	11%	18%	18%
	Dover – England	4%	5%	5%
	Boulogne-sur-Mer – France	4%	6%	4%
	St. Helier, Jersey - Channel Islands	5%	3%	3%
	Brest – France	2%	2%	2%
Firths of Scotland and North Sea	Amelander-Westgat– Holland	10%	9%	10%
	Platform A12, North Sea	5%	5%	5%
	Platform J6, North Sea	5%	5%	5%
	Cromer – England	4%	5%	5%
	Immingham – England	3%	6%	5%
	RE, Western North Sea	5%	5%	5%
	RL, Western North Sea	6%	6%	6%
	Goteborg Torshamnen – Sweden	12%	12%	12%
	Stavanger – Norway	14%	13%	14%
	PJONSDAP,R56, North Sea	7%	9%	8%
	North Cormorant, North Sea	7%	7%	7%

	PJONSDAP,R53, North Sea	6%	6%	6%
	Wick – Scotland	5%	5%	5%
	Lerwick – Shetland Isles	3%	3%	3%

The similarities in the N-RMSE values between scenarios (within 0-2% except at Bournemouth: 7%) demonstrate further that the value of the "free surface gradient compatibility criteria" parameter (within a reasonable range) has little or no effect on the water levels predicted by the CCSM, and supports the value of 0.9 selected in this project for both the CCSM and DCSM.

It is noted that the default value of 1 created oscillations close to the edge of the continental shelf.

4.3.6 Sensitivity to turbulence model employed

In the same way that friction is represented, another set of numerical parameters can be tuned to represent the physical process of turbulence. Three laws were tested in the CSM: (a) a constant viscosity (Cst); (b) the Elder turbulence model; and (c) the Smagorinski turbulence model. More information on turbulence in the TELEMAC system can be found in the theoretical and scientific documentation prepared under D06 Part A.

The results of this analysis are reported in the table below for the CCSM, for all the calibration and validation locations, and in terms of the N-RMSE values for the water levels.

	Sites	Cst	Elder	Smago.
Celtic Sea and Severn Estuary	RG, Celtic Sea	6%	6%	6%
	RD, Celtic Sea	8%	9%	9%
	Castletownbere – Ireland	6%	6%	6%
	Wexford – Ireland	8%	8%	8%
	Milford Haven – Wales	7%	7%	7%
	Hinkley Point – England	4%	4%	4%
	Avonmouth – England	2%	4%	4%
Irish Sea to Malin Sea	Malin Head – Ireland	3%	3%	3%
	Port Ellen – Scotland	6%	6%	6%
	RB, North Channel	8%	10%	10%
	Portpatrick – Scotland	7%	7%	7%
	Workington – England	5%	5%	5%
	Liverpool – England	4%	4%	4%
	Holyhead – Wales	6%	7%	6%
	RGE, Irish Sea	7%	7%	7%
English Channel	Newlyn – England	8%	7%	7%
	Bournemouth – England	11%	18%	18%
	Dover – England	4%	5%	5%
	Boulogne-sur-Mer – France	4%	4%	4%
	St. Helier, Jersey - Channel Islands	5%	3%	3%
	Brest – France	2%	2%	2%
Firths of Scotland and North Sea	Amelander-Westgat– Holland	10%	10%	10%
	Platform A12, North Sea	5%	5%	5%
	Platform J6, North Sea	5%	5%	5%
	Cromer – England	4%	5%	5%
	Immingham – England	3%	6%	6%
	RE, Western North Sea	5%	5%	5%
	RL, Western North Sea	6%	6%	6%
	Goteborg Torshamnen – Sweden	12%	12%	12%
	Stavanger – Norway	14%	14%	14%
	PJONSDAP,R56, North Sea	7%	8%	8%
	North Cormorant, North Sea	7%	7%	7%

	PJONSDAP,R53, North Sea	6%	6%	6%
	Wick – Scotland	5%	5%	5%
	Lerwick – Shetland Isles	3%	3%	3%

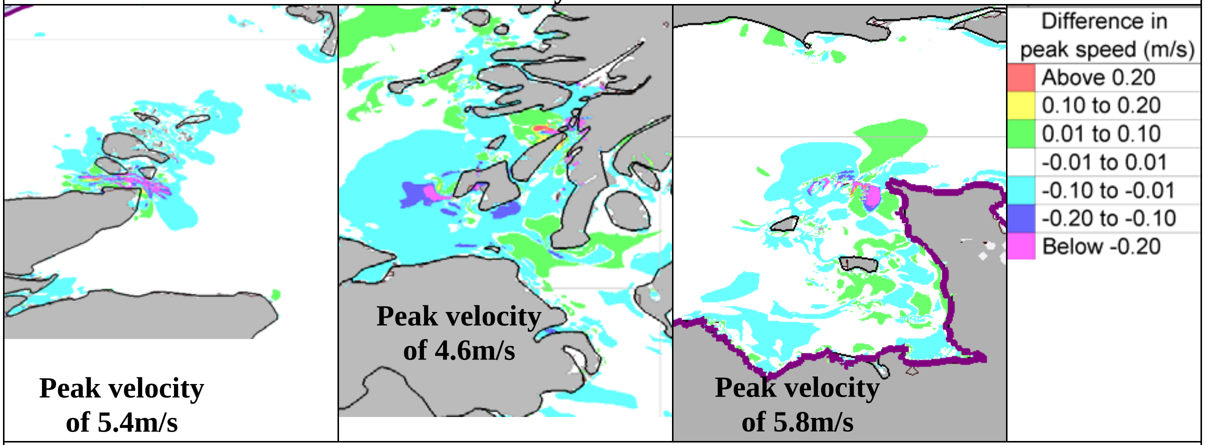
The similarities in the N-RMSE values between scenarios (within 0-2%, except at Bournemouth: 7%) demonstrate that the turbulence law has little or no effect on the water levels predicted by the CCSM. This can be explained by the fact that the model resolution is too coarse to represent accurately small sub-element effects such as turbulence. Using the Elder turbulence model results in marginally stronger tidal currents (by up to 0.1 m/s) in the Mont St Michel Bay and around the Channel Islands, and marginally weaker currents in the North Channel and the Pentland Firth, between Orkney and mainland Scotland (by up to -0.1 m/s). Similar observations can be made with the Smagorinski turbulence model but the area of influence extends to the Fall of Warness, for example.

Because of the limitations in the resolution of the CCSM, the same tests were repeated with the DCSM. The results of this additional analysis are reported in the table below in the same form.

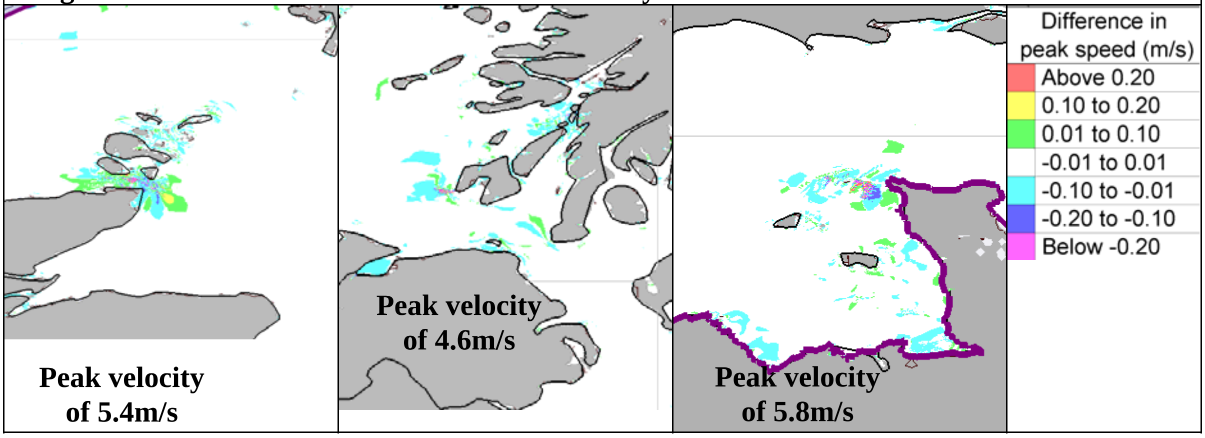
	Sites	**Cstt**	**Elder**	**Smago.**
Celtic Sea and Severn Estuary	RG, Celtic Sea	4%	4%	4%
	RD, Celtic Sea	7%	7%	7%
	Castletownbere – Ireland	3%	3%	3%
	Wexford – Ireland	11%	12%	11%
	Milford Haven – Wales	5%	5%	5%
	Hinkley Point – England	4%	4%	4%
	Avonmouth – England	5%	5%	5%
Irish Sea to Malin Sea	Malin Head – Ireland	3%	3%	3%
	Port Ellen – Scotland	5%	5%	5%
	RB, North Channel	10%	10%	10%
	Portpatrick – Scotland	7%	7%	7%
	Workington – England	4%	4%	4%
	Liverpool – England	5%	5%	5%
	Holyhead – Wales	6%	6%	6%
	RGE, Irish Sea	7%	7%	7%
English Channel	Newlyn – England	6%	6%	6%
	Bournemouth – England	15%	15%	15%
	Dover – England	7%	7%	7%
	Boulogne-sur-Mer – France	4%	4%	4%
	St. Helier, Jersey - Channel Islands	3%	3%	3%
	Brest – France	3%	3%	3%
Firths of Scotland and North Sea	Amelander-Westgat– Holland	12%	12%	12%
	Platform A12, North Sea	8%	8%	8%
	Platform J6, North Sea	8%	9%	8%
	Cromer – England	7%	7%	7%
	Immingham – England	7%	7%	7%
	RE, Western North Sea	7%	7%	7%
	RL, Western North Sea	7%	7%	7%
	Goteborg Torshamnen – Sweden	11%	11%	11%
	Stavanger – Norway	13%	13%	13%
	PJONSDAP,R56, North Sea	7%	7%	7%
	North Cormorant, North Sea	5%	5%	5%
	PJONSDAP,R53, North Sea	8%	8%	8%
	Wick – Scotland	7%	7%	7%
	Lerwick – Shetland Isles	4%	4%	4%

Again, the results are virtually identical between scenarios (generally within 1%, even at Bournemouth where the refined resolution of the DCSM lessens discrepancies across scenarios), demonstrating that the turbulence law has little or no effect on the water levels predicted by the DCSM. Some effect is, however, noted on the tidal currents as illustrated in the figures below, where the changes to the predicted peak current speed are compared to the constant viscosity model . With the Elder turbulence model, the area of influence is generalised to shallow waters (± 0.2 m/s) in the DCSM, with markedly higher discrepancies at high velocity tidal current sites such as the Pentland Firth (up to -2.0 m/s at a few concentrated locations), west of Islay (up to -1.5m/s at a few concentrated locations) and Alderney (up to -1.0 m/s, again, at a few concentrated locations). The same observations are true of the Smagorinski turbulence model at sites of interest, but the area of influence is considerably reduced, only local to the Mont St Michel Bay / Alderney, the North Channel and Scottish Sounds, Orkney Islands and the Pentland Firth in particular.

Elder turbulence model vs. constant viscosity model:



Smagorinski turbulence model vs. constant viscosity model:



The Elder turbulence model was subsequently used in the DCSM predictions on the grounds that this model is the most commonly used at HRW. Observed velocity data in key areas would be required to confirm the model predictions with one turbulence scheme or the other.

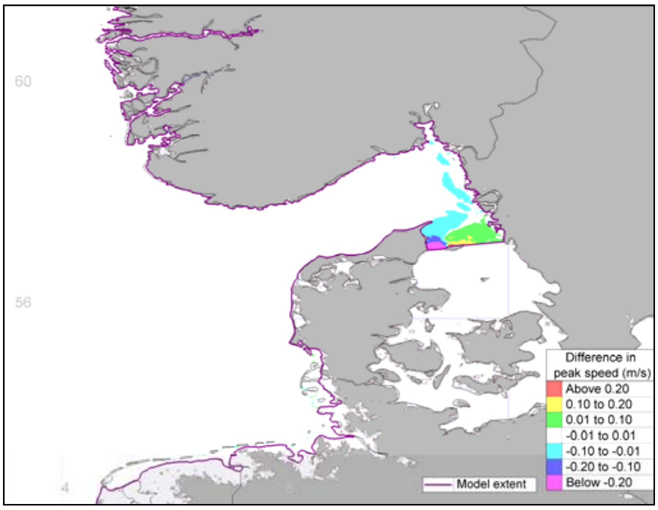
4.3.7 Sensitivity to discharges

Tests were also performed to assess the sensitivity of the CCSM to discharge flows imposed in the Thames, and from the Baltic Sea (in addition to the tidal boundary defined there in the CSM).

A discharge of 65 m^3/s imposed upstream of the Thames resulted in differences in peak current speed lesser than 1 cm/s in the Estuary and outside of the mouth.

A discharge of 2,000 m^3/s, corresponding to an annual mean discharge, imposed through the Kattegat, between Denmark and the island of Læsø, resulted in the differences shown in the figure opposite.

In this figure, differences in current speeds lower than 1 cm/s are identified in white. It is clear that the effects are very local to the Kattegat and are not noted in the Skagerrak, or further out in the North Sea. The maximum difference is predicted at approximately 0.55 m/s.



4.3.8 Sensitivity to tidal force

A final test was carried out in the CCSM to identify the sensitivity of the model to the implementation of the tidal force (an optional extra term in the momentum equation of the TELEMAC system, distinct from tidal boundary forcing, much like Coriolis is an extra term). It has been shown in other studies, and was demonstrated again in this study, that this term has little effect on the model predictions. Its implementation mostly manifests here as a minimal reduction in tidal range, of up to 0.1 m, in the Irish Sea, the Severn Estuary, part of the English Channel, the Wash and the seas north of Inverness in Scotland.

5 KEY FINDINGS

- The CCSM resolution has been improved compared to the model specifications, and the anticipated total number of computational points more than tripled as a consequence. This has direct implications on the expected accuracy of the model predictions.

- In addition to the anticipated navigation charts (resolution of Level 1, 2, 3), it was necessary to purchase Level 4 and Level 5 charts in certain areas to provide further details in key areas included within or close to the selected Sites of Interest (e.g. the Mersey Estuary or the Thames Estuary). It is noted that other sites would benefit from higher resolution bathymetry data to fully define them and this is recommended for consideration at a later stage as a means to improve the model predictions (in the period of the project covered by the 'fee for service' agreement).

- Data scouring around the UK and within the model area of the CSM identified more than one hundred observation stations providing suitable tidal gauge data. 35 stations were used in the CSM calibration and validation exercise (c.f. the 20 originally planned). The remainder of the data, if used for model verification, would provide further understanding of the accuracy of the CSM and its findings. Suitable sources of velocity data were also identified in this project, as a result of previous work carried out by HRW in highly energetic regions. These data were obtained from MCT (off Anglesey) and Thetis Energy (within the Northern Ireland Strategic Zone 2).

- The CSM was calibrated at a global level, whereby it was expected that the model performed well (target deviation from observed tidal levels of 10% on N-RMSE values) at all the calibration sites, globally. The calibration was first carried out based on a single Chézy friction value for the whole model extent, before being further refined into just 4 zones.

- The CSM performs well against observed level and velocity data in key areas of interest. The two versions of the CSM generally compare to within 1%-2% on water levels (overall N-RMSE) despite significant differences in their resolution. This gives confidence in the resolution selected for the models and their specification. Therefore, both versions of the CSM can be expected to give similar predictions for future scenarios. The principal measure chosen in this study (N-RMSE) is indeed more stringent than that imposed on the peak tidal range alone, as it assesses the CSM performance against observations throughout the whole 15-day period.

- The CSM also compares favourably against published tidal atlases of the UK waters, in particular the existing UK Marine Renewable Energy Resources Atlas. It is noted that the DCSM resolution generally is 100 times finer than that of the Atlas in coastal zones and areas of interest. Consequently, it provides a better definition of the high energy areas of interest in this study.

- It is recommended that the CCSM be used for high level tidal range and broad tidal current investigations, and the DCSM for tidal current schemes, as the greater resolution predicts tidal currents (and spatial variability thereof) more accurately, and detailed site investigations into tidal range schemes, as more detailed bathymetry can be incorporated in the model.

- Computing time for the CCSM is under 15 minutes on a 12-core desktop computer and under 3 hours on a standard multi-core desktop computer. That for the DCSM is under 1.5 hour on an 8 12-core blade cluster. This allows simulations to be run efficiently and could open the way for parameter estimation and optimisation and ultimately for uncertainty analysis.

6 CONCLUSIONS AND CSM EXPLOITATION

In accordance with the agreed scope of work and acceptance criteria, two models have been developed and calibrated/verified: one coarse-resolution model (CCSM) and one detailed-resolution model (DCSM) of the UK waters. The DCSM is capable of performing detailed scenario simulations over 15 days within 1.5 hour, well below the target specification of 12 hours on high performance computing resources. The CCSM is capable of performing scenario simulations over 15 days within 3 hours, below the target specification of 4 hours on a standard desktop computer.

This report includes discussion of the results of the calibration and validation exercise. This analysis indicated that the CCSM predictions are virtually always within 10% of observed water level data (exceptions: Bournemouth, Goteborg Torshamnen (Sweden) and Stavanger (Norway)). The DCSM predictions are always within 10% of observed water level data. This is in accordance with performance targets set out in Section 3.2.4. It is noted that the CSM predictions along the east coast of England consistently lag by 45 minutes compared to observations. This is not considered to have an important impact on tidal range or tidal current energy scheme applications, although needs to be borne in mind in any later potential optimisation related to smoothing tidal energy production.

Verification of the CSM against observed velocity data obtained at two discrete locations for tidal current, and against published atlases of the UK waters (maximum tidal range and peak speeds) shows good overall agreement. It is noted that the finer resolution of the CSM (10 times for the CCSM and 100 times for the DCSM) compared to the existing UK Marine Renewable Energy Resources Atlas makes the initial results of the CSM (without any tidal energy schemes implemented) far more suitable to the tidal energy industry, as it provides a better definition of the high energy areas of interest. Furthermore, the fact that the ETI and the industry can later use the models themselves to assess scenarios is of course a major benefit.

The sensitivity analysis, performed primarily on the CCSM, indicated that bottom friction has the most significant impact on the model predictions. In general terms, the other parameters tested in this study (numerical scheme, turbulence model, discharge rate and tidal force) proved to have little impact on the model predictions although it is noted that the turbulence model has a noticeable effect on the predicted current speeds. In the absence of observed velocity data in many sites of interest to calibrate the CSM against, it is difficult to discard (or favour) one formulation over the other. It should be noted that bathymetry often has a predominant effect on model predictions. This observation draws from extensive previous experience with hydrodynamic models.

Overall, it is considered that the Continental Shelf Model of the UK waters developed in this study is robust and will fulfil the objectives set by the ETI, which aim to answer the following questions:

1. How will the interactions between tidal range and tidal stream systems positioned around the UK’s waters combine to form an overall effect?
2. Will the extraction of tidal energy resource in one site impact the tidal energy resource at distant sites around the UK and Europe?
3. What constraints might these interactions place on the design, development and location of future systems?

It is noted that the D08 and D09 scope of work is to provide a *Detailed Tidal Range Model* (DTRM). The correlation of the DTRM with the CSM is dependent on the final extent of the DTRM selected during scoping of D08. The extent of the DTRM is dependent upon the end use of the model. For simple technology checks, a small extent out to the mouth of an estuary would be sufficient to provide a tool for looking at technology behaviour, where tidal behaviour within the estuary did not have to be representative. For site specific consideration and optimisation of a location, the DTRM should be as large as possible to consider the water movements entering the sea, channel and finally the estuary in question as well as to consider the regional / international extent of the impact of the tidal energy schemes tested. In the latter case, the deciding factor with regard to the extent of the DTRM will be the available computing capacity for users. The larger the DTRM the closer the alignment to / duplication with the DCSM. In addition, should a range of estuaries be , ideally, looked at in detail by the user it may be most sensible to refine the DCSM in these estuaries rather than limiting the user to a single estuary in the DTRM. During Project Review meeting 1, it was planned that discussions with principal interested parties (Rolls Royce in particular) would be organised to define the requirements of the primary users of the DTRM. This could potentially lead to a change in scope for D08 and D09 and an associated variation request.

GLOSSARY

0-d model – zero-dimensional / flat estuary model. A 0-d model uses only two water levels (sea level and basin level). Sea level is a user defined input and, as such, the effect of barrage operations on sea levels is not represented. The basin level is calculated assuming that the water level upstream of the impoundment line is uniform.

1-d model – one-dimensional model. A 1-d model represents water levels in an estuary using a series of cross-sections. Hence water levels can vary moving upstream or downstream from the impoundment line but levels are uniform across the estuary. This means that the effect of a barrage/lagoon on downstream sea levels is represented to some extent.

2-d model – two-dimensional model. A 2-d model uses a mesh or grid to represent the sea and coastline. Water levels can vary both parallel and perpendicular to the coastline. As such, a 2-d model represents the constriction and expansion as water flows into and out of the basin, through the turbine and sluice caissons.

ADP – Acoustic Doppler Profiler.

AEP – Annual Energy Production.

Barrage – an impoundment line across an estuary comprising embankment, turbines and usually sluices. Electricity is generated by creating a water level differential across the barrage between the impounded basin and the open sea. Barrages and (coastal) lagoons are similar.

Basin – the impounded area, usually landside, within the barrage/lagoon alignment.

Cavitation – the formation and immediate implosion of cavities in water as it passes through turbines. Cavitation can cause significant damage to turbines and is prevented by providing adequate submergence (installing the turbines deep enough below low tide level).

CCSM – Coarse Continental Shelf Model.

CD - Chart Datum. This is the datum used to show levels on Admiralty charts and usually corresponds to lowest astronomical tide level.

CoE – Cost of Energy.

Cp – Device coefficient of performance, i.e. mechanical efficiency at which the device extracts energy from the incoming flow.

DCSM – Detailed Continental Shelf Model.

Dual mode generation – power generation on both the ebb and flood tides.

Ebb tide – the seaward flow of water as the tide level falls.

Embankment – an artificial bank used to intercept and prevent the passage of water, forcing it through the turbine and sluice caissons whilst they are open.

Energy yield – the amount of energy generated by a scheme, usually quoted as an annual total in watt hours.

Flood tide – the landward flow of water as the tide level rises.

Free-wheeling – when turbines are not generating power but the turbine passage is kept open, which aids filling and emptying of the basin.

Generator capacity – maximum power output from each turbine unit, which usually includes an allowance for generator losses applied to the raw turbine power output.

GW – gigawatt, unit of power equal to one billion (10^9) watts.

GWh – gigawatt hours, unit of energy equal to one billion (10^9) watt hours. For constant power, energy in watt hours is the product of power (in watts) and time (in hours).

HAA – Horizontal Axis Axial flow turbine.

HAC – Horizontal Axis Cross flow turbine.

HC – Hydraulic current system.

Head – the hydraulic head, which is equal to the elevation plus velocity head (v2/2g), where v is velocity and g is gravitational acceleration. Head is often used meaning the total head difference (energy loss) across the barrage/lagoon structure.

Headloss – loss of energy experienced by the water flow as it moves through a constriction. Headlosses will occur as water passes through turbines and sluice gates channels or where bed levels are shallow.

Hill chart – turbine performance chart relating head, flow and efficiency, usually shown in non-dimensional form.

Impoundment length – the total length of the barrage/lagoon alignment including embankments, turbine and sluice caissons.

Installed capacity – the total peak power output of the turbine generators (equal to number of turbines multiplied by unit generator capacity).

Intertidal area – seabed of estuary or coastline exposed at low tide but submerged at high tide.

Lagoon (coastal) – similar to a barrage except that the impoundment line can be connected to any coastline rather than specifically across an estuary. A lagoon, therefore, will usually require a longer embankment than a barrage to give the same impounded area.

Lagoon (offshore) – an impoundment that is not connected to the coastline. An offshore lagoon must, therefore, be enclosed on all sides by an artificial embankment.

MAE – Mean Absolute Error

MHWS – Mean High Water Springs
The height of Mean High Water Springs is the average, throughout a year, of the heights of two successive high waters during those periods of 24 hours (approximately once a fortnight) when the range of the tide is greatest.

MLWS – Mean Low Water Springs

The height of Mean Low Water Springs is the average, throughout a year, of the heights of two successive low waters during the same periods.

MSL – Mean Sea Level.

MW – megawatt, equal to one million (10^6) watts.

MWh – megawatt hours, unit of energy equal to one million (10^6) watt hours.

N-RMSE – Normalised Root Mean Square Error, obtained by normalising the RMSE using the higher of the maximum tidal range at the location and 1 m.

Outages – times when turbines are unavailable for power generation. This may be due to routine maintenance or malfunction of some or all of the turbines.

PD – Power Density.

Pmax – The maximum total mean power harvested across the tidal cycle considered for a specified tidal system.

Practical Resource – The energy (which is a proportion of the technical resource) that can be harvested after consideration of external constraints (e.g. grid accessibility, competing uses such as MOD, shipping lanes, etc.). This level of assessment fundamentally requires detailed project design and investigation on a case-by-case basis. The practical resource is hence a proportion of the technical resource.

Qmax – The mean of the local maximum volume fluxes (m^3/s) for a particular tidal system over the tidal cycle considered.

Rated head – the lowest head difference across the turbines for which the power output is equal to the generator capacity.

RES – resonant (basin) system.

RMSE – Root Mean Square Error

Runner – the rotating part of a turbine. Energy is transferred from the water flowing through the turbine by the force on the turbine blades spinning the runner and driving the turbine generator.

SNR – Signal to Noise Ratio. This is a measure of the relevance of the tidal constituents extracted by harmonic analysis of a water level or velocity record. It is generally considered that constituents with a Signal to Noise Ratio lower than 2 should be discarded.

SoI – The sites of interest, which group both tidal current energy schemes and to tidal range energy schemes.
The tidal current sites are: (a) Around the Orkney Islands: north of the North Ronaldsay Firth and the North Ronaldsay Firth itself, the Westray Firth and the deeps and shallows of the Pentland Firth; (b) Within the North Channel: west and south of Islay and the Mull of Oa, Rathlin Island, the Mull of Kintyre and the Mull of Galloway; (c) In the Irish Sea: west of Carmel Head and west of Ramsey Island; (d) In the Bristol Channel: Minehead; (e) On the south coast of England: south of the Isle of Wight; (f) Around Alderney: east and west of Casquets and the Race of Alderney; and (g) Around Jersey: north-east and south of Jersey and south of Minquiers.
The tidal range sites are: (a) In the Irish Sea: Wigtown Bay, the outer and inner the Solway Firth, the

Cumbria Lagoon south of St Bees, the Duddon Estuary, Morecambe Bay, the Dee Estuary and around the Wirral and the Mersey Estuaries; (b) In the Bristol Channel: Oxwich Bay, Morte Bay, the outer and inner Severn Estuary, the Cardiff-Weston alignment, Bridgewater Bay, south of Rhoose and south-west of Aberthaw; (c) Around Dover: Dymchurch Bay and Rye Bay; (d) In the Thames Estuary, the inner and outer Thames Estuary; and (e) On the east coast of England: the Wash and the inner and outer Humber Estuary.

TEC – Tidal Energy Converter, a device which captures energy from tidal currents.

Technical Resource – The energy that can be harvested from tidal currents using envisaged technology options and restrictions (including project economics) without undue impact on the underlying tidal hydrodynamic environment. The technical resource is hence a proportion of the theoretical resource.

Theoretical Resource – Maximum energy that can be harvested from tidal currents in the region of interest without consideration of technical, economic or environmental constraints.

Tidal Current – where Tidal Stream is referred to in the Scope of Works it is replaced with Tidal Current within the Tidal Resource Modelling reporting. This is due to a general acceptance that there are three hydraulic mechanisms which, combined, accurately define the hydraulics. Tidal Stream is one of the three hydraulic mechanisms, therefore to complete the Tidal Resource Modelling credibly and accurately, Tidal Current will be used and referred to.

Total Resource – Total energy that exists within a defined tidal system.

TS – Tidal streaming.

TW - terawatt, equal to one trillion (1012) watts.

TWh – terawatt hours, unit of energy equal to one trillion (1012) watt hours.

Vmnp (m/s) – Mean neap peak velocity as defined by the Admiralty charts for a particular site, 5 m below the surface.

Vmsp (m/s) – Mean spring peak velocity as defined by the Admiralty charts for a particular site, 5 m below surface.

Vrated (m/s) – Rated velocity of tidal stream device. Rated velocity is the velocity at which the device reaches maximum (rated) output.

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MIKE C-MAP, Version 9.0.1020 and C-Map's 93.3 database. Copyright © 2002 DHI Water & Environment. Copyright © 2002 C-Map Norway.

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FIGURES

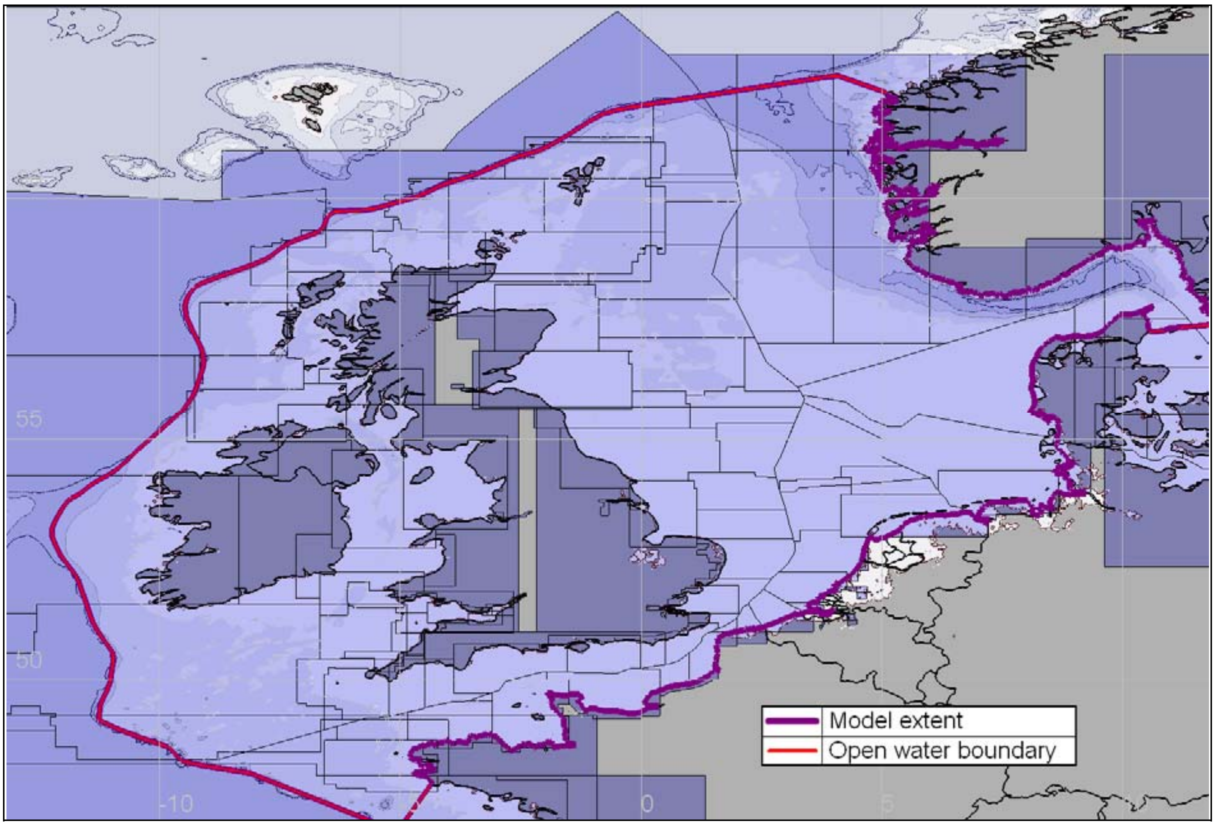

Figure 1 Coastal Shelf Model extent and outlines of navigation charts included in the CSM

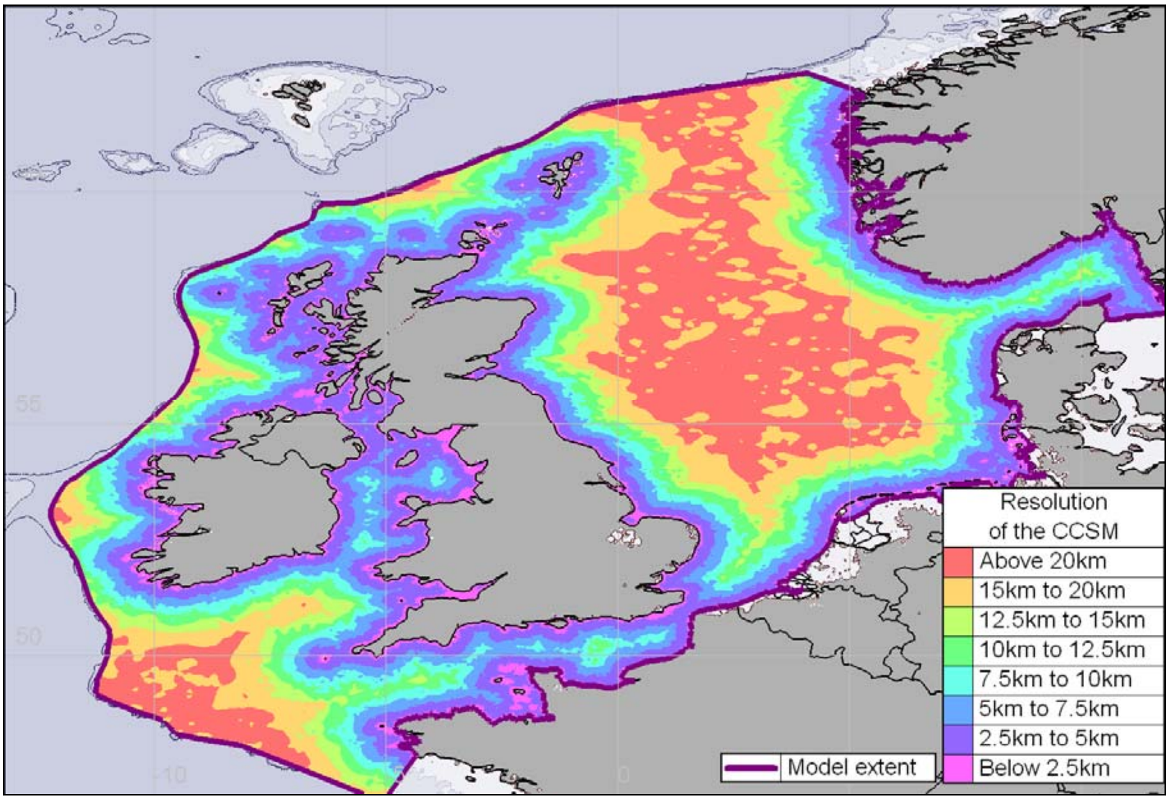

Figure 2 Resolution of the CCSM

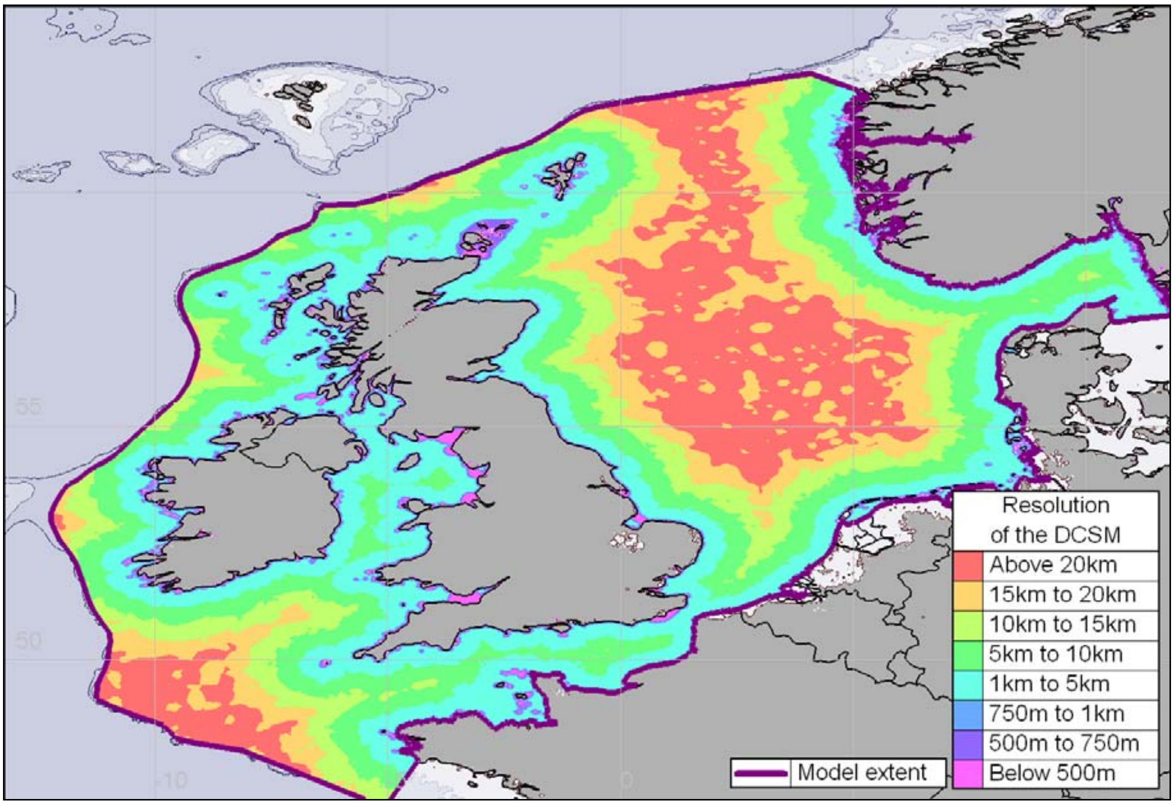

Figure 3 Resolution of the DCSM

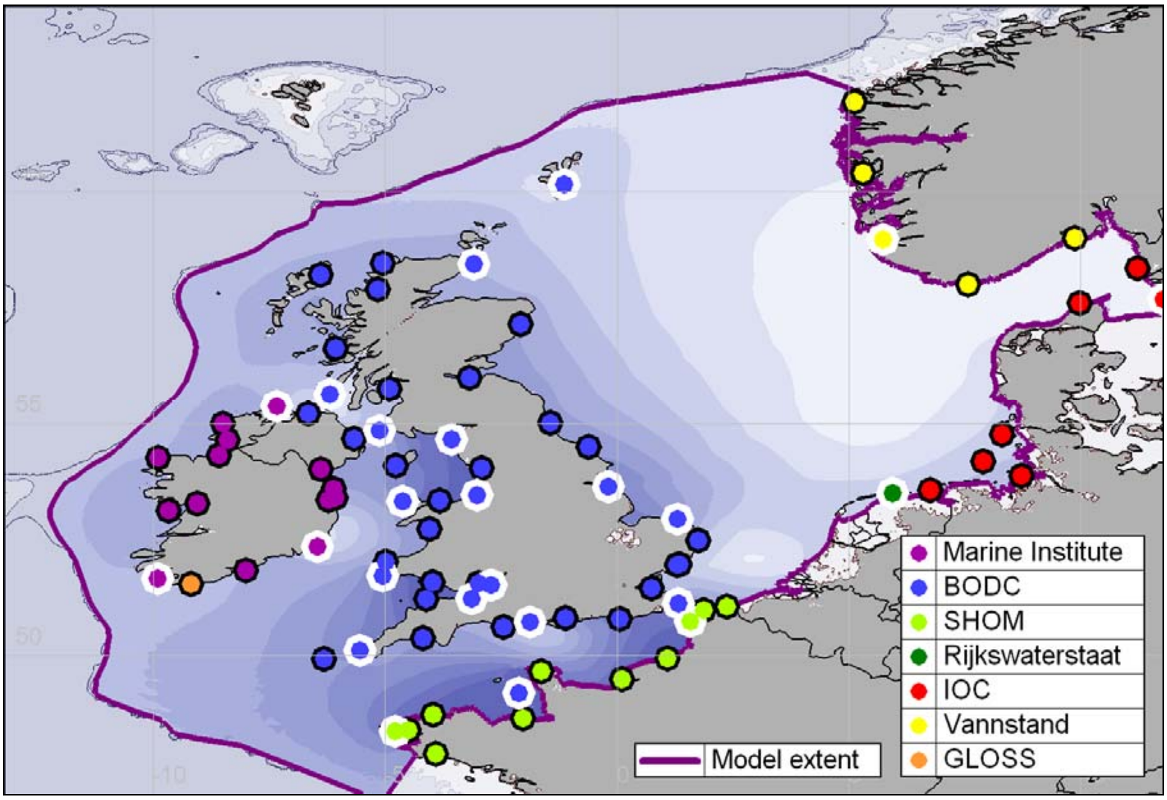

Figure 4 Location of observation stations and those used in the CSM calibration exercise

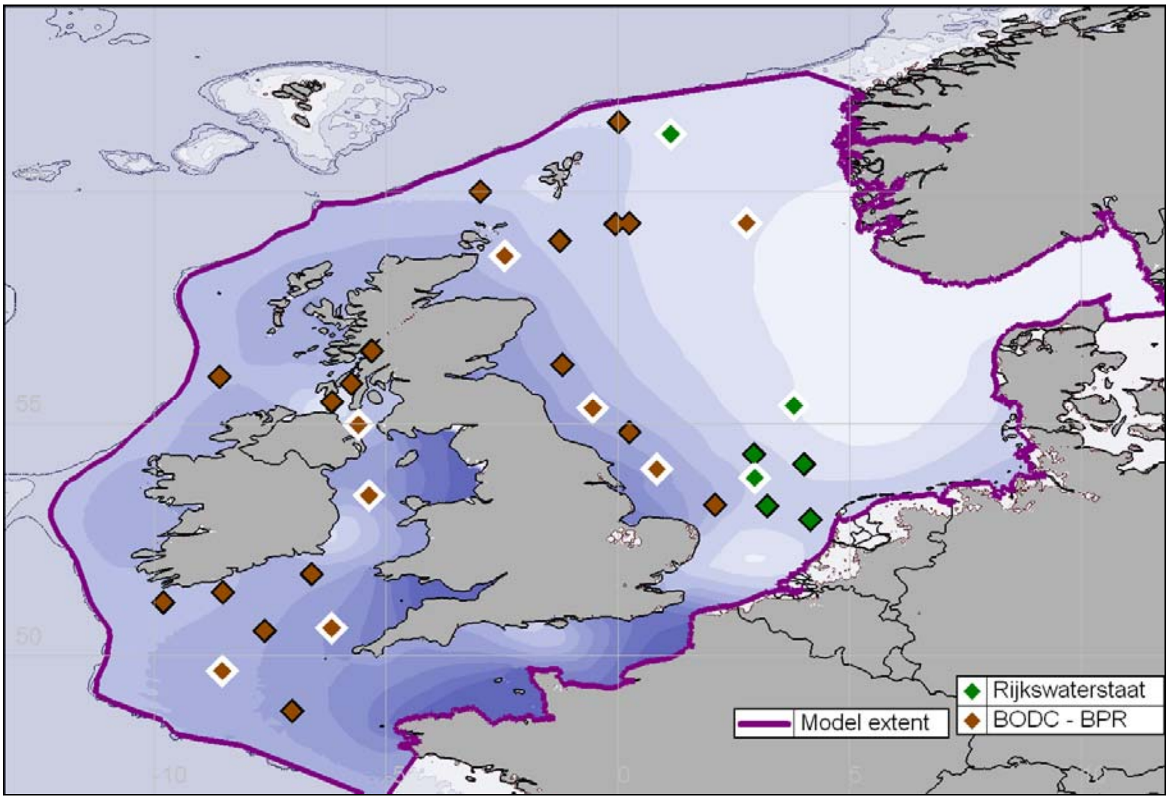

Figure 5 Location of observation stations and those used in the CSM validation exercise

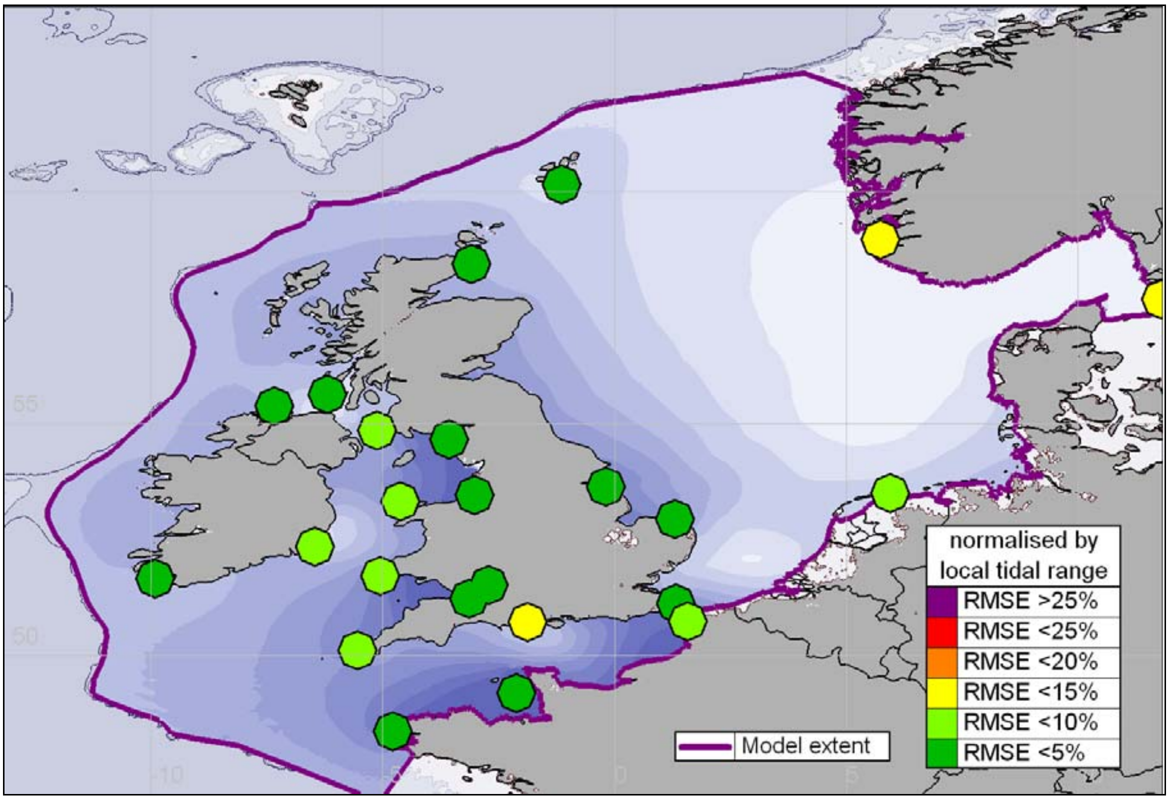

Figure 6 Quality of the CCSM calibration exercise

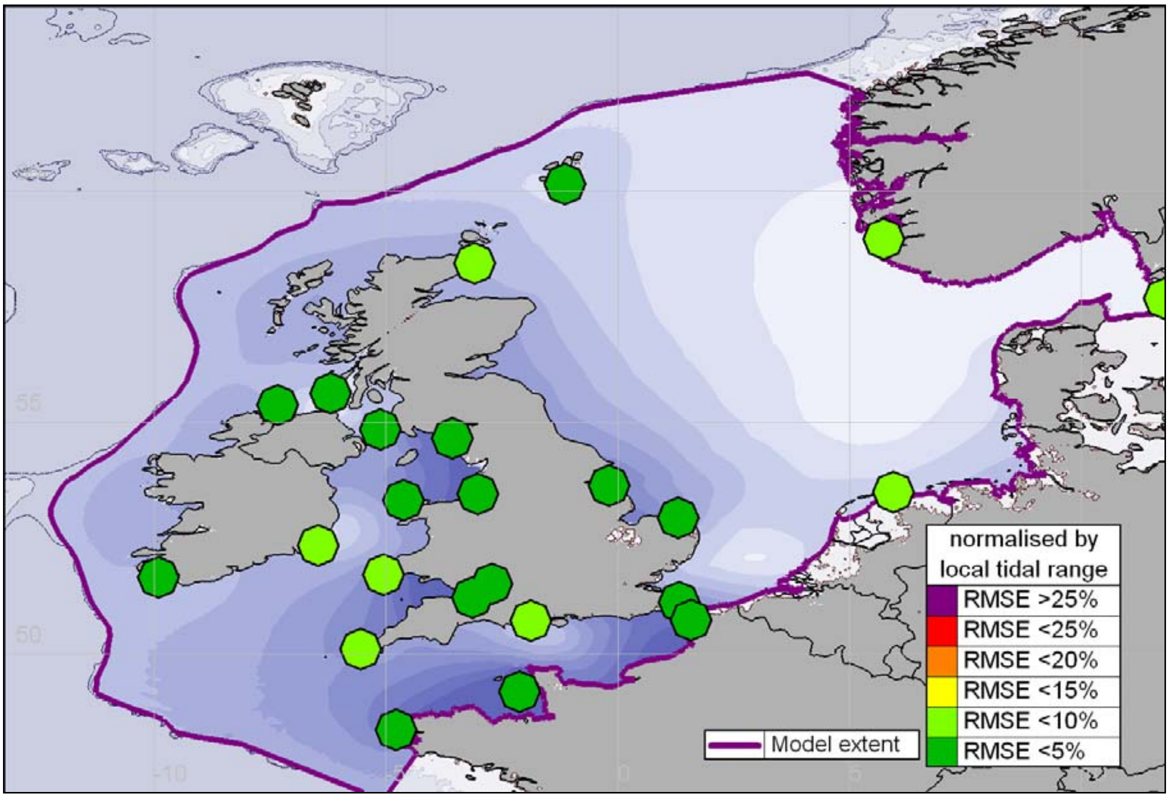

Figure 7 Quality of the DCSM calibration exercise

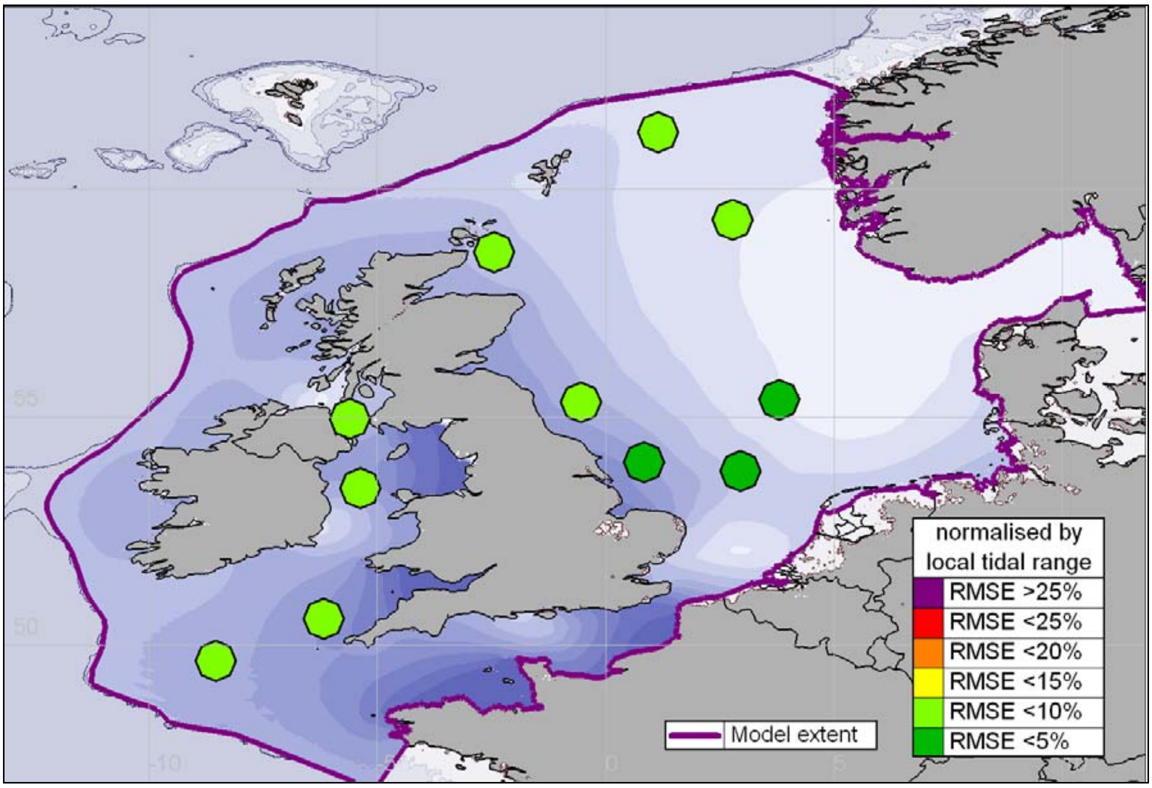

Figure 8 Quality of the CCSM validation exercise

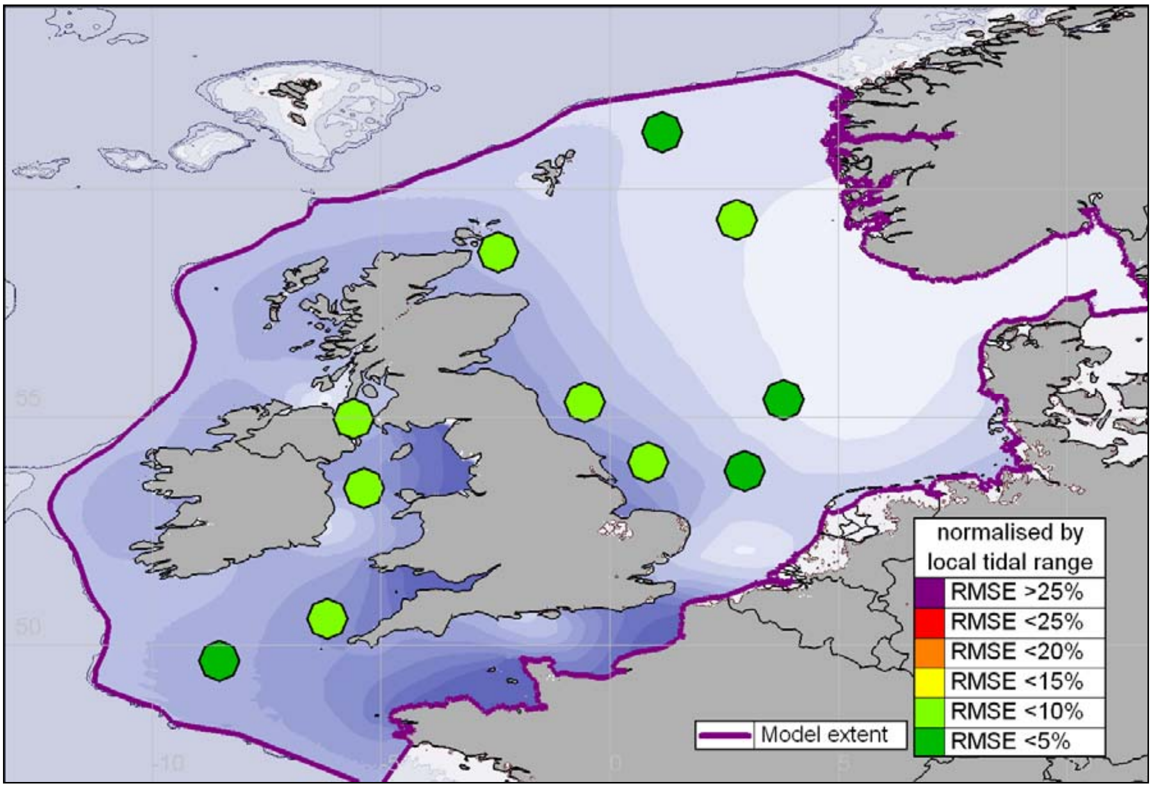

Figure 9 Quality of the DCSM validation exercise

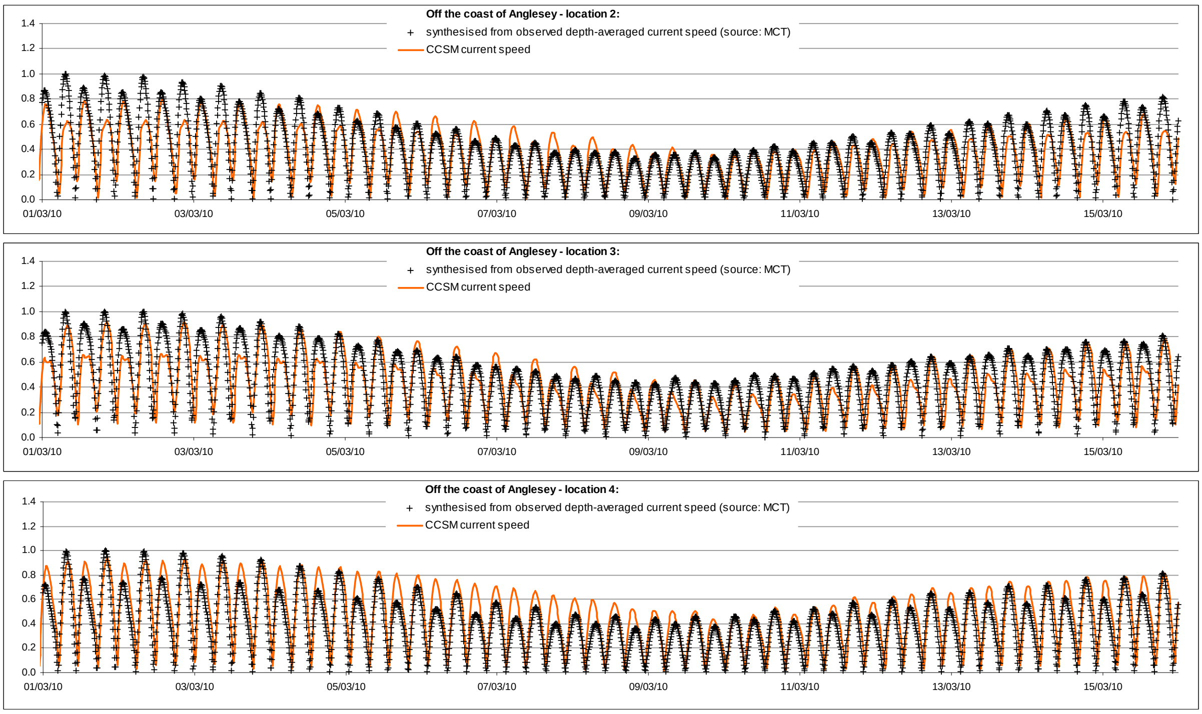

Figure 10 Current speed from MCT. CCSM comparison against observed data

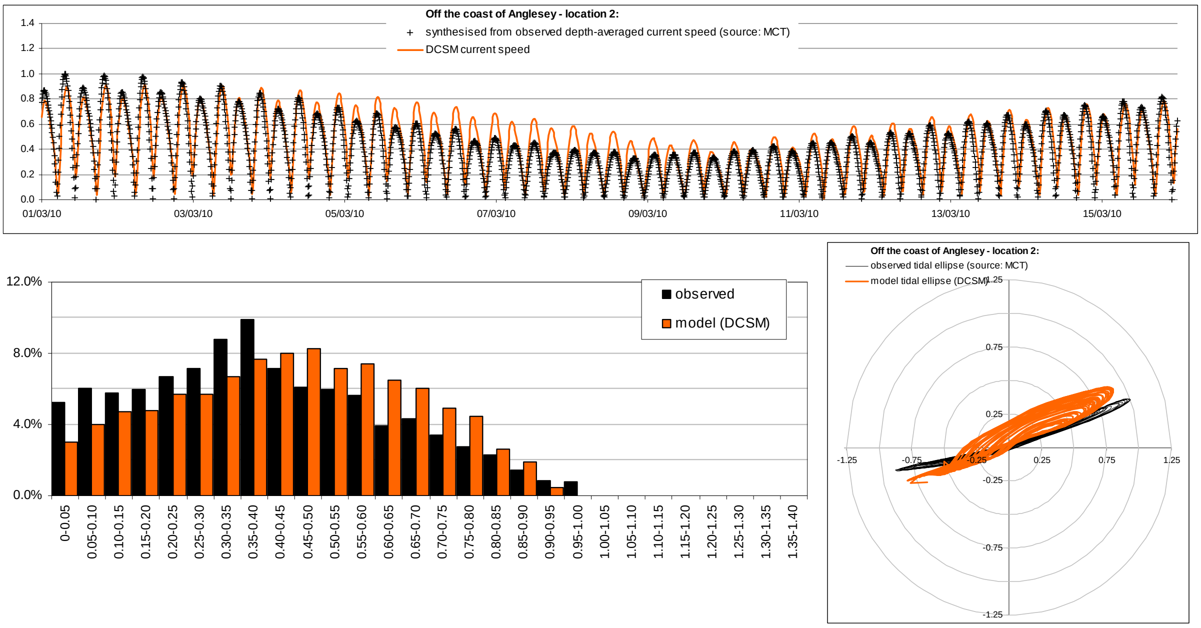

Figure 11 Current speed time histories, distribution and tidal ellipse at MCT location 2. DCSM comparison against observed data

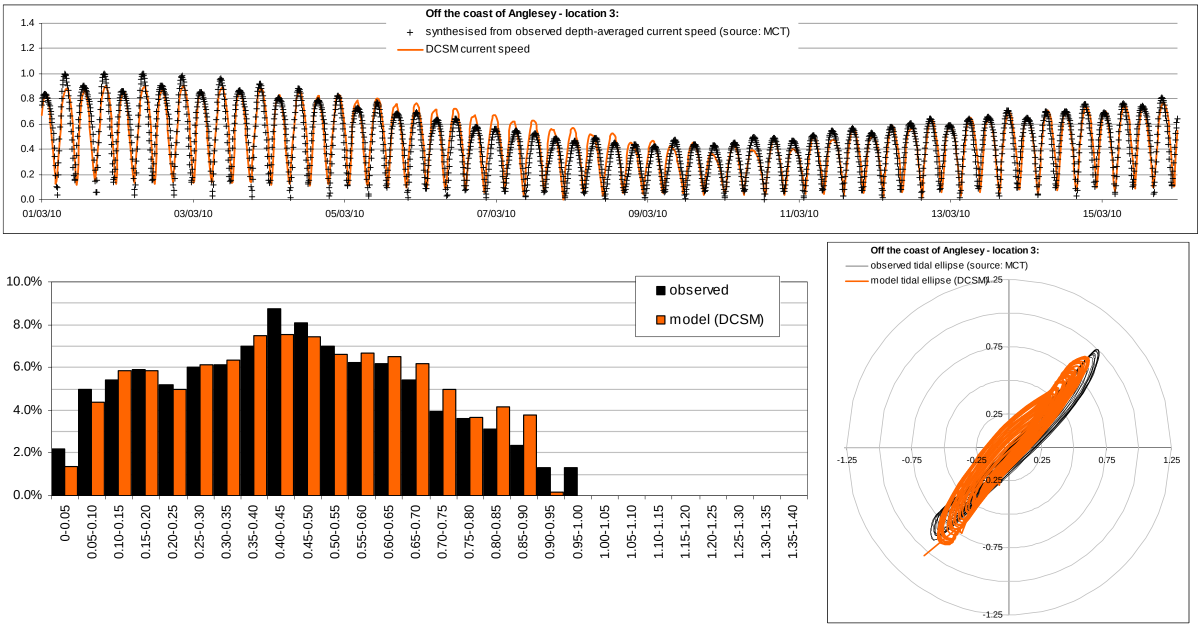

Figure 12 Current speed time histories, distribution and tidal ellipse at MCT location 3. DCSM comparison against observed data

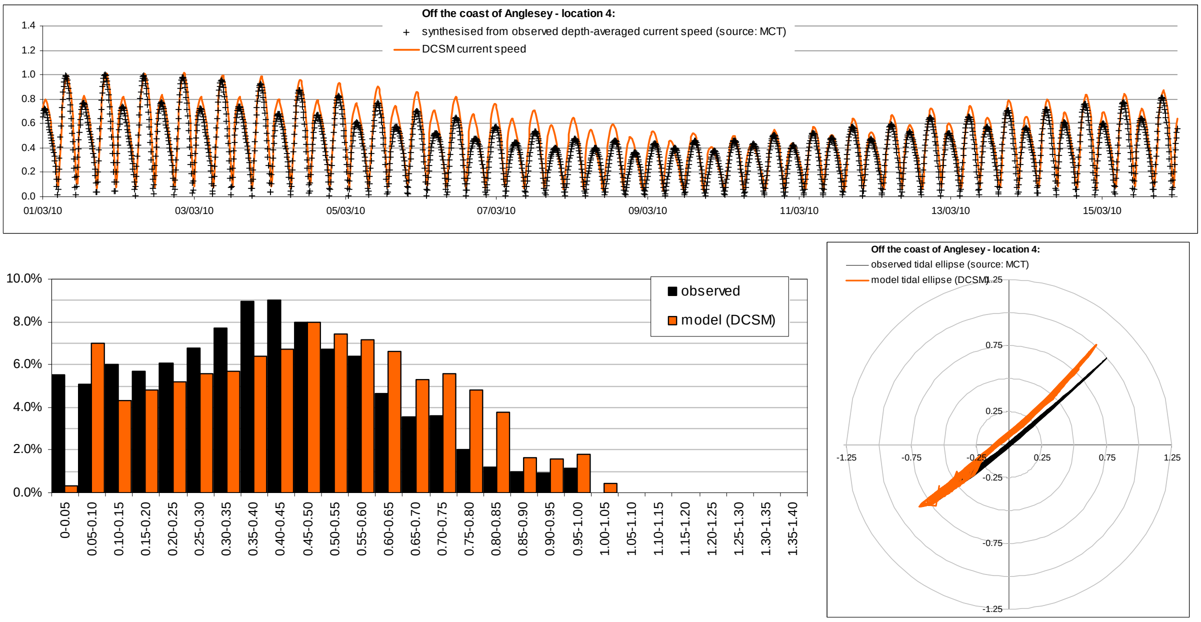

Figure 13 Current speed time histories, distribution and tidal ellipse at MCT location 4. DCSM comparison against observed data

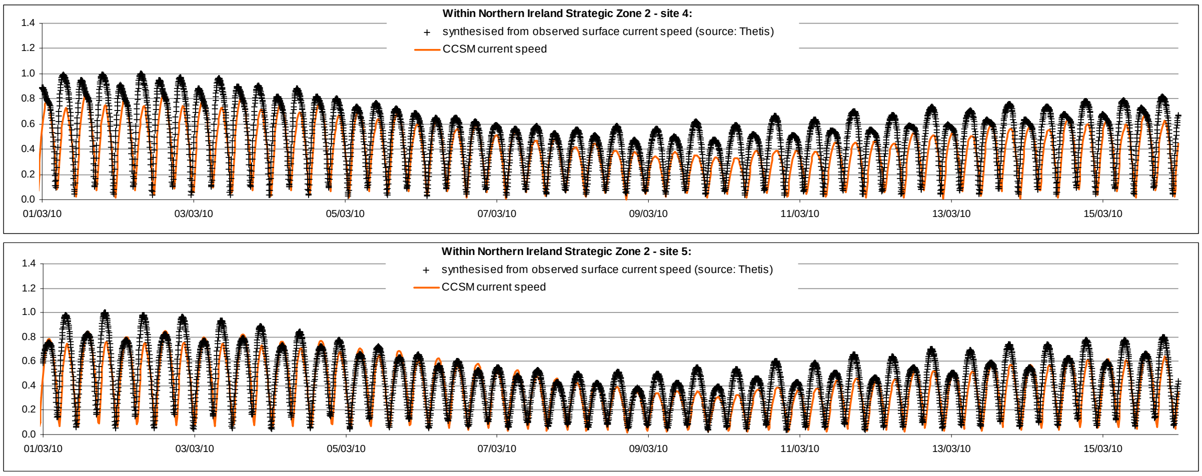

Figure 14 Current speed from Thetis. CCSM comparison against observed data

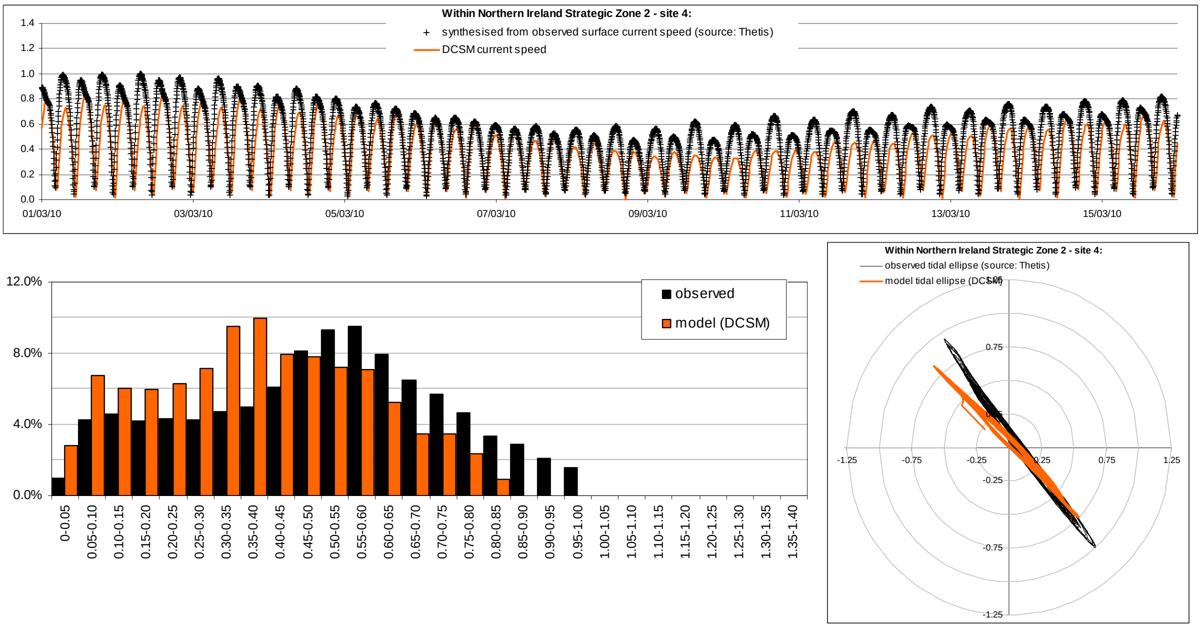

Figure 15 Current speed time histories, distribution and tidal ellipse at Thetis Site 4. DCSM comparison against observed data

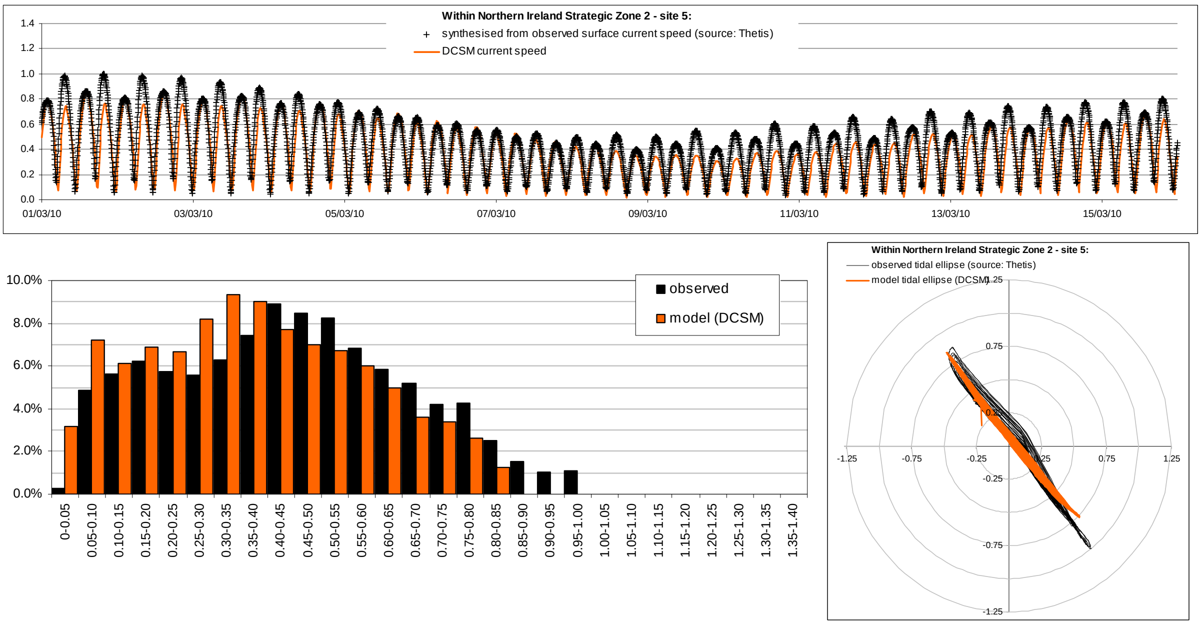

Figure 16 Current speed time histories, distribution and tidal ellipse at Thetis Site 5. DCSM comparison against observed data

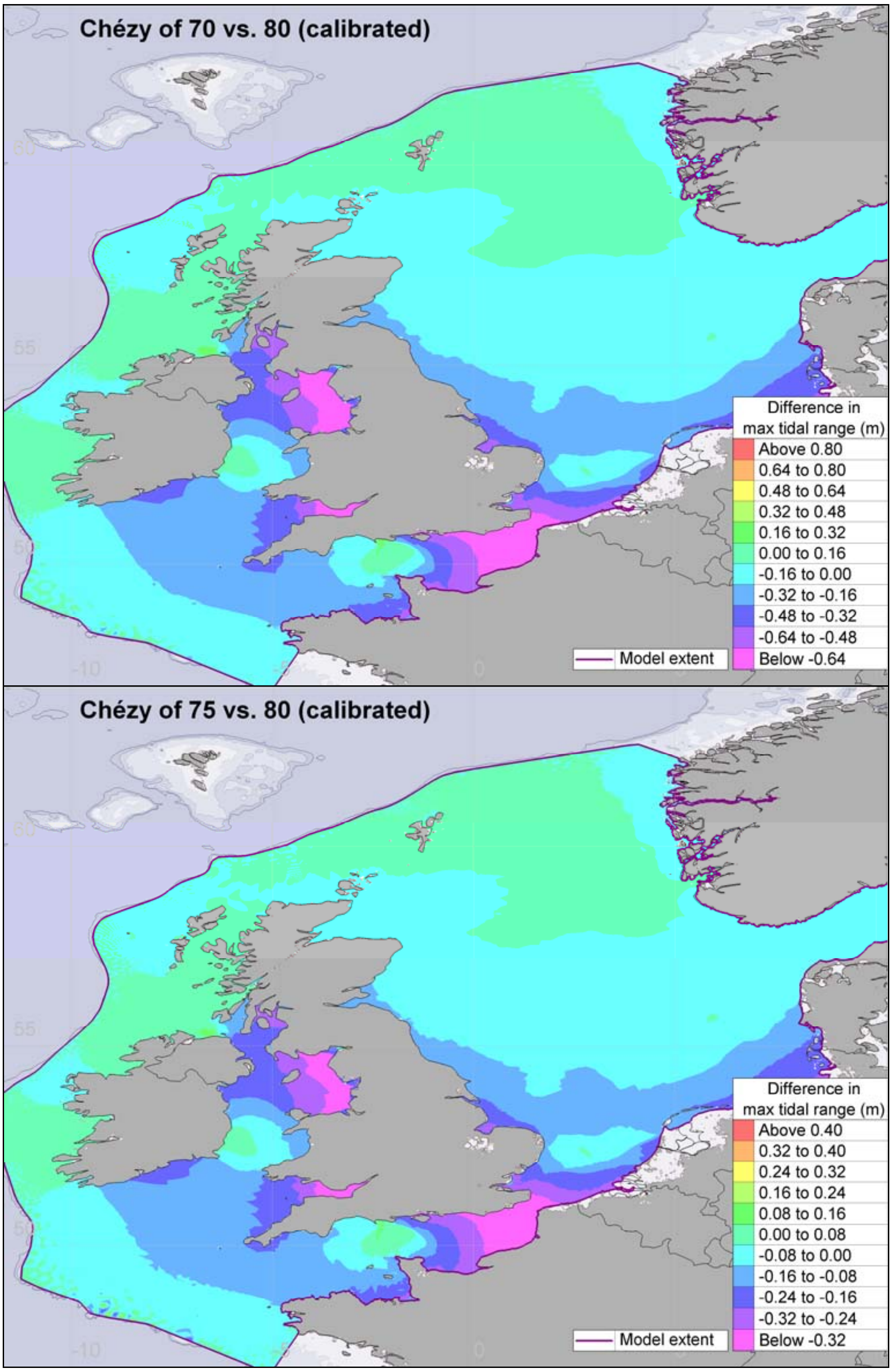

Figure 17 Sensitivity to Chézy friction parameter in the CCSM (1). Differences in maximum tidal range

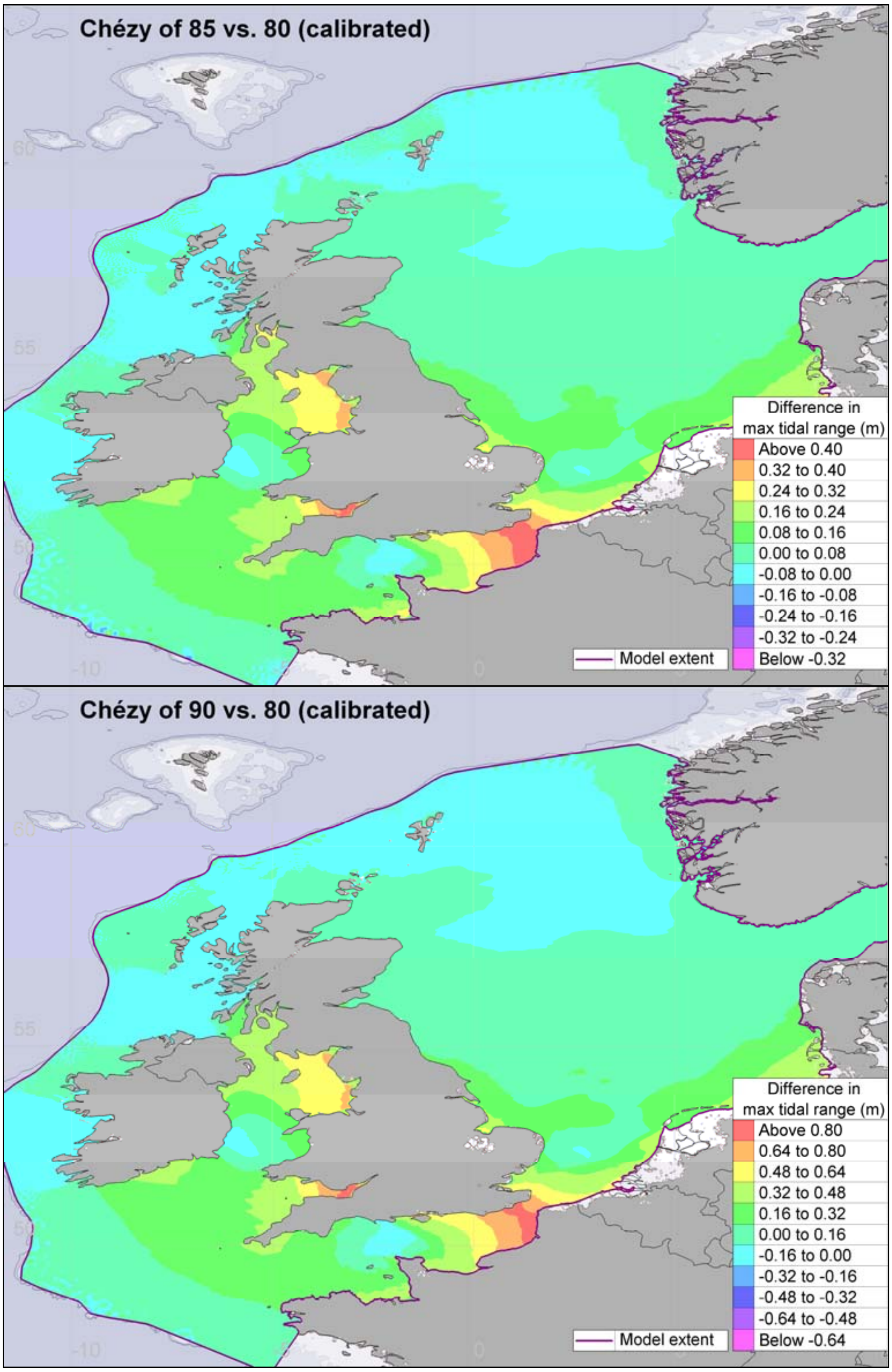

Figure 18 Sensitivity to Chézy friction parameter in the CCSM (2). Differences in maximum tidal range

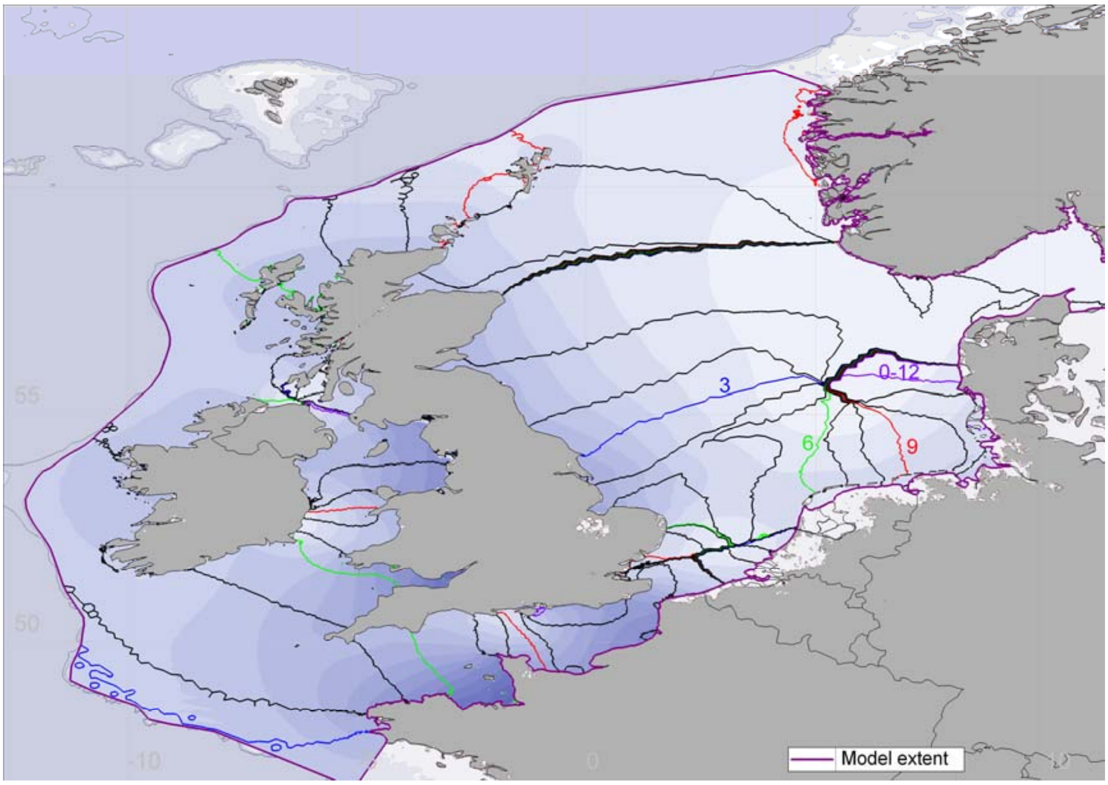

Figure 19 Atlas of the time of the peak of the tide produced by the CCSM

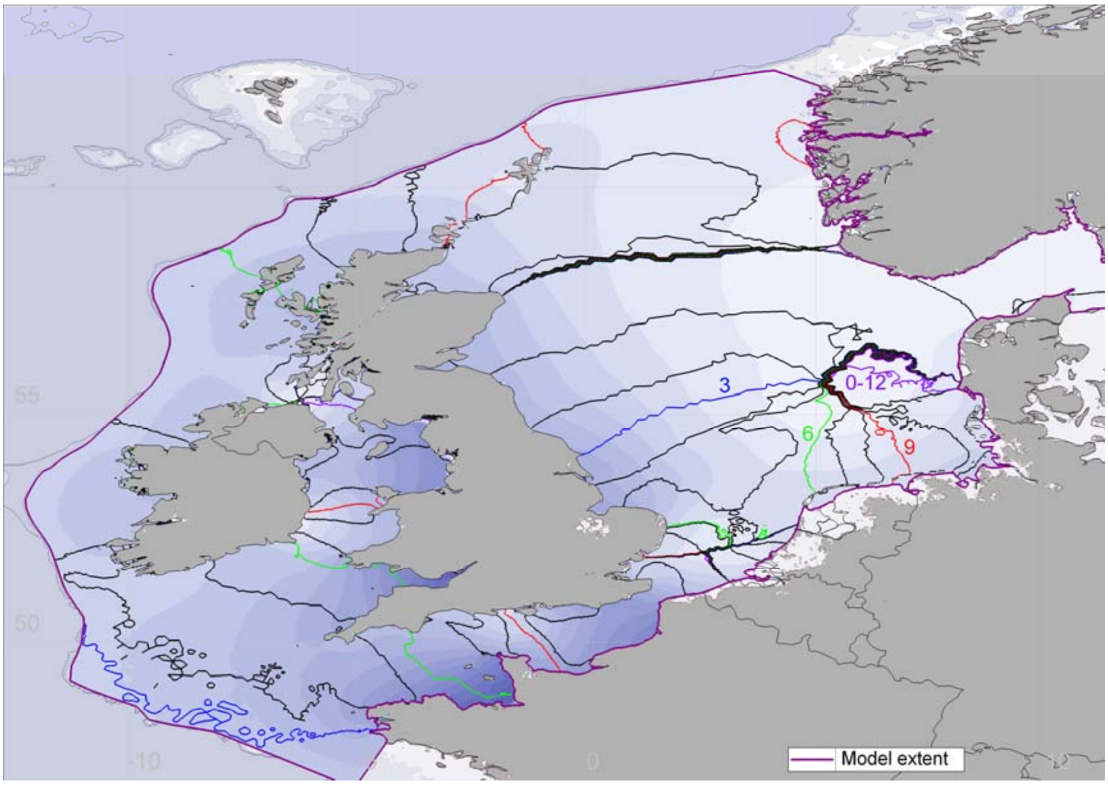

Figure 20 Atlas of the time of the peak of the tide produced by the DCSM

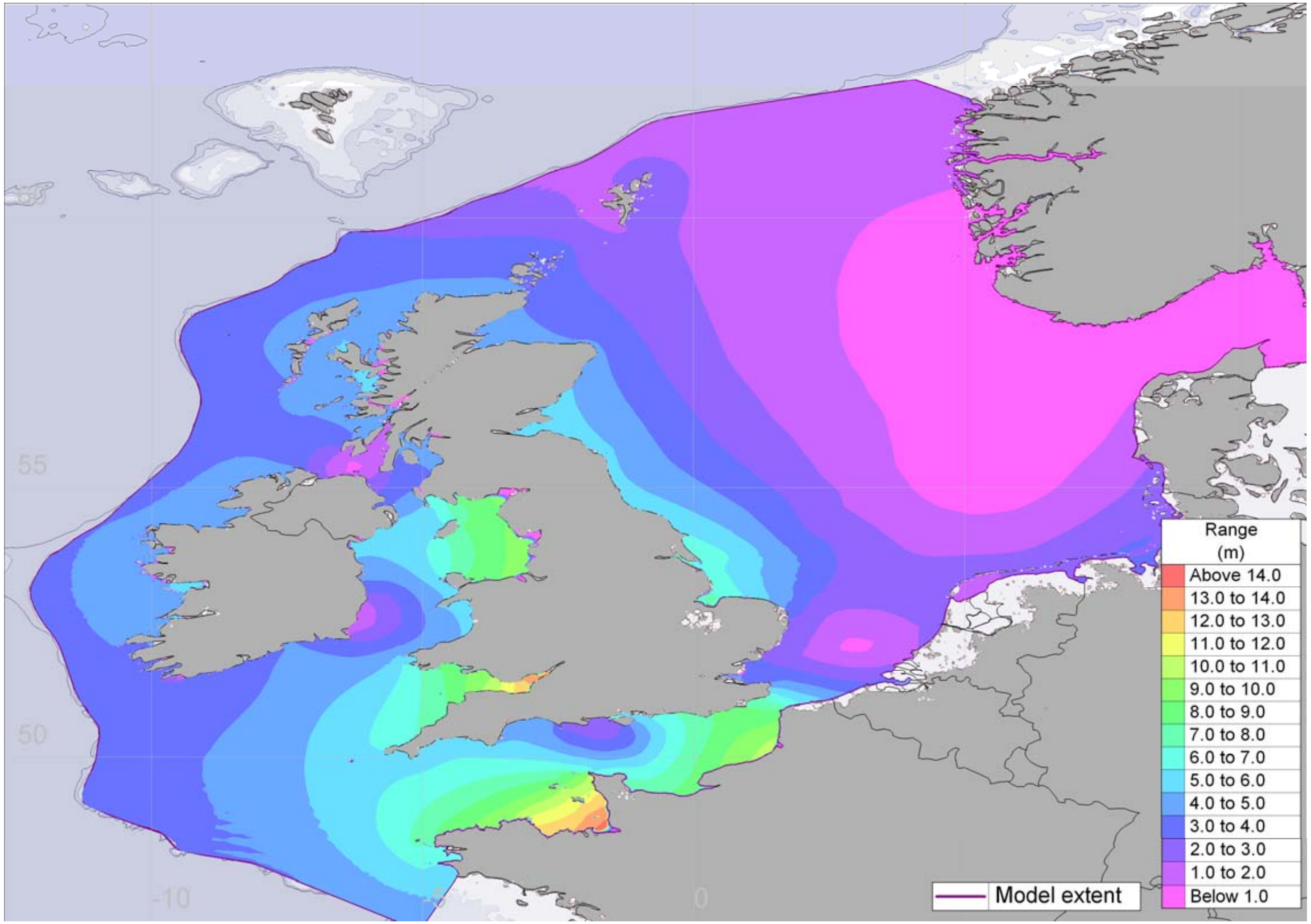

Figure 21 Maximum tidal range Atlas produced by the CCSM

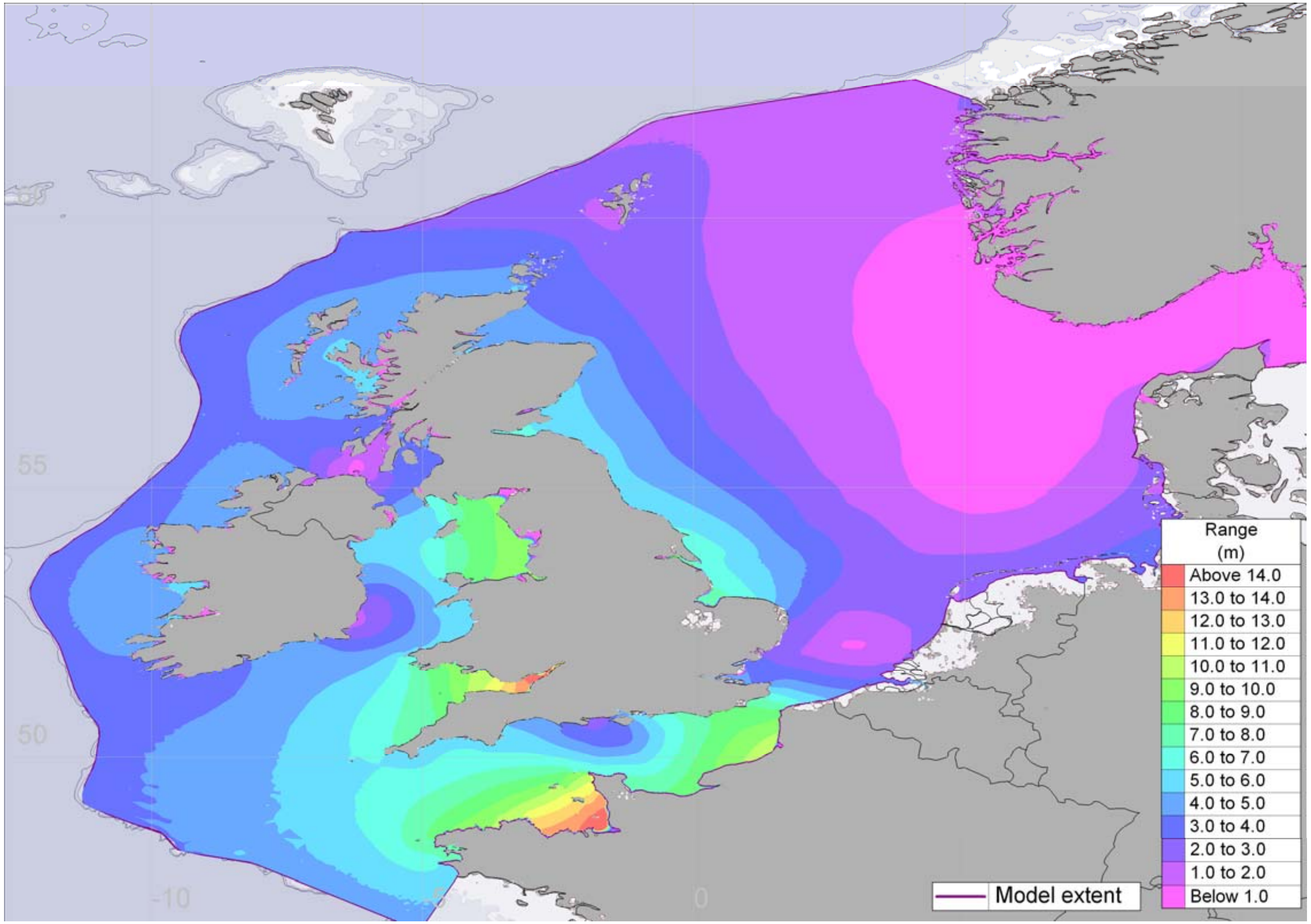

Figure 22 Maximum tidal range Atlas produced by the DCSM

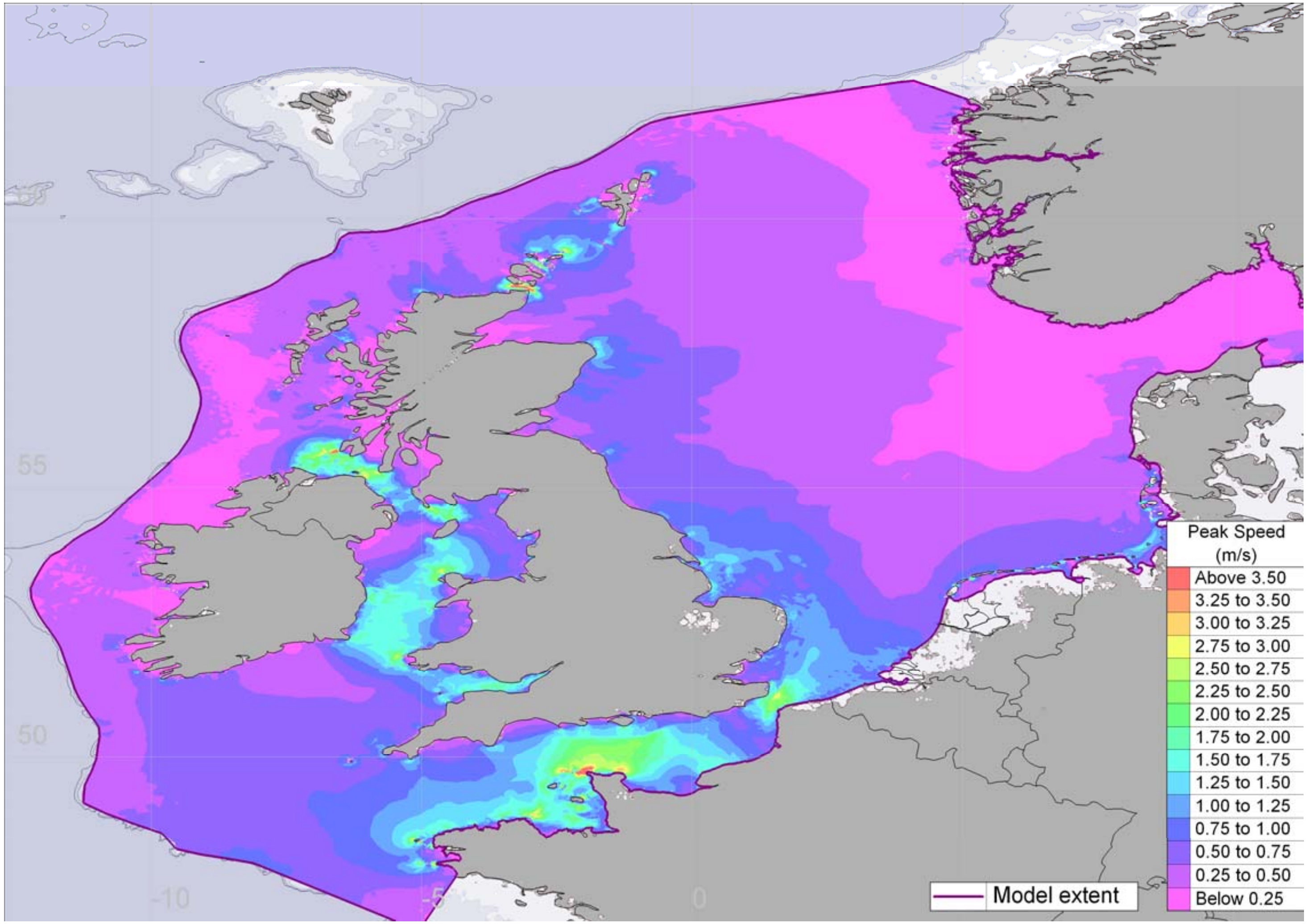

Figure 23 Peak current speed Atlas produced by the CCSM

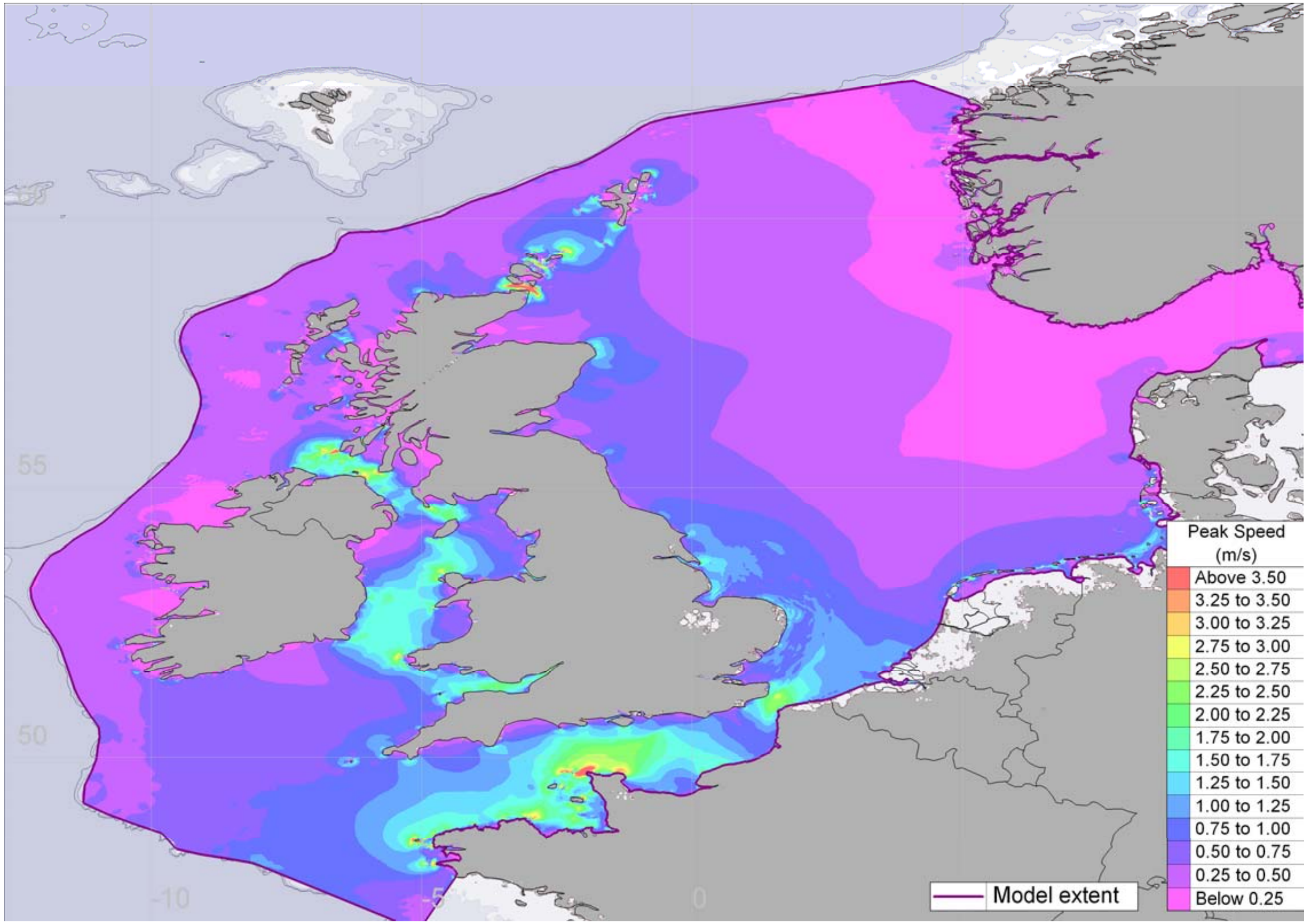

Figure 24 Peak current speed Atlas produced by the DCSM

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Appendix A –Harmonic analysis of tidal gauge data
Appendix B – CCSM comparison against tidal gauge data
Appendix C – DCSM comparison against tidal gauge data
Appendix D – CCSM vs. DCSM

APPENDIX A – HARMONIC ANALYSIS OF TIDAL GAUGE DATA

Observed tidal levels are in part the result of atmospheric pressure variations, winds and other events, which cannot be included in the CSM without a complete incorporation of spatially varying atmospheric conditions for the simulated period. In order to make the comparison with simulated tidal levels possible, a harmonic analysis was carried out on the observed tidal levels to correct mean sea level variations (due to seasonal weather, storms and surges for example) and to re-synthesise a tidal signal using only known astronomical periods (or tidal constituents).

The results of this analysis are presented in this appendix.

The geographical location of the observation station is marked by a yellow circle on a reduced version of Figures 4 and 5 combined. The observed (blue line) and re-synthesised (green line) time histories are compared and the level difference indicated as a red line. Tables of harmonic constituents are also presented, where the first 8 constituents are indicated in bold (these are reproduced in Appendices B and C), and where those constituents which are not relevant (SNR below 2) are identified in grey. It is noted that the harmonic analysis was performed on the full observation period, with a maximum of 365 days (a year).

It should be remembered that tidal harmonic analysis is highly dependent on the length of the selected period and the quality of the original observed tidal levels, resulting in a different number of harmonic constituents at each site. In particular, tidal harmonic analysis is less reliable near amphidromic points where the amplitude of the tide alone is of the same order as the variations due to atmospheric conditions or surges.

Observed harmonic constituents

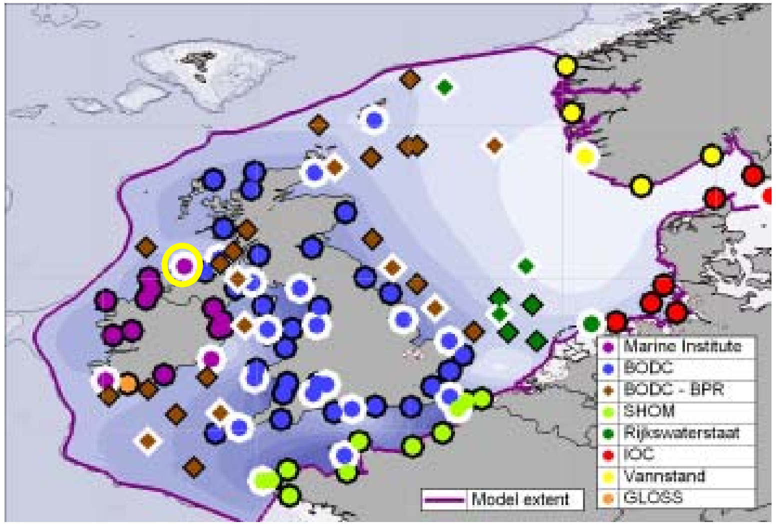
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.0846**	**178.1**	**430000**
S2	**12.00**	**0.4221**	**206.5**	**79000**
N2	**12.66**	**0.2274**	**155.4**	**24000**
K2	**11.97**	**0.1184**	**204.3**	**6100**
K1	**23.93**	**0.0938**	**158.7**	**3900**
O1	**25.82**	**0.0809**	**15.7**	**3000**
MU2	**12.87**	**0.0541**	**105.7**	**1200**
MSM	**763.48**	**0.0479**	**278.4**	**980**
NU2	12.63	0.0400	169.6	710
Q1	26.87	0.0332	304.4	600
2N2	12.91	0.0290	110.4	450
M3	8.28	0.0328	79.3	430
P1	24.07	0.0279	157.8	380
SSA	4382.12	0.0236	9.6	230
MF	327.86	0.0219	209.4	210
MSF	354.37	0.0180	230.4	160
M4	6.21	0.0190	203.1	130
MS4	6.10	0.0168	266.9	100
EPS2	13.13	0.0144	69.1	98
MO3	8.39	0.0139	12.6	93
NO1	24.83	0.0096	51.5	81
SK3	7.99	0.0110	249.3	56
MK3	8.18	0.0107	186.5	45
ETA2	11.75	0.0079	227.0	36
2Q1	28.01	0.0069	237.0	22
RHO1	26.72	0.0074	293.0	22
MM	661.29	0.0070	281.8	20
L2	12.19	0.0085	255.7	19
MSN2	11.79	0.0072	207.9	18
MKS2	12.39	0.0059	152.1	17
SO1	22.42	0.0058	123.2	16
ALP1	29.07	0.0050	224.7	15

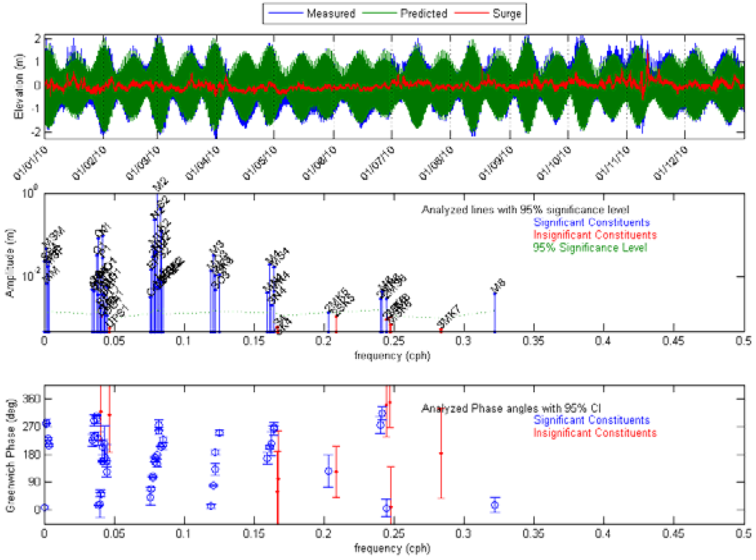
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
SO3	8.19	0.0049	131.6	12
LDA2	12.22	0.0053	274.4	11
MN4	6.27	0.0042	167.5	8.5
SIG1	27.85	0.0046	288.9	8.4
PHI1	23.80	0.0040	203.9	7.7
M6	4.14	0.0045	313.8	6.7
MK4	6.09	0.0045	262.2	6.5
J1	23.10	0.0036	171.3	6.4
TAU1	25.67	0.0039	230.4	6.1
M8	3.11	0.0039	16.6	5.9
OQ2	13.16	0.0032	40.4	5.7
2MN6	4.17	0.0030	275.5	3.3
2MS6	4.09	0.0031	6.7	3.1
BET1	24.97	0.0020	20.4	1.4
SN4	6.16	0.0020	213.4	1.4
OO1	22.31	0.0012	160.0	1.3
THE1	23.21	0.0014	215.6	1.2
2MK5	4.93	0.0015	125.7	1
CHI1	24.71	0.0011	318.6	0.7
2SK5	4.80	0.0011	122.6	0.65
2SM6	4.05	0.0011	347.5	0.64
2MK6	4.09	0.0009	341.1	0.57
MSK6	4.04	0.0007	10.3	0.37
UPS1	21.58	0.0006	306.3	0.35
3MK7	3.53	0.0006	183.3	0.31
S4	6.00	0.0006	60.1	0.26
SK4	5.99	0.0004	100.6	0.11

Number of days: 365
Number of constituents: 59
MSL = 0.01 m





A 1. Re-synthesis of the observed data at Malin Head, Ireland

Observed harmonic constituents

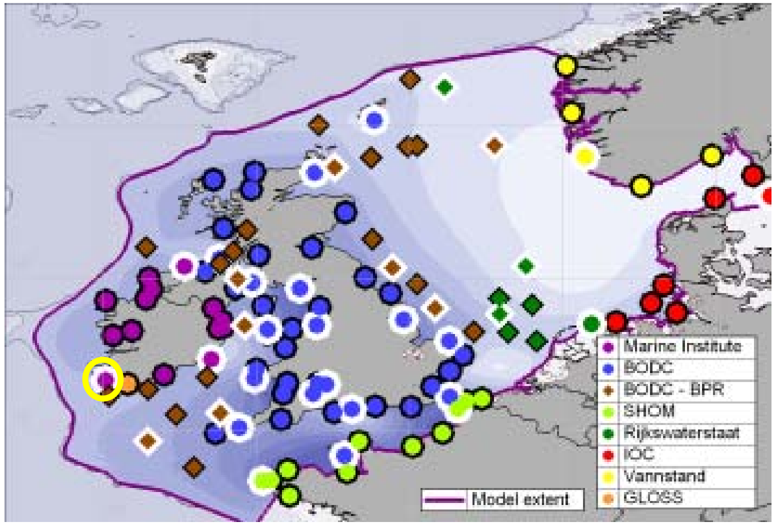
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.1144**	**130.2**	**690000**
S2	**12.00**	**0.3662**	**161.9**	**66000**
N2	**12.66**	**0.2306**	**106.8**	**35000**
K2	**11.97**	**0.1033**	**160.3**	**8700**
NU2	**12.63**	**0.0472**	**116.7**	**1500**
K1	**23.93**	**0.0427**	**40.6**	**1100**
MSM	**763.48**	**0.0358**	**278.7**	**790**
M4	**6.21**	**0.0332**	**280.7**	**600**
MU2	12.87	0.0271	46.3	470
L2	12.19	0.0333	171.2	430
2N2	12.91	0.0237	73.4	390
MM	661.29	0.0242	358.3	380
O1	25.82	0.0185	295.0	240
MS4	6.10	0.0186	354.5	170
MSF	354.37	0.0118	302.5	110
MF	327.86	0.0132	186.9	110
P1	24.07	0.0144	35.2	110
SSA	4382.12	0.0128	17.9	83
MN4	6.27	0.0112	238.0	80
LDA2	12.22	0.0108	167.0	64
M3	8.28	0.0090	12.2	64
Q1	26.87	0.0066	225.8	32
EPS2	13.13	0.0053	354.9	24
ETA2	11.75	0.0049	182.9	20
MK4	6.09	0.0054	356.8	19
NO1	24.83	0.0031	36.6	13
J1	23.10	0.0042	86.6	12
SIG1	27.85	0.0045	242.1	9.8
TAU1	25.67	0.0041	28.0	9.8
M6	4.14	0.0041	299.0	8.9
MSN2	11.79	0.0036	81.0	8.1
RHO1	26.72	0.0037	351.4	7.8

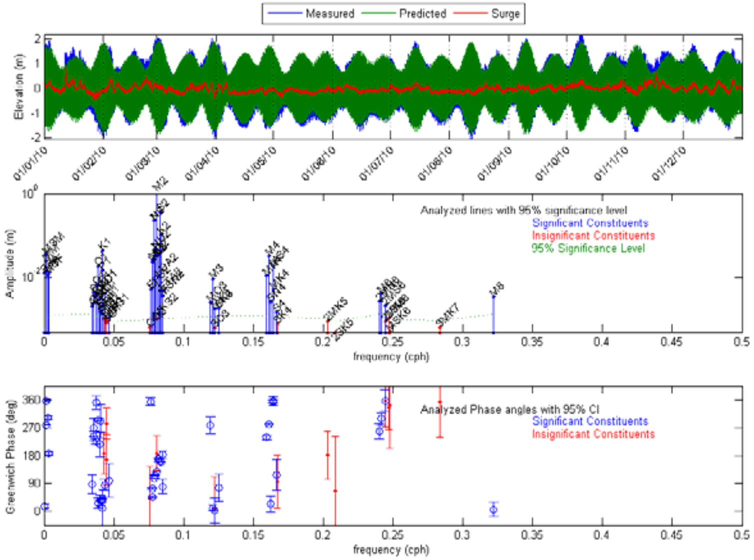
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M8	3.11	0.0034	6.2	6.2
2Q1	28.01	0.0025	270.1	5.4
MO3	8.39	0.0027	277.4	4.9
2MN6	4.17	0.0028	257.8	4
SN4	6.16	0.0026	24.0	3.3
ALP1	29.07	0.0021	88.6	2.5
MK3	8.18	0.0018	4.2	2.4
SK3	7.99	0.0019	77.4	2.4
2MS6	4.09	0.0022	358.2	2.1
BET1	24.97	0.0019	215.8	2
CHI1	24.71	0.0016	290.7	1.6
UPS1	21.58	0.0012	100.3	1.6
S4	6.00	0.0015	118.9	1.6
PHI1	23.80	0.0014	12.1	1.3
THE1	23.21	0.0010	187.6	0.97
OO1	22.31	0.0009	283.4	0.97
MKS2	12.39	0.0011	187.2	0.96
2MK6	4.09	0.0009	356.6	0.95
2SM6	4.05	0.0011	334.1	0.91
2MK5	4.93	0.0009	181.6	0.72
SO1	22.42	0.0008	167.0	0.5
SK4	5.99	0.0008	95.9	0.48
3MK7	3.53	0.0006	352.9	0.48
OQ2	13.16	0.0007	42.7	0.44
SO3	8.19	0.0006	11.8	0.39
MSK6	4.04	0.0005	342.6	0.25
2SK5	4.80	0.0003	65.0	0.11

Number of days: 365
Number of constituents: 59
MSL = -0.18 m





A 2. Re-synthesis of the observed data at Castletownbere, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.4647**	**184.6**	**88000**
S2	**12.00**	**0.2009**	**256.4**	**23000**
MU2	**12.87**	**0.0999**	**230.3**	**5600**
N2	**12.66**	**0.0776**	**180.5**	**2700**
O1	**25.82**	**0.0619**	**51.2**	**2100**
L2	**12.19**	**0.0784**	**167.7**	**2000**
K2	**11.97**	**0.0586**	**252.9**	**1700**
K1	**23.93**	**0.0546**	**193.7**	**1300**
MSM	763.48	0.0365	280.7	710
2N2	12.91	0.0319	187.9	560
EPS2	13.13	0.0285	196.0	480
MS4	6.10	0.0350	33.9	460
NU2	12.63	0.0254	129.0	410
Q1	26.87	0.0217	345.9	360
LDA2	12.22	0.0273	157.7	360
M4	6.21	0.0292	12.0	350
MM	661.29	0.0223	2.0	280
MKS2	12.39	0.0145	309.0	140
MN4	6.27	0.0164	13.1	130
P1	24.07	0.0162	199.3	110
SSA	4382.12	0.0150	8.3	100
MSN2	11.79	0.0147	26.0	93
MSF	354.37	0.0117	353.6	79
MO3	8.39	0.0111	181.0	67
MF	327.86	0.0107	185.5	59
OQ2	13.16	0.0098	156.0	58
NO1	24.83	0.0072	88.4	56
S4	6.00	0.0102	118.3	52
MK4	6.09	0.0092	37.3	42
SN4	6.16	0.0089	45.0	40
2MS6	4.09	0.0087	266.0	35
TAU1	25.67	0.0082	324.9	33

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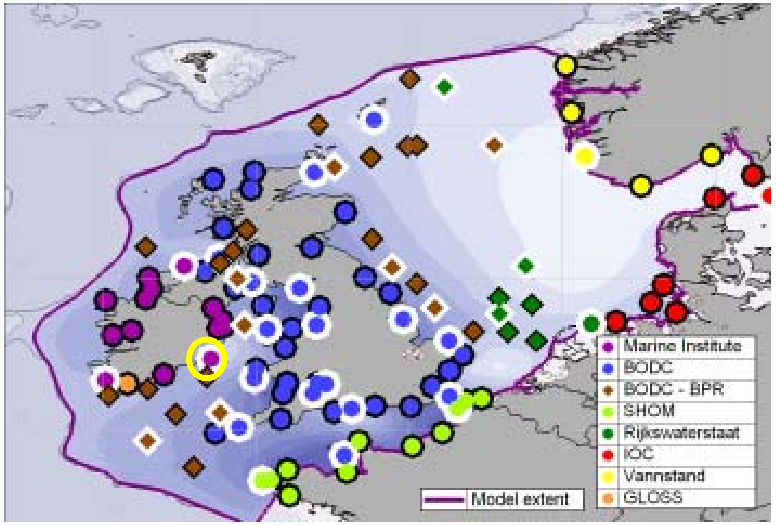
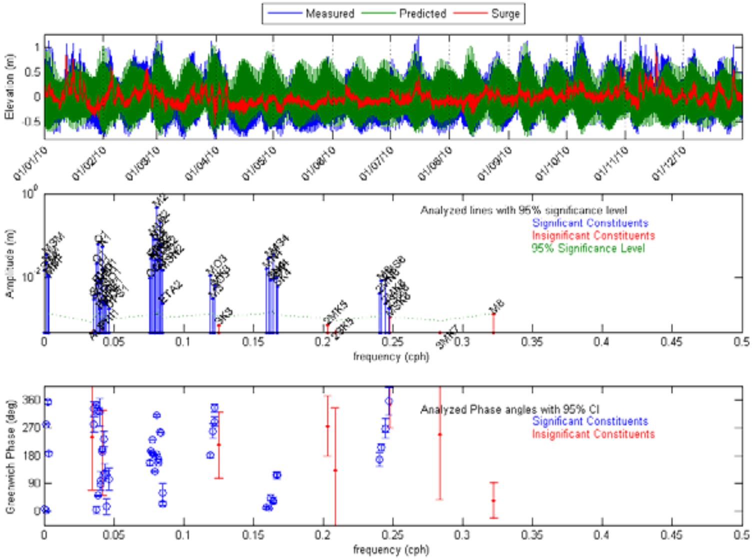
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M6	4.14	0.0084	205.5	28
SO1	22.42	0.0062	119.6	26
RHO1	26.72	0.0071	5.2	25
MK3	8.18	0.0067	333.9	24
SK4	5.99	0.0059	118.0	22
SO3	8.19	0.0053	289.5	20
2MN6	4.17	0.0042	167.2	12
2Q1	28.01	0.0038	332.1	9
THE1	23.21	0.0028	232.8	5.9
OO1	22.31	0.0022	16.0	5.8
SIG1	27.85	0.0030	279.7	4.9
M3	8.28	0.0032	259.4	4.7
ETA2	11.75	0.0024	59.5	4.5
J1	23.10	0.0027	124.4	3.6
2MK6	4.09	0.0024	267.0	3.2
CHI1	24.71	0.0026	99.1	3.1
UPS1	21.58	0.0018	104.3	3
2SM6	4.05	0.0019	355.7	2
BET1	24.97	0.0018	321.0	1.5
M8	3.11	0.0014	36.4	0.93
MSK6	4.04	0.0011	344.9	0.88
2MK5	4.93	0.0007	275.1	0.49
SK3	7.99	0.0007	213.8	0.33
PHI1	23.80	0.0006	189.7	0.26
ALP1	29.07	0.0003	240.0	0.13
2SK5	4.80	0.0003	132.6	0.11
3MK7	3.53	0.0002	247.9	0.044

Number of days: 365
Number of constituents: 59
MSL = -0.07 m





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A 3. Re-synthesis of the observed data at Wexford, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	**12.42**	**0.1535**	**88.3**	**4300**
S2	**12.00**	**0.1422**	**154.5**	**2400**
O1	**25.82**	**0.0828**	**42.0**	**1100**
K1	**23.93**	**0.0903**	**186.2**	**1100**
MSM	**763.48**	**0.0529**	**278.5**	**420**
K2	**11.97**	**0.0411**	**150.9**	**350**
M3	**8.28**	**0.0400**	**103.3**	**210**
Q1	**26.87**	**0.0303**	**325.8**	**200**
MU2	12.87	0.0340	104.4	150
M6	4.14	0.0279	115.3	110
P1	24.07	0.0278	183.4	95
2MS6	4.09	0.0291	159.4	92
L2	12.19	0.0327	30.3	79
SSA	4382.12	0.0242	8.1	77
N2	12.66	0.0213	76.0	67
M4	6.21	0.0211	69.7	66
MF	327.86	0.0214	217.1	55
NO1	24.83	0.0094	53.5	37
MO3	8.39	0.0159	41.8	35
2MN6	4.17	0.0148	84.0	29
MM	661.29	0.0133	354.7	28
SK3	7.99	0.0125	283.6	27
MK3	8.18	0.0124	222.8	21
MS4	6.10	0.0124	70.7	21
EPS2	13.13	0.0099	80.7	20
LDA2	12.22	0.0113	13.4	19
MN4	6.27	0.0109	43.4	18
MSN2	11.79	0.0095	242.5	16
2N2	12.91	0.0093	64.9	14
MKS2	12.39	0.0071	152.9	8.8
2MK6	4.09	0.0074	160.3	8.7
SO3	8.19	0.0069	152.7	8.2

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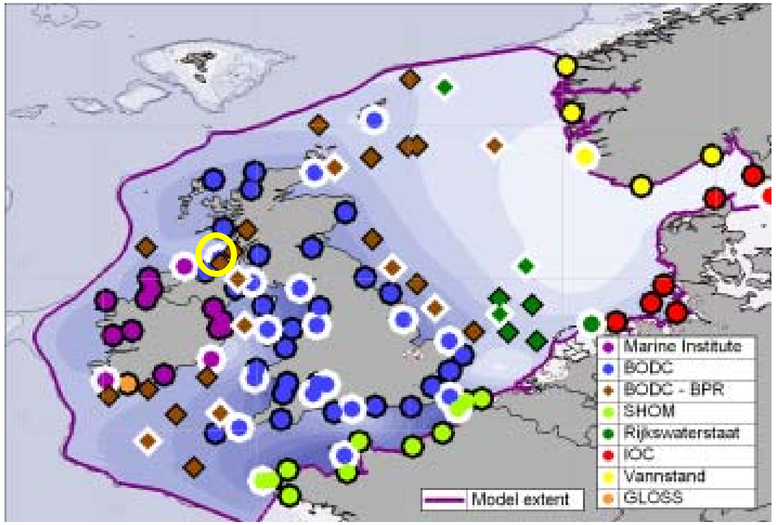
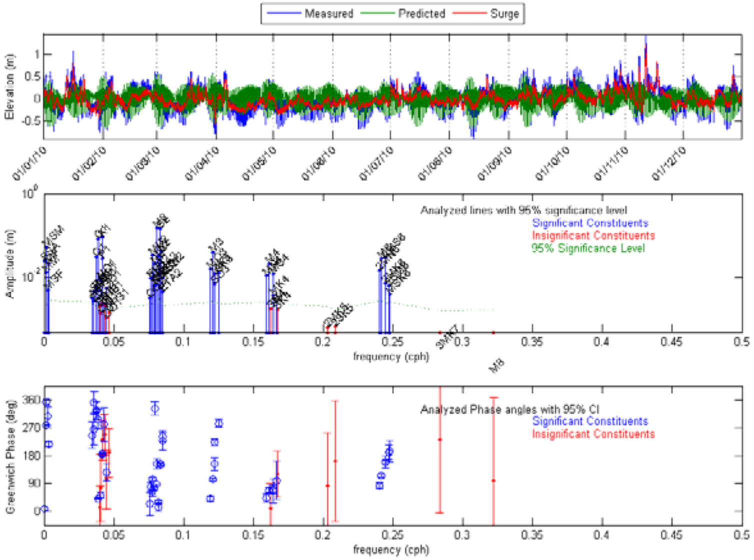
Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
2SM6	4.05	0.0063	190.4	6.8
NU2	12.63	0.0066	331.9	6.4
MSF	354.37	0.0051	307.8	5.5
RHO1	26.72	0.0055	325.4	5.5
SO1	22.42	0.0054	126.0	5.5
ETA2	11.75	0.0045	227.0	4.6
SIG1	27.85	0.0046	352.6	4
TAU1	25.67	0.0047	297.4	3.8
MSK6	4.04	0.0040	193.9	2.3
OQ2	13.16	0.0034	23.7	2.2
MK4	6.09	0.0038	66.7	2.1
ALP1	29.07	0.0033	245.5	1.6
2Q1	28.01	0.0028	263.2	1.6
S4	6.00	0.0026	100.2	1.2
THE1	23.21	0.0024	279.5	1
J1	23.10	0.0022	247.7	0.98
PHI1	23.80	0.0025	229.8	0.97
BET1	24.97	0.0021	14.4	0.7
UPS1	21.58	0.0015	188.3	0.69
SN4	6.16	0.0018	10.1	0.53
SK4	5.99	0.0017	121.8	0.53
OO1	22.31	0.0011	103.2	0.46
CHI1	24.71	0.0014	76.4	0.38
2SK5	4.80	0.0007	161.8	0.16
2MK5	4.93	0.0006	81.7	0.095
3MK7	3.53	0.0002	229.8	0.013
M8	3.11	0.0001	98.3	0.00095

Number of days: 365
Number of constituents: 59
MSL = -0.04 m





A 4. Re-synthesis of the observed data at Port Ellen, Scotland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	**12.42**	**1.3480**	**331.6**	**210000**
S2	**12.00**	**0.3732**	**16.7**	**23000**
N2	**12.66**	**0.2527**	**304.4**	**8400**
O1	**25.82**	**0.0984**	**42.7**	**1700**
K2	**11.97**	**0.1094**	**16.7**	**1700**
K1	**23.93**	**0.1092**	**188.2**	**1500**
L2	**12.19**	**0.0607**	**4.9**	**880**
NU2	**12.63**	**0.0621**	**306.6**	**580**
2N2	12.91	0.0402	300.6	270
LDA2	12.22	0.0343	359.0	150
Q1	26.87	0.0238	339.5	130
P1	24.07	0.0340	188.0	130
MU2	12.87	0.0316	128.0	120
MM	661.29	0.0234	186.6	88
MSF	354.37	0.0232	25.2	80
MF	327.86	0.0212	106.5	63
M3	8.28	0.0201	103.9	48
MSN2	11.79	0.0195	230.7	43
MSM	763.48	0.0137	334.7	27
NO1	24.83	0.0141	39.7	25
MKS2	12.39	0.0114	124.9	22
SSA	4382.12	0.0116	180.5	16
EPS2	13.13	0.0093	102.6	15
MO3	8.39	0.0100	37.4	14
MS4	6.10	0.0093	78.5	13
RHO1	26.72	0.0086	23.6	12
MK3	8.18	0.0090	222.8	9.8
OQ2	13.16	0.0070	284.6	8.4
2Q1	28.01	0.0064	281.8	8.3
TAU1	25.67	0.0080	223.7	6.7
SK3	7.99	0.0062	282.5	6.3
THE1	23.21	0.0054	285.7	5.6

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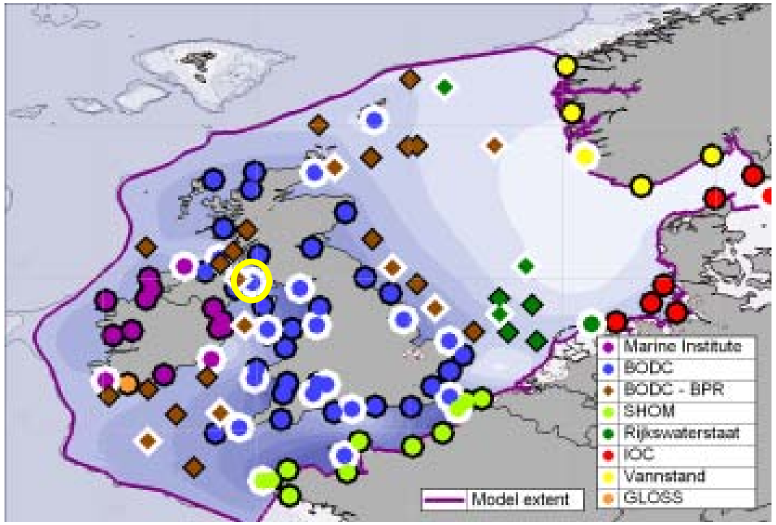
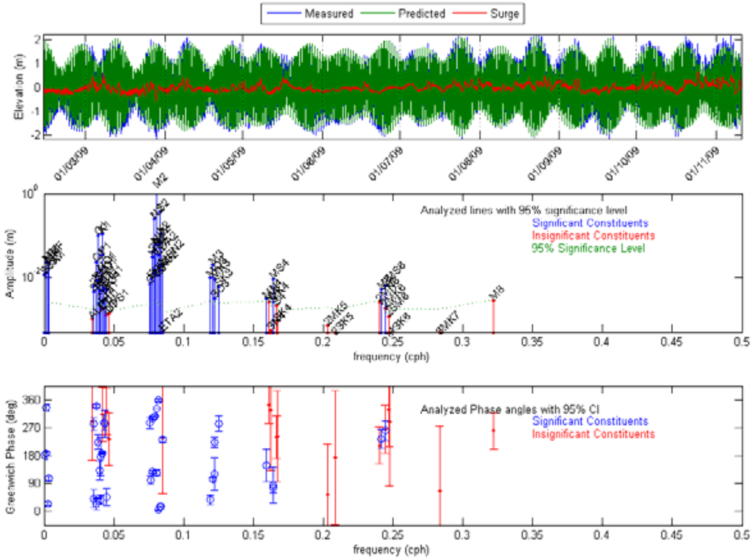
Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
2MS6	4.09	0.0062	260.5	5.2
SO1	22.42	0.0051	48.0	4.4
BET1	24.97	0.0048	132.5	3.1
SIG1	27.85	0.0045	42.4	3
M6	4.14	0.0052	233.1	2.6
J1	23.10	0.0032	282.5	2.1
SO3	8.19	0.0031	121.5	1.8
CHI1	24.71	0.0026	176.7	1.5
MN4	6.27	0.0032	148.8	1.3
MK4	6.09	0.0026	84.9	1.2
S4	6.00	0.0022	239.5	0.98
M4	6.21	0.0026	344.1	0.92
M8	3.11	0.0029	260.5	0.92
2MN6	4.17	0.0026	212.2	0.82
UPS1	21.58	0.0014	233.8	0.72
2MK6	4.09	0.0019	264.1	0.69
OO1	22.31	0.0013	322.4	0.51
PHI1	23.80	0.0018	313.1	0.45
2SM6	4.05	0.0012	328.2	0.34
ALP1	29.07	0.0010	291.0	0.33
SK4	5.99	0.0009	242.5	0.27
ETA2	11.75	0.0005	235.0	0.12
2MK5	4.93	0.0007	54.6	0.12
SN4	6.16	0.0005	327.1	0.068
2SK5	4.80	0.0004	174.2	0.056
3MK7	3.53	0.0004	67.4	0.055
MSK6	4.04	0.0004	289.1	0.042

Number of days: 271
Number of constituents: 59
MSL = 0.11 m





A 5. Re-synthesis of the observed data at Portpatrick, Scotland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**2.7397**	**331.2**	**780000**
S2	**12.00**	**0.8766**	**14.9**	**79000**
N2	**12.66**	**0.5220**	**306.5**	**31000**
K2	**11.97**	**0.2474**	**12.6**	**8600**
M4	**6.21**	**0.1415**	**251.8**	**1700**
K1	**23.93**	**0.1193**	**194.4**	**1600**
L2	**12.19**	**0.1494**	**356.0**	**1600**
NU2	**12.63**	**0.1159**	**304.9**	**1500**
O1	25.82	0.1079	45.8	1300
MS4	6.10	0.0713	300.1	440
MN4	6.27	0.0564	215.8	400
2N2	12.91	0.0485	294.7	290
MSM	763.48	0.0495	296.0	270
LDA2	12.22	0.0519	341.5	260
Q1	26.87	0.0351	332.9	170
P1	24.07	0.0384	193.9	170
SSA	4382.12	0.0347	20.8	120
MSN2	11.79	0.0222	221.7	66
MM	661.29	0.0248	8.0	62
MKS2	12.39	0.0226	134.9	58
MU2	12.87	0.0236	58.7	52
MK4	6.09	0.0194	303.5	41
2MS6	4.09	0.0200	325.6	41
M3	8.28	0.0192	333.1	39
EPS2	13.13	0.0156	48.1	30
NO1	24.83	0.0099	49.3	28
M6	4.14	0.0176	283.5	27
MSF	354.37	0.0143	216.9	26
MF	327.86	0.0122	197.4	18
TAU1	25.67	0.0127	280.7	17
MO3	8.39	0.0111	289.6	16
SN4	6.16	0.0092	284.5	12

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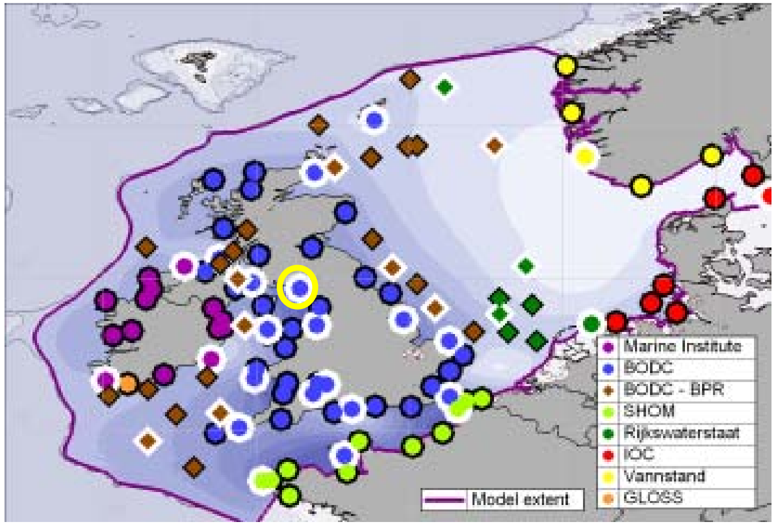
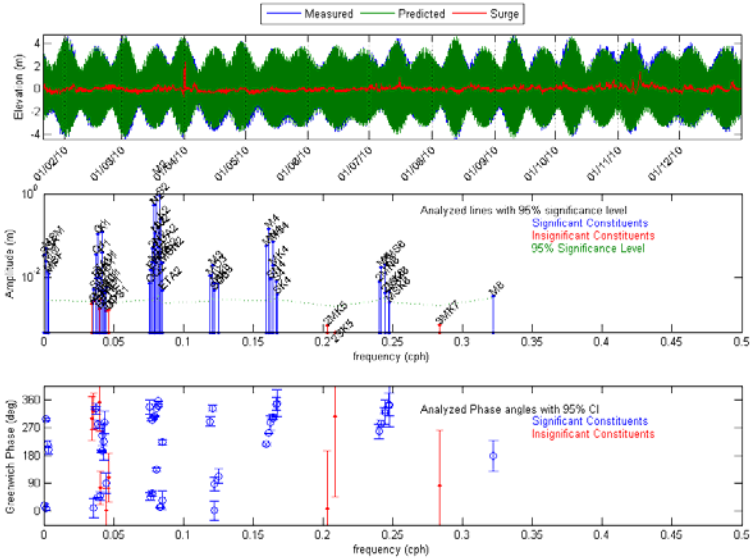
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
RHO1	26.72	0.0098	331.3	9.2
2MN6	4.17	0.0080	257.0	7.5
S4	6.00	0.0081	347.3	6.4
MK3	8.18	0.0073	88.3	6.1
SK3	7.99	0.0074	113.4	6.1
OQ2	13.16	0.0072	337.3	5.8
ETA2	11.75	0.0051	36.7	4.4
SO1	22.42	0.0058	90.2	4.1
SO3	8.19	0.0049	2.0	3.3
2SM6	4.05	0.0049	343.9	3.2
SIG1	27.85	0.0052	10.0	2.8
J1	23.10	0.0045	286.6	2.7
2MK6	4.09	0.0044	319.1	2.7
PHI1	23.80	0.0049	245.8	2.1
SK4	5.99	0.0041	348.3	1.8
M8	3.11	0.0037	178.5	1.3
THE1	23.21	0.0028	225.7	1.1
MSK6	4.04	0.0027	342.9	1.1
2Q1	28.01	0.0028	323.5	0.94
CHI1	24.71	0.0031	75.8	0.91
ALP1	29.07	0.0024	300.1	0.78
OO1	22.31	0.0016	3.6	0.57
BET1	24.97	0.0018	350.7	0.53
UPS1	21.58	0.0017	109.0	0.49
2MK5	4.93	0.0007	8.8	0.11
3MK7	3.53	0.0007	81.5	0.11
2SK5	4.80	0.0003	305.8	0.017

Number of days: 344.47
Number of constituents: 59
MSL = -0.07





A 6. Re-synthesis of the observed data at Workington, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	**12.42**	**3.0075**	**320.4**	**440000**
S2	**12.00**	**0.9447**	**4.4**	**51000**
N2	**12.66**	**0.5803**	**297.3**	**19000**
K2	**11.97**	**0.2660**	**358.0**	**3600**
M4	**6.21**	**0.2527**	**199.8**	**2800**
L2	**12.19**	**0.1691**	**338.2**	**1100**
MS4	**6.10**	**0.1499**	**242.1**	**1000**
NU2	**12.63**	**0.1309**	**305.7**	**940**
K1	23.93	0.1252	188.1	880
O1	25.82	0.1096	43.8	730
MN4	6.27	0.1043	175.8	570
SSA	4382.12	0.0774	291.7	320
2N2	12.91	0.0640	303.3	240
LDA2	12.22	0.0601	338.3	180
MU2	12.87	0.0492	37.4	140
MK4	6.09	0.0497	248.1	140
MSM	763.48	0.0418	315.3	110
P1	24.07	0.0370	192.9	92
M6	4.14	0.0428	343.3	92
M3	8.28	0.0360	296.5	87
Q1	26.87	0.0294	324.8	74
MM	661.29	0.0334	69.9	68
MKS2	12.39	0.0300	163.4	57
SN4	6.16	0.0294	213.1	45
2MS6	4.09	0.0354	28.6	45
MSF	354.37	0.0253	259.7	42
MO3	8.39	0.0264	253.3	42
2MN6	4.17	0.0237	317.9	40
S4	6.00	0.0224	291.5	30
SK3	7.99	0.0189	99.0	23
MF	327.86	0.0220	213.2	22
MSN2	11.79	0.0211	180.0	22

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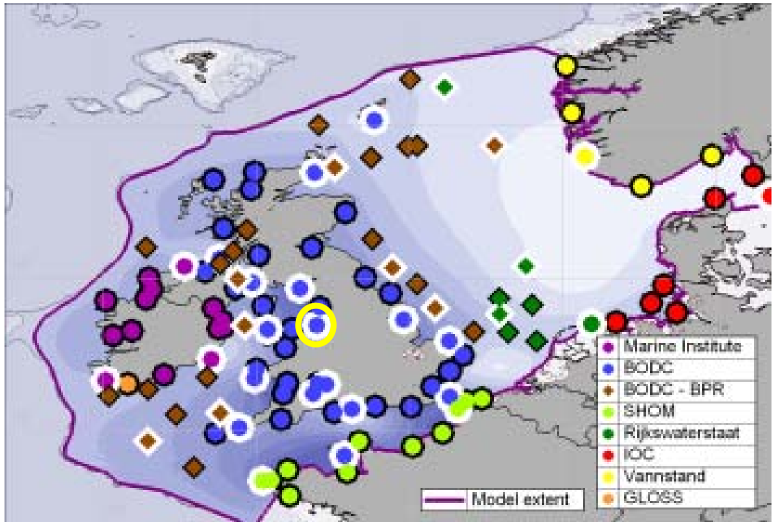
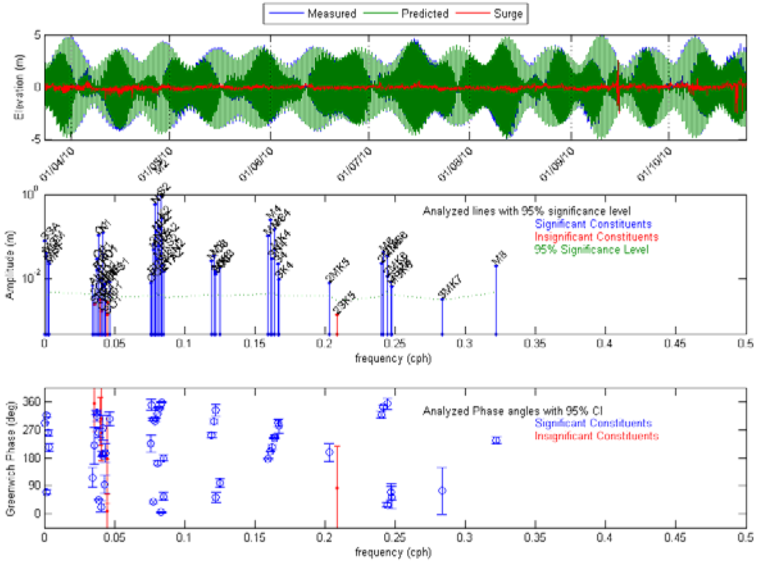
Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M8	3.11	0.0208	236.1	19
TAU1	25.67	0.0170	259.7	18
ETA2	11.75	0.0149	56.3	18
RHO1	26.72	0.0161	312.2	15
EPS2	13.13	0.0129	349.8	14
MK3	8.18	0.0150	52.4	12
NO1	24.83	0.0092	23.6	11
SO3	8.19	0.0126	331.3	11
2MK6	4.09	0.0114	353.1	7.4
SK4	5.99	0.0098	281.6	6.4
UPS1	21.58	0.0082	303.9	5.1
2SM6	4.05	0.0086	70.2	4.3
OQ2	13.16	0.0081	224.6	4.1
2MK5	4.93	0.0080	196.8	4.1
THE1	23.21	0.0072	94.2	3.9
J1	23.10	0.0079	195.3	3.8
PHI1	23.80	0.0065	275.6	2.8
ALP1	29.07	0.0071	116.5	2.7
MSK6	4.04	0.0066	52.6	2.6
2Q1	28.01	0.0041	218.9	1.1
3MK7	3.53	0.0033	73.8	1
BET1	24.97	0.0032	295.7	0.94
OO1	22.31	0.0028	7.8	0.92
SIG1	27.85	0.0025	354.9	0.48
CHI1	24.71	0.0017	306.1	0.33
SO1	22.42	0.0014	174.6	0.25
2SK5	4.80	0.0015	83.3	0.23

Number of days: 214.86
Number of constituents: 59
MSL = 0.05 m





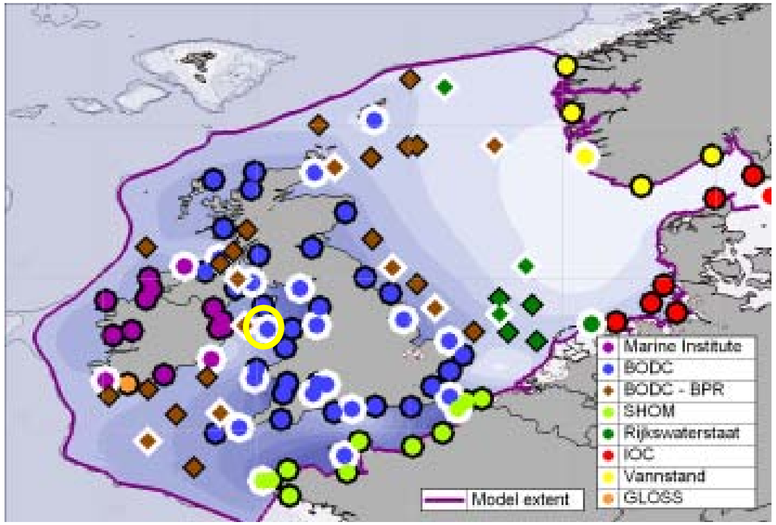
A 7. Re-synthesis of the observed data at Liverpool, England

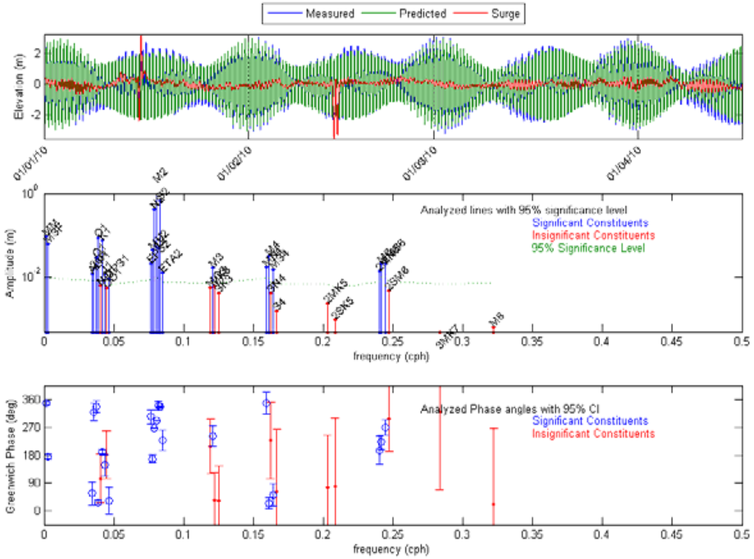
Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.7735**	**291.7**	**41000**
S2	**12.00**	**0.6672**	**336.6**	**4400**
N2	**12.66**	**0.4256**	**266.6**	**2100**
MM	**661.29**	**0.0971**	**349.1**	**88**
O1	**25.82**	**0.0873**	**28.6**	**82**
K1	**23.93**	**0.0769**	**190.2**	**56**
MSF	**354.37**	**0.0619**	**175.9**	**43**
L2	**12.19**	**0.0504**	**341.9**	**24**
MU2	12.87	0.0447	168.7	21
Q1	26.87	0.0301	338.0	14
M4	6.21	0.0322	25.4	11
EPS2	13.13	0.0214	303.7	6.2
M6	4.14	0.0210	222.0	4.4
2Q1	28.01	0.0164	319.8	4.1
2MS6	4.09	0.0215	269.2	4
M3	8.28	0.0173	240.9	3.3
MN4	6.27	0.0176	349.1	3.3
J1	23.10	0.0120	147.5	3
MS4	6.10	0.0154	53.0	2.9
2MN6	4.17	0.0137	196.2	2.9
ETA2	11.75	0.0128	228.3	2.8
ALP1	29.07	0.0120	56.8	2
UPS1	21.58	0.0092	33.3	1.9
NO1	24.83	0.0062	105.3	0.68
MK3	8.18	0.0062	36.3	0.68
MO3	8.39	0.0058	208.3	0.6
OO1	22.31	0.0055	180.5	0.59
2SM6	4.05	0.0049	298.0	0.38
SK3	7.99	0.0043	33.4	0.35
SN4	6.16	0.0041	228.9	0.34
2MK5	4.93	0.0024	76.5	0.12
S4	6.00	0.0016	63.6	0.05
2SK5	4.80	0.0010	78.8	0.033
M8	3.11	0.0007	21.9	0.0082
3MK7	3.53	0.0002	322.6	0.00074

(…)

Number of days: 105.73
Number of constituents: 35
MSL = -0.02 m





A 8. Re-synthesis of the observed data at Holyhead, Wales

Observed harmonic constituents

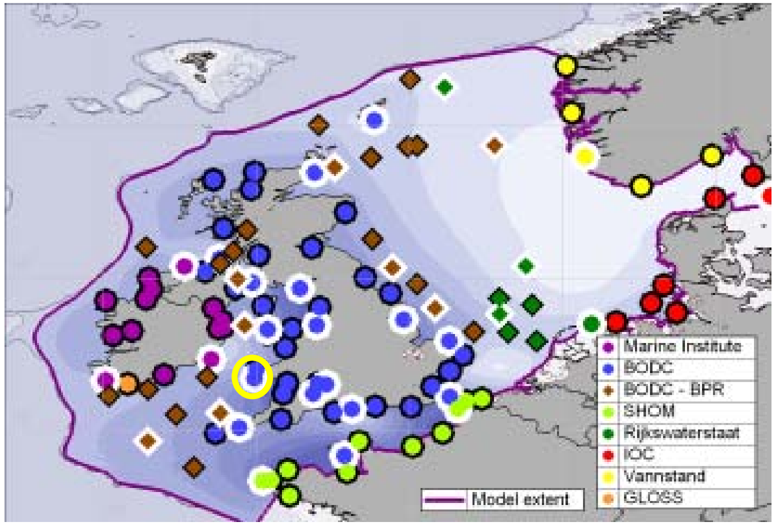
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**2.1960**	**172.1**	**330000**
S2	**12.00**	**0.7976**	**216.6**	**35000**
N2	**12.66**	**0.4142**	**151.2**	**12000**
K2	**11.97**	**0.2349**	**217.3**	**3200**
L2	**12.19**	**0.1394**	**167.1**	**600**
NU2	**12.63**	**0.0793**	**150.2**	**450**
MU2	**12.87**	**0.0832**	**190.7**	**430**
O1	**25.82**	**0.0660**	**352.6**	**300**
K1	23.93	0.0649	127.5	270
2N2	12.91	0.0538	129.5	220
M4	6.21	0.0638	307.8	220
MM	661.29	0.0511	349.5	190
LDA2	12.22	0.0378	166.5	93
MSM	763.48	0.0303	311.4	64
MS4	6.10	0.0310	358.6	52
Q1	26.87	0.0245	291.1	46
MN4	6.27	0.0238	270.5	39
MSN2	11.79	0.0246	24.2	34
MKS2	12.39	0.0192	266.8	33
P1	24.07	0.0236	121.3	32
EPS2	13.13	0.0175	178.0	27
ETA2	11.75	0.0156	286.4	20
M3	8.28	0.0156	127.1	19
MF	327.86	0.0159	252.7	17
NO1	24.83	0.0088	34.8	13
M6	4.14	0.0142	144.8	10
2MS6	4.09	0.0133	197.0	9.8
OQ2	13.16	0.0106	54.5	7.7
MK4	6.09	0.0092	1.6	5.6
SSA	4382.12	0.0091	57.9	5.4
2Q1	28.01	0.0068	291.4	4
TAU1	25.67	0.0076	258.4	3.9

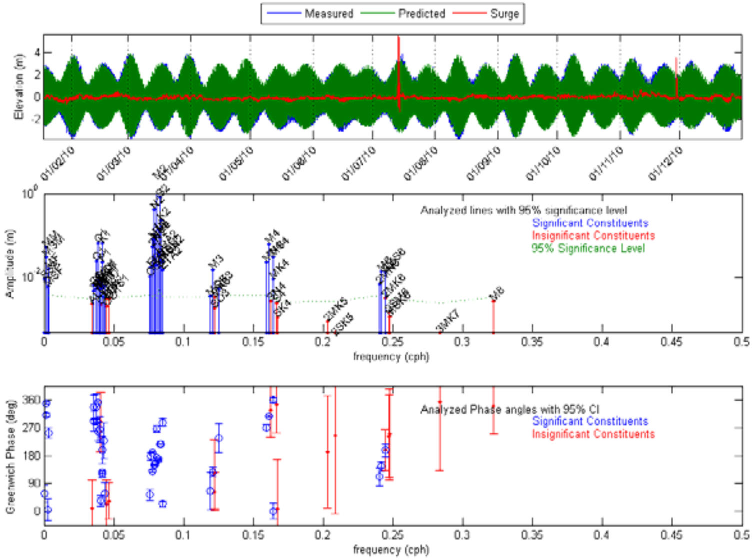
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2MN6	4.17	0.0071	112.0	3.4
J1	23.10	0.0062	58.0	2.6
MSF	354.37	0.0059	5.6	2.5
RHO1	26.72	0.0056	337.8	2.3
PHI1	23.80	0.0055	198.4	2.2
SK3	7.99	0.0053	237.3	1.9
BET1	24.97	0.0054	263.8	1.8
SIG1	27.85	0.0049	337.0	1.6
MO3	8.39	0.0037	66.7	1.2
THE1	23.21	0.0035	228.1	1.1
2MK6	4.09	0.0034	197.9	0.97
SO1	22.42	0.0031	22.7	0.96
MK3	8.18	0.0035	64.6	0.9
OO1	22.31	0.0021	26.2	0.89
UPS1	21.58	0.0031	34.5	0.88
SN4	6.16	0.0027	325.7	0.72
M8	3.11	0.0027	341.0	0.64
S4	6.00	0.0025	345.8	0.6
ALP1	29.07	0.0024	11.5	0.59
CHI1	24.71	0.0022	288.7	0.44
SO3	8.19	0.0019	120.5	0.35
2SM6	4.05	0.0015	242.9	0.26
SK4	5.99	0.0011	7.4	0.19
MSK6	4.04	0.0012	249.7	0.14
2MK5	4.93	0.0009	191.6	0.11
3MK7	3.53	0.0005	353.4	0.036
2SK5	4.80	0.0004	244.8	0.023

Number of days: 347.91
Number of constituents: 59
MSL = 0.12 m





A 9. Re-synthesis of the observed data at Milford Haven, Wales

Observed harmonic constituents

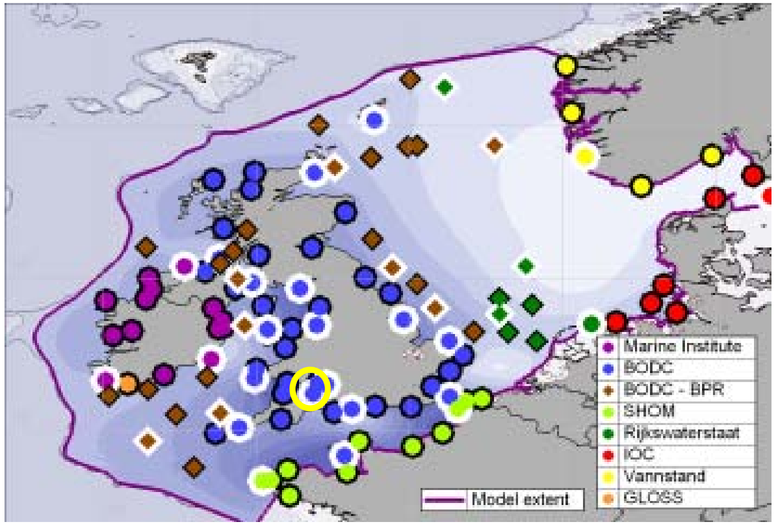
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**3.9460**	**181.9**	**490000**
S2	**12.00**	**1.3771**	**237.5**	**68000**
N2	**12.66**	**0.6977**	**166.6**	**17000**
K2	**11.97**	**0.3848**	**235.0**	**6000**
MU2	**12.87**	**0.3341**	**231.1**	**3600**
L2	**12.19**	**0.3303**	**176.2**	**2100**
M4	**6.21**	**0.1087**	**20.4**	**330**
EPS2	**13.13**	**0.0816**	**204.2**	**240**
MSN2	11.79	0.0802	35.1	180
K1	23.93	0.0748	128.0	170
MSF	354.37	0.0640	37.0	150
MKS2	12.39	0.0610	299.1	150
O1	25.82	0.0691	354.0	130
2MS6	4.09	0.0585	249.2	110
MM	661.29	0.0562	22.4	100
MN4	6.27	0.0527	335.2	94
SSA	4382.12	0.0510	286.7	86
M6	4.14	0.0451	209.7	63
M3	8.28	0.0436	175.0	55
MS4	6.10	0.0325	27.2	32
P1	24.07	0.0282	119.9	27
Q1	26.87	0.0217	290.4	18
S4	6.00	0.0229	45.4	18
MF	327.86	0.0215	82.7	17
2SM6	4.05	0.0213	320.6	17
2MN6	4.17	0.0217	195.3	16
SK3	7.99	0.0175	296.5	15
ETA2	11.75	0.0161	355.8	14
NO1	24.83	0.0124	17.6	9.1
MK3	8.18	0.0156	140.9	8.4
SN4	6.16	0.0164	342.7	7.9
SK4	5.99	0.0123	47.2	6.6

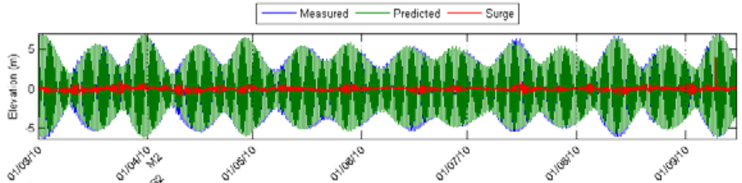
(…)

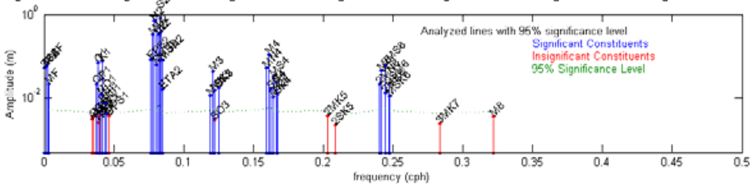
(…)

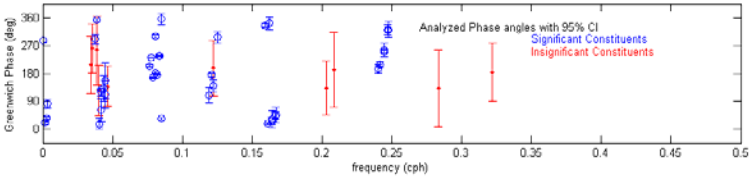
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2MK6	4.09	0.0136	255.5	5.5
MO3	8.39	0.0117	108.9	5.3
MK4	6.09	0.0107	32.4	4.9
MSK6	4.04	0.0113	322.0	4.9
PHI1	23.80	0.0081	62.1	2.8
SO1	22.42	0.0075	113.5	2.4
J1	23.10	0.0076	131.5	1.8
OO1	22.31	0.0042	157.0	1.1
UPS1	21.58	0.0039	137.8	0.79
BET1	24.97	0.0037	126.0	0.63
2MK5	4.93	0.0038	133.1	0.57
SO3	8.19	0.0030	197.7	0.56
M8	3.11	0.0036	183.5	0.56
2Q1	28.01	0.0036	260.3	0.51
ALP1	29.07	0.0032	207.9	0.47
TAU1	25.67	0.0026	254.4	0.35
2SK5	4.80	0.0023	191.9	0.34
3MK7	3.53	0.0025	131.0	0.32

Number of days: 198.45
Number of constituents: 50
MSL = 0.20 m









A 10. Re-synthesis of the observed data at Hinkley Point, England

Observed harmonic constituents

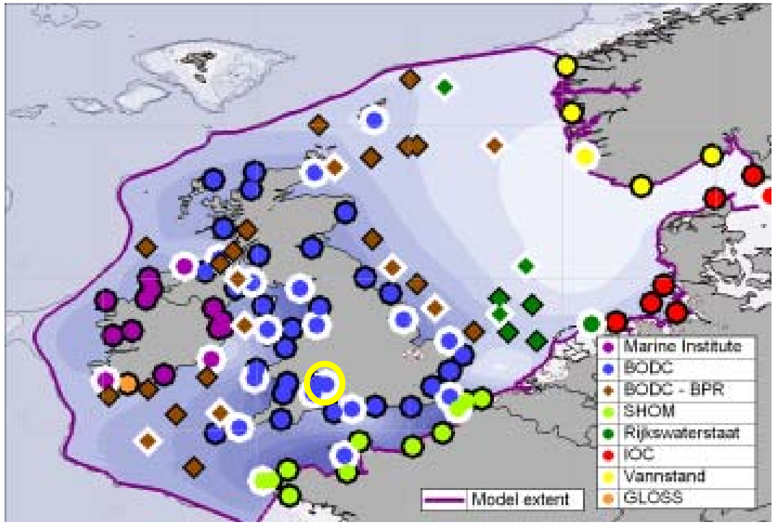
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**4.2153**	**202.2**	**650000**
S2	**12.00**	**1.5060**	**261.9**	**81000**
N2	**12.66**	**0.7450**	**186.7**	**15000**
MU2	**12.87**	**0.4718**	**253.1**	**7500**
K2	**11.97**	**0.4159**	**257.3**	**6800**
L2	**12.19**	**0.4196**	**194.5**	**3500**
M4	**6.21**	**0.2700**	**351.5**	**2300**
MS4	**6.10**	**0.2590**	**24.0**	**1800**
NU2	12.63	0.2094	145.8	1700
2N2	12.91	0.1824	197.5	1300
MSF	354.37	0.1376	45.5	740
LDA2	12.22	0.1359	184.4	710
EPS2	13.13	0.1292	222.9	640
MN4	6.27	0.1301	337.4	640
2MS6	4.09	0.1523	334.3	600
M6	4.14	0.1213	280.1	410
MKS2	12.39	0.0881	10.2	320
MSN2	11.79	0.0783	57.3	260
O1	25.82	0.0749	354.5	220
S4	6.00	0.0696	102.3	190
MM	661.29	0.0635	20.1	150
MK4	6.09	0.0647	24.1	150
K1	23.93	0.0591	131.5	130
OQ2	13.16	0.0517	188.3	110
SN4	6.16	0.0550	39.7	110
M3	8.28	0.0515	220.7	97
2MN6	4.17	0.0519	250.5	82
SSA	4382.12	0.0427	26.3	63
SK4	5.99	0.0382	98.5	55
2SM6	4.05	0.0411	77.4	53
MSM	763.48	0.0345	275.8	44
NO1	24.83	0.0230	23.2	42

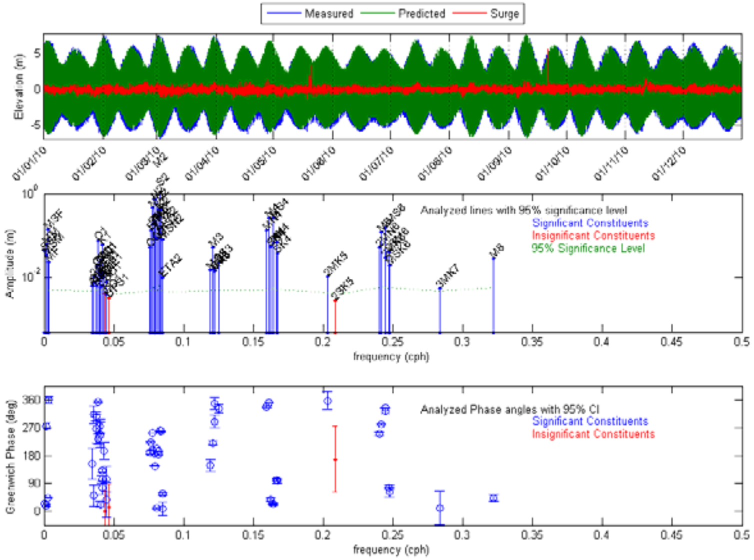
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2MK6	4.09	0.0303	324.8	32
P1	24.07	0.0255	103.6	23
M8	3.11	0.0276	43.3	23
MF	327.86	0.0235	359.6	21
SK3	7.99	0.0221	332.5	19
Q1	26.87	0.0182	305.5	16
TAU1	25.67	0.0193	232.6	14
MSK6	4.04	0.0191	62.9	11
MO3	8.39	0.0156	148.9	10
SO3	8.19	0.0151	348.3	9.2
BET1	24.97	0.0135	275.8	8.1
MK3	8.18	0.0137	289.5	7.3
PHI1	23.80	0.0137	78.0	6.2
2MK5	4.93	0.0106	357.7	5.8
THE1	23.21	0.0105	195.6	5.5
ETA2	11.75	0.0102	8.6	5.1
2Q1	28.01	0.0105	311.8	3.8
SO1	22.42	0.0081	105.1	2.9
SIG1	27.85	0.0076	52.0	2
ALP1	29.07	0.0063	154.3	1.7
OO1	22.31	0.0041	38.0	1.7
RHO1	26.72	0.0064	265.9	1.3
CHI1	24.71	0.0061	246.7	1.3
3MK7	3.53	0.0054	12.1	1.3
J1	23.10	0.0043	0.4	0.92
UPS1	21.58	0.0033	14.5	0.65
2SK5	4.80	0.0029	168.3	0.53

Number of days: 365
Number of constituents: 59
MSL = 0.07 m





A 11. Re-synthesis of the observed data at Avonmouth, England

Observed harmonic constituents

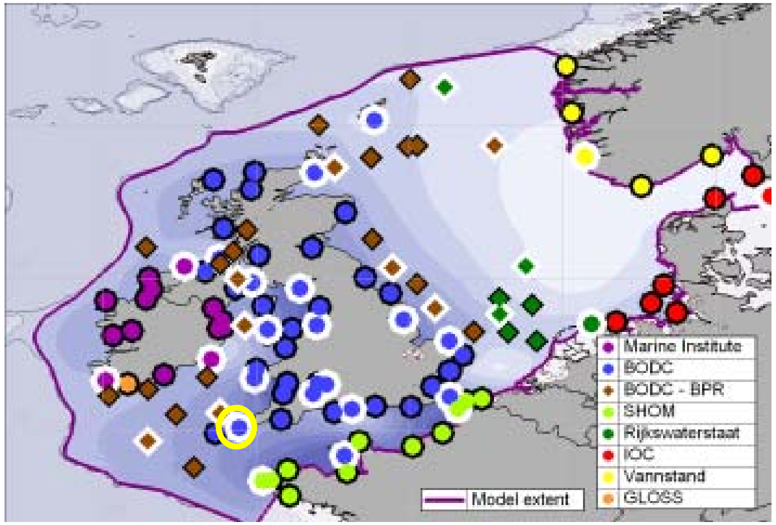
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.7093**	**133.4**	**140000**
S2	**12.00**	**0.5877**	**170.0**	**20000**
N2	**12.66**	**0.3256**	**108.5**	**6700**
M4	**6.21**	**0.1138**	**166.3**	**600**
MS4	**6.10**	**0.0757**	**210.6**	**350**
MU2	**12.87**	**0.0705**	**177.2**	**260**
K1	**23.93**	**0.0641**	**104.6**	**230**
L2	**12.19**	**0.0905**	**136.7**	**200**
O1	25.82	0.0530	347.2	140
MSF	354.37	0.0404	329.1	96
MN4	6.27	0.0408	133.7	70
MM	661.29	0.0183	348.6	20
EPS2	13.13	0.0153	146.0	14
Q1	26.87	0.0156	265.8	13
SN4	6.16	0.0122	211.3	11
2MS6	4.09	0.0100	15.3	6.3
M6	4.14	0.0105	326.2	6.1
M3	8.28	0.0099	37.9	5.6
S4	6.00	0.0088	257.0	4.5
2MN6	4.17	0.0054	287.9	2.1

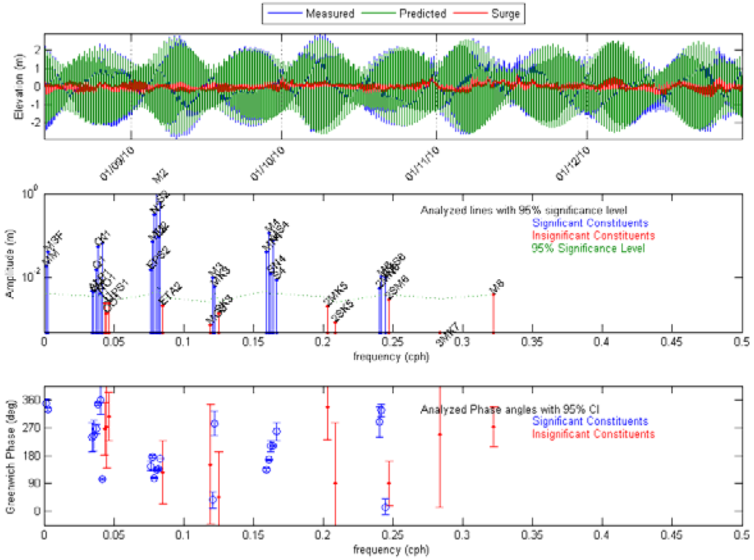
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
ALP1	29.07	0.0048	238.9	1.8
NO1	24.83	0.0042	358.6	1.7
MK3	8.18	0.0060	283.2	1.7
2Q1	28.01	0.0046	244.4	1.6
M8	3.11	0.0039	273.0	0.94
UPS1	21.58	0.0025	305.7	0.75
J1	23.10	0.0025	266.1	0.71
2SM6	4.05	0.0030	90.6	0.56
ETA2	11.75	0.0021	126.5	0.4
2MK5	4.93	0.0021	339.1	0.37
OO1	22.31	0.0015	273.2	0.34
SK3	7.99	0.0014	46.8	0.26
2SK5	4.80	0.0009	92.1	0.12
MO3	8.39	0.0008	152.2	0.081
3MK7	3.53	0.0002	246.1	0.005

Number of days: 139.39
Number of constituents: 35
MSL = 0.10 m





A 12. Re-synthesis of the observed data at Newlyn, England

Observed harmonic constituents

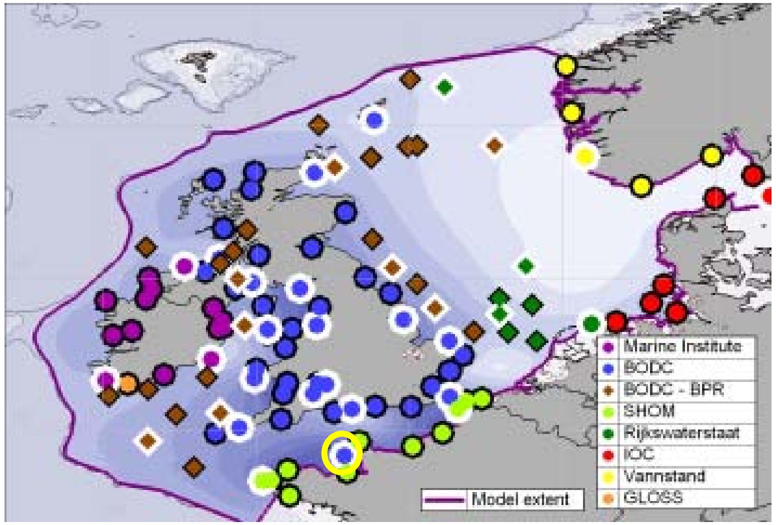
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**3.3303**	**181.1**	**1300000**
S2	**12.00**	**1.3099**	**230.8**	**290000**
N2	**12.66**	**0.6483**	**163.5**	**65000**
K2	**11.97**	**0.3704**	**229.3**	**18000**
MU2	**12.87**	**0.2241**	**192.7**	**7000**
L2	**12.19**	**0.2234**	**163.0**	**4700**
M4	**6.21**	**0.1932**	**298.7**	**3900**
MS4	**6.10**	**0.1465**	**354.7**	**2600**
2N2	12.91	0.1179	150.9	2200
NU2	12.63	0.1028	150.9	1400
K1	23.93	0.0939	97.0	1200
O1	25.82	0.0799	347.0	980
LDA2	12.22	0.0780	146.2	780
MN4	6.27	0.0672	273.2	690
EPS2	13.13	0.0550	165.9	500
MKS2	12.39	0.0477	267.2	430
MK4	6.09	0.0419	356.7	310
MSM	763.48	0.0421	299.8	270
MSN2	11.79	0.0469	18.4	260
P1	24.07	0.0338	90.7	140
M3	8.28	0.0281	171.4	130
MSF	354.37	0.0246	298.6	110
MM	661.29	0.0257	337.8	100
OQ2	13.16	0.0198	135.9	76
SN4	6.16	0.0268	0.9	76
Q1	26.87	0.0203	298.8	75
MF	327.86	0.0220	197.2	72
S4	6.00	0.0215	77.8	63
ETA2	11.75	0.0132	313.9	31
MO3	8.39	0.0145	112.9	27
SK4	5.99	0.0115	77.3	19
MK3	8.18	0.0122	232.0	18

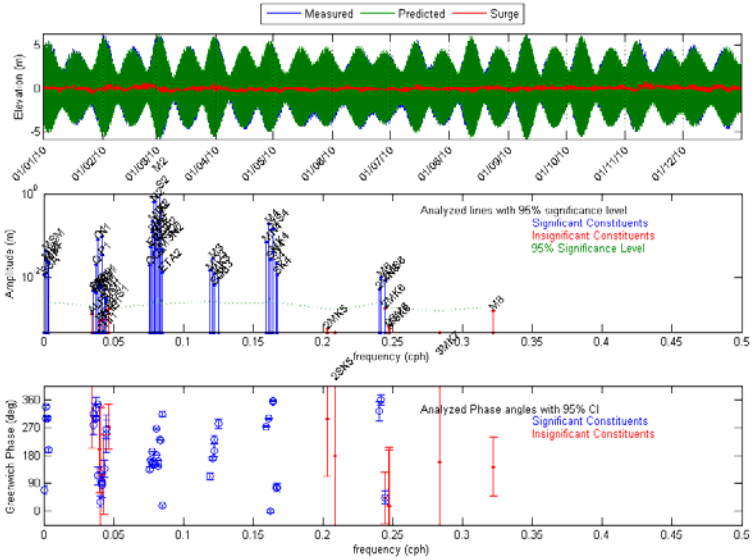
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
SSA	4382.12	0.0117	69.5	16
SK3	7.99	0.0096	282.1	15
NO1	24.83	0.0064	31.5	13
M6	4.14	0.0101	359.7	12
2MS6	4.09	0.0084	45.2	8.9
SO3	8.19	0.0068	196.2	6.8
2MN6	4.17	0.0053	323.3	4.6
SIG1	27.85	0.0051	316.4	4.2
TAU1	25.67	0.0057	114.8	4.2
J1	23.10	0.0052	137.9	4.1
2Q1	28.01	0.0048	277.0	3.8
OO1	22.31	0.0032	264.2	3.1
RHO1	26.72	0.0044	333.1	2.9
PHI1	23.80	0.0039	84.3	2.1
SO1	22.42	0.0026	249.9	1.1
UPS1	21.58	0.0018	272.9	0.87
2MK6	4.09	0.0019	43.2	0.73
M8	3.11	0.0017	143.5	0.67
ALP1	29.07	0.0014	307.3	0.41
THE1	23.21	0.0010	117.5	0.26
BET1	24.97	0.0009	200.6	0.17
2SM6	4.05	0.0007	18.2	0.14
2MK5	4.93	0.0006	297.5	0.11
MSK6	4.04	0.0006	15.4	0.1
CHI1	24.71	0.0005	141.7	0.065
3MK7	3.53	0.0001	159.5	0.0069
2SK5	4.80	0.0000	179.2	0.00042

Number of days: 365
Number of constituents: 59
MSL = 0.00 m





A 13. Re-synthesis of the observed data at St. Helier, Jersey, Channel Islands

Observed harmonic constituents

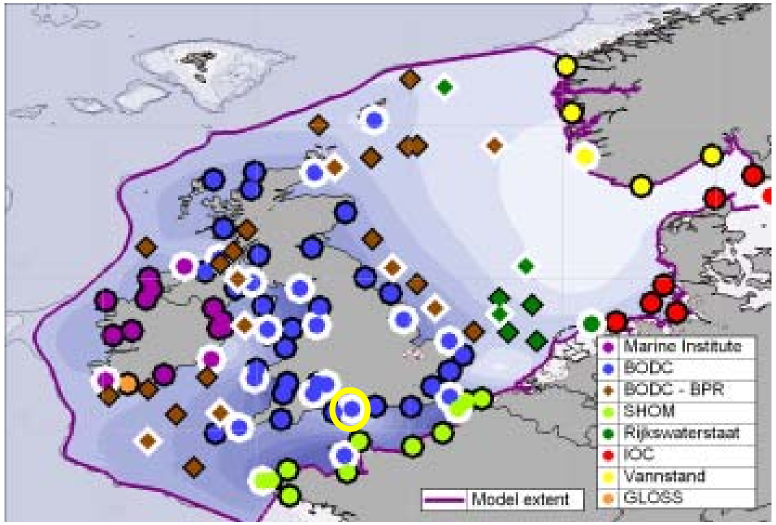
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.4107**	**273.8**	**48000**
M4	**6.21**	**0.1936**	**20.8**	**11000**
S2	**12.00**	**0.1850**	**292.8**	**7400**
MS4	**6.10**	**0.1222**	**75.2**	**3600**
N2	**12.66**	**0.1056**	**249.1**	**3000**
K1	**23.93**	**0.0931**	**111.6**	**2100**
MU2	**12.87**	**0.0700**	**187.5**	**1300**
2MS6	**4.09**	**0.0746**	**122.1**	**1200**
MN4	6.27	0.0667	351.4	1100
M6	4.14	0.0727	79.8	1000
K2	11.97	0.0502	291.5	720
O1	25.82	0.0416	354.3	470
MSF	354.37	0.0373	17.0	390
MSM	763.48	0.0364	311.9	350
P1	24.07	0.0365	109.7	350
2MN6	4.17	0.0403	52.9	340
MK4	6.09	0.0343	75.1	270
MM	661.29	0.0276	356.7	210
2N2	12.91	0.0222	177.5	130
EPS2	13.13	0.0201	142.6	120
L2	12.19	0.0277	90.9	120
2SM6	4.05	0.0215	172.5	120
2MK6	4.09	0.0198	123.8	94
NU2	12.63	0.0162	283.7	74
SN4	6.16	0.0147	93.8	65
SSA	4382.12	0.0169	17.4	62
MSK6	4.04	0.0124	171.4	46
LDA2	12.22	0.0118	62.2	34
MK3	8.18	0.0110	130.0	33
MF	327.86	0.0102	197.5	28
S4	6.00	0.0092	151.0	18
Q1	26.87	0.0070	316.8	17

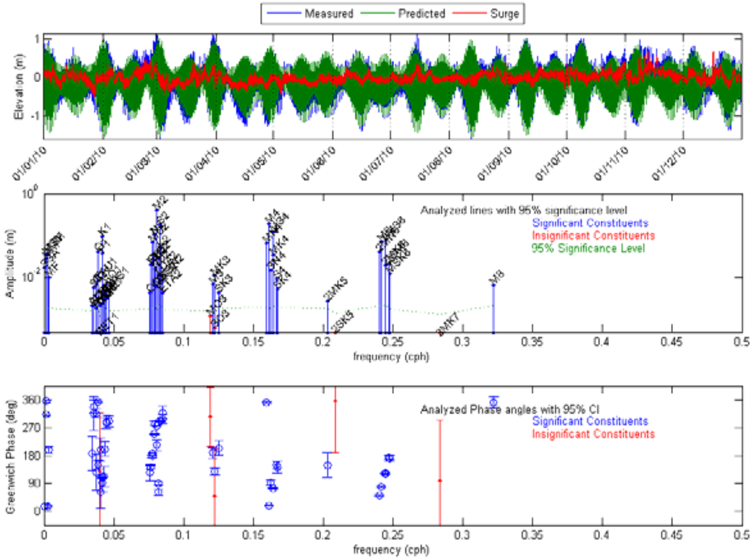
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
MSN2	11.79	0.0089	297.8	17
TAU1	25.67	0.0083	152.1	15
SO1	22.42	0.0070	284.5	14
M3	8.28	0.0071	188.6	14
MKS2	12.39	0.0060	213.6	13
SIG1	27.85	0.0057	338.8	11
M8	3.11	0.0068	352.8	10
UPS1	21.58	0.0048	290.1	8.6
SK4	5.99	0.0053	143.0	7.2
ETA2	11.75	0.0045	319.4	6.7
J1	23.10	0.0044	201.6	5.7
SK3	7.99	0.0044	204.7	5.7
OQ2	13.16	0.0043	125.6	5.6
OO1	22.31	0.0033	288.1	4.7
PHI1	23.80	0.0039	92.9	3.5
THE1	23.21	0.0030	113.7	3
NO1	24.83	0.0023	198.7	2.7
2MK5	4.93	0.0028	149.5	2.1
ALP1	29.07	0.0021	187.2	1.8
2Q1	28.01	0.0022	315.8	1.3
RHO1	26.72	0.0019	126.4	1.2
CHI1	24.71	0.0021	62.3	1.1
MO3	8.39	0.0012	305.5	0.58
SO3	8.19	0.0006	50.7	0.19
2SK5	4.80	0.0005	357.9	0.11
BET1	24.97	0.0004	129.5	0.1
3MK7	3.53	0.0004	99.5	0.074

Number of days: 365
Number of constituents: 59
MSL = -0.05 m





A 14. Re-synthesis of the observed data at Bournemouth, England

Observed harmonic constituents

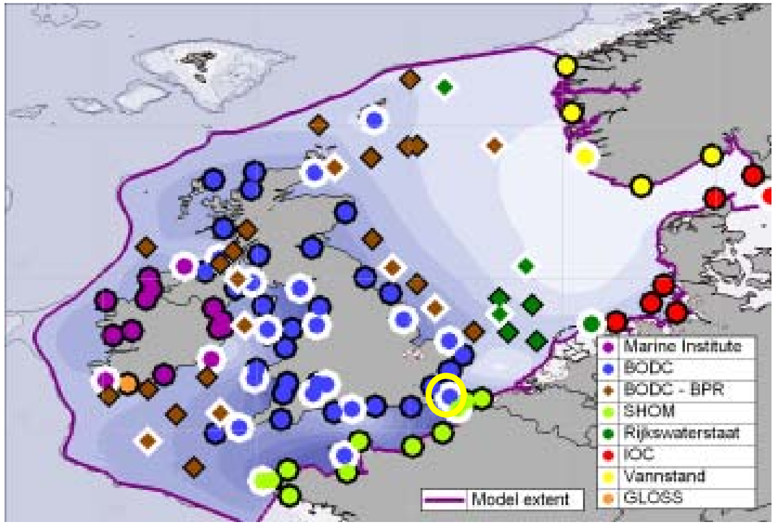
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**2.2586**	**331.5**	**580000**
S2	**12.00**	**0.7119**	**23.5**	**91000**
N2	**12.66**	**0.4099**	**308.2**	**24000**
M4	**6.21**	**0.2629**	**221.6**	**8600**
K2	**11.97**	**0.2007**	**21.8**	**7000**
MS4	**6.10**	**0.1705**	**273.0**	**3200**
L2	**12.19**	**0.1692**	**345.0**	**2000**
NU2	**12.63**	**0.1009**	**301.2**	**1700**
MN4	6.27	0.0930	192.9	1300
MU2	12.87	0.0910	42.4	1100
LDA2	12.22	0.0622	330.1	580
2MS6	4.09	0.0655	149.6	530
M6	4.14	0.0692	105.4	510
O1	25.82	0.0528	175.3	420
K1	23.93	0.0515	43.0	360
2N2	12.91	0.0473	317.7	360
2MN6	4.17	0.0375	75.6	260
MK4	6.09	0.0466	272.9	250
EPS2	13.13	0.0297	17.7	150
MSN2	11.79	0.0296	203.6	140
MSM	763.48	0.0283	342.2	130
M8	3.11	0.0247	14.8	93
MKS2	12.39	0.0211	100.6	87
Q1	26.87	0.0205	95.4	85
SN4	6.16	0.0204	291.2	69
SSA	4382.12	0.0192	41.2	49
P1	24.07	0.0217	31.6	49
NO1	24.83	0.0122	189.9	44
2MK6	4.09	0.0169	152.2	44
MF	327.86	0.0161	190.3	42
MK3	8.18	0.0168	7.3	42
S4	6.00	0.0158	354.0	38

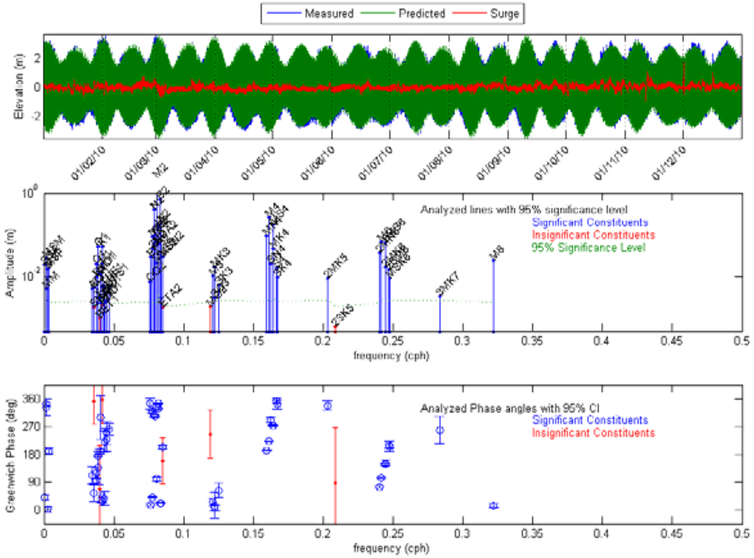
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
MSF	354.37	0.0151	2.8	34
2SM6	4.05	0.0147	210.9	29
RHO1	26.72	0.0100	121.6	14
M3	8.28	0.0107	26.4	14
SK4	5.99	0.0097	342.2	14
2MK5	4.93	0.0093	339.0	12
MSK6	4.04	0.0091	205.3	11
OQ2	13.16	0.0076	344.7	9.5
THE1	23.21	0.0062	38.5	7
UPS1	21.58	0.0055	259.7	5.4
SK3	7.99	0.0064	64.1	5.4
2Q1	28.01	0.0056	55.3	4.7
ALP1	29.07	0.0053	113.8	4
MM	661.29	0.0052	332.6	3.8
J1	23.10	0.0044	220.8	3.2
SO1	22.42	0.0039	227.0	1.9
OO1	22.31	0.0026	249.3	1.9
SO3	8.19	0.0032	15.1	1.6
3MK7	3.53	0.0034	257.9	1.6
TAU1	25.67	0.0031	136.6	1.5
CHI1	24.71	0.0024	298.6	1.1
ETA2	11.75	0.0019	159.0	0.9
PHI1	23.80	0.0022	357.0	0.79
MO3	8.39	0.0020	245.4	0.67
SIG1	27.85	0.0019	350.8	0.65
BET1	24.97	0.0010	68.2	0.35
2SK5	4.80	0.0006	89.1	0.11

Number of days: 364.19
Number of constituents: 59
MSL = 0.01 m





A 15. Re-synthesis of the observed data at Dover, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.5350**	**188.6**	**100000**
S2	**12.00**	**0.5121**	**234.4**	**17000**
N2	**12.66**	**0.2919**	**164.1**	**5100**
O1	**25.82**	**0.1602**	**132.5**	**1600**
K1	**23.93**	**0.1473**	**298.5**	**1300**
K2	**11.97**	**0.1339**	**234.4**	**960**
M4	**6.21**	**0.0911**	**276.2**	**470**
MS4	**6.10**	**0.0740**	**323.5**	**310**
NU2	12.63	0.0653	154.2	240
L2	12.19	0.0806	208.4	180
MF	327.86	0.0468	167.1	150
Q1	26.87	0.0460	48.3	140
P1	24.07	0.0520	288.5	110
NO1	24.83	0.0223	164.8	55
MN4	6.27	0.0331	256.2	55
LDA2	12.22	0.0308	181.9	47
2N2	12.91	0.0275	164.2	45
MK3	8.18	0.0305	49.6	44
MO3	8.39	0.0252	243.4	43
M6	4.14	0.0272	41.9	38
SSA	4382.12	0.0255	273.3	35
MSF	354.37	0.0226	270.0	32
MU2	12.87	0.0264	200.3	32
M3	8.28	0.0210	256.2	28
2MS6	4.09	0.0258	80.0	23
MK4	6.09	0.0186	307.0	19
BET1	24.97	0.0182	230.3	17
TAU1	25.67	0.0179	29.8	15
ETA2	11.75	0.0125	10.9	15
2MK5	4.93	0.0157	137.4	15
SO3	8.19	0.0149	316.1	13
RHO1	26.72	0.0148	81.2	12

(…)

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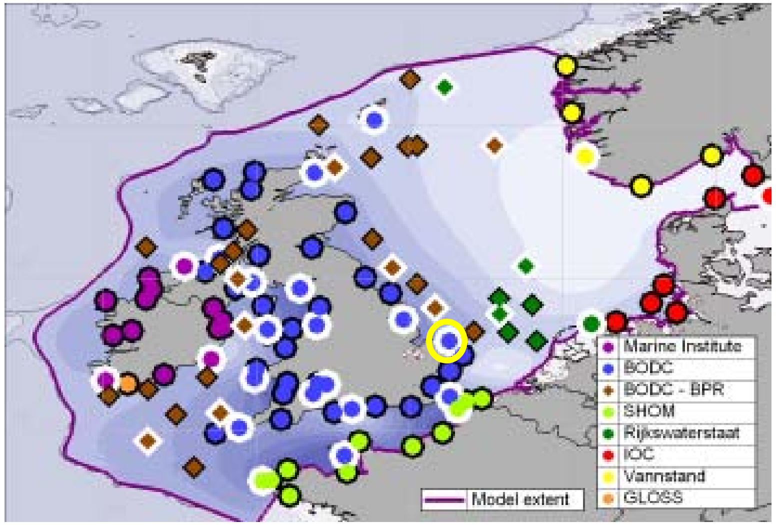
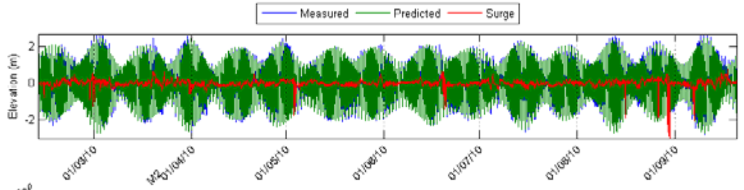
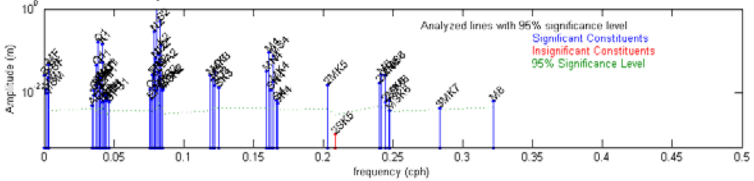
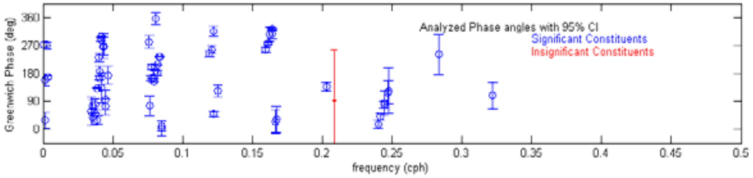
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2MN6	4.17	0.0166	17.4	12
SK3	7.99	0.0136	123.2	10
OQ2	13.16	0.0120	280.8	9.7
SIG1	27.85	0.0116	76.2	9.4
MKS2	12.39	0.0118	357.8	9
MM	661.29	0.0121	160.1	8
CHI1	24.71	0.0135	187.4	7.8
SN4	6.16	0.0114	305.8	6.7
MSN2	11.79	0.0117	2.6	6.6
MSM	763.48	0.0096	29.4	5.9
OO1	22.31	0.0066	73.8	5.2
J1	23.10	0.0086	267.7	4.5
2Q1	28.01	0.0088	40.0	4.1
EPS2	13.13	0.0070	75.9	4
SO1	22.42	0.0076	95.4	3.2
THE1	23.21	0.0061	267.6	2.6
UPS1	21.58	0.0059	173.5	2.4
S4	6.00	0.0065	24.6	2.3
2MK6	4.09	0.0060	85.2	2.3
2SM6	4.05	0.0069	119.5	2.3
PHI1	23.80	0.0062	133.5	2
SK4	5.99	0.0056	32.2	1.9
M8	3.11	0.0062	109.1	1.9
ALP1	29.07	0.0051	58.8	1.5
3MK7	3.53	0.0044	240.4	1.3
MSK6	4.04	0.0037	124.4	1.1
2SK5	4.80	0.0010	92.6	0.11

Number of days: 221.29
Number of constituents: 59
MSL = 0.11 m









A 16. Re-synthesis of the observed data at Cromer, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**2.2263**	**161.4**	**580000**
S2	**12.00**	**0.7331**	**212.1**	**96000**
N2	**12.66**	**0.4139**	**139.8**	**25000**
K2	**11.97**	**0.2081**	**210.7**	**5400**
O1	**25.82**	**0.1686**	**114.3**	**4700**
K1	**23.93**	**0.1506**	**283.2**	**3100**
L2	**12.19**	**0.1511**	**166.0**	**2100**
NU2	**12.63**	**0.0942**	**133.4**	**1500**
MU2	12.87	0.0864	217.8	1200
2N2	12.91	0.0557	147.4	530
LDA2	12.22	0.0569	157.0	420
Q1	26.87	0.0476	48.3	380
P1	24.07	0.0514	273.3	340
MK3	8.18	0.0366	28.7	180
EPS2	13.13	0.0306	193.1	150
MO3	8.39	0.0316	219.0	140
MS4	6.10	0.0286	250.8	110
MSN2	11.79	0.0288	18.3	99
MKS2	12.39	0.0230	271.8	97
M3	8.28	0.0217	215.4	78
SSA	4382.12	0.0209	35.7	61
MSF	354.37	0.0191	343.8	60
MSM	763.48	0.0180	317.1	50
MF	327.86	0.0191	165.5	49
SO3	8.19	0.0159	283.5	47
2MS6	4.09	0.0205	206.5	46
SK3	7.99	0.0162	87.4	39
M4	6.21	0.0162	194.6	37
NO1	24.83	0.0110	135.0	36
RHO1	26.72	0.0163	74.0	35
M8	3.11	0.0131	179.7	24
2MK5	4.93	0.0115	313.5	22

(…)

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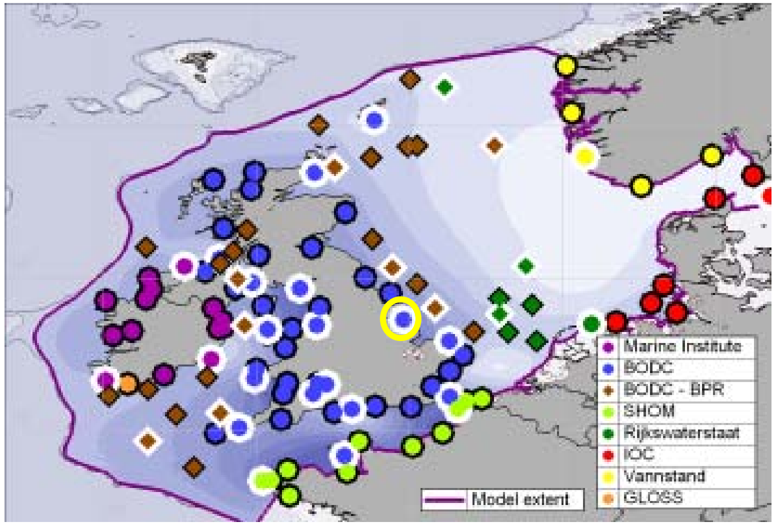
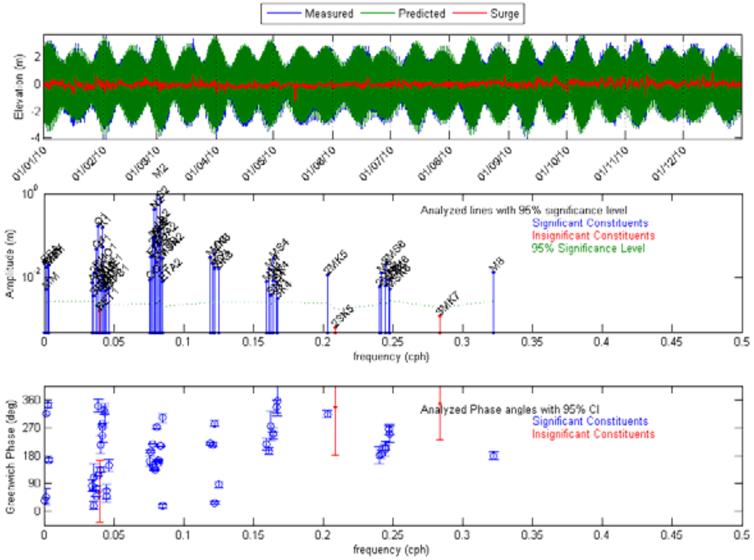
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2Q1	28.01	0.0119	20.9	21
THE1	23.21	0.0103	326.7	18
M6	4.14	0.0128	184.2	18
ETA2	11.75	0.0081	300.8	15
OQ2	13.16	0.0087	162.4	13
2SM6	4.05	0.0087	263.2	10
MN4	6.27	0.0081	217.4	9.7
MK4	6.09	0.0083	250.3	9
S4	6.00	0.0075	339.1	8.5
TAU1	25.67	0.0077	341.9	8.4
OO1	22.31	0.0050	65.1	8.1
SO1	22.42	0.0070	50.2	8
ALP1	29.07	0.0076	82.9	7.6
2MK6	4.09	0.0064	201.9	7.4
2MN6	4.17	0.0060	182.0	6.9
UPS1	21.58	0.0055	149.4	5.9
PHI1	23.80	0.0063	245.9	4.6
MM	661.29	0.0053	48.0	3.8
J1	23.10	0.0049	317.2	3.6
MSK6	4.04	0.0052	249.7	3.4
SN4	6.16	0.0038	275.9	3.1
CHI1	24.71	0.0051	214.5	2.9
SIG1	27.85	0.0036	110.8	1.9
SK4	5.99	0.0031	358.0	1.5
BET1	24.97	0.0016	64.3	0.49
3MK7	3.53	0.0012	348.2	0.4
2SK5	4.80	0.0007	336.9	0.13

Number of days: 365
Number of constituents: 59
MSL = 0.05 m





A 17. Re-synthesis of the observed data at Immingham, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.0109**	**321.8**	**110000**
S2	**12.00**	**0.3155**	**3.0**	**8800**
N2	**12.66**	**0.1985**	**305.0**	**4000**
O1	**25.82**	**0.1130**	**27.0**	**1300**
K1	**23.93**	**0.1172**	**173.7**	**1100**
MSF	**354.37**	**0.0394**	**319.5**	**160**
M4	**6.21**	**0.0397**	**317.4**	**140**
Q1	**26.87**	**0.0306**	**325.3**	**100**
L2	12.19	0.0449	306.1	100
MM	661.29	0.0284	178.0	82
MS4	6.10	0.0186	54.2	30
NO1	24.83	0.0113	64.0	23
MU2	12.87	0.0163	285.4	21
M3	8.28	0.0137	232.1	17
MN4	6.27	0.0116	272.2	13
ETA2	11.75	0.0075	6.2	6.8
M6	4.14	0.0069	231.4	4.3
2Q1	28.01	0.0052	278.1	3.5
2MS6	4.09	0.0059	265.2	3.5
MK3	8.18	0.0057	25.9	3.3
J1	23.10	0.0044	197.6	2.5
EPS2	13.13	0.0045	318.9	2.1

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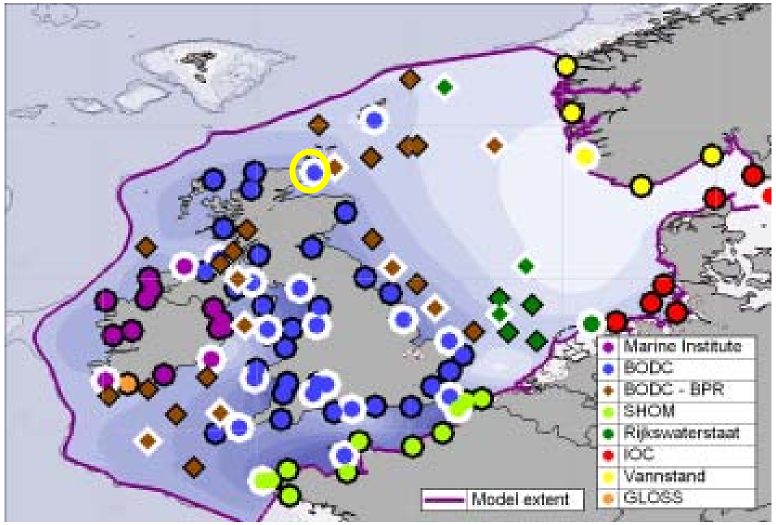
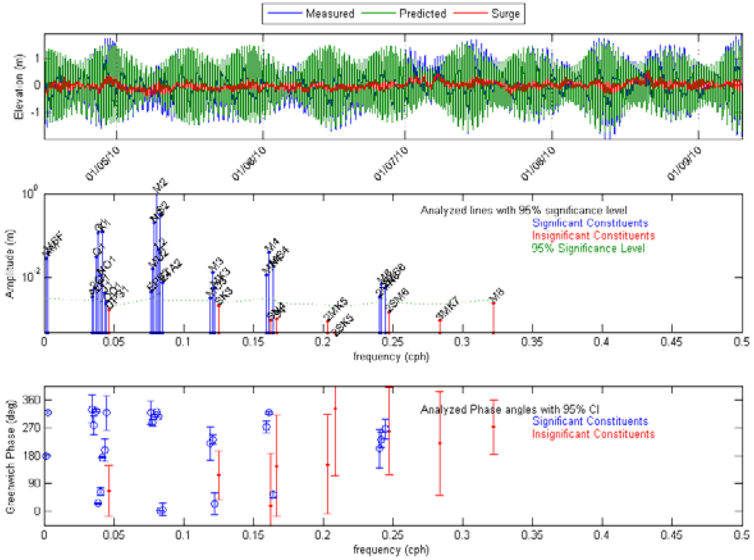
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2MN6	4.17	0.0035	202.2	1.8
ALP1	29.07	0.0035	330.3	1.5
OO1	22.31	0.0026	317.6	1.3
MO3	8.39	0.0032	219.0	1.2
SK3	7.99	0.0022	117.3	0.77
UPS1	21.58	0.0017	66.2	0.73
M8	3.11	0.0025	271.7	0.68
2SM6	4.05	0.0015	258.7	0.36
S4	6.00	0.0010	146.5	0.16
3MK7	3.53	0.0010	219.6	0.16
SN4	6.16	0.0010	18.7	0.14
2MK5	4.93	0.0009	152.4	0.14
2SK5	4.80	0.0004	331.4	0.037

Number of days: 147.73
Number of constituents: 35
MSL = -0.07 m





A 18. Re-synthesis of the observed data at Wick, Scotland

Observed harmonic constituents

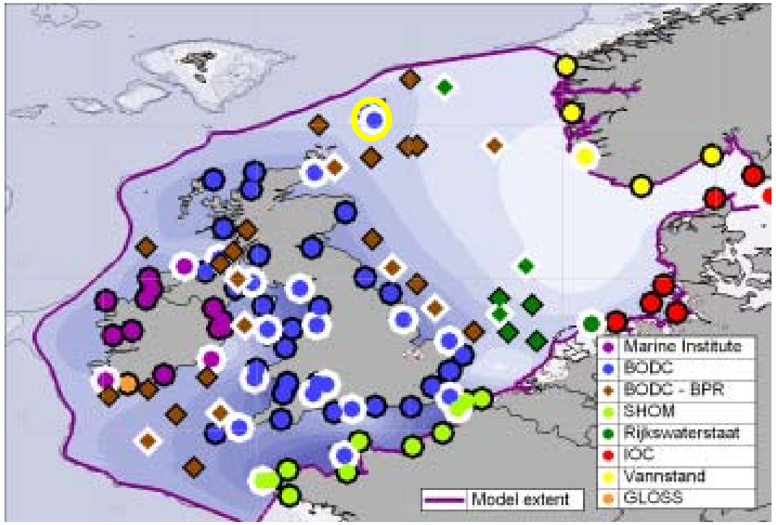
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.5764**	**312.1**	**79000**
S2	**12.00**	**0.2049**	**348.1**	**10000**
N2	**12.66**	**0.1210**	**291.7**	**2800**
O1	**25.82**	**0.0769**	**32.2**	**1500**
K1	**23.93**	**0.0750**	**164.1**	**1200**
K2	**11.97**	**0.0576**	**343.3**	**810**
MSM	**763.48**	**0.0414**	**261.5**	**450**
SSA	**4382.12**	**0.0377**	**359.5**	**320**
Q1	26.87	0.0243	330.7	250
P1	24.07	0.0228	151.0	140
MF	327.86	0.0237	191.1	130
MU2	12.87	0.0226	263.2	130
NU2	12.63	0.0220	300.4	110
M4	6.21	0.0156	278.0	61
2N2	12.91	0.0141	254.8	59
MM	661.29	0.0138	346.3	47
MS4	6.10	0.0124	4.7	39
L2	12.19	0.0154	292.2	34
2MS6	4.09	0.0130	265.9	33
NO1	24.83	0.0079	77.3	29
M6	4.14	0.0119	222.9	27
MSF	354.37	0.0084	324.4	20
M3	8.28	0.0071	194.7	11
2MN6	4.17	0.0068	195.6	9.9
EPS2	13.13	0.0057	258.5	9.6
ETA2	11.75	0.0045	14.4	9
MN4	6.27	0.0045	225.2	4.9
RHO1	26.72	0.0046	352.0	4.6
2Q1	28.01	0.0039	274.1	4
SIG1	27.85	0.0040	302.9	3.8
J1	23.10	0.0032	187.8	3
OQ2	13.16	0.0029	249.8	3

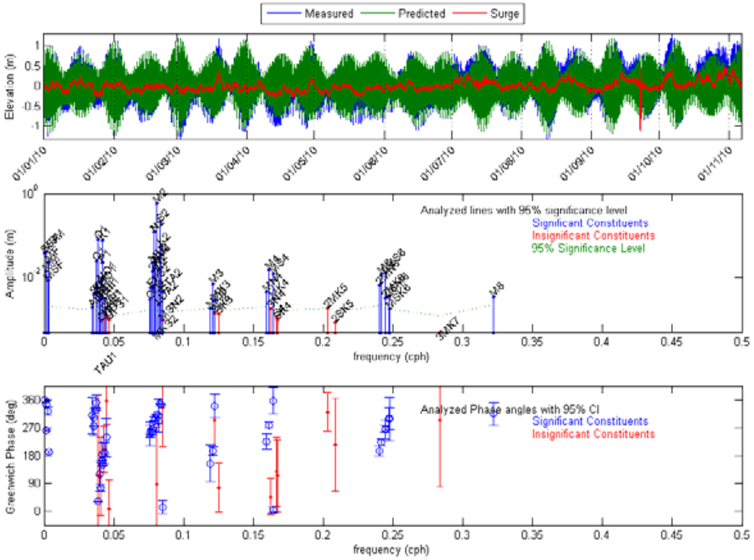
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2SM6	4.05	0.0034	300.5	2.8
2MK6	4.09	0.0033	264.7	2.6
PHI1	23.80	0.0033	183.2	2.4
MK4	6.09	0.0032	358.3	2.4
BET1	24.97	0.0029	120.2	2.3
MK3	8.18	0.0029	340.5	2.3
M8	3.11	0.0034	314.9	2.3
ALP1	29.07	0.0020	309.1	1.3
LDA2	12.22	0.0023	309.4	1.3
SO1	22.42	0.0019	237.8	1.1
MSK6	4.04	0.0018	298.7	1.1
MO3	8.39	0.0019	154.4	1
SN4	6.16	0.0018	47.7	0.95
2MK5	4.93	0.0018	321.2	0.94
OO1	22.31	0.0011	358.0	0.86
THE1	23.21	0.0015	200.1	0.81
UPS1	21.58	0.0010	7.6	0.71
SK3	7.99	0.0013	77.8	0.67
SO3	8.19	0.0014	293.9	0.64
S4	6.00	0.0012	128.1	0.43
MSN2	11.79	0.0009	335.8	0.41
SK4	5.99	0.0010	114.4	0.35
CHI1	24.71	0.0009	113.1	0.33
2SK5	4.80	0.0009	215.6	0.29
MKS2	12.39	0.0003	87.7	0.065
3MK7	3.53	0.0003	294.9	0.063
TAU1	25.67	0.0000	115.3	0.0012

Number of days: 309.94
Number of constituents: 59
MSL = -0.02 m





A 19. Re-synthesis of the observed data at Lerwick, Shetland Isles

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**2.0493**	**108.7**	**1400000**
S2	**12.00**	**0.7561**	**148.5**	**200000**
N2	**12.66**	**0.4157**	**89.9**	**63000**
K2	**11.97**	**0.2122**	**146.5**	**21000**
MU2	**12.87**	**0.0882**	**101.7**	**2400**
NU2	**12.63**	**0.0743**	**88.0**	**1900**
L2	**12.19**	**0.0904**	**95.5**	**1700**
K1	**23.93**	**0.0658**	**76.0**	**1600**
O1	25.82	0.0639	328.6	1400
2N2	12.91	0.0626	71.3	1400
M4	6.21	0.0580	108.9	990
MM	661.29	0.0381	356.0	510
MSM	763.48	0.0353	297.8	470
MS4	6.10	0.0358	182.7	360
MSF	354.37	0.0303	355.0	350
M6	4.14	0.0311	357.5	320
LDA2	12.22	0.0278	80.6	240
EPS2	13.13	0.0212	79.2	180
M3	8.28	0.0197	16.3	170
Q1	26.87	0.0185	270.6	150
MN4	6.27	0.0200	60.5	150
P1	24.07	0.0228	67.2	130
2MN6	4.17	0.0195	321.5	120
SSA	4382.12	0.0174	71.3	84
MKS2	12.39	0.0139	194.1	70
2MS6	4.09	0.0161	61.8	67
MSN2	11.79	0.0143	284.7	65
MF	327.86	0.0136	173.0	61
MK4	6.09	0.0106	183.3	43
NO1	24.83	0.0071	6.0	35
ETA2	11.75	0.0080	203.9	30
OQ2	13.16	0.0080	65.0	22
SIG1	27.85	0.0060	275.9	11
2Q1	28.01	0.0047	246.9	7.5
J1	23.10	0.0043	84.1	7.4
SK3	7.99	0.0044	80.6	6.9
RHO1	26.72	0.0044	301.2	6.2
SN4	6.16	0.0042	161.9	5.5
MO3	8.39	0.0032	315.5	4.6
2MK6	4.09	0.0033	60.1	4.2
MK3	8.18	0.0032	259.1	3.5
2SM6	4.05	0.0030	300.8	3.4
2MK5	4.93	0.0022	37.6	2.3
PHI1	23.80	0.0028	54.8	2.2
S4	6.00	0.0023	257.8	2.2
THE1	23.21	0.0021	92.3	2.1
M8	3.11	0.0024	233.9	2.1
TAU1	25.67	0.0025	91.9	1.9
ALP1	29.07	0.0023	273.9	1.6
SO1	22.42	0.0019	85.5	1.4
MSK6	4.04	0.0021	295.9	1.4
UPS1	21.58	0.0013	200.2	1.1
SO3	8.19	0.0014	138.1	0.79
OO1	22.31	0.0007	224.4	0.62
SK4	5.99	0.0012	287.7	0.61
CHI1	24.71	0.0013	101.1	0.6
2SK5	4.80	0.0006	54.0	0.21
BET1	24.97	0.0006	2.1	0.17
3MK7	3.53	0.0004	151.8	0.1

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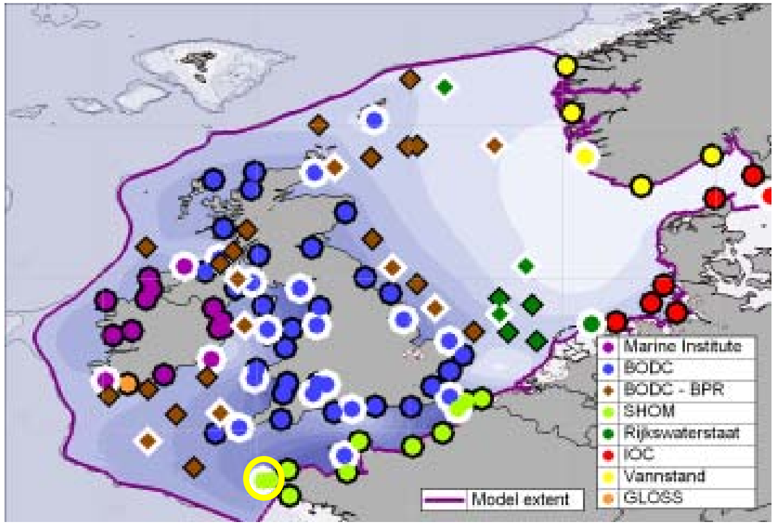
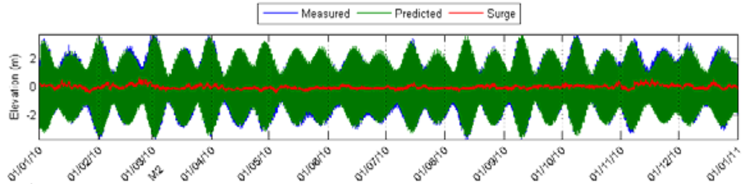
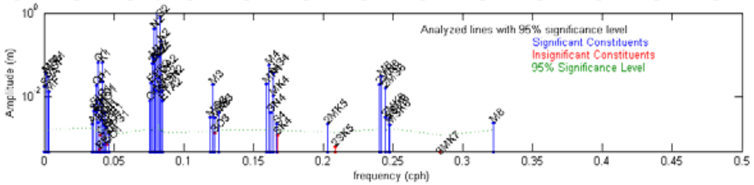
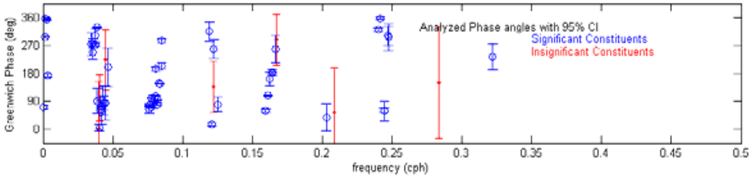
(…)

Number of days: 365.01
Number of constituents: 59
MSL = 0.06 m









A 20. Re-synthesis of the observed data at Brest, France

Observed harmonic constituents

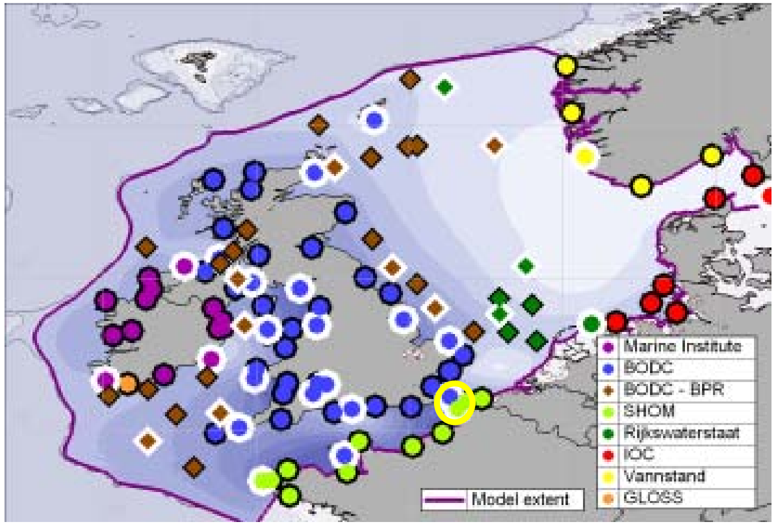
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**2.9458**	**329.0**	**850000**
S2	**12.00**	**0.9735**	**20.8**	**83000**
N2	**12.66**	**0.5306**	**309.6**	**28000**
M4	**6.21**	**0.3442**	**219.5**	**8200**
K2	**11.97**	**0.2748**	**16.6**	**6500**
MS4	**6.10**	**0.2189**	**273.7**	**3600**
L2	**12.19**	**0.2136**	**344.3**	**2200**
NU2	**12.63**	**0.1327**	**309.4**	**1600**
MN4	6.27	0.1112	192.0	1200
MU2	12.87	0.1161	21.0	1100
2N2	12.91	0.0862	321.5	660
M6	4.14	0.0735	88.6	450
2MS6	4.09	0.0694	132.5	340
MK4	6.09	0.0618	272.9	330
MSN2	11.79	0.0513	181.7	300
LDA2	12.22	0.0575	332.4	280
K1	23.93	0.0472	126.1	220
MSF	354.37	0.0414	29.8	170
MKS2	12.39	0.0398	90.4	160
MSM	763.48	0.0398	312.8	140
2MN6	4.17	0.0378	61.3	120
O1	25.82	0.0326	92.3	100
M8	3.11	0.0280	344.4	71
OQ2	13.16	0.0251	274.7	66
Q1	26.87	0.0194	51.4	55
SN4	6.16	0.0274	278.5	51
ETA2	11.75	0.0174	66.1	43
SSA	4382.12	0.0218	67.1	38
S4	6.00	0.0191	356.3	35
2MK6	4.09	0.0181	134.9	31
M3	8.28	0.0154	11.5	28
MK3	8.18	0.0157	26.2	24

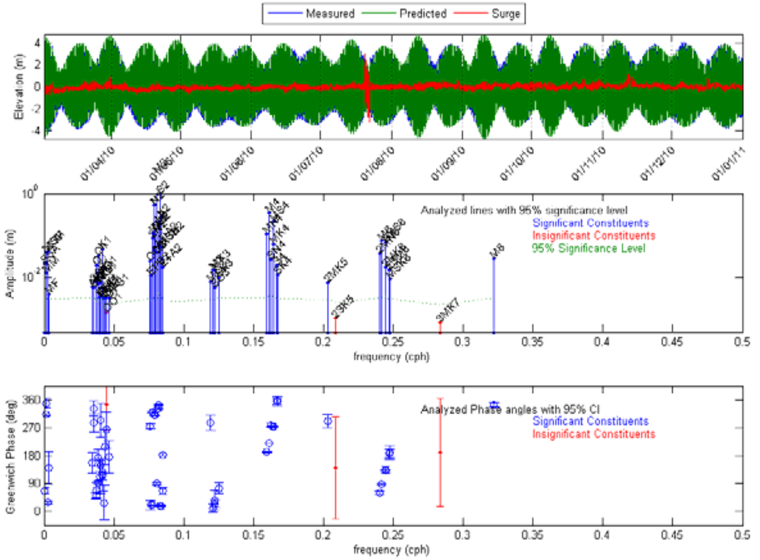
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2SM6	4.05	0.0156	187.7	23
MM	661.29	0.0130	350.1	19
P1	24.07	0.0139	114.4	15
EPS2	13.13	0.0111	21.5	15
SK4	5.99	0.0116	356.1	13
NO1	24.83	0.0077	147.3	12
SK3	7.99	0.0100	75.2	9.3
MSK6	4.04	0.0093	189.0	8.9
2Q1	28.01	0.0079	331.7	6.8
MO3	8.39	0.0079	285.0	6.8
2MK5	4.93	0.0078	291.3	6.6
RHO1	26.72	0.0080	68.4	6.1
TAU1	25.67	0.0069	173.4	4.6
ALP1	29.07	0.0060	156.7	3.4
SO3	8.19	0.0057	37.0	3.4
SIG1	27.85	0.0058	285.1	2.8
UPS1	21.58	0.0033	175.7	2
MF	327.86	0.0039	141.4	1.5
CHI1	24.71	0.0037	293.7	1.4
J1	23.10	0.0035	208.3	1.4
SO1	22.42	0.0034	262.5	1.3
BET1	24.97	0.0034	114.0	1.2
PHI1	23.80	0.0035	118.8	1.1
THE1	23.21	0.0032	28.8	1.1
OO1	22.31	0.0015	346.2	0.55
2SK5	4.80	0.0011	140.1	0.17
3MK7	3.53	0.0009	190.0	0.14

Number of days: 304.32
Number of constituents: 59
MSL = 0.06 m





A 21. Re-synthesis of the observed data at Boulogne-sur-Mer, France

Observed harmonic constituents

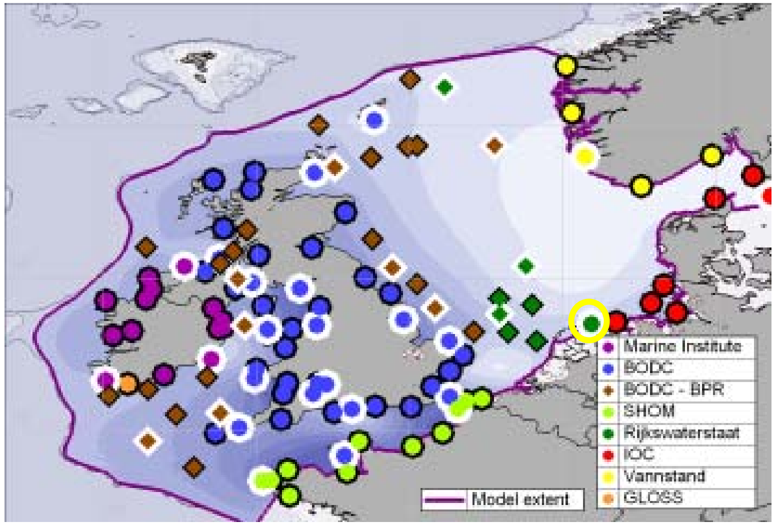
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.9718**	**230.0**	**84000**
S2	**12.00**	**0.2600**	**292.6**	**6600**
N2	**12.66**	**0.1544**	**201.9**	**2000**
O1	**25.82**	**0.0913**	**199.1**	**1000**
M4	**6.21**	**0.0968**	**312.7**	**870**
L2	**12.19**	**0.0883**	**263.3**	**760**
K2	**11.97**	**0.0754**	**287.5**	**630**
MU2	**12.87**	**0.0761**	**321.4**	**570**
NU2	12.63	0.0633	191.0	530
MM	661.29	0.0621	356.1	470
K1	23.93	0.0682	349.4	470
MS4	6.10	0.0663	20.1	400
MSF	354.37	0.0490	47.5	280
SSA	4382.12	0.0549	316.8	270
MSM	763.48	0.0478	327.5	240
2MS6	4.09	0.0409	133.6	180
2N2	12.91	0.0326	230.3	160
M6	4.14	0.0449	71.6	160
MN4	6.27	0.0346	277.4	140
MKS2	12.39	0.0254	27.4	95
LDA2	12.22	0.0298	240.5	94
EPS2	13.13	0.0241	295.5	86
P1	24.07	0.0302	5.3	76
Q1	26.87	0.0206	124.0	58
2MN6	4.17	0.0241	38.7	57
MF	327.86	0.0221	267.5	44
MSN2	11.79	0.0199	135.0	35
MK4	6.09	0.0149	9.8	24
NO1	24.83	0.0102	244.2	22
M8	3.11	0.0157	233.3	22
MO3	8.39	0.0133	344.0	20
2MK6	4.09	0.0076	130.1	7.2

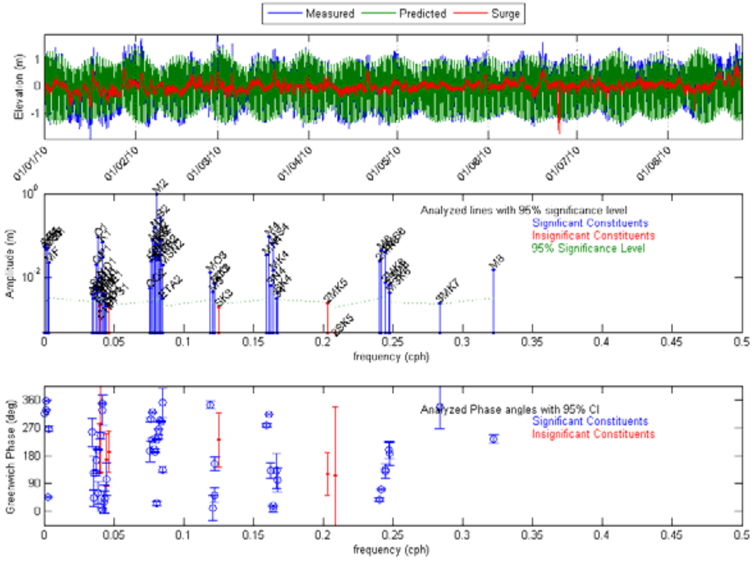
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
SO3	8.19	0.0071	53.6	6.1
MK3	8.18	0.0074	154.0	5.9
2SM6	4.05	0.0066	197.5	4.6
OQ2	13.16	0.0055	194.2	3.9
SIG1	27.85	0.0059	44.6	3.5
SN4	6.16	0.0063	131.0	3.4
M3	8.28	0.0047	10.7	3.3
TAU1	25.67	0.0051	60.5	3
THE1	23.21	0.0043	30.2	2.9
MSK6	4.04	0.0043	185.6	2.6
ETA2	11.75	0.0032	350.7	2.4
SK4	5.99	0.0044	101.7	2.3
ALP1	29.07	0.0039	254.3	2.1
RHO1	26.72	0.0042	163.7	1.8
J1	23.10	0.0036	40.3	1.8
S4	6.00	0.0032	130.7	1.5
PHI1	23.80	0.0038	326.5	1.4
2Q1	28.01	0.0031	123.8	1.2
3MK7	3.53	0.0025	336.6	1.1
OO1	22.31	0.0022	104.1	1
2MK5	4.93	0.0025	121.1	0.94
UPS1	21.58	0.0020	192.4	0.89
SK3	7.99	0.0020	231.7	0.65
SO1	22.42	0.0022	167.2	0.64
BET1	24.97	0.0022	204.1	0.58
CHI1	24.71	0.0010	283.2	0.2
2SK5	4.80	0.0004	115.7	0.04

Number of days: 237.43
Number of constituents: 59
MSL = 0.14 m





A 22. Re-synthesis of the observed data at Amelander-Westgat Platform, Holland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	**12.42**	**0.0716**	**131.1**	**990**
SSA	**4382.12**	**0.0356**	**40.3**	**250**
MSM	**763.48**	**0.0265**	**304.4**	**150**
MM	**661.29**	**0.0247**	**138.7**	**150**
MSF	**354.37**	**0.0231**	**358.7**	**110**
O1	**25.82**	**0.0212**	**292.9**	**100**
MF	**327.86**	**0.0212**	**205.1**	**86**
N2	**12.66**	**0.0164**	**77.3**	**57**
S2	12.00	0.0143	76.4	43
MU2	12.87	0.0143	287.4	37
NU2	12.63	0.0083	130.9	15
M4	6.21	0.0102	311.1	15
L2	12.19	0.0111	251.9	14
MKS2	12.39	0.0059	47.6	9.4
Q1	26.87	0.0058	253.4	8
EPS2	13.13	0.0057	238.6	7.4
K1	23.93	0.0059	287.4	6.9
RHO1	26.72	0.0052	213.0	5.8
M6	4.14	0.0059	69.6	5.2
2MS6	4.09	0.0056	135.4	5.2
LDA2	12.22	0.0048	244.9	4.6
MN4	6.27	0.0042	254.8	3.7
SIG1	27.85	0.0040	71.2	3
MS4	6.10	0.0042	27.1	2.9
2MN6	4.17	0.0033	21.9	2.8
NO1	24.83	0.0023	331.5	2.2
K2	11.97	0.0032	60.7	2.2
UPS1	21.58	0.0022	105.6	1.8
ALP1	29.07	0.0030	51.4	1.7
2N2	12.91	0.0022	249.9	1.2
P1	24.07	0.0026	242.9	1.1
BET1	24.97	0.0024	3.6	0.93

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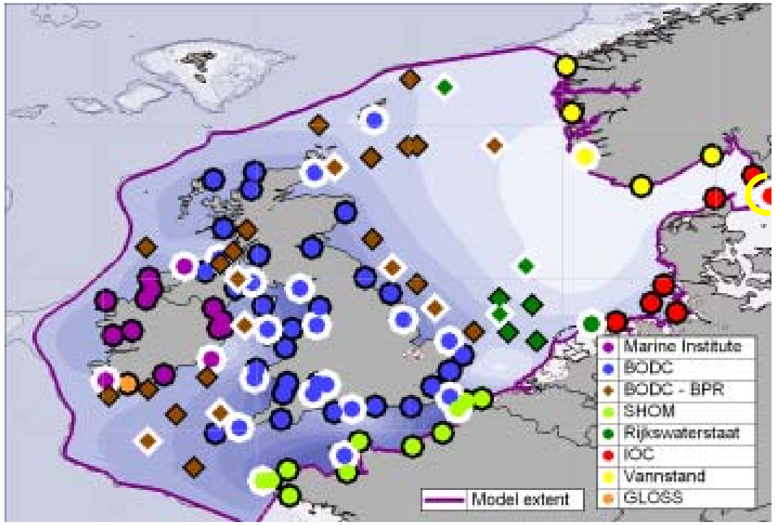
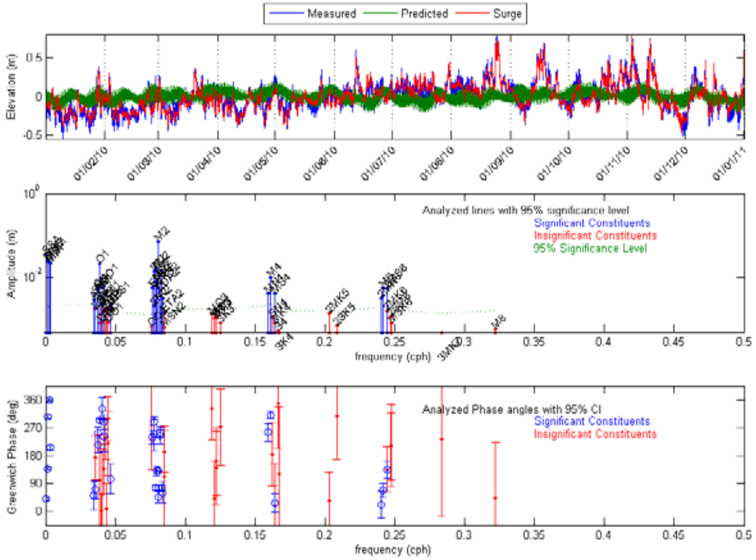
(…)

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
2Q1	28.01	0.0018	172.2	0.81
THE1	23.21	0.0017	234.9	0.8
SO1	22.42	0.0019	299.2	0.79
J1	23.10	0.0016	9.7	0.75
2MK5	4.93	0.0014	36.4	0.71
ETA2	11.75	0.0015	193.4	0.7
PHI1	23.80	0.0018	136.9	0.64
2MK6	4.09	0.0016	135.2	0.56
MO3	8.39	0.0013	332.5	0.54
OO1	22.31	0.0009	219.9	0.5
M3	8.28	0.0011	40.3	0.45
SO3	8.19	0.0012	140.2	0.44
2SM6	4.05	0.0012	210.4	0.39
MK3	8.18	0.0011	160.8	0.37
SN4	6.16	0.0011	184.1	0.35
OQ2	13.16	0.0007	278.4	0.27
CHI1	24.71	0.0009	54.7	0.25
MSK6	4.04	0.0008	212.8	0.23
SK3	7.99	0.0008	272.7	0.22
MK4	6.09	0.0008	20.5	0.22
2SK5	4.80	0.0007	307.9	0.21
TAU1	25.67	0.0008	100.4	0.2
MSN2	11.79	0.0006	114.0	0.12
M8	3.11	0.0006	45.2	0.12
S4	6.00	0.0005	350.0	0.089
SK4	5.99	0.0002	121.3	0.013
3MK7	3.53	0.0001	234.5	0.0051

Number of days: 365.01
Number of constituents: 59
MSL = -0.08 m





A 23. Re-synthesis of the observed data at Goteborg Torshamnen, Sweden

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.1579**	**271.9**	**7600**
S2	**12.00**	**0.0696**	**323.7**	**1500**
SSA	**4382.12**	**0.0469**	**349.2**	**710**
MF	**327.86**	**0.0304**	**189.5**	**340**
N2	**12.66**	**0.0271**	**259.1**	**300**
M6	**4.14**	**0.0255**	**73.4**	**240**
MSM	**763.48**	**0.0231**	**313.2**	**210**
K2	**11.97**	**0.0202**	**321.1**	**190**
2MS6	4.09	0.0253	128.7	160
MSF	354.37	0.0179	10.5	130
O1	25.82	0.0156	3.4	99
K1	23.93	0.0174	177.1	94
MU2	12.87	0.0148	274.3	68
2MN6	4.17	0.0134	37.6	58
MM	661.29	0.0124	43.3	53
L2	12.19	0.0125	260.9	36
M4	6.21	0.0099	239.1	29
MS4	6.10	0.0089	341.9	21
2MK6	4.09	0.0066	131.6	20
2N2	12.91	0.0059	239.9	16
NU2	12.63	0.0049	219.5	9.4
2SM6	4.05	0.0052	181.6	8.5
Q1	26.87	0.0040	291.9	8.3
P1	24.07	0.0052	182.7	7.8
MKS2	12.39	0.0037	18.3	6.9
M8	3.11	0.0046	323.4	6
EPS2	13.13	0.0034	232.6	5.5
M3	8.28	0.0037	202.5	4.4
LDA2	12.22	0.0037	249.0	4.1
MSK6	4.04	0.0032	180.3	3.3
ALP1	29.07	0.0025	353.9	3.1
NO1	24.83	0.0018	61.2	3.1

(…)

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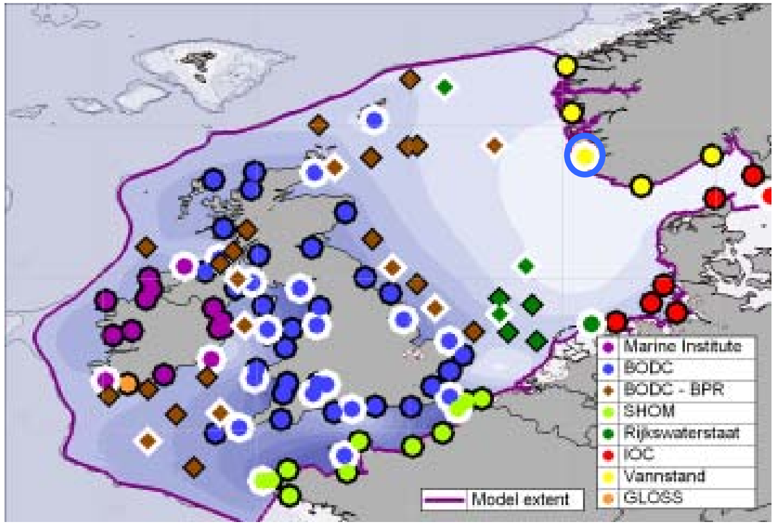
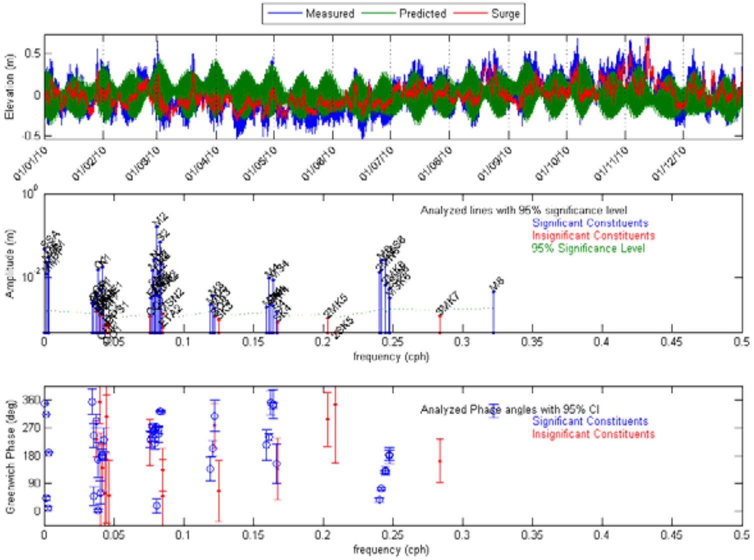
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
SIG1	27.85	0.0027	50.6	2.7
2Q1	28.01	0.0023	243.9	2.5
THE1	23.21	0.0022	231.8	2.4
MO3	8.39	0.0023	137.2	2.3
SN4	6.16	0.0022	351.2	1.8
MN4	6.27	0.0019	213.2	1.7
MK4	6.09	0.0022	344.8	1.7
MK3	8.18	0.0019	308.6	1.6
TAU1	25.67	0.0018	166.6	1.3
S4	6.00	0.0015	154.0	1
RHO1	26.72	0.0016	233.0	0.9
SO3	8.19	0.0012	276.1	0.79
OQ2	13.16	0.0012	222.5	0.76
PHI1	23.80	0.0013	140.1	0.69
2MK5	4.93	0.0011	296.9	0.66
MSN2	11.79	0.0014	134.3	0.62
SK3	7.99	0.0010	66.0	0.62
BET1	24.97	0.0013	353.5	0.57
3MK7	3.53	0.0012	162.7	0.54
SK4	5.99	0.0009	138.3	0.48
UPS1	21.58	0.0007	51.9	0.47
ETA2	11.75	0.0006	49.4	0.38
SO1	22.42	0.0008	305.1	0.34
J1	23.10	0.0007	57.8	0.3
2SK5	4.80	0.0003	347.3	0.089
CHI1	24.71	0.0003	51.6	0.082
OO1	22.31	0.0002	168.9	0.075

Number of days: 365.01
Number of constituents: 59
MSL = -0.01 m





A 24. Re-synthesis of the observed data at Stavanger, Norway

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.5189**	**287.3**	**84000**
S2	**12.00**	**0.1821**	**322.1**	**13000**
N2	**12.66**	**0.1035**	**265.3**	**3200**
K1	**23.93**	**0.0653**	**168.3**	**1600**
O1	**25.82**	**0.0591**	**37.5**	**1500**
K2	**11.97**	**0.0506**	**320.2**	**810**
MF	**327.86**	**0.0379**	**171.4**	**510**
SSA	**4382.12**	**0.0263**	**355.5**	**220**
MM	661.29	0.0259	133.1	220
MSM	763.48	0.0213	296.3	190
Q1	26.87	0.0184	333.3	170
NU2	12.63	0.0195	269.6	170
MSF	354.37	0.0203	316.5	160
P1	24.07	0.0174	152.7	94
MU2	12.87	0.0156	243.6	79
2N2	12.91	0.0134	234.2	72
L2	12.19	0.0124	296.1	35
NO1	24.83	0.0061	85.0	26
MS4	6.10	0.0053	342.5	8.3
2MS6	4.09	0.0049	305.8	8.3
M3	8.28	0.0045	163.9	7
2Q1	28.01	0.0039	274.5	6.9
SIG1	27.85	0.0040	309.7	6.9
M6	4.14	0.0046	252.5	5.9
RHO1	26.72	0.0038	343.2	5.6
LDA2	12.22	0.0035	293.3	5.2
EPS2	13.13	0.0031	219.7	4.5
M4	6.21	0.0039	244.4	4.5
PHI1	23.80	0.0025	158.3	2.8
ETA2	11.75	0.0025	344.9	2.8
BET1	24.97	0.0022	176.5	2.1
THE1	23.21	0.0019	189.8	1.9

(…)

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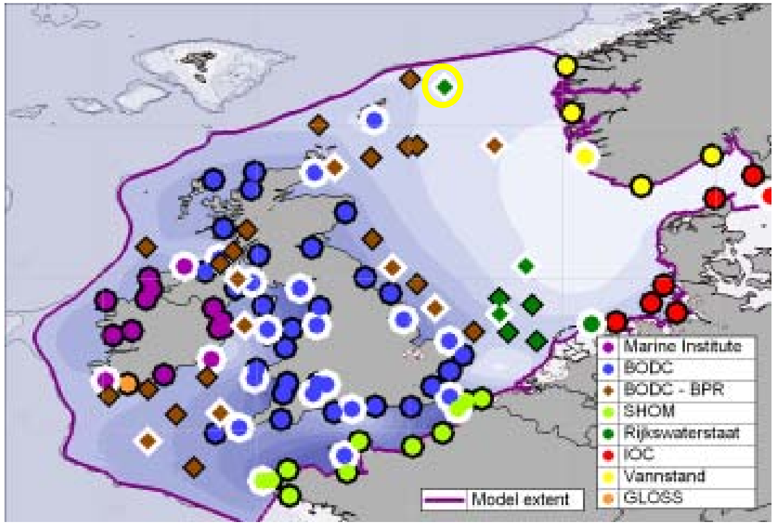
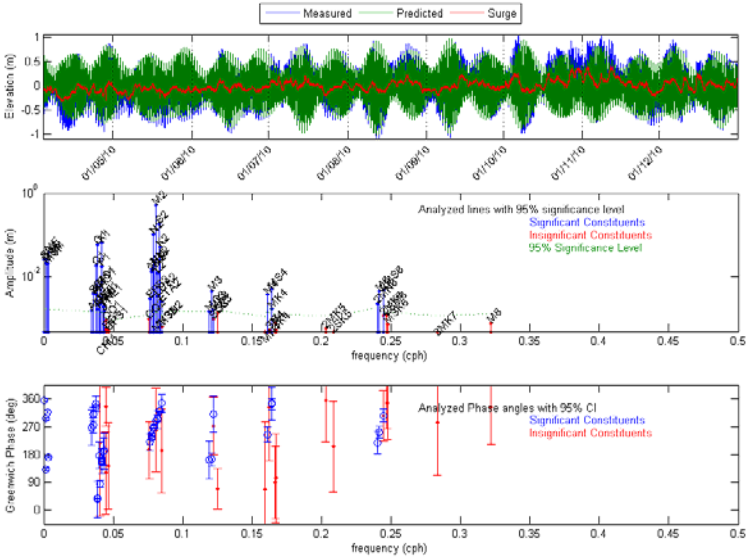
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
2MN6	4.17	0.0022	218.3	1.6
TAU1	25.67	0.0016	34.6	1.2
MK3	8.18	0.0016	309.6	1.2
MK4	6.09	0.0017	344.6	1.2
ALP1	29.07	0.0016	265.5	1.1
J1	23.10	0.0016	191.4	1.1
MO3	8.39	0.0015	161.5	1.1
2SM6	4.05	0.0012	347.0	0.78
SK3	7.99	0.0013	69.2	0.74
OO1	22.31	0.0009	335.3	0.73
2MK6	4.09	0.0012	304.7	0.71
OQ2	13.16	0.0010	194.4	0.62
SO3	8.19	0.0010	272.2	0.52
S4	6.00	0.0008	89.9	0.41
M8	3.11	0.0008	333.6	0.35
UPS1	21.58	0.0005	143.2	0.34
MSN2	11.79	0.0006	191.0	0.27
MSK6	4.04	0.0007	346.8	0.27
2MK5	4.93	0.0006	352.9	0.26
SO1	22.42	0.0006	120.2	0.23
MKS2	12.39	0.0005	259.3	0.2
SN4	6.16	0.0005	331.6	0.19
SK4	5.99	0.0005	104.2	0.19
2SK5	4.80	0.0005	205.1	0.18
3MK7	3.53	0.0004	281.6	0.11
MN4	6.27	0.0003	66.2	0.054
CHI1	24.71	0.0001	216.1	0.014

Number of days: 271.93
Number of constituents: 59
MSL = 0.20 m





A 25. Re-synthesis of the (offshore) observed data at North Cormorant

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.2735**	**131.5**	**17000**
S2	**12.00**	**0.0756**	**173.1**	**1800**
N2	**12.66**	**0.0520**	**103.1**	**770**
M4	**6.21**	**0.0406**	**353.3**	**490**
O1	**25.82**	**0.0394**	**157.9**	**450**
K1	**23.93**	**0.0370**	**310.9**	**390**
SSA	**4382.12**	**0.0412**	**66.5**	**350**
MF	**327.86**	**0.0309**	**213.3**	**210**
K2	11.97	0.0220	169.5	130
MSM	763.48	0.0195	356.6	97
MM	661.29	0.0144	129.0	61
NU2	12.63	0.0134	110.3	55
MS4	6.10	0.0138	72.1	53
MN4	6.27	0.0145	302.2	51
Q1	26.87	0.0122	99.6	46
P1	24.07	0.0123	298.0	45
MSF	354.37	0.0113	354.0	39
L2	12.19	0.0160	170.5	36
M6	4.14	0.0073	39.4	12
NO1	24.83	0.0032	233.2	6.7
2N2	12.91	0.0042	82.7	6.5
LDA2	12.22	0.0047	154.0	6.3
MU2	12.87	0.0051	291.5	5.9
2MN6	4.17	0.0046	357.3	4.9
2MS6	4.09	0.0046	95.5	3.9
MK4	6.09	0.0035	68.7	3.4
MSN2	11.79	0.0028	39.0	2.2
EPS2	13.13	0.0023	241.7	1.9
M8	3.11	0.0027	294.9	1.8
2Q1	28.01	0.0024	33.7	1.6
J1	23.10	0.0023	312.2	1.6
BET1	24.97	0.0024	193.1	1.5

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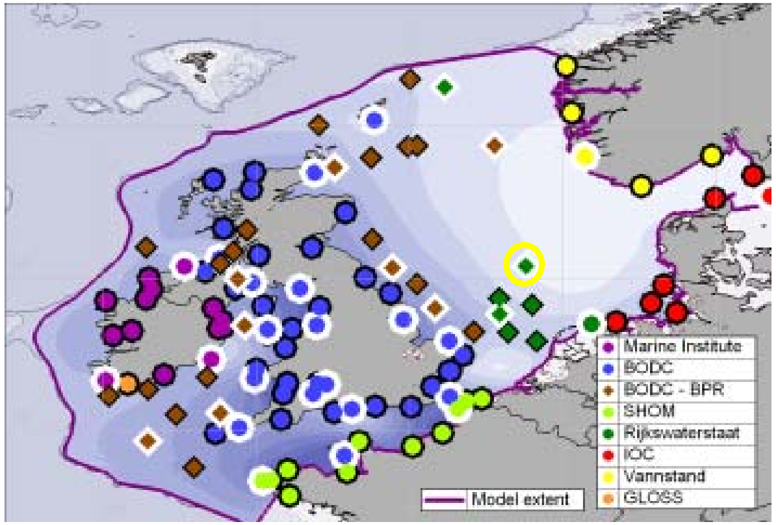
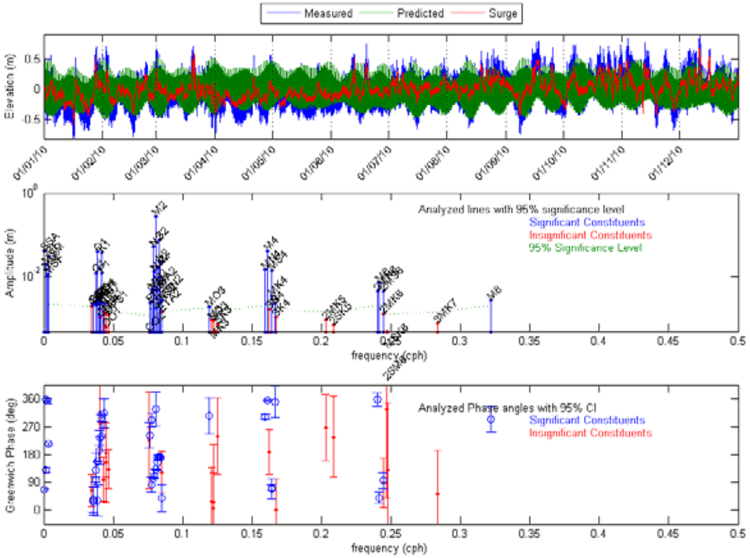
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
S4	6.00	0.0023	349.9	1.5
SIG1	27.85	0.0023	28.8	1.4
PHI1	23.80	0.0024	239.5	1.4
TAU1	25.67	0.0022	31.2	1.3
RHO1	26.72	0.0021	130.4	1.2
MO3	8.39	0.0019	304.9	1.2
MKS2	12.39	0.0018	325.6	1.1
ALP1	29.07	0.0020	64.2	0.98
ETA2	11.75	0.0014	122.3	0.93
THE1	23.21	0.0015	98.5	0.82
UPS1	21.58	0.0012	132.5	0.69
SN4	6.16	0.0016	187.7	0.68
2MK6	4.09	0.0013	88.6	0.59
SO1	22.42	0.0013	184.8	0.52
SK4	5.99	0.0011	1.0	0.48
CHI1	24.71	0.0011	281.3	0.42
2MK5	4.93	0.0009	265.6	0.4
SO3	8.19	0.0009	5.6	0.38
OO1	22.31	0.0006	153.2	0.36
3MK7	3.53	0.0008	53.6	0.32
M3	8.28	0.0009	28.4	0.3
SK3	7.99	0.0008	239.3	0.25
2SK5	4.80	0.0007	237.3	0.25
OQ2	13.16	0.0005	225.9	0.18
MK3	8.18	0.0003	25.2	0.083
MSK6	4.04	0.0002	129.8	0.022
2SM6	4.05	0.0000	326.2	0.00079

Number of days: 365.01
Number of constituents: 59
MSL = -0.02 m





A 26. Re-synthesis of the (offshore) observed data at Platform A12

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.6905**	**169.9**	**100000**
S2	**12.00**	**0.2293**	**220.8**	**13000**
N2	**12.66**	**0.1297**	**148.9**	**4000**
O1	**25.82**	**0.0912**	**155.6**	**2100**
K1	**23.93**	**0.0821**	**321.3**	**1800**
K2	**11.97**	**0.0640**	**219.8**	**980**
L2	**12.19**	**0.0482**	**172.6**	**290**
SSA	**4382.12**	**0.0293**	**47.5**	**210**
Q1	26.87	0.0263	89.9	200
NU2	12.63	0.0294	136.9	190
P1	24.07	0.0250	308.9	170
MU2	12.87	0.0252	211.1	170
MSM	763.48	0.0245	352.9	130
MF	327.86	0.0230	205.6	120
M4	6.21	0.0226	261.0	93
2N2	12.91	0.0166	147.5	70
LDA2	12.22	0.0167	162.4	70
MSF	354.37	0.0160	3.8	65
M6	4.14	0.0168	181.8	50
MS4	6.10	0.0155	295.4	48
2MS6	4.09	0.0145	238.3	43
MO3	8.39	0.0128	253.8	37
MK3	8.18	0.0104	62.9	28
NO1	24.83	0.0074	204.4	27
MSN2	11.79	0.0094	35.3	24
MN4	6.27	0.0092	236.5	23
MKS2	12.39	0.0084	283.9	21
2MN6	4.17	0.0092	143.5	20
MM	661.29	0.0084	137.8	19
2Q1	28.01	0.0080	50.0	14
RHO1	26.72	0.0071	104.4	12
EPS2	13.13	0.0062	192.5	10

(…)

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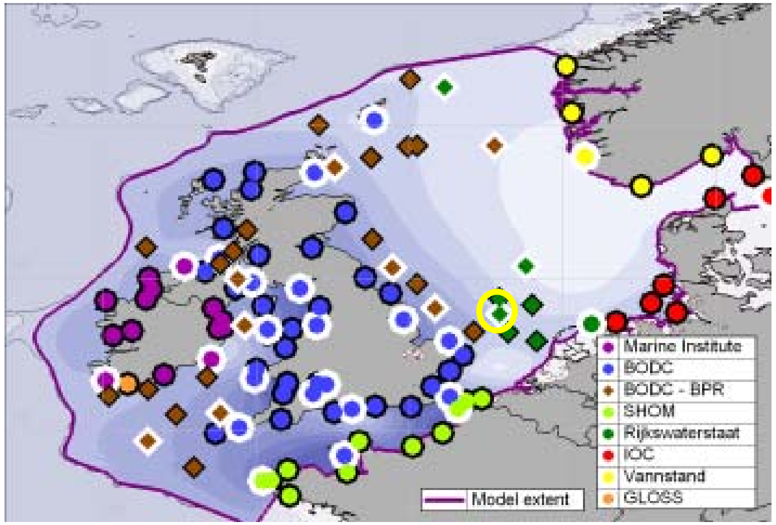
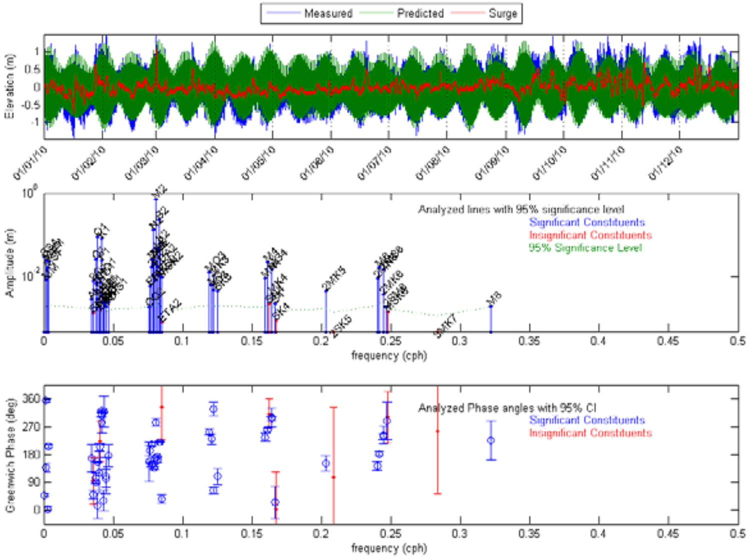
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M3	8.28	0.0063	229.8	8.9
2MK5	4.93	0.0047	150.6	7.3
SO3	8.19	0.0049	325.9	5.7
SK3	7.99	0.0045	109.4	5
MK4	6.09	0.0040	299.5	4.4
2MK6	4.09	0.0039	243.0	3.6
THE1	23.21	0.0032	29.4	3.5
OO1	22.31	0.0026	102.8	3.1
ALP1	29.07	0.0029	168.1	2.8
PHI1	23.80	0.0035	282.7	2.7
UPS1	21.58	0.0025	176.1	2.3
TAU1	25.67	0.0030	13.5	2.2
J1	23.10	0.0023	318.1	1.5
S4	6.00	0.0022	23.9	1.5
SO1	22.42	0.0019	111.0	1.3
BET1	24.97	0.0019	121.5	1.2
2SM6	4.05	0.0019	288.9	1.2
M8	3.11	0.0019	224.0	1.1
OQ2	13.16	0.0019	157.6	1
SN4	6.16	0.0022	311.1	0.95
MSK6	4.04	0.0014	301.5	0.7
SIG1	27.85	0.0014	95.4	0.57
CHI1	24.71	0.0016	223.2	0.53
SK4	5.99	0.0009	2.7	0.35
ETA2	11.75	0.0008	332.3	0.3
3MK7	3.53	0.0003	256.4	0.075
2SK5	4.80	0.0004	106.3	0.063

Number of days: 365.01
Number of constituents: 59
MSL = -0.06 m





A 27. Re-synthesis of the (offshore) observed data at Platform J6

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.3165**	**309.0**	**4800**
S2	**12.00**	**0.1486**	**341.4**	**1100**
N2	**12.66**	**0.0731**	**288.8**	**330**
MSF	**354.37**	**0.0305**	**269.1**	**57**
O1	**25.82**	**0.0362**	**54.4**	**50**
MU2	**12.87**	**0.0266**	**264.9**	**42**
K1	**23.93**	**0.0208**	**172.3**	**21**
MM	**661.29**	**0.0179**	**185.6**	**19**
M4	6.21	0.0121	261.6	12
Q1	26.87	0.0150	275.9	8.5
OO1	22.31	0.0120	274.1	4.8
MS4	6.10	0.0084	2.9	4.4
M6	4.14	0.0056	40.8	3.3
NO1	24.83	0.0053	201.5	2.8
2MS6	4.09	0.0063	97.5	2.8

(…)

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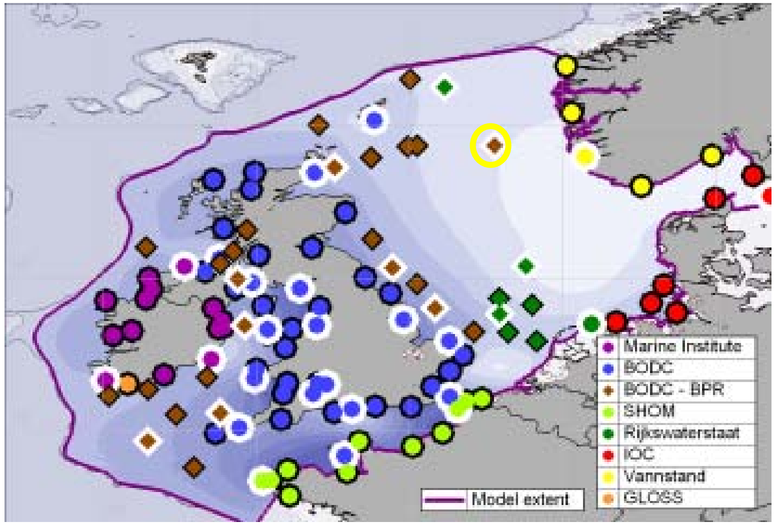
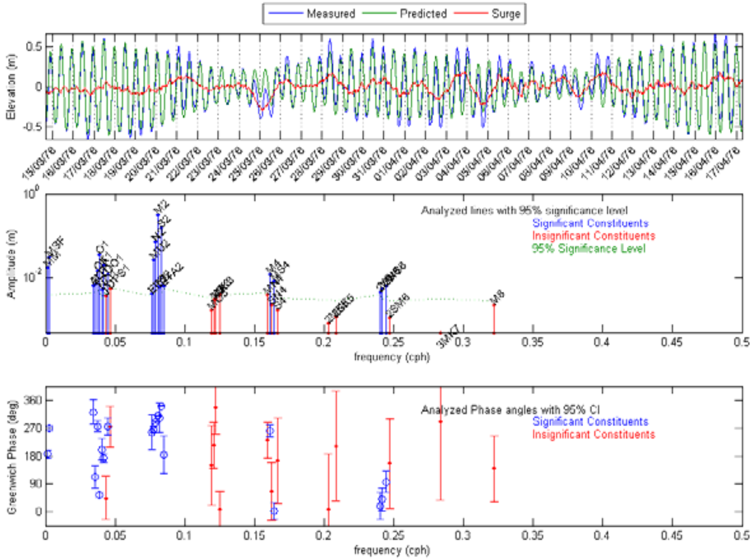
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
L2	12.19	0.0061	302.9	1.8
ETA2	11.75	0.0063	183.6	1.3
2MN6	4.17	0.0046	19.6	1.3
EPS2	13.13	0.0042	256.4	1.2
SK3	7.99	0.0040	9.9	1
J1	23.10	0.0037	45.0	0.93
UPS1	21.58	0.0056	275.0	0.9
MN4	6.27	0.0039	231.1	0.81
M3	8.28	0.0031	214.5	0.76
M8	3.11	0.0023	139.1	0.65
MK3	8.18	0.0031	338.1	0.56
SN4	6.16	0.0023	66.2	0.38
MO3	8.39	0.0017	150.8	0.26
S4	6.00	0.0017	164.7	0.26
2SK5	4.80	0.0012	212.6	0.18
2SM6	4.05	0.0012	156.3	0.15

Number of days: 33.64
Number of constituents: 35
MSL = -0.91 m





A 28. Re-synthesis of the (offshore) observed data at PJONSDAP, R56 [59.3251;2.7779]

Observed harmonic constituents

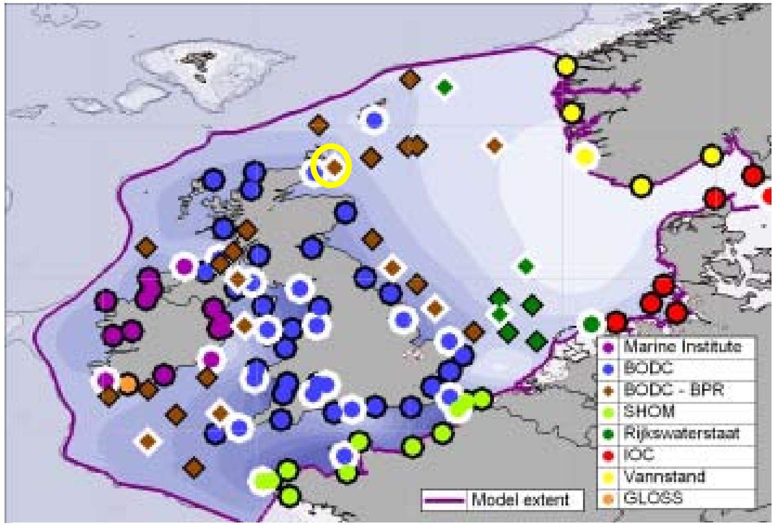
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.7527**	**326.0**	**30000**
S2	**12.00**	**0.3199**	**0.9**	**6600**
N2	**12.66**	**0.1836**	**306.1**	**2400**
O1	**25.82**	**0.0939**	**31.0**	**350**
MM	**661.29**	**0.0675**	**136.0**	**330**
MU2	**12.87**	**0.0489**	**282.0**	**160**
K1	**23.93**	**0.0512**	**179.3**	**150**
MSF	**354.37**	**0.0362**	**252.9**	**95**
Q1	26.87	0.0391	316.7	88
M4	6.21	0.0201	310.2	31
L2	12.19	0.0159	306.9	13
M3	8.28	0.0117	229.7	11
EPS2	13.13	0.0116	221.3	9.2
MS4	6.10	0.0101	45.3	7.8
MN4	6.27	0.0094	279.2	7.3
J1	23.10	0.0115	313.1	7.2
2Q1	28.01	0.0096	224.8	6.8
ALP1	29.07	0.0091	33.3	5.3
M6	4.14	0.0070	172.1	5.3
2MS6	4.09	0.0076	207.3	4.8
SN4	6.16	0.0048	161.3	2.5

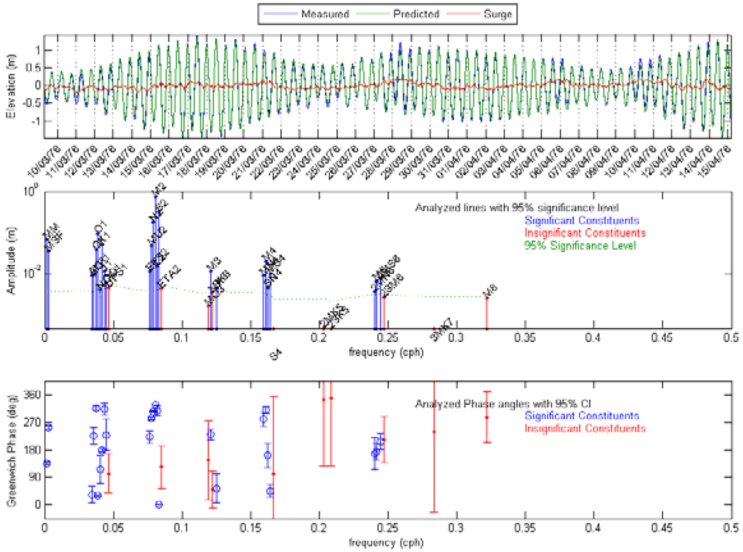
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
NO1	24.83	0.0041	115.4	1.9
SK3	7.99	0.0046	53.0	1.5
OO1	22.31	0.0062	229.0	1.4
2MN6	4.17	0.0037	166.8	1.3
MK3	8.18	0.0036	50.5	0.89
M8	3.11	0.0026	286.8	0.84
UPS1	21.58	0.0049	102.1	0.82
ETA2	11.75	0.0046	123.2	0.78
2SM6	4.05	0.0028	212.6	0.77
MO3	8.39	0.0017	145.4	0.26
2SK5	4.80	0.0005	347.9	0.045
2MK5	4.93	0.0005	344.2	0.041
3MK7	3.53	0.0002	240.0	0.0067
S4	6.00	0.0001	101.7	0.001

Number of days: 36.90
Number of constituents: 35
MSL = 0.16 m





A 29. Re-synthesis of the (offshore) observed data at PJONSDAP, R53 [58.6166;-2.4375]

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.2671**	**87.5**	**100000**
S2	**12.00**	**0.3757**	**119.0**	**12000**
N2	**12.66**	**0.2905**	**58.8**	**9000**
K1	**23.93**	**0.1111**	**226.2**	**1100**
O1	**25.82**	**0.1161**	**81.4**	**680**
L2	**12.19**	**0.0790**	**106.1**	**530**
Q1	**26.87**	**0.0457**	**36.8**	**180**
MSF	**354.37**	**0.0382**	**6.5**	**120**
MU2	12.87	0.0336	57.4	88
MM	661.29	0.0297	220.3	78
M4	6.21	0.0177	107.9	22
J1	23.10	0.0149	299.1	21
MN4	6.27	0.0123	74.7	14
NO1	24.83	0.0123	276.5	12
2Q1	28.01	0.0103	345.7	9.6
M6	4.14	0.0090	22.7	8.1
MS4	6.10	0.0096	70.9	7.7
MK3	8.18	0.0093	194.9	6.5
MO3	8.39	0.0095	71.0	6.4
ALP1	29.07	0.0085	2.6	5.2
M3	8.28	0.0076	37.0	5.1
2MS6	4.09	0.0077	70.8	4.8
OO1	22.31	0.0078	9.7	2.8
EPS2	13.13	0.0055	346.1	2.8
ETA2	11.75	0.0067	161.3	2.5

(…)

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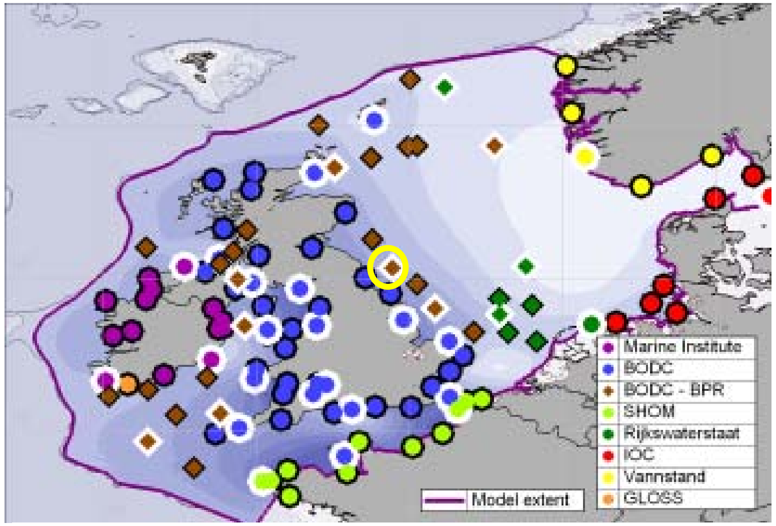
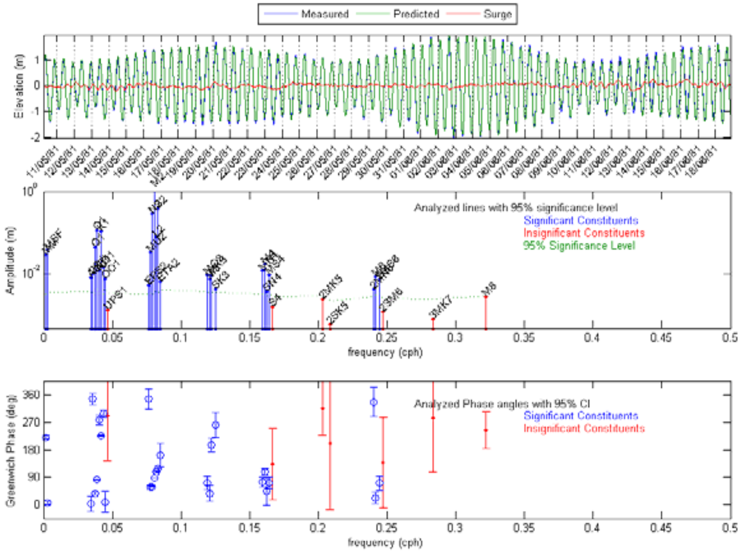
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
SN4	6.16	0.0038	43.5	1.8
SK3	7.99	0.0043	260.7	1.5
M8	3.11	0.0028	244.2	0.86
2MK5	4.93	0.0025	316.3	0.68
S4	6.00	0.0017	132.9	0.32
2SM6	4.05	0.0012	137.1	0.23
UPS1	21.58	0.0014	291.0	0.16
3MK7	3.53	0.0008	282.7	0.11
2SK5	4.80	0.0006	201.8	0.068

Number of days: 39.65
Number of constituents: 35
MSL = 4.38 m





A 30. Re-synthesis of the (offshore) observed data at RL [55.3266;-0.5449]

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**0.9437**	**325.0**	**59000**
N2	**12.66**	**0.2269**	**297.8**	**5300**
S2	**12.00**	**0.2508**	**16.3**	**3700**
L2	**12.19**	**0.0970**	**1.6**	**640**
K1	**23.93**	**0.1007**	**201.9**	**630**
O1	**25.82**	**0.0837**	**48.4**	**370**
MSF	**354.37**	**0.0529**	**223.7**	**200**
Q1	**26.87**	**0.0435**	**355.1**	**87**
M3	8.28	0.0278	113.6	48
MU2	12.87	0.0230	127.4	39
MS4	6.10	0.0218	108.7	33
M4	6.21	0.0168	79.6	21
ETA2	11.75	0.0315	140.3	20
EPS2	13.13	0.0141	77.2	13
ALP1	29.07	0.0155	28.3	12
SK3	7.99	0.0142	333.2	11
MK3	8.18	0.0140	229.9	8.9
J1	23.10	0.0130	257.0	8.6
MM	661.29	0.0106	113.8	6.9
OO1	22.31	0.0162	341.1	5.5
2MS6	4.09	0.0081	213.8	4.9
MN4	6.27	0.0073	99.1	4.7
M6	4.14	0.0062	165.2	3.3
MO3	8.39	0.0066	174.8	2.5

(…)

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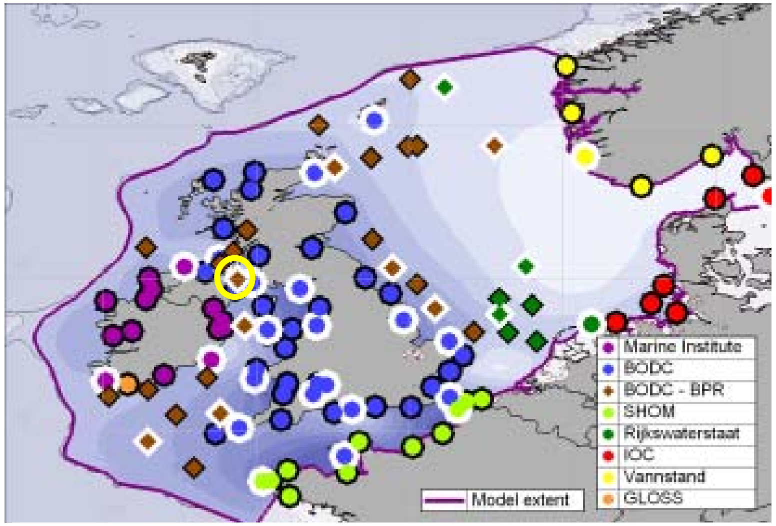
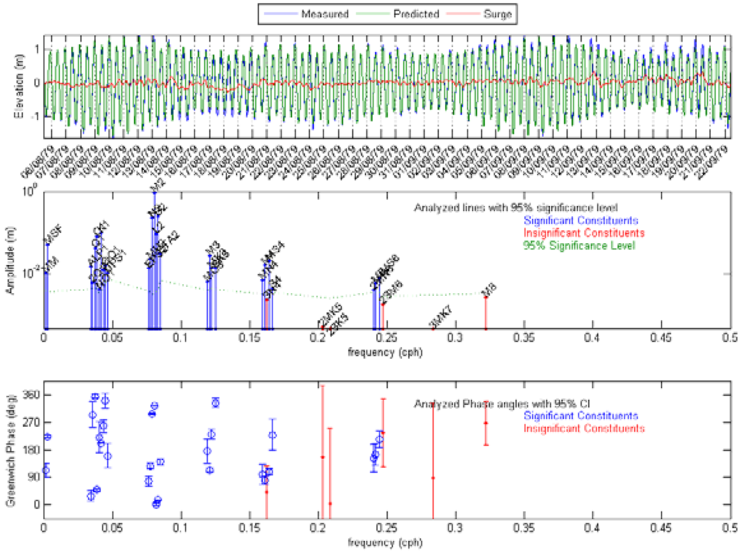
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
UPS1	21.58	0.0106	159.8	1.9
2Q1	28.01	0.0063	295.1	1.7
NO1	24.83	0.0043	220.8	1.6
S4	6.00	0.0046	228.6	1.5
2MN6	4.17	0.0043	151.6	1.4
SN4	6.16	0.0024	40.3	0.62
M8	3.11	0.0027	266.0	0.61
2SM6	4.05	0.0019	236.1	0.44
2MK5	4.93	0.0005	157.2	0.038
3MK7	3.53	0.0005	89.1	0.024
2SK5	4.80	0.0003	3.3	0.015

Number of days: 47.99
Number of constituents: 35
MSL = -4.63 m





A 31. Re-synthesis of the (offshore) observed data at RB [54.9616;-5.5949]

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	**12.42**	**1.4513**	**139.6**	**120000**
S2	**12.00**	**0.4468**	**174.9**	**8700**
N2	**12.66**	**0.3318**	**110.8**	**5900**
K1	**23.93**	**0.1424**	**254.7**	**840**
O1	**25.82**	**0.1495**	**108.9**	**630**
L2	**12.19**	**0.0935**	**151.6**	**340**
Q1	**26.87**	**0.0596**	**59.5**	**160**
MU2	**12.87**	**0.0454**	**120.8**	**84**
MS4	6.10	0.0200	153.5	20
M4	6.21	0.0199	116.6	19
J1	23.10	0.0188	311.5	16
2Q1	28.01	0.0154	17.9	13
NO1	24.83	0.0182	299.0	13
M6	4.14	0.0127	260.5	8.3
MO3	8.39	0.0127	204.3	6.9
MSF	354.37	0.0116	24.3	6.8
ALP1	29.07	0.0128	22.7	6
MM	661.29	0.0102	122.6	4.4
2MS6	4.09	0.0099	318.5	4.4
2MN6	4.17	0.0089	222.7	4.2
M3	8.28	0.0083	135.3	3.4
SK3	7.99	0.0071	27.7	3.2
MK3	8.18	0.0083	331.5	2.8
MN4	6.27	0.0083	109.5	2.7
EPS2	13.13	0.0065	89.4	2.6

(…)

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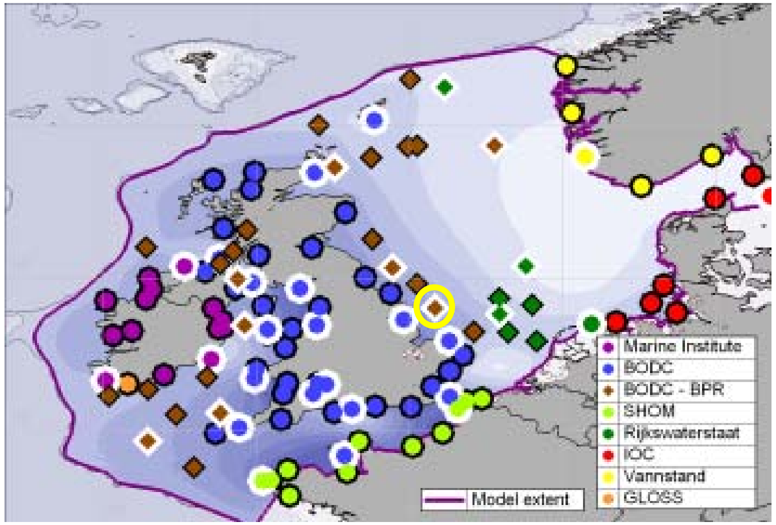
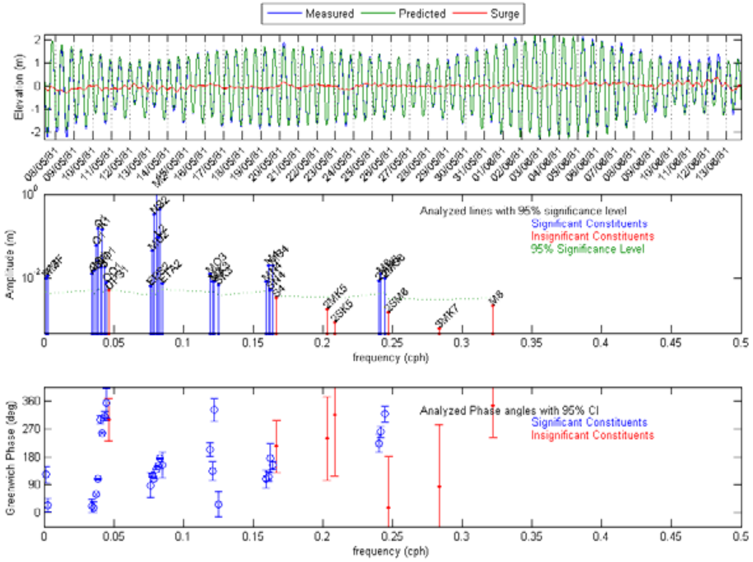
Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
ETA2	11.75	0.0075	153.8	1.8
OO1	22.31	0.0080	353.1	1.7
SN4	6.16	0.0053	175.4	1.7
UPS1	21.58	0.0053	299.2	0.91
S4	6.00	0.0035	213.0	0.83
M8	3.11	0.0023	346.4	0.43
2MK5	4.93	0.0019	239.1	0.27
2SM6	4.05	0.0016	17.1	0.23
2SK5	4.80	0.0009	315.0	0.074
3MK7	3.53	0.0006	85.1	0.041

Number of days: 37.42
Number of constituents: 35
MSL = 2.41 m





A 32. Re-synthesis of the (offshore) observed data at RE [54.0099;0.8399]

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.3924**	**309.1**	**61000**
S2	**12.00**	**0.5759**	**334.3**	**8000**
N2	**12.66**	**0.2583**	**296.8**	**2000**
MM	**661.29**	**0.1165**	**46.4**	**310**
O1	**25.82**	**0.1053**	**39.4**	**310**
MU2	**12.87**	**0.1070**	**170.8**	**280**
K1	**23.93**	**0.0710**	**188.4**	**190**
L2	**12.19**	**0.0634**	**302.6**	**130**
M4	6.21	0.0725	53.7	130
MS4	6.10	0.0465	96.4	58
MSF	354.37	0.0419	276.7	49
EPS2	13.13	0.0319	183.3	32
Q1	26.87	0.0243	352.5	26
MN4	6.27	0.0267	41.5	14
ETA2	11.75	0.0150	284.7	11
M3	8.28	0.0147	249.7	4.8
SN4	6.16	0.0114	29.6	4.3
J1	23.10	0.0078	230.1	3.2
S4	6.00	0.0090	109.0	2.1

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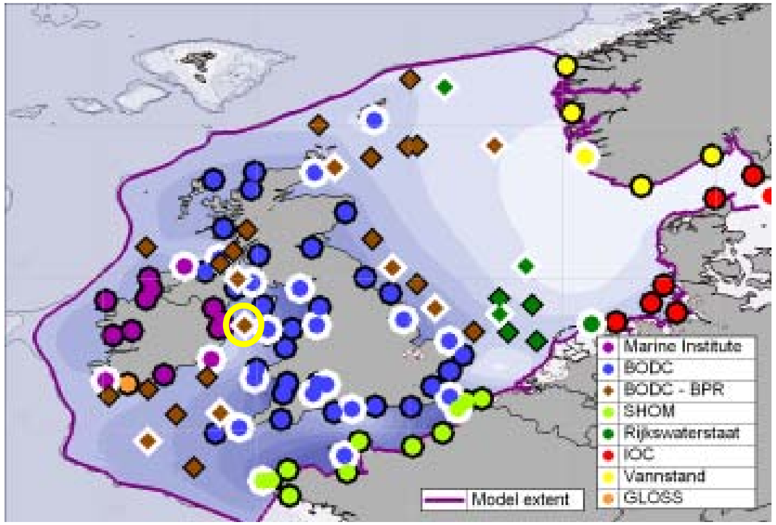
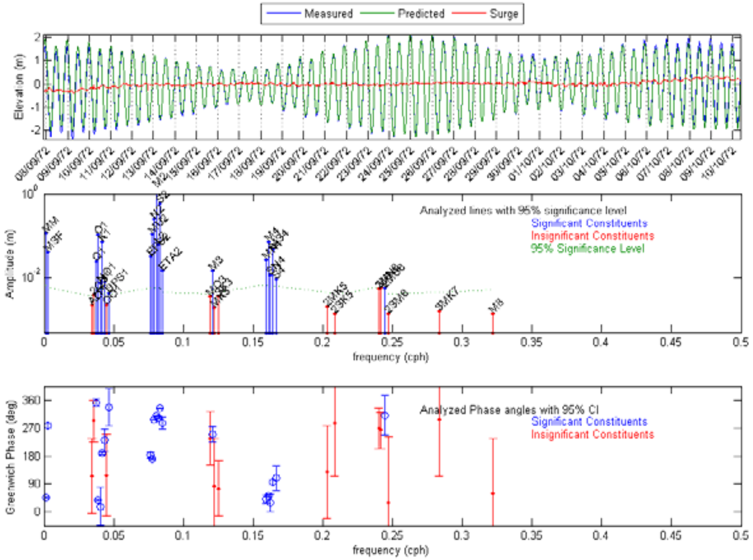
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
NO1	24.83	0.0077	17.9	1.2
2MS6	4.09	0.0058	311.3	1.2
UPS1	21.58	0.0043	337.5	1.1
M6	4.14	0.0057	262.6	0.92
2MN6	4.17	0.0055	269.3	0.84
2Q1	28.01	0.0041	293.2	0.79
MO3	8.39	0.0037	236.9	0.78
SK3	7.99	0.0036	75.0	0.57
ALP1	29.07	0.0023	116.1	0.39
OO1	22.31	0.0023	118.0	0.35
MK3	8.18	0.0020	81.8	0.19
2MK5	4.93	0.0020	128.2	0.19
2SK5	4.80	0.0014	284.8	0.13
3MK7	3.53	0.0017	295.7	0.13
2SM6	4.05	0.0014	31.4	0.11
M8	3.11	0.0014	61.6	0.073

Number of days: 32.53
Number of constituents: 35
MSL = 1.84 m





A 33. Re-synthesis of the (offshore) observed data at RGE [53.4416;-5.3666]

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	**12.42**	**1.8868**	**141.7**	**380000**
S2	**12.00**	**0.5923**	**183.3**	**25000**
N2	**12.66**	**0.3803**	**127.8**	**17000**
L2	**12.19**	**0.0794**	**143.9**	**510**
M4	**6.21**	**0.0525**	**218.2**	**230**
K1	**23.93**	**0.0579**	**96.9**	**180**
O1	**25.82**	**0.0547**	**351.5**	**170**
MU2	**12.87**	**0.0383**	**129.7**	**100**
MM	661.29	0.0260	178.5	49
MS4	6.10	0.0224	268.4	44
MN4	6.27	0.0190	191.8	35
MSF	354.37	0.0207	280.5	32
Q1	26.87	0.0194	300.6	15
M3	8.28	0.0130	61.4	14
EPS2	13.13	0.0118	158.7	10
ETA2	11.75	0.0196	176.2	7.1
M6	4.14	0.0068	84.6	4.6
NO1	24.83	0.0087	147.4	3.6
SK3	7.99	0.0061	170.2	2.9
2MS6	4.09	0.0057	123.2	2.8
MO3	8.39	0.0063	198.0	2.7
2MN6	4.17	0.0043	69.4	2.2

(…)

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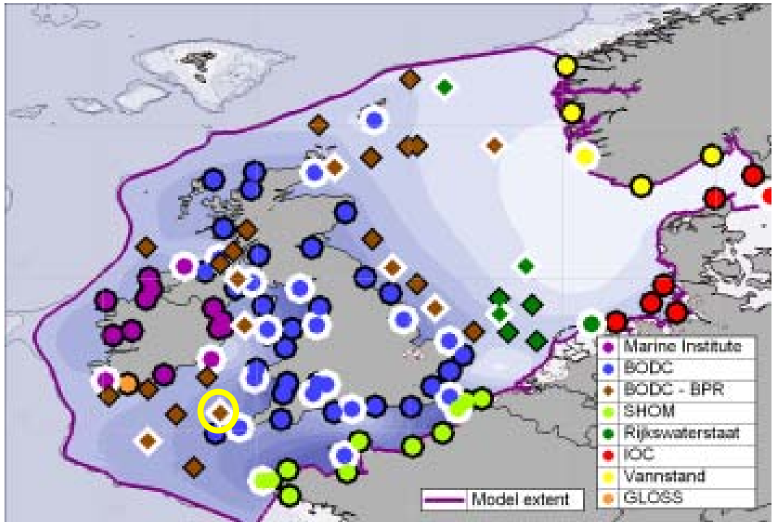
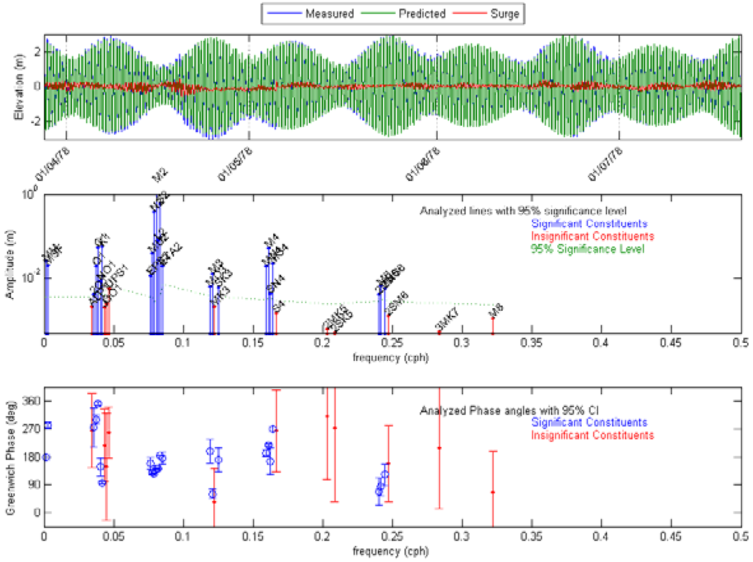
Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
SN4	6.16	0.0043	165.6	1.7
2Q1	28.01	0.0042	274.9	1.1
UPS1	21.58	0.0058	259.3	0.79
MK3	8.18	0.0022	36.2	0.42
ALP1	29.07	0.0022	264.3	0.36
J1	23.10	0.0020	218.0	0.29
S4	6.00	0.0015	264.6	0.25
2SM6	4.05	0.0013	158.3	0.22
M8	3.11	0.0011	66.2	0.22
OO1	22.31	0.0025	149.0	0.15
2MK5	4.93	0.0006	310.6	0.064
3MK7	3.53	0.0005	208.5	0.045
2SK5	4.80	0.0005	273.0	0.042

Number of days: 114.84
Number of constituents: 35
MSL = 0.05 m





A 34. Re-synthesis of the (offshore) observed data at RD [50.5833;-6.1666]

Observed harmonic constituents

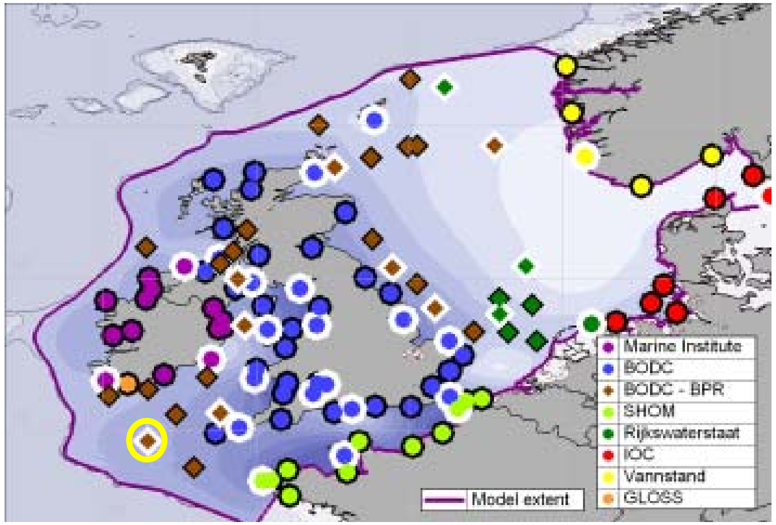
Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	**12.42**	**1.3646**	**122.9**	**250000**
S2	**12.00**	**0.5510**	**155.0**	**55000**
N2	**12.66**	**0.3323**	**106.8**	**26000**
MU2	**12.87**	**0.0577**	**80.4**	**540**
O1	**25.82**	**0.0541**	**337.4**	**510**
L2	**12.19**	**0.0647**	**128.4**	**460**
K1	**23.93**	**0.0467**	**92.5**	**390**
M4	**6.21**	**0.0276**	**232.2**	**130**
MSF	354.37	0.0197	174.4	71
MM	661.29	0.0196	3.3	66
MS4	6.10	0.0189	285.2	66
Q1	26.87	0.0219	302.9	62
MN4	6.27	0.0144	214.2	44
ETA2	11.75	0.0223	41.7	43
2MS6	4.09	0.0128	47.0	32
M3	8.28	0.0105	8.7	22
M6	4.14	0.0098	357.5	19
EPS2	13.13	0.0093	127.9	17
2Q1	28.01	0.0079	268.1	11
2MN6	4.17	0.0077	321.9	11
2SM6	4.05	0.0041	148.4	3.3
MO3	8.39	0.0040	105.8	2.3
NO1	24.83	0.0029	154.6	2.1
ALP1	29.07	0.0035	237.6	2

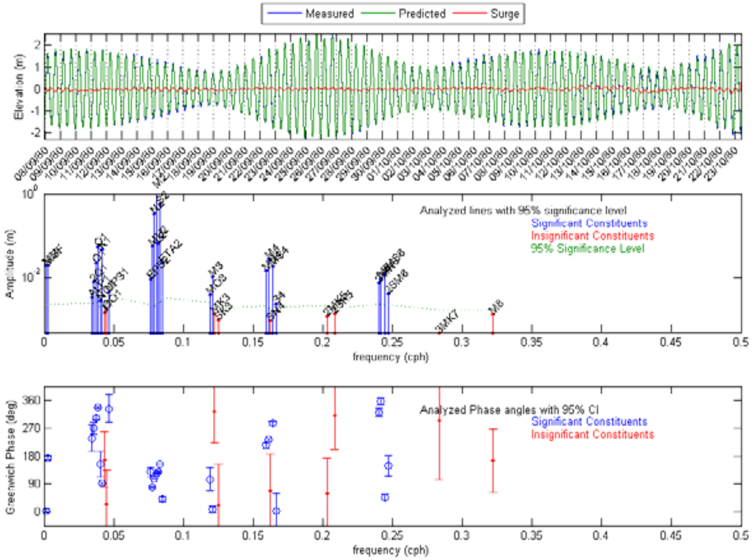
(…)

(…)

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
UPS1	21.58	0.0046	333.6	1.7
S4	6.00	0.0024	3.7	1.4
M8	3.11	0.0014	165.1	0.66
J1	23.10	0.0015	168.9	0.63
2SK5	4.80	0.0015	309.7	0.62
OO1	22.31	0.0018	24.1	0.49
MK3	8.18	0.0014	323.9	0.41
2MK5	4.93	0.0012	61.9	0.33
SN4	6.16	0.0010	68.9	0.32
SK3	7.99	0.0010	21.1	0.28
3MK7	3.53	0.0005	294.3	0.07

Number of days: 45.52
Number of constituents: 35
MSL = -0.31 m





A 35. Re-synthesis of the (offshore) observed data at RG [49.6599;-8.5283]

APPENDIX B – CCSM COMPARISON AGAINST TIDAL GAUGE DATA

Calibration and validation of the CSM was achieved through a comparison of predicted water levels against water levels re-synthesised by tidal harmonic analysis from observed levels at a number of coastal tidal gauges in Northern Europe (refer Sections 4 and 4.2.1, and Figures 4 and 5).

The figures in this appendix present the results of this analysis for each location, displayed in terms of:

- An inset indicating the geographical location of the observation station (yellow circle). The underlying map is a reduced version of Figures 6 and 8 combined, illustrating the CCSM performance in terms of N-RMSE values across the model area.

- Time histories of tidal levels predicted by the CCSM over the calibration/validation period. These are displayed as thick orange lines and compared to the re-synthesised time histories of observed tidal levels for the same period (shown as black crosses). When available concurrently to the calibration/validation period, the observations are represented by a thick light green line.

- MAE and N-RMSE values (normalised using the higher of the maximum tidal range at that location over the calibration period and 1 m). These statistics quantify how closely the CCSM predictions agree with re-synthesised observed data. N-RMSE values below 10% are deemed to reflect a good calibration of the model at a particular site (see Section 3.2.4).

- Tables of primary harmonic constituents (first 8) resulting from tidal harmonic analysis of both the CCSM predictions and the observed data. For this analysis specifically, the CCSM was rerun from the calibration period for 90 days, as noted in Section 3.2.3. For consistency, the harmonic analysis was then performed on the same period for the observed and predicted datasets, i.e. March 1st to May 30th 2010 wherever possible. There were, however, occasions when the observed dataset did not hold 90 days of data (or any data) during that period. These instances are clearly identified in the following, and when less than 35 harmonic constituents were extracted, those derived from the full measurement period (up to a year) are repeated from Appendix A for reference. It is noted that, strictly, no comparisons can be drawn between constituents extracted from a 365-day period (say) and those from a 90-day period.

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.0873	178.1	94000
S2	12.00	0.4572	200.3	20000
N2	12.66	0.2253	148.3	6000
O1	25.82	0.0826	17.7	980
K1	23.93	0.0796	148.7	650
MM	661.29	0.0583	15.1	350
MU2	12.87	0.0508	117.9	270
M3	8.28	0.0316	77.1	110

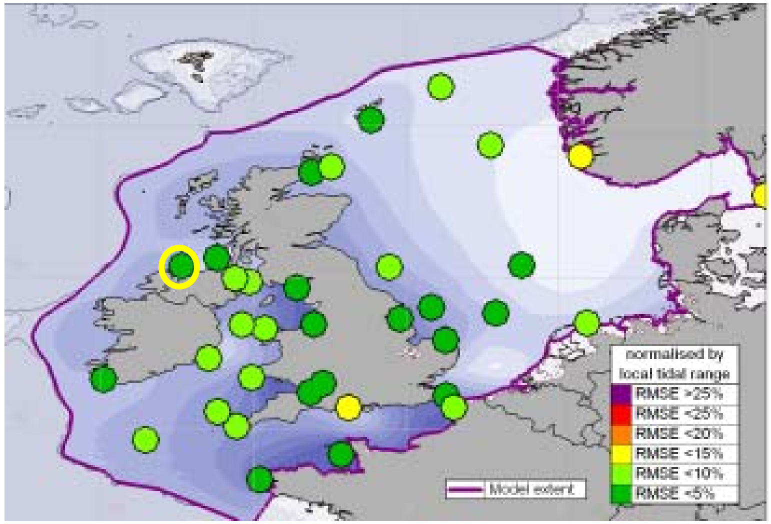
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.08 m

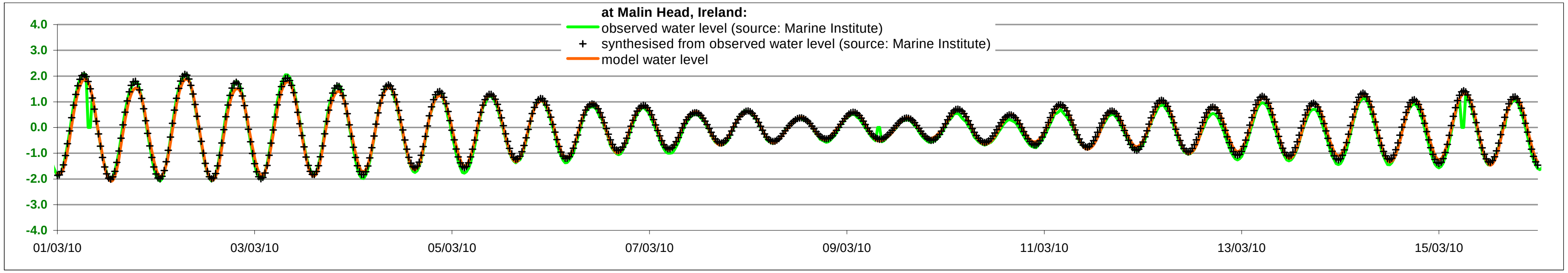
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.0732	183.2	190000
S2	12.00	0.4640	202.0	39000
N2	12.66	0.2355	160.3	11000
K1	23.93	0.1108	121.6	2100
O1	25.82	0.0847	358.9	2000
M4	6.21	0.0351	159.1	220
Q1	26.87	0.0312	301.1	200
L2	12.19	0.0312	30.7	170

Number of days: 90
Number of constituents: 35
MSL = -0.04 m



MAE = 0.08 m or N-RMSE of 3% of maximum tidal range in calibration period



B 1. CCSM comparison against observed data at Malin Head, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.1180	130.4	120000
S2	12.00	0.3978	155.3	22000
N2	12.66	0.2211	98.8	7100
MM	661.29	0.0747	21.9	750
K1	23.93	0.0403	24.3	240
M4	6.21	0.0325	281.9	140
MS4	6.10	0.0200	347.4	63
MU2	12.87	0.0186	53.7	39

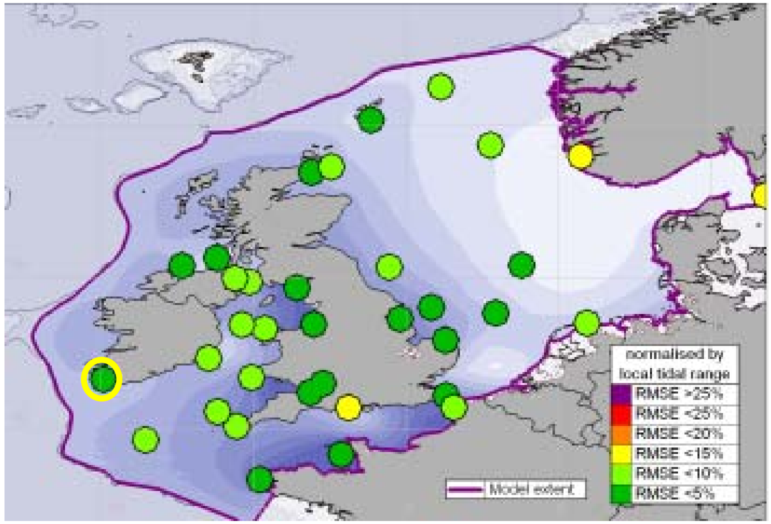
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.24 m

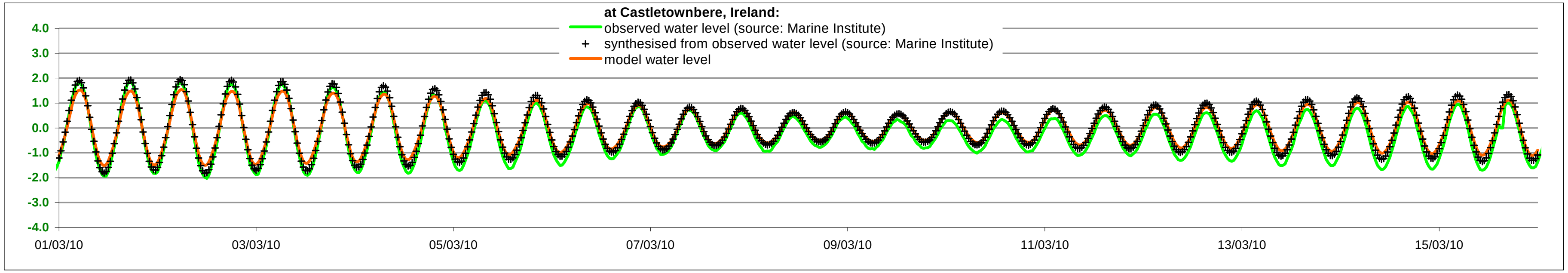
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.9656	133.2	250000
S2	12.00	0.3358	152.4	40000
N2	12.66	0.2005	107.3	20000
M4	6.21	0.0479	298.7	980
O1	25.82	0.0207	358.8	230
MU2	12.87	0.0261	342.4	220
MS4	6.10	0.0245	5.5	220
K1	23.93	0.0196	50.3	190

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.12 m or N-RMSE of 5% of maximum tidal range in calibration period



B 2. CCSM comparison against observed data at Castletownbere, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.4701	187.8	31000
S2	12.00	0.2159	252.5	7400
MU2	12.87	0.1059	246.9	1600
N2	12.66	0.0624	178.6	820
O1	25.82	0.0642	54.6	700
MM	661.29	0.0680	20.7	670
K1	23.93	0.0459	181.0	320
MS4	6.10	0.0401	29.7	250

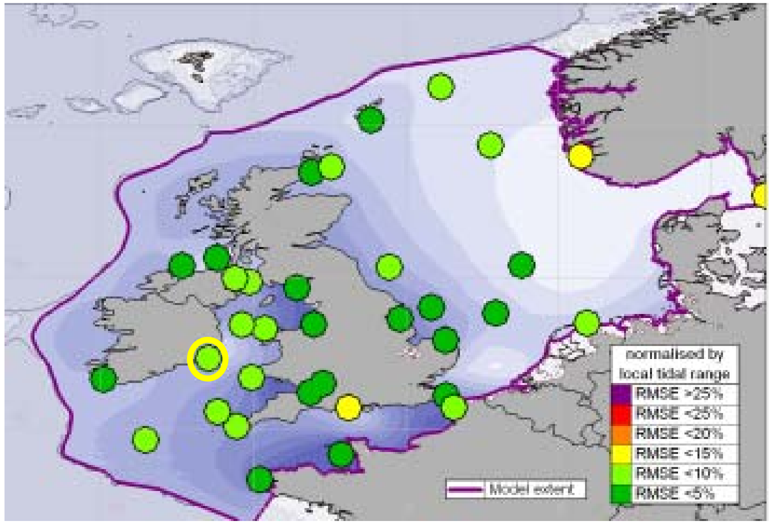
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.15 m

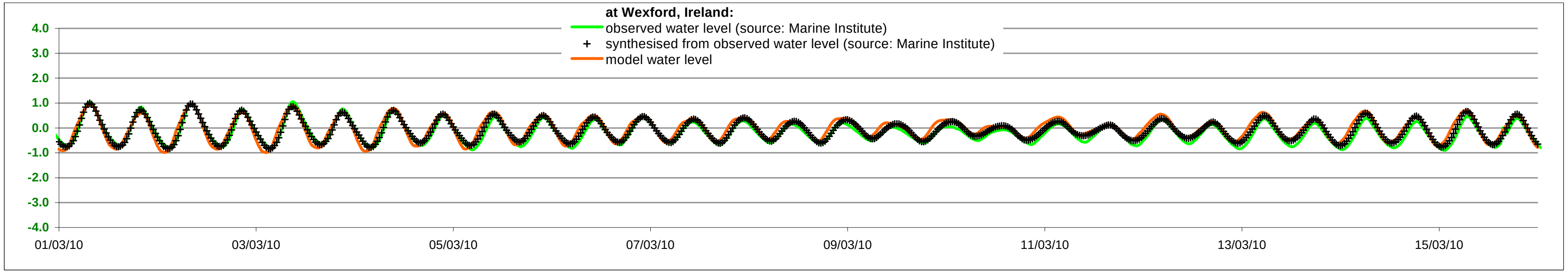
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.5041	174.0	60000
S2	12.00	0.2436	232.3	19000
K1	23.93	0.0948	155.3	2500
O1	25.82	0.0878	34.8	2300
N2	12.66	0.0794	188.3	2100
MU2	12.87	0.0874	232.6	2000
M4	6.21	0.0575	106.0	1100
L2	12.19	0.0498	149.0	440

Number of days: 90
Number of constituents: 35
MSL = -0.04 m



MAE = 0.12 m or N-RMSE of 8% of maximum tidal range in calibration period



B 3. CCSM comparison against observed data at Wexford, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
S2	12.00	0.1539	147.4	1100
M2	12.42	0.1619	87.3	980
K1	23.93	0.0789	175.3	300
O1	25.82	0.0813	44.1	290
MM	661.29	0.0740	17.4	270
MU2	12.87	0.0383	117.9	67
M3	8.28	0.0391	102.1	64
2MS6	4.09	0.0319	153.5	45

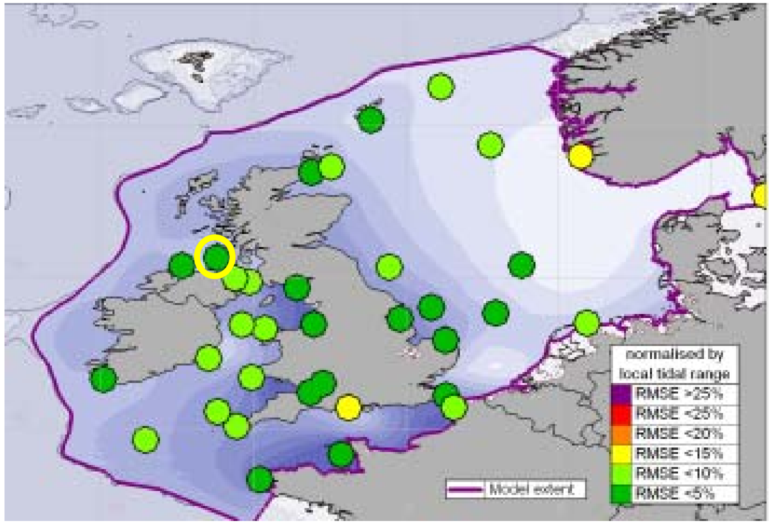
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.12 m

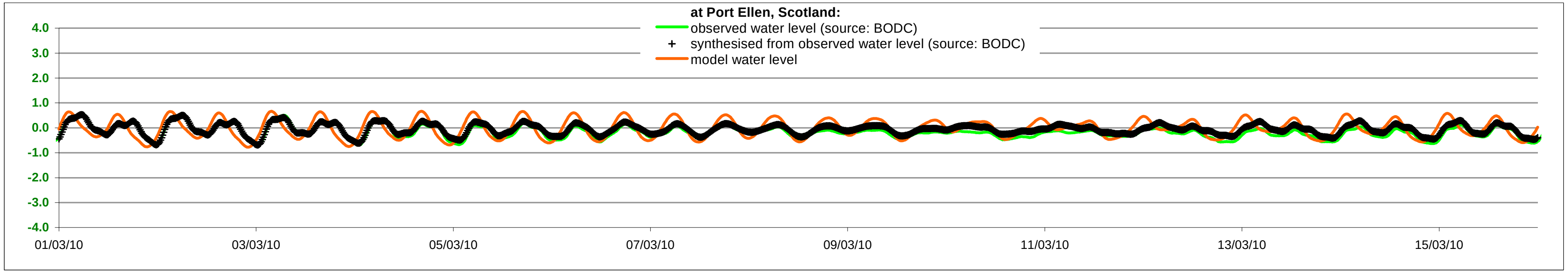
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.4395	34.5	130000
S2	12.00	0.1739	108.4	15000
K1	23.93	0.1178	151.4	6900
O1	25.82	0.0926	32.8	4300
N2	12.66	0.0584	13.1	1900
MU2	12.87	0.0528	138.2	1400
MS4	6.10	0.0423	97.8	1100
M4	6.21	0.0432	101.1	930

Number of days: 90
Number of constituents: 35
MSL = -0.03 m



MAE = 0.24 m or N-RMSE of 5% of maximum tidal range in calibration period



B 4. CCSM comparison against observed data at Port Ellen, Scotland

Observed harmonic constituents

Harmonic Constituents[1,2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.3480	331.6	210000
S2	12.00	0.3732	16.7	23000
N2	12.66	0.2527	304.4	8400
O1	25.82	0.0984	42.7	1700
K2	11.97	0.1094	16.7	1700
K1	23.93	0.1092	188.2	1500
L2	12.19	0.0607	4.9	880
NU2	12.63	0.0621	306.6	580

[1] Only the first 8 constituents are listed

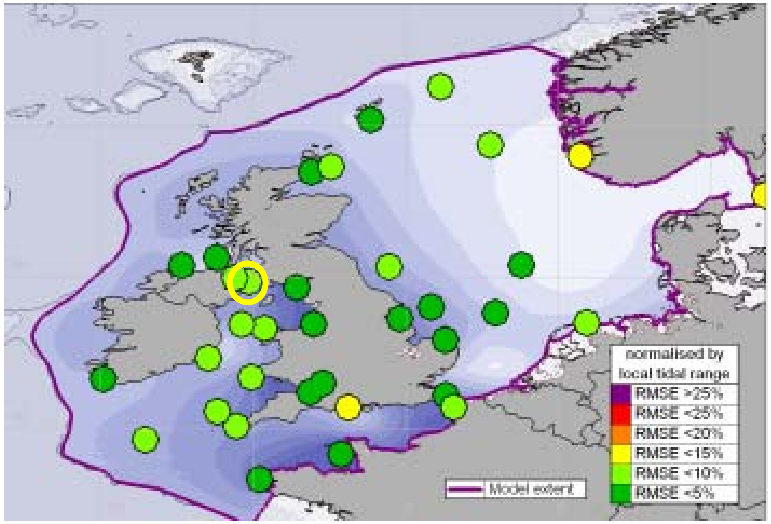
[2] Constituents from full observation period (for reference only)

Number of days: 271
Number of constituents: 59
MSL = 0.11 m

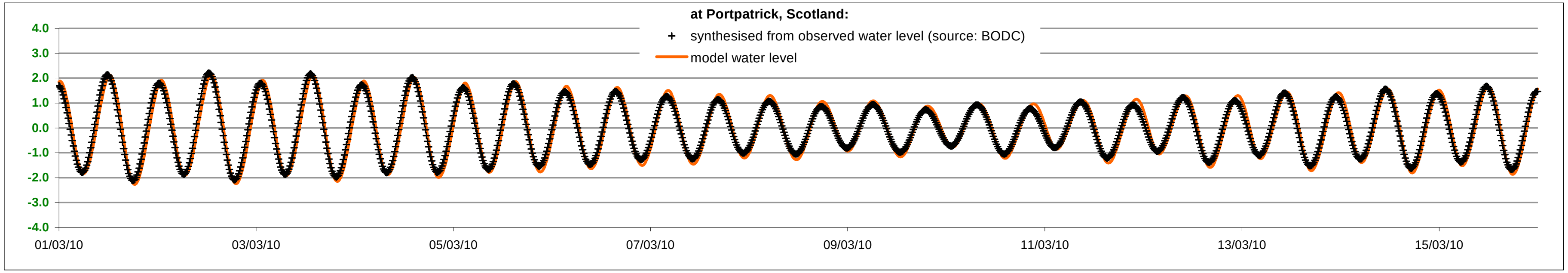
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.5025	344.5	260000
S2	12.00	0.4431	21.2	27000
N2	12.66	0.2641	316.2	15000
K1	23.93	0.1384	152.6	2700
O1	25.82	0.1112	34.1	1800
MU2	12.87	0.0881	126.3	1100
MS4	6.10	0.0459	81.0	340
Q1	26.87	0.0303	332.1	170

Number of days: 90
Number of constituents: 35
MSL = -0.03 m



MAE = 0.22 m or N-RMSE of 6% of maximum tidal range in calibration period



B 5. CCSM comparison against observed data at Portpatrick, Scotland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	2.7588	331.4	110000
S2	12.00	0.9475	7.7	14000
N2	12.66	0.4693	299.4	4700
M4	6.21	0.1419	255.1	360
K1	23.93	0.1043	179.6	180
O1	25.82	0.1076	47.3	170
MM	661.29	0.0875	26.9	130
MS4	6.10	0.0793	296.3	120

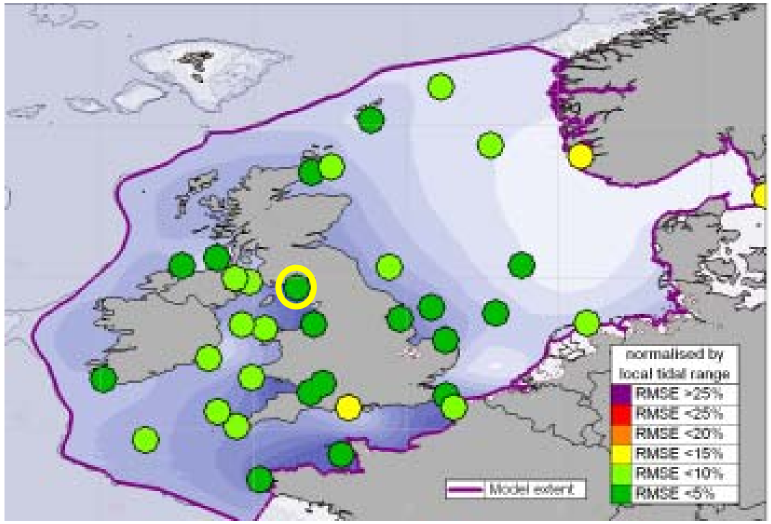
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.15 m

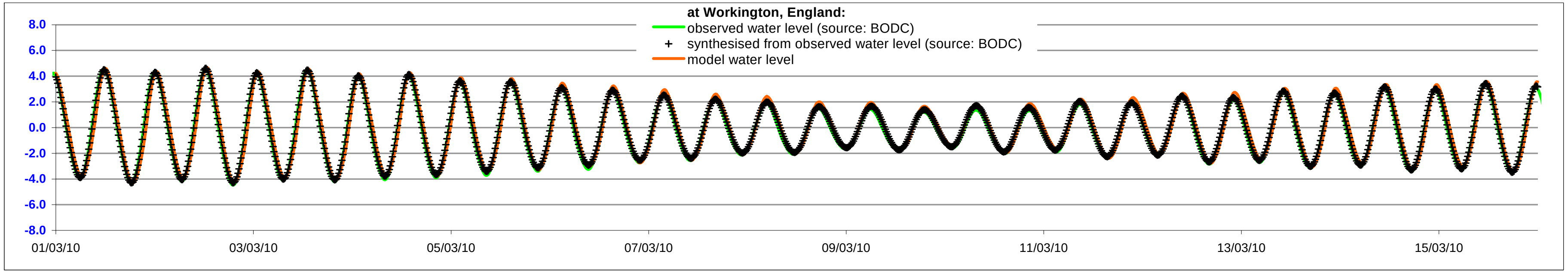
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	2.9070	342.3	240000
S2	12.00	0.9729	17.0	29000
N2	12.66	0.5221	317.3	14000
M4	6.21	0.1929	279.1	1300
K1	23.93	0.1590	156.0	840
O1	25.82	0.1303	37.8	600
MU2	12.87	0.1281	110.9	600
MS4	6.10	0.1059	312.1	480

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.35 m or N-RMSE of 5% of maximum tidal range in calibration period



B 6. CCSM comparison against observed data at Workington, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	3.0158	319.8	110000
S2	12.00	0.9574	352.9	13000
N2	12.66	0.4930	286.9	4200
M4	6.21	0.2752	199.5	970
MS4	6.10	0.1794	228.4	450
K1	23.93	0.1230	168.2	260
O1	25.82	0.1066	42.7	230
MM	661.29	0.1158	58.4	200

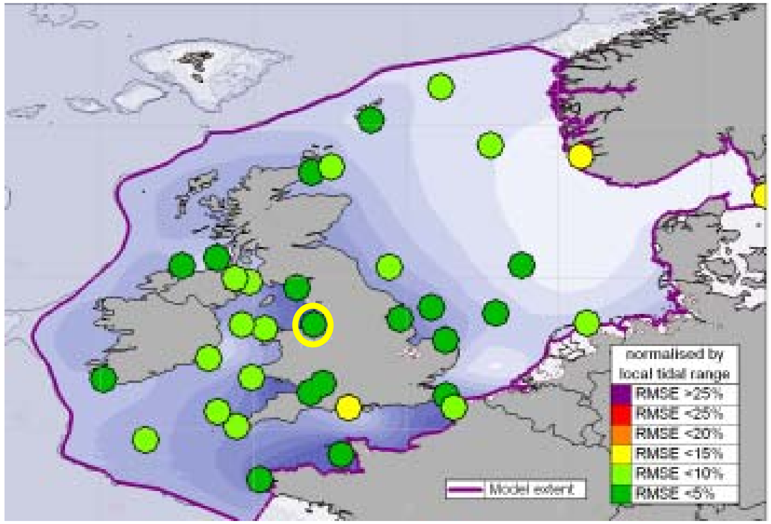
[1] Only the first 8 constituents are listed

Number of days: 67.28
Number of constituents: 35
MSL = -0.04 m

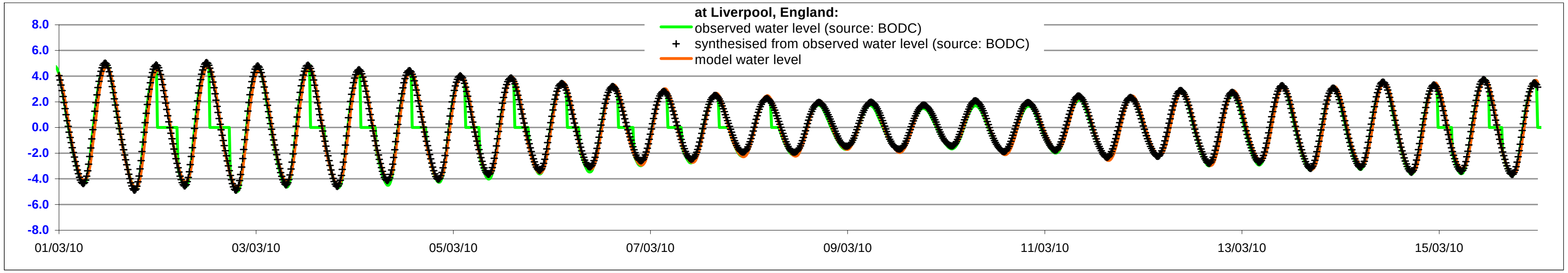
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	3.1373	328.3	210000
S2	12.00	1.0639	1.9	36000
N2	12.66	0.5673	303.7	9600
M4	6.21	0.2223	236.9	1400
K1	23.93	0.1613	149.9	1000
O1	25.82	0.1329	32.0	710
MS4	6.10	0.1437	261.2	650
MU2	12.87	0.1327	96.7	530

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.29 m or N-RMSE of 4% of maximum tidal range in calibration period



B 7. CCSM comparison against observed data at Liverpool, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.8176	291.5	110000
S2	12.00	0.7587	326.7	17000
N2	12.66	0.3931	256.5	4900
MM	661.29	0.1430	359.5	590
O1	25.82	0.1011	34.2	250
MSF	354.37	0.0836	181.8	190
K1	23.93	0.0712	167.0	190
L2	12.19	0.0730	347.4	130

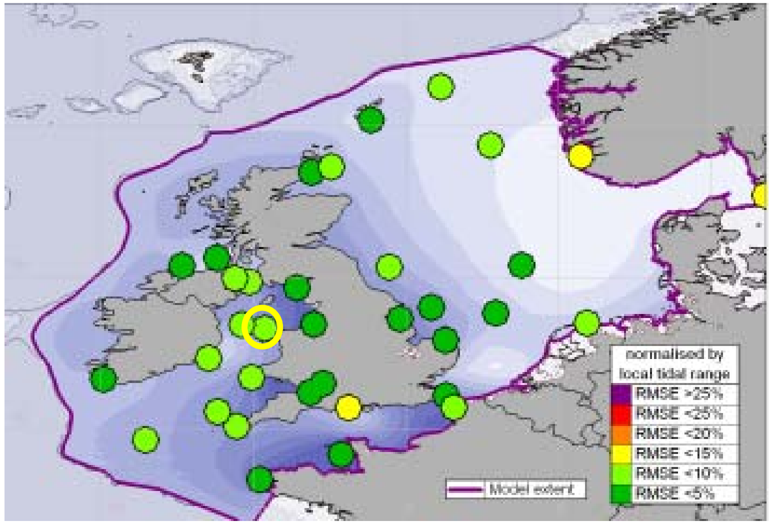
[1] Only the first 8 constituents are listed

Number of days: 46.73
Number of constituents: 35
MSL = -0.03 m

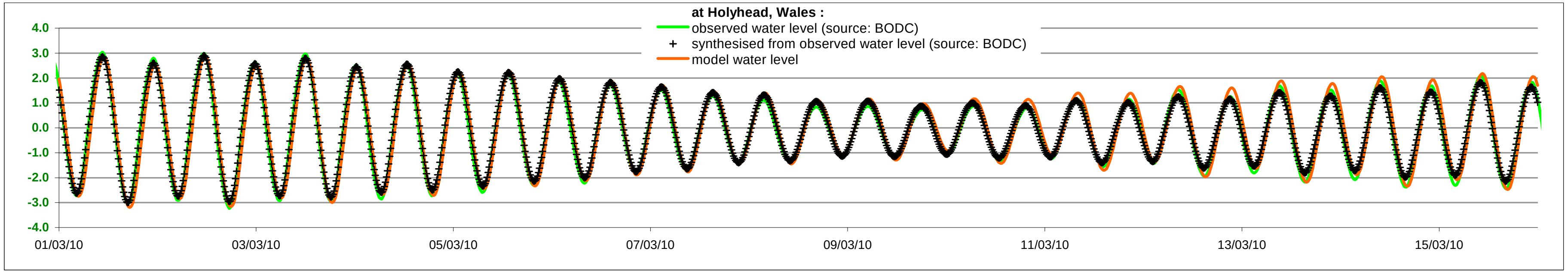
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.9232	305.1	230000
S2	12.00	0.6577	333.6	34000
N2	12.66	0.3683	278.9	13000
K1	23.93	0.1412	141.5	1800
O1	25.82	0.1203	23.9	1500
MU2	12.87	0.0663	102.8	400
MSF	354.37	0.0390	206.9	160
Q1	26.87	0.0306	325.4	95

Number of days: 90
Number of constituents: 35
MSL = -0.07 m



MAE = 0.27 m or N-RMSE of 6% of maximum tidal range in calibration period



B 8. CCSM comparison against observed data at Holyhead, Wales

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.2315	172.1	90000
S2	12.00	0.8743	210.1	19000
N2	12.66	0.3987	145.8	4600
MU2	12.87	0.0925	208.4	180
MM	661.29	0.0790	21.7	160
O1	25.82	0.0664	359.6	150
M4	6.21	0.0653	308.3	100
L2	12.19	0.0739	181.8	93

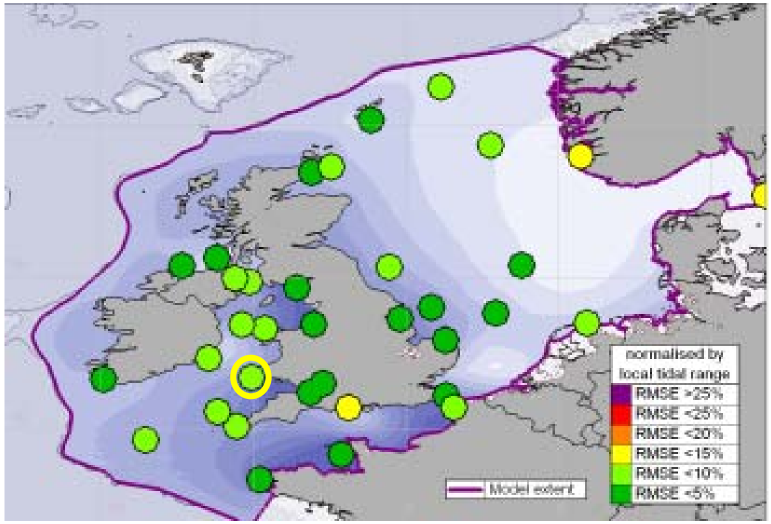
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.04 m

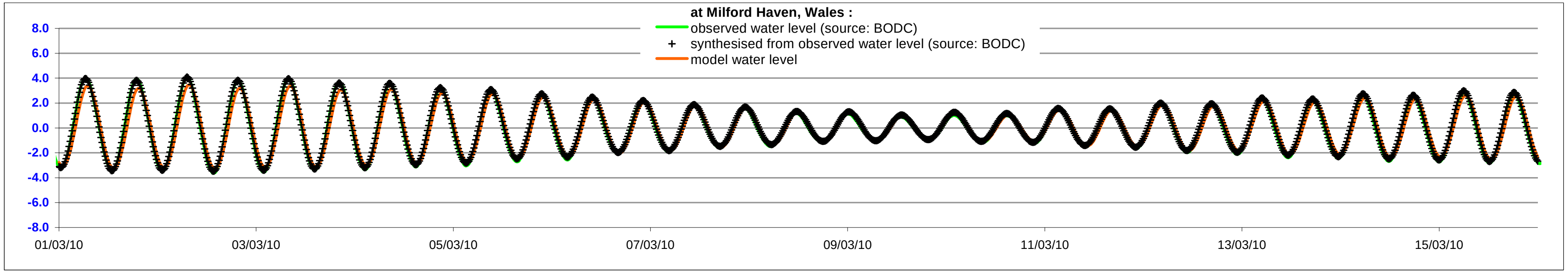
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.1173	185.7	210000
S2	12.00	0.8043	222.1	37000
N2	12.66	0.3830	168.5	9000
O1	25.82	0.0761	359.2	480
MU2	12.87	0.0817	267.2	440
K1	23.93	0.0819	108.7	350
M4	6.21	0.0583	0.7	200
MS4	6.10	0.0266	43.9	39

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.33 m or N-RMSE of 7% of maximum tidal range in calibration period



B 9. CCSM comparison against observed data at Milford Haven, Wales

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.9763	182.2	99000
S2	12.00	1.5245	229.7	17000
N2	12.66	0.6186	161.3	2900
MU2	12.87	0.3915	245.2	1000
L2	12.19	0.2288	195.6	330
M4	6.21	0.1062	20.6	81
MM	661.29	0.0954	26.9	73
O1	25.82	0.0751	0.7	64

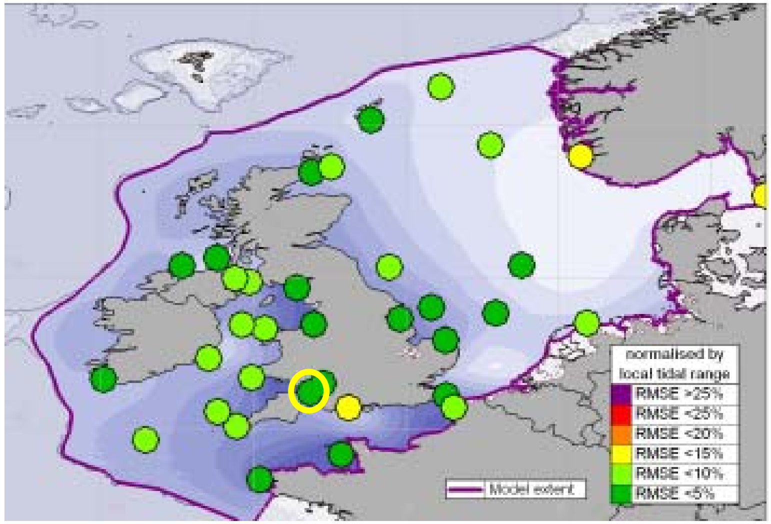
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.17 m

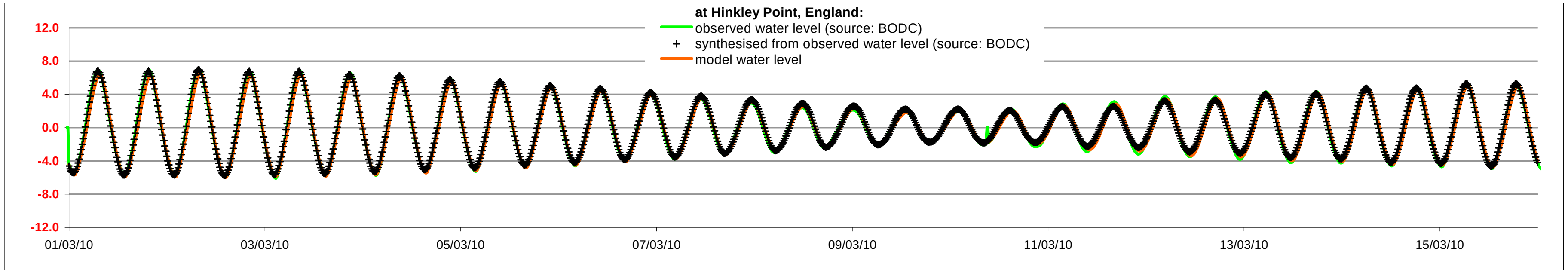
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.9119	190.6	180000
S2	12.00	1.5129	234.2	32000
N2	12.66	0.6620	179.3	5600
MU2	12.87	0.3139	265.4	1400
M4	6.21	0.1622	74.9	310
O1	25.82	0.0827	0.2	130
L2	12.19	0.1194	178.0	120
2MS6	4.09	0.0885	279.0	96

Number of days: 90
Number of constituents: 35
MSL = 0.02 m



MAE = 0.42 m or N-RMSE of 4% of maximum tidal range in calibration period



B 10. CCSM comparison against observed data at Hinkley Point, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	4.1981	205.1	88000
S2	12.00	1.6110	256.2	12000
N2	12.66	0.5584	186.8	1400
MU2	12.87	0.5010	269.6	1200
MS4	6.10	0.2765	16.7	330
M4	6.21	0.2568	349.7	270
L2	12.19	0.2634	209.6	260
MSF	354.37	0.1732	48.1	140

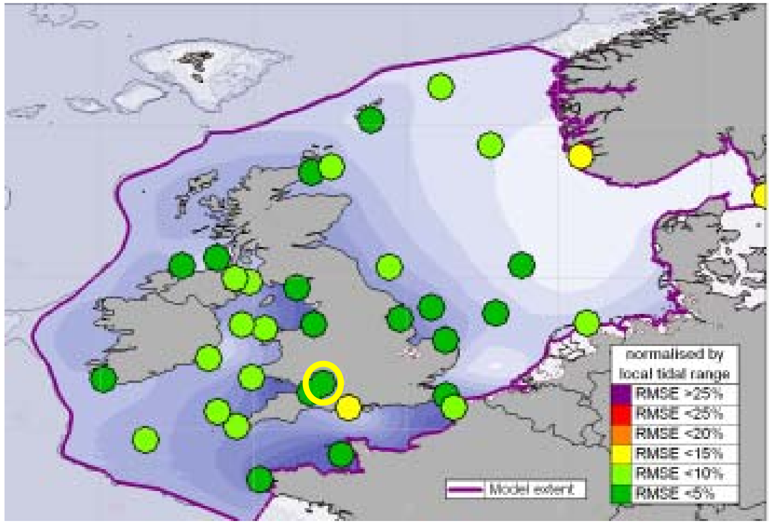
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.02 m

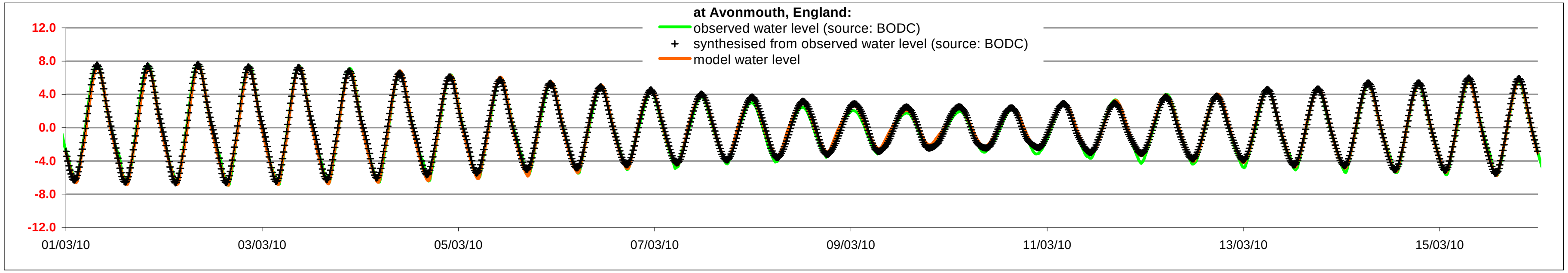
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	4.3915	203.7	170000
S2	12.00	1.7037	251.7	23000
N2	12.66	0.7320	196.6	4700
MU2	12.87	0.4646	275.4	1800
MS4	6.10	0.2696	20.8	570
M4	6.21	0.2180	358.6	340
L2	12.19	0.1745	194.5	190
2MS6	4.09	0.1569	333.7	180

Number of days: 90
Number of constituents: 35
MSL = 0.02 m



MAE = 0.25 m or N-RMSE of 2% of maximum tidal range in calibration period



B 11. CCSM comparison against observed data at Avonmouth, England

Observed harmonic constituents

Harmonic Constituents[1,2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.7093	133.4	140000
S2	12.00	0.5877	170.0	20000
N2	12.66	0.3256	108.5	6700
M4	6.21	0.1138	166.3	600
MS4	6.10	0.0757	210.6	350
MU2	12.87	0.0705	177.2	260
K1	23.93	0.0641	104.6	230
L2	12.19	0.0905	136.7	200

[1] Only the first 8 constituents are listed

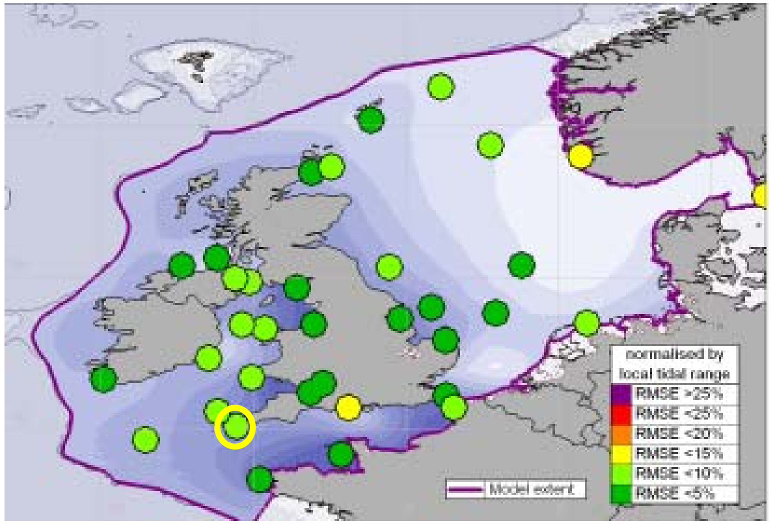
[2] Constituents from full observation period (for reference only)

Number of days: 139.39
Number of constituents: 35
MSL = 0.10 m

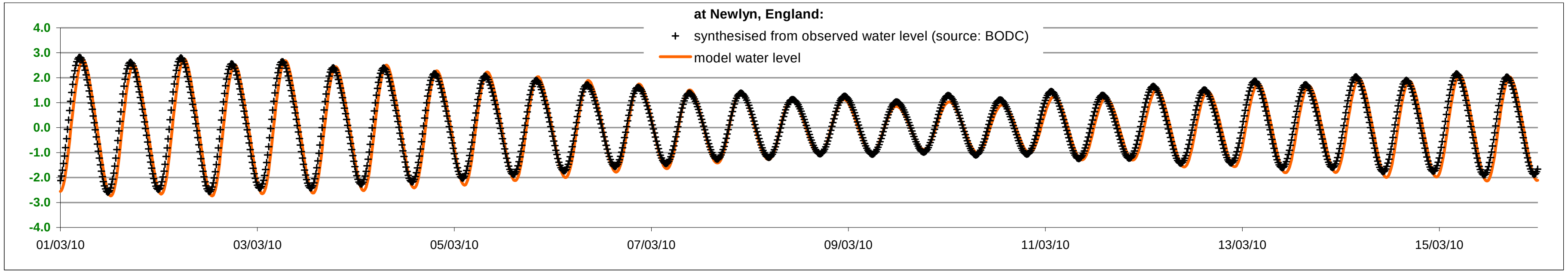
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.7617	146.9	210000
S2	12.00	0.6193	184.4	28000
N2	12.66	0.3086	129.4	14000
M4	6.21	0.1138	197.8	1100
MU2	12.87	0.0930	237.8	710
MS4	6.10	0.0787	234.6	580
O1	25.82	0.0544	344.8	360
K1	23.93	0.0602	92.0	290

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.32 m or N-RMSE of 8% of maximum tidal range in calibration period



B 12. CCSM comparison against observed data at Newlyn, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	3.3767	181.5	100000
S2	12.00	1.4182	224.5	21000
N2	12.66	0.6052	159.6	4000
MU2	12.87	0.2441	212.1	570
M4	6.21	0.1989	300.9	510
MS4	6.10	0.1614	348.4	280
L2	12.19	0.1561	174.1	170
O1	25.82	0.0812	341.9	99

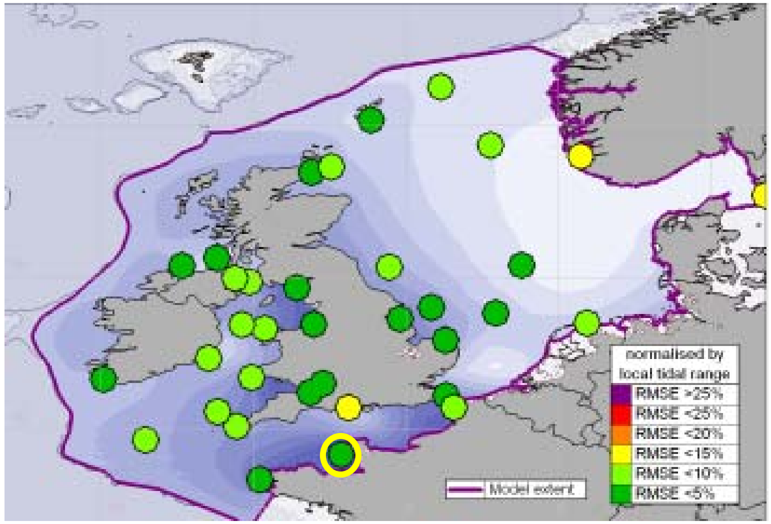
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.09 m

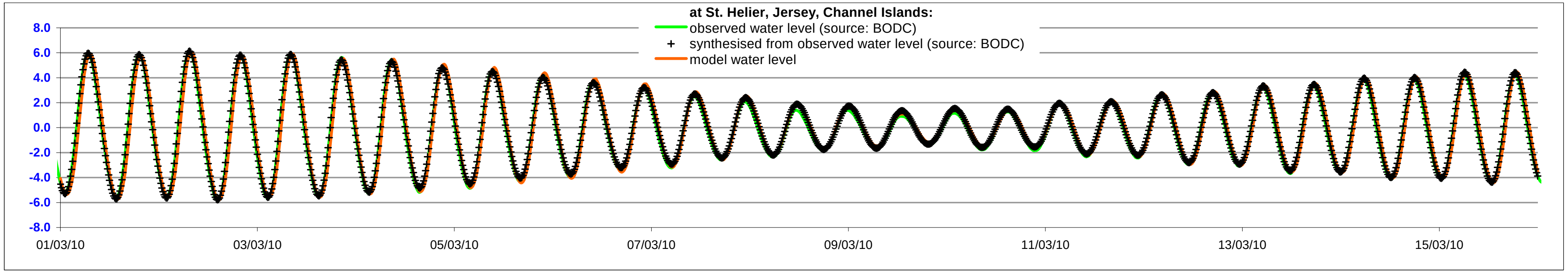
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	3.5583	192.5	170000
S2	12.00	1.5144	234.0	36000
N2	12.66	0.6838	181.8	7000
MU2	12.87	0.2306	236.2	700
M4	6.21	0.1807	325.5	440
MS4	6.10	0.1667	11.4	420
O1	25.82	0.0845	354.3	150
K1	23.93	0.0992	89.8	120

Number of days: 90
Number of constituents: 35
MSL = -0.06 m



MAE = 0.41 m or N-RMSE of 5% of maximum tidal range in calibration period



B 13. CCSM comparison against observed data at St. Helier, Jersey, Channel Islands

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.4089	272.7	7500
S2	12.00	0.2005	286.6	2300
M4	6.21	0.1974	22.8	2100
MS4	6.10	0.1351	68.8	1200
N2	12.66	0.1090	242.5	760
K1	23.93	0.0872	94.1	450
2MS6	4.09	0.0827	116.9	420
M6	4.14	0.0715	81.1	410

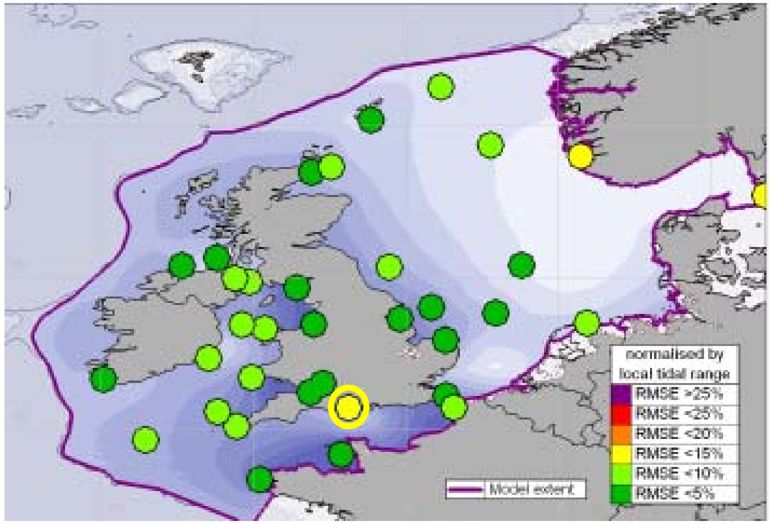
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.12 m

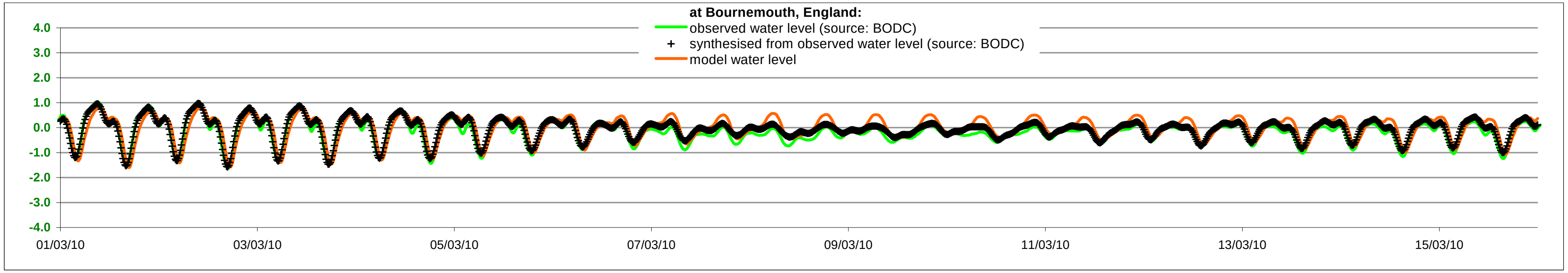
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.5192	307.7	42000
S2	12.00	0.2038	308.5	9600
M4	6.21	0.2131	43.0	7700
MS4	6.10	0.1417	89.8	4700
N2	12.66	0.1397	272.8	4600
MU2	12.87	0.0827	180.5	1200
K1	23.93	0.0722	106.6	1000
2MS6	4.09	0.0633	154.2	840

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.22 m or N-RMSE of 11% of maximum tidal range in calibration period



B 14. CCSM comparison against observed data at Bournemouth, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.2829	332.0	92000
S2	12.00	0.7693	16.6	11000
N2	12.66	0.3722	300.1	4500
M4	6.21	0.2695	223.5	1300
MS4	6.10	0.1868	266.8	870
MU2	12.87	0.1159	62.6	290
L2	12.19	0.1073	8.3	200
MN4	6.27	0.0854	183.3	130

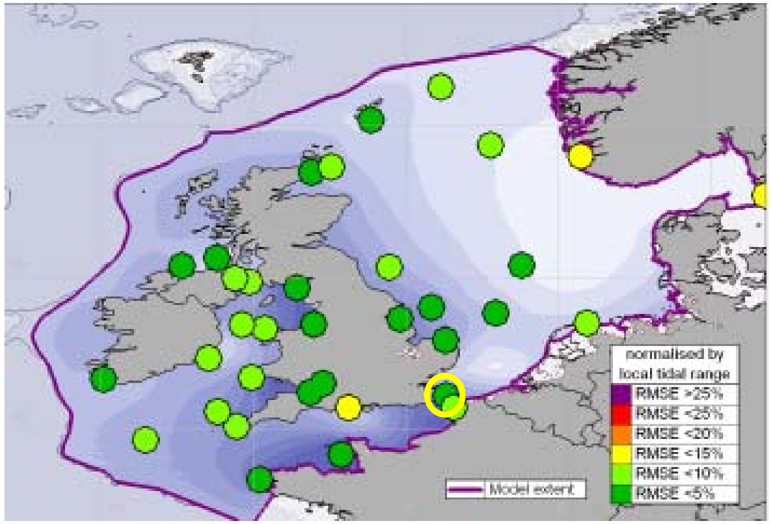
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.06 m

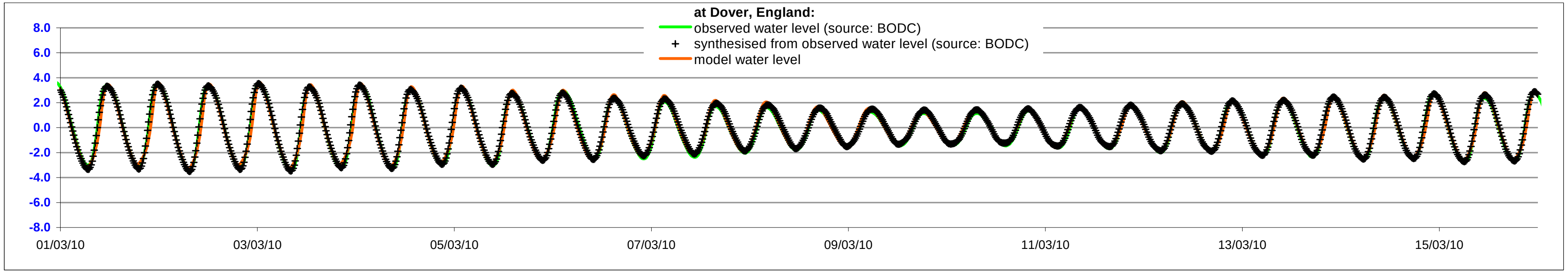
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.3027	335.0	160000
S2	12.00	0.7790	20.6	22000
N2	12.66	0.3691	315.3	7800
M4	6.21	0.2816	255.9	2700
MS4	6.10	0.1980	301.9	1800
MU2	12.87	0.1703	72.7	990
MN4	6.27	0.0878	236.0	340
2MS6	4.09	0.0828	235.9	230

Number of days: 90
Number of constituents: 35
MSL = -0.07 m



MAE = 0.19 m or N-RMSE of 4% of maximum tidal range in calibration period



B 15. CCSM comparison against observed data at Dover, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.5512	188.3	53000
S2	12.00	0.5632	226.2	7800
N2	12.66	0.2819	159.6	2100
O1	25.82	0.1710	137.0	870
K1	23.93	0.1211	290.2	350
M4	6.21	0.0930	277.2	230
MS4	6.10	0.0833	316.0	180
Q1	26.87	0.0415	42.9	64

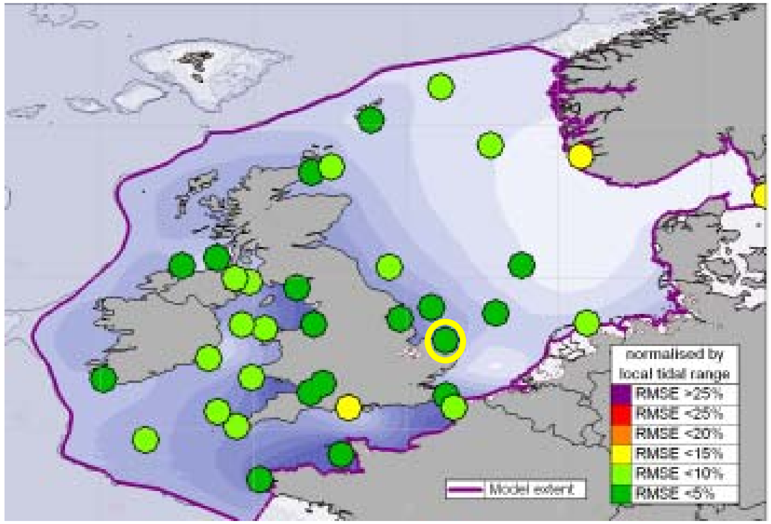
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.09 m

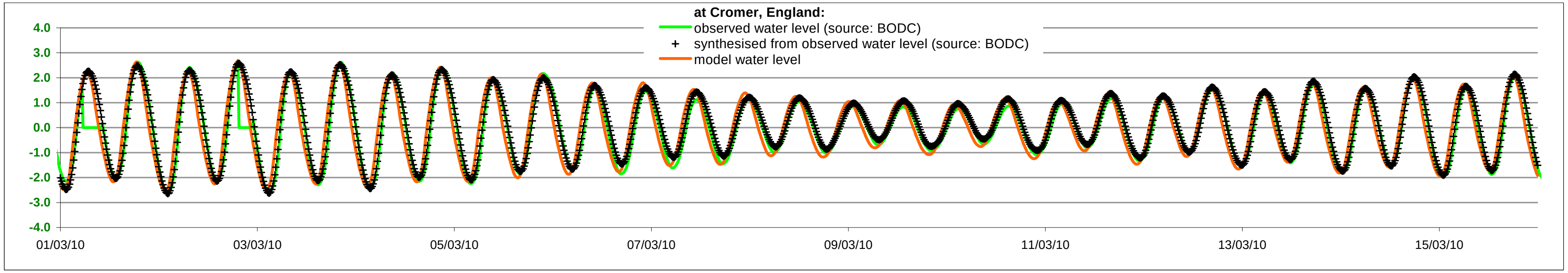
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.6552	166.2	210000
S2	12.00	0.5588	204.4	29000
N2	12.66	0.3020	140.0	13000
O1	25.82	0.1501	134.0	2400
K1	23.93	0.1334	265.7	1600
M4	6.21	0.0914	268.1	810
MU2	12.87	0.0761	287.1	580
MS4	6.10	0.0611	296.5	430

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.16 m or N-RMSE of 4% of maximum tidal range in calibration period



B 16. CCSM comparison against observed data at Cromer, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	**(m)**	**(º)**	**(-)**
M2	12.42	2.2376	162.0	90000
S2	12.00	0.7937	205.7	13000
N2	12.66	0.3743	132.3	4800
O1	25.82	0.1844	117.5	700
K1	23.93	0.1249	272.6	320
MU2	12.87	0.1076	239.9	240
L2	12.19	0.0884	183.9	130
Q1	26.87	0.0457	30.7	48

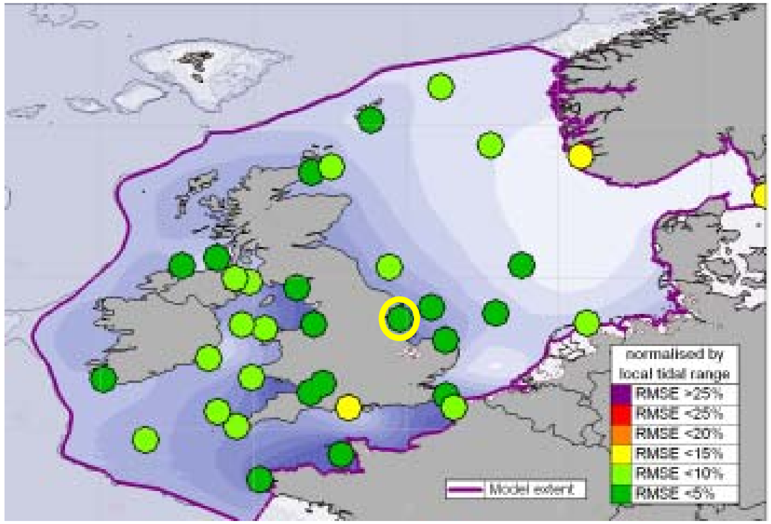
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.02 m

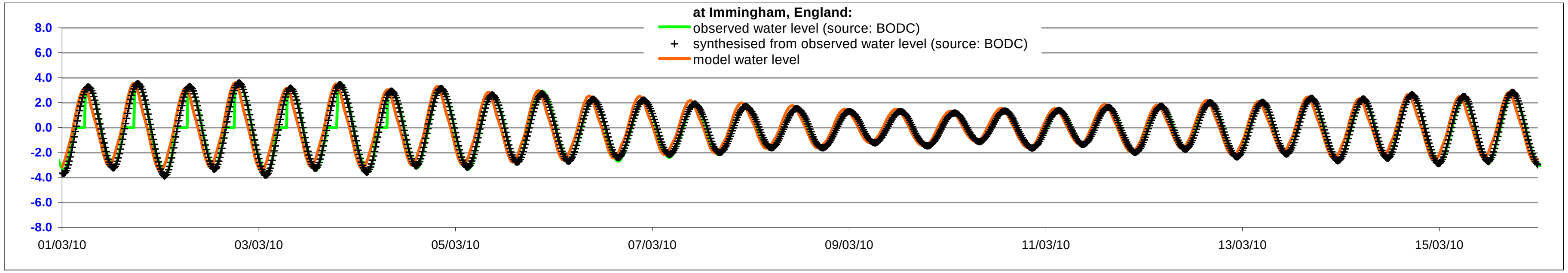
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	**(m)**	**(º)**	**(-)**
M2	12.42	2.2255	136.7	200000
S2	12.00	0.7368	176.6	26000
N2	12.66	0.3891	111.7	10000
K1	23.93	0.1440	245.2	1400
O1	25.82	0.1585	113.7	1300
MU2	12.87	0.1297	249.7	880
2MS6	4.09	0.0853	57.1	370
M4	6.21	0.0746	243.1	270

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.18 m or N-RMSE of 3% of maximum tidal range in calibration period



B 17. CCSM comparison against observed data at Immingham, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	1.0108	321.4	60000
S2	12.00	0.3144	346.6	8300
N2	12.66	0.1665	296.9	2300
O1	25.82	0.1144	27.0	1100
K1	23.93	0.1089	156.2	1100
MSF	354.37	0.0868	15.3	640
MM	661.29	0.0476	39.8	180
M4	6.21	0.0413	322.9	150

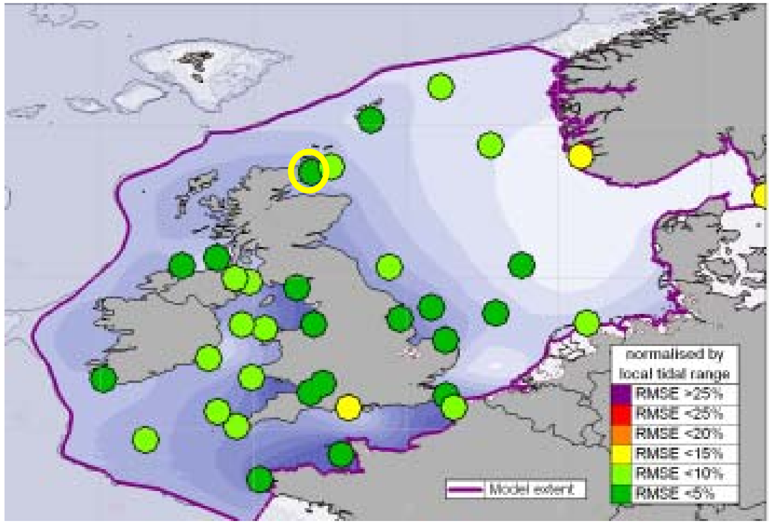
[1] Only the first 8 constituents are listed

Number of days: 44.44
Number of constituents: 35
MSL = -0.14 m

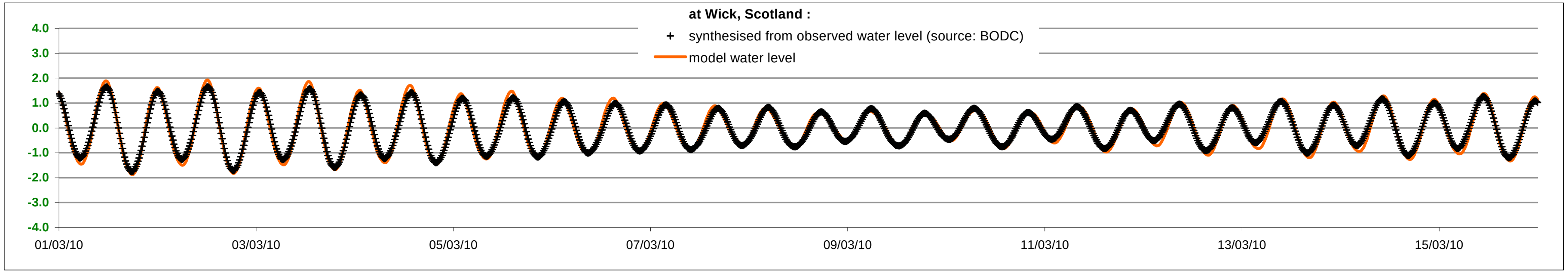
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	1.0871	320.1	220000
S2	12.00	0.3820	346.9	33000
N2	12.66	0.2205	295.7	17000
O1	25.82	0.1013	33.4	2600
K1	23.93	0.0950	159.6	2300
M4	6.21	0.0474	226.4	470
Q1	26.87	0.0332	332.1	350
MS4	6.10	0.0304	307.8	290

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.13 m or N-RMSE of 5% of maximum tidal range in calibration period



B 18. CCSM comparison against observed data at Wick, Scotland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.5807	312.1	25000
S2	12.00	0.2258	340.9	3800
N2	12.66	0.1141	285.3	1000
O1	25.82	0.0798	30.9	410
K1	23.93	0.0630	152.3	410
MSF	354.37	0.0312	67.2	88
MM	661.29	0.0280	6.7	53
Q1	26.87	0.0226	325.3	39

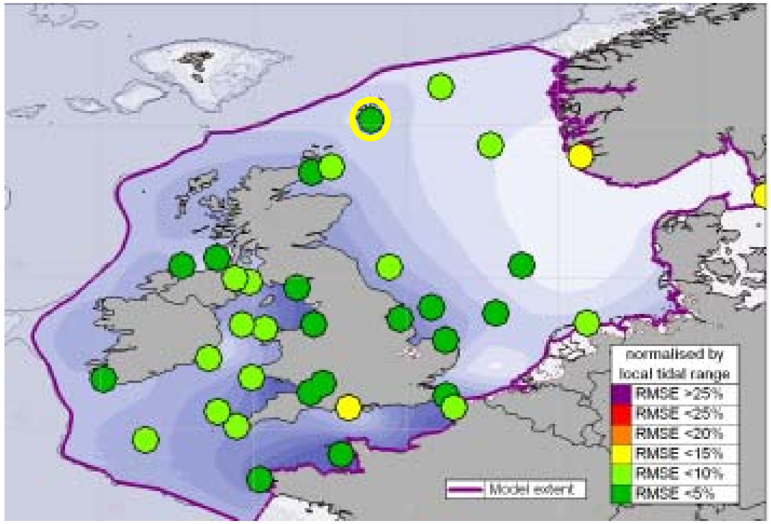
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.07 m

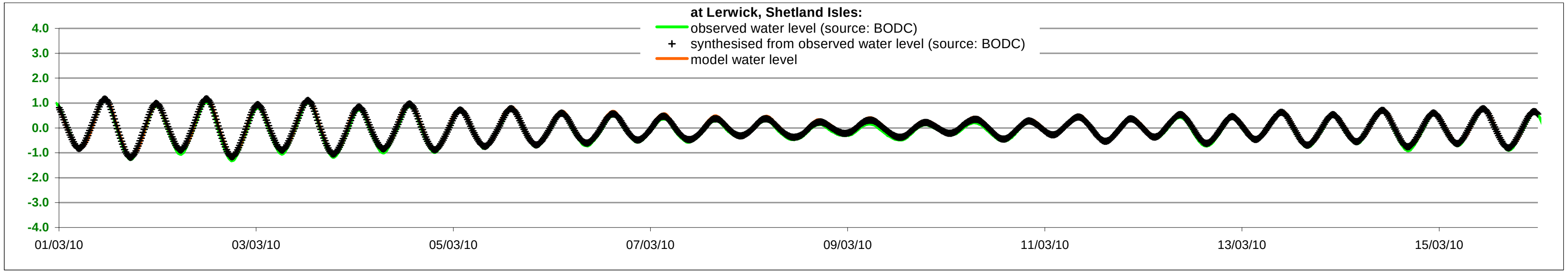
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.6176	317.4	190000
S2	12.00	0.2223	342.3	33000
N2	12.66	0.1315	293.0	15000
O1	25.82	0.0766	37.5	4100
K1	23.93	0.0761	156.8	3900
Q1	26.87	0.0245	335.8	540
M4	6.21	0.0259	230.1	380
MS4	6.10	0.0140	293.6	150

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.05 m or N-RMSE of 3% of maximum tidal range in calibration period



B 19. CCSM comparison against observed data at Lerwick, Shetland Isles

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	2.0712	108.5	140000
S2	12.00	0.8198	141.9	29000
N2	12.66	0.3933	83.6	7900
MU2	12.87	0.0903	125.2	360
MM	661.29	0.0836	23.9	270
O1	25.82	0.0670	326.2	190
M4	6.21	0.0578	109.8	160
K1	23.93	0.0539	57.7	110

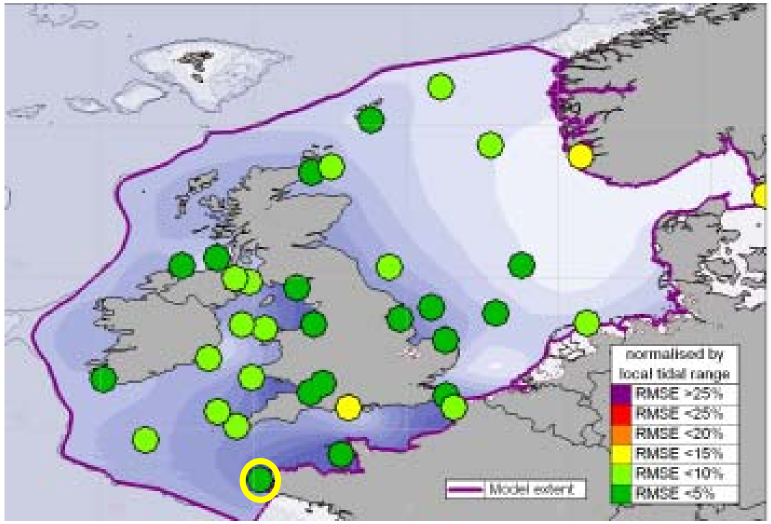
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.0 m

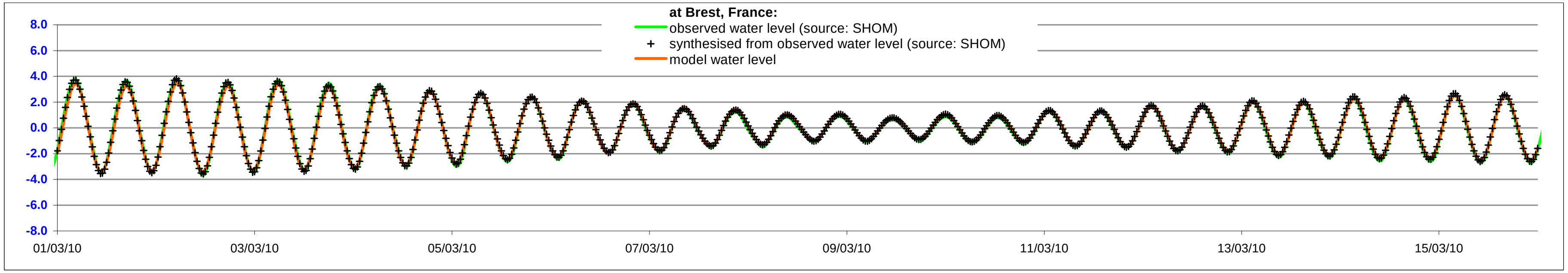
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	2.0689	111.6	190000
S2	12.00	0.8080	141.1	43000
N2	12.66	0.4135	94.6	13000
K1	23.93	0.0634	64.7	330
O1	25.82	0.0650	328.2	310
MU2	12.87	0.0350	167.3	66
Q1	26.87	0.0217	279.7	38
L2	12.19	0.0233	11.4	26

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.10 m or N-RMSE of 2% of maximum tidal range in calibration period



B 20. CCSM comparison against observed data at Brest, France

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	2.9918	329.3	130000
S2	12.00	1.0415	13.2	24000
N2	12.66	0.4928	298.8	5600
M4	6.21	0.3484	221.4	2600
MS4	6.10	0.2435	265.8	1100
MU2	12.87	0.1407	50.8	340
MN4	6.27	0.1076	179.0	260
L2	12.19	0.1319	6.3	200

[1] Only the first 8 constituents are listed

Number of days: 88.32

Number of constituents: 35

MSL = -0.04 m

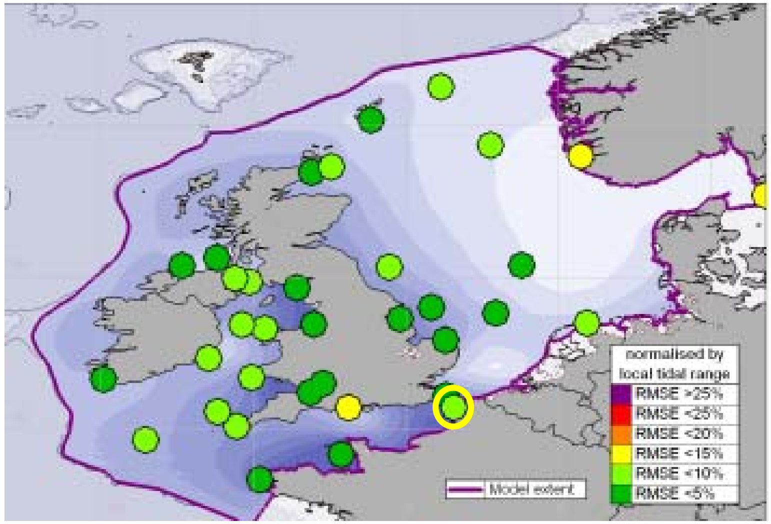
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.0130	340.1	170000
S2	12.00	1.0640	23.8	26000
N2	12.66	0.5080	322.2	8400
M4	6.21	0.3482	251.5	2700
MS4	6.10	0.2463	298.4	1600
MU2	12.87	0.1858	73.9	760
MN4	6.27	0.1084	232.3	330
2MS6	4.09	0.0719	203.7	140

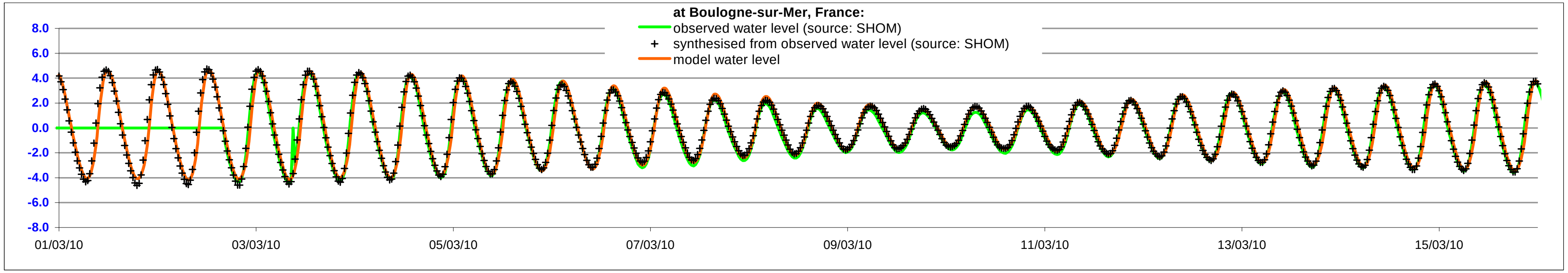
Number of days: 90

Number of constituents: 35

MSL = -0.01 m



MAE = 0.33 m or N-RMSE of 6% of maximum tidal range in calibration period



B 21. CCSM comparison against observed data at Boulogne-sur-Mer, France

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.9754	231.5	63000
S2	12.00	0.2825	283.5	4400
N2	12.66	0.1328	190.1	1100
O1	25.82	0.0907	201.3	610
M4	6.21	0.0967	319.7	510
MU2	12.87	0.0960	335.2	480
MS4	6.10	0.0710	14.5	290
MM	661.29	0.0650	16.9	270

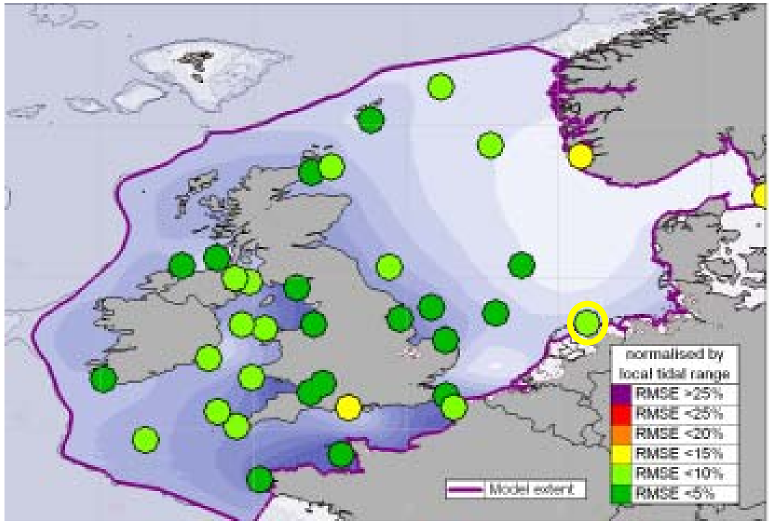
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.12 m

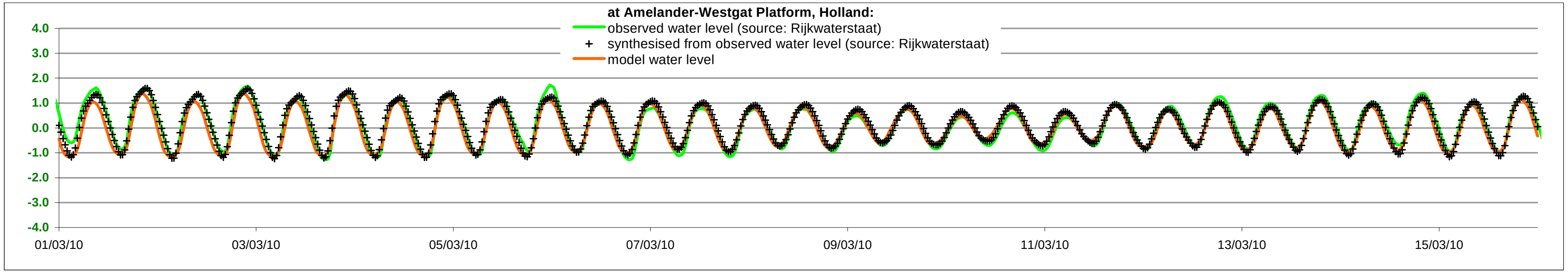
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.9325	226.0	200000
S2	12.00	0.2830	275.9	17000
N2	12.66	0.1372	199.9	5500
O1	25.82	0.0985	193.4	3000
K1	23.93	0.0820	318.4	2000
MU2	12.87	0.0802	336.3	1500
Q1	26.87	0.0301	121.4	330
MS4	6.10	0.0317	50.9	260

Number of days: 90
Number of constituents: 35
MSL = 0.01 m



MAE = 0.19 m or N-RMSE of 9% of maximum tidal range in calibration period



B 22. CCSM comparison against observed data at Amelander-Westgat Platform, Holland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.0681	135.5	390
MM	661.29	0.0450	357.6	250
MSF	354.37	0.0445	43.5	250
O1	25.82	0.0242	299.7	63
N2	12.66	0.0206	54.7	50
MU2	12.87	0.0198	296.7	49
S2	12.00	0.0150	66.8	28
M4	6.21	0.0104	318.8	12

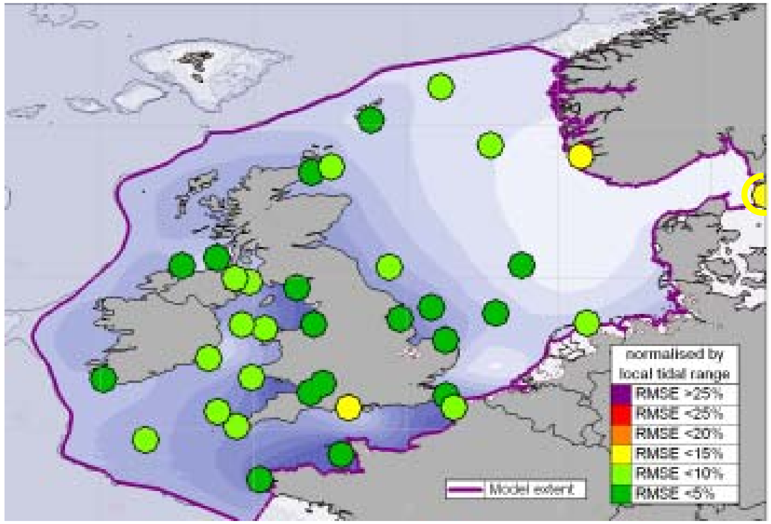
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.15 m

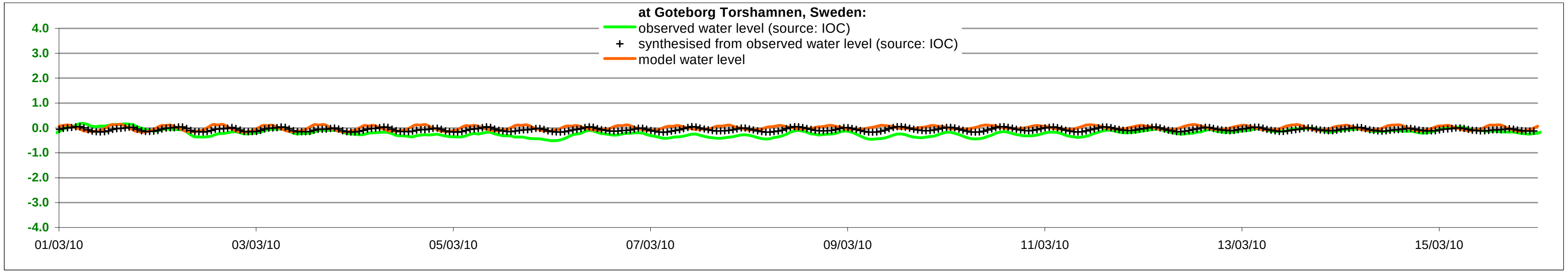
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.1017	35.1	88000
S2	12.00	0.0346	63.2	8300
N2	12.66	0.0188	2.3	2400
MM	661.29	0.0110	201.6	830
MSF	354.37	0.0101	153.4	720
K1	23.93	0.0110	292.7	710
M4	6.21	0.0074	84.0	360
MU2	12.87	0.0054	177.0	170

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.10 m or N-RMSE of 12% of maximum tidal range in calibration period



B 23. CCSM comparison against observed data at Goteborg Torshamnen, Sweden

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.1615	271.5	2700
S2	12.00	0.0741	317.2	880
MSF	354.37	0.0472	61.6	310
2MS6	4.09	0.0278	121.5	100
M6	4.14	0.0252	73.0	97
N2	12.66	0.0240	260.2	83
MM	661.29	0.0198	32.0	59
O1	25.82	0.0180	9.5	55

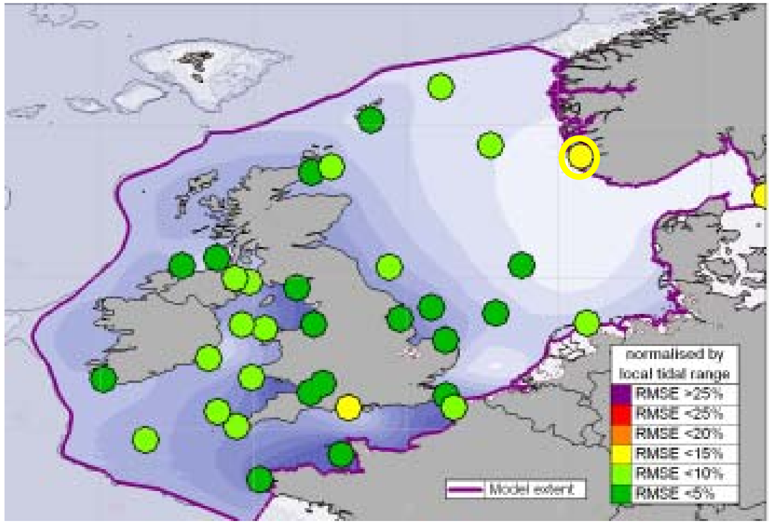
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.10 m

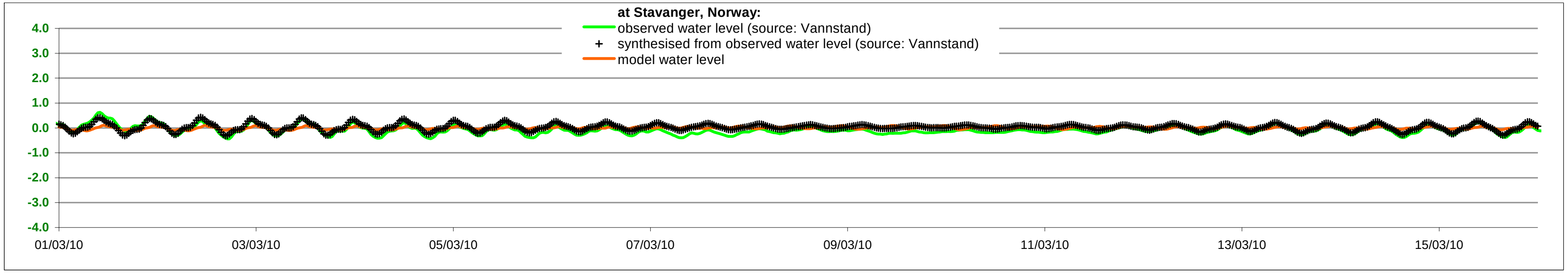
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.0330	341.3	5400
S2	12.00	0.0267	319.2	3300
M4	6.21	0.0266	265.2	2800
N2	12.66	0.0150	327.4	1100
MSF	354.37	0.0109	129.2	490
MU2	12.87	0.0103	247.9	430
MM	661.29	0.0100	199.0	380
M6	4.14	0.0085	31.8	350

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.10 m or N-RMSE of 13% of maximum tidal range in calibration period



B 24. CCSM comparison against observed data at Stavanger, Norway

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	0.5141	287.3	27000
S2	12.00	0.1768	309.9	4100
N2	12.66	0.0865	261.6	1000
MSF	354.37	0.0637	60.0	570
K1	23.93	0.0620	150.0	440
O1	25.82	0.0573	37.5	400
MM	661.29	0.0526	82.0	360
Q1	26.87	0.0126	329.3	32

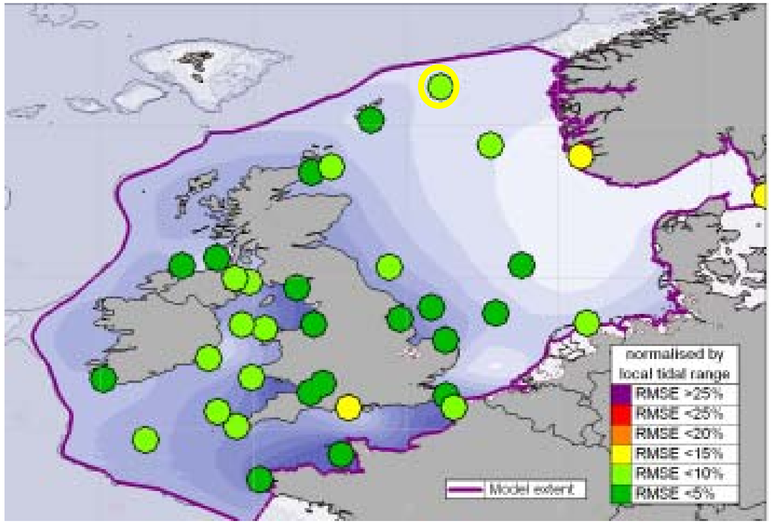
[1] Only the first 8 constituents are listed

Number of days: 55.98
Number of constituents: 35
MSL = 0.11 m

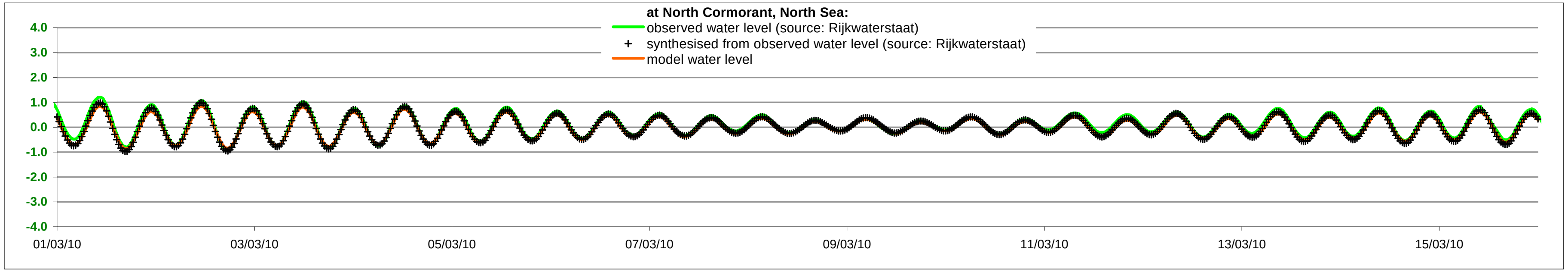
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	0.4616	290.9	170000
S2	12.00	0.1772	316.7	31000
N2	12.66	0.0945	267.5	9800
O1	25.82	0.0538	49.9	3100
K1	23.93	0.0522	163.9	2900
Q1	26.87	0.0185	343.2	540
MM	661.29	0.0151	189.1	230
MSF	354.37	0.0126	130.7	180

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.09 m or N-RMSE of 7% of maximum tidal range in calibration period



B 25. CCSM comparison against (offshore) observed data at North Cormorant

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.2729	132.3	6700
S2	12.00	0.0819	164.5	850
N2	12.66	0.0501	91.3	360
O1	25.82	0.0419	160.0	290
M4	6.21	0.0396	0.7	200
K1	23.93	0.0294	287.1	99
MM	661.29	0.0220	16.9	64
MSF	354.37	0.0216	78.4	58

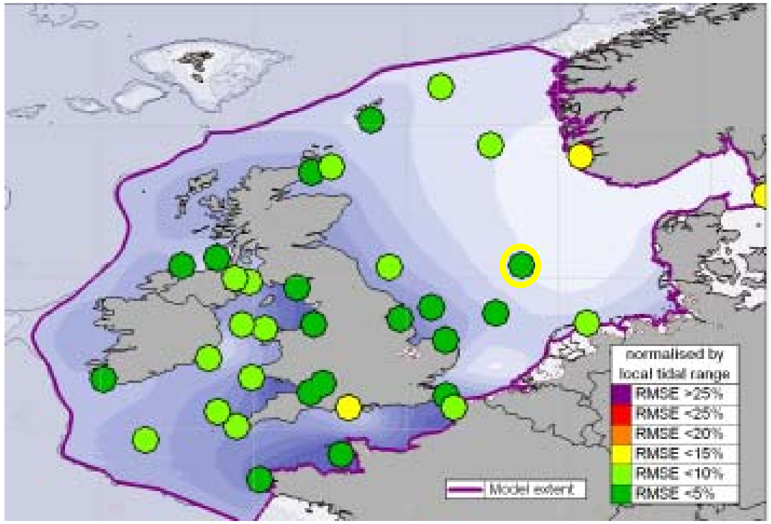
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.08 m

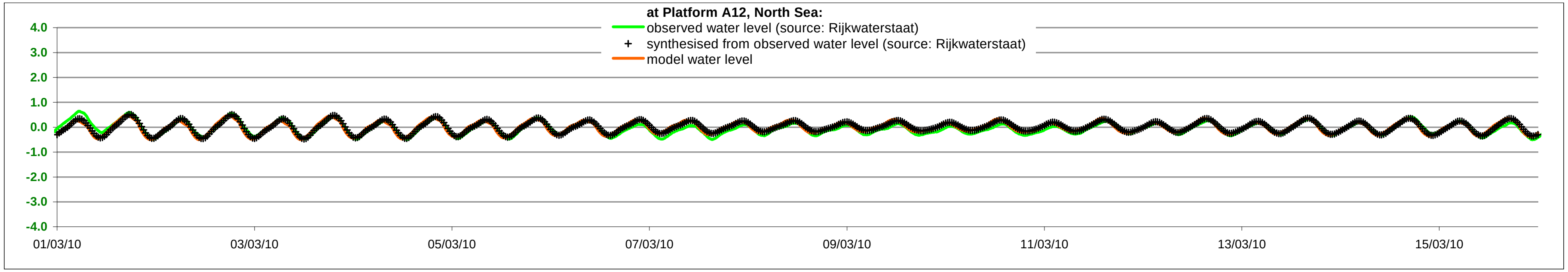
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.2903	114.1	100000
S2	12.00	0.0875	145.9	14000
N2	12.66	0.0534	81.3	5300
O1	25.82	0.0496	151.4	5000
M4	6.21	0.0453	330.5	3300
K1	23.93	0.0427	279.1	3100
MS4	6.10	0.0208	38.6	810
Q1	26.87	0.0177	86.3	690

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.04 m or N-RMSE of 4% of maximum tidal range in calibration period



B 26. CCSM comparison against (offshore) observed data at Platform A12

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	0.6960	170.3	41000
S2	12.00	0.2467	214.5	6800
N2	12.66	0.1157	141.0	1400
O1	25.82	0.0962	157.3	890
K1	23.93	0.0685	305.5	460
MU2	12.87	0.0341	233.0	110
Q1	26.87	0.0273	69.3	80
L2	12.19	0.0318	190.1	68

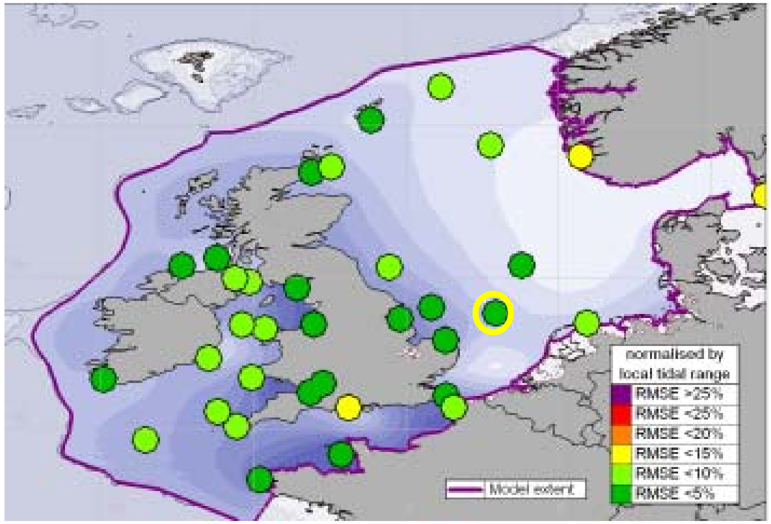
[1] Only the first 8 constituents are listed

Number of days: 89.76
Number of constituents: 35
MSL = -0.13 m

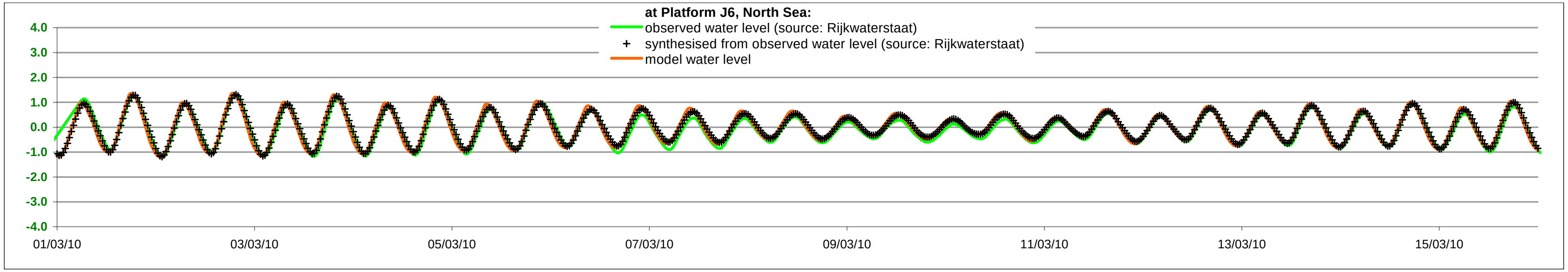
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	0.7666	158.3	190000
S2	12.00	0.2631	197.9	24000
N2	12.66	0.1391	135.1	12000
O1	25.82	0.0982	153.1	4400
K1	23.93	0.0842	283.5	2700
M4	6.21	0.0447	274.1	780
Q1	26.87	0.0314	87.3	480
MU2	12.87	0.0336	263.5	470

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.07 m or N-RMSE of 4% of maximum tidal range in calibration period



B 27. CCSM comparison against (offshore) observed data at Platform J6

Observed harmonic constituents

Harmonic Constituents[1 2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.3165	309.0	4800
S2	12.00	0.1486	341.4	1100
N2	12.66	0.0731	288.8	330
MSF	354.37	0.0305	269.1	57
O1	25.82	0.0362	54.4	50
MU2	12.87	0.0266	264.9	42
K1	23.93	0.0208	172.3	21
MM	661.29	0.0179	185.6	19

[1] Only the first 8 constituents are listed

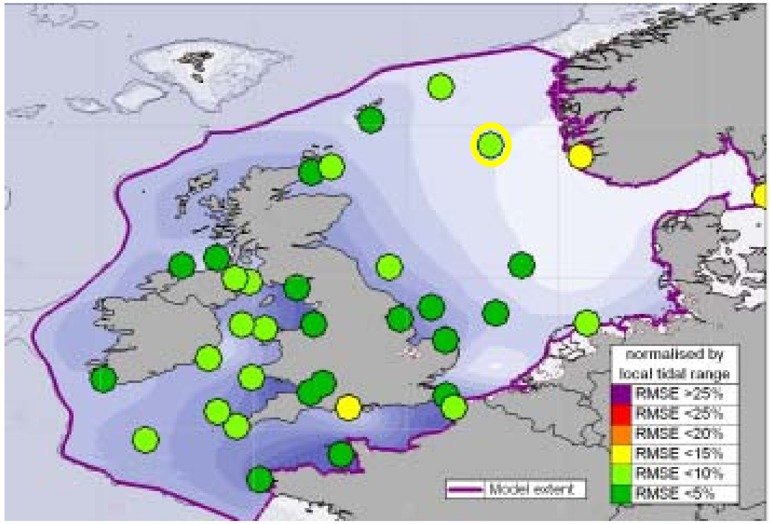
[2] Constituents from original observation period (for reference only)

Number of days: 33.64
Number of constituents: 35
MSL = -0.91 m

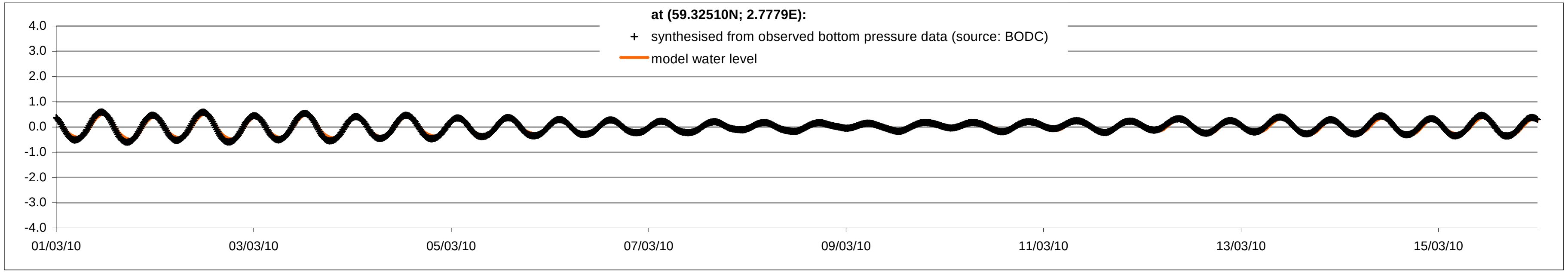
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.2662	321.3	110000
S2	12.00	0.1061	342.1	21000
N2	12.66	0.0585	300.0	10000
O1	25.82	0.0290	60.3	1600
K1	23.93	0.0260	177.0	1400
M4	6.21	0.0267	252.7	1300
MSF	354.37	0.0130	132.5	430
MM	661.29	0.0118	205.1	290

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.06 m or N-RMSE of 7% of maximum tidal range in calibration period



B 28. CCSM comparison against (offshore) observed data at PJONSDAP, R56 [59.3251;2.7779]

Observed harmonic constituents

Harmonic Constituents[1 2]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.7527	326.0	30000
S2	12.00	0.3199	0.9	6600
N2	12.66	0.1836	306.1	2400
O1	25.82	0.0939	31.0	350
MM	661.29	0.0675	136.0	330
MU2	12.87	0.0489	282.0	160
K1	23.93	0.0512	179.3	150
MSF	354.37	0.0362	252.9	95

[1] Only the first 8 constituents are listed

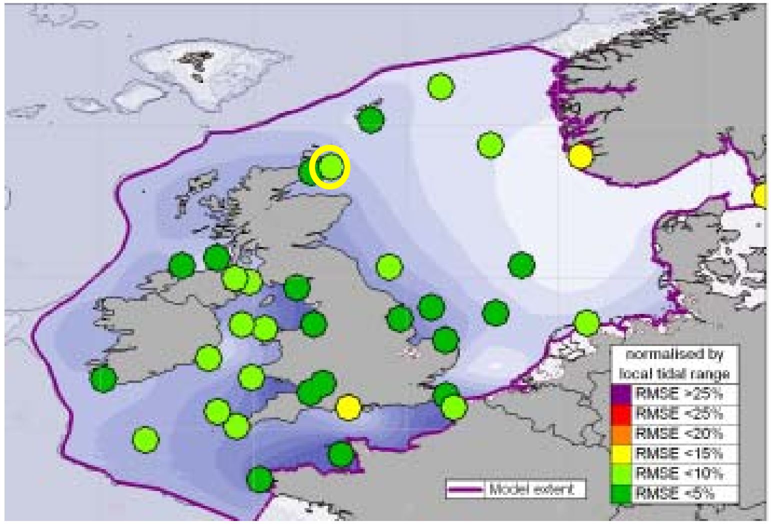
[2] Constituents from original observation period (for reference only)

Number of days: 36.90
Number of constituents: 35
MSL = 0.16 m

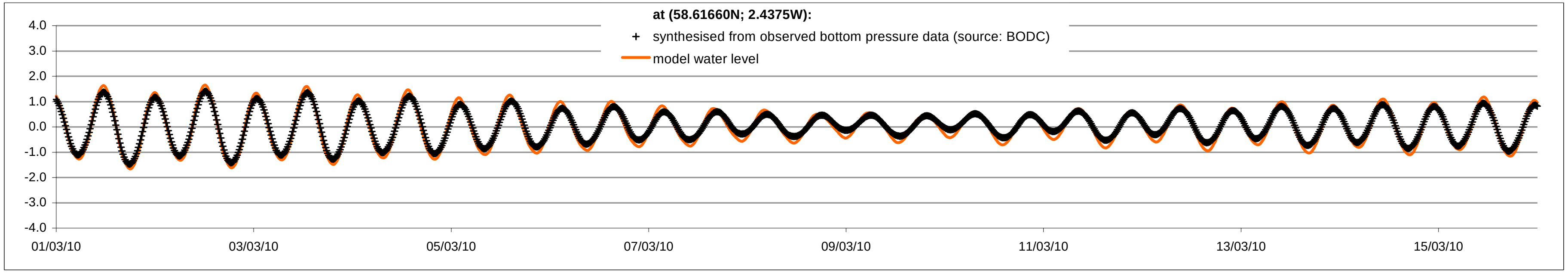
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.9280	324.2	220000
S2	12.00	0.3302	350.8	33000
N2	12.66	0.1928	299.9	18000
O1	25.82	0.0941	36.9	3000
K1	23.93	0.0880	162.5	2500
M4	6.21	0.0391	225.1	430
Q1	26.87	0.0311	335.7	420
MS4	6.10	0.0237	302.7	230

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.15 m or N-RMSE of 6% of maximum tidal range in calibration period



B 29. CCSM comparison against observed data at PJONSDAP, R53 [58.6166;-2.4375]

Observed harmonic constituents

Harmonic Constituents[1,2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.2671	87.5	100000
S2	12.00	0.3757	119.0	12000
N2	12.66	0.2905	58.8	9000
K1	23.93	0.1111	226.2	1100
O1	25.82	0.1161	81.4	680
L2	12.19	0.0790	106.1	530
Q1	26.87	0.0457	36.8	180
MSF	354.37	0.0382	6.5	120

[1] Only the first 8 constituents are listed

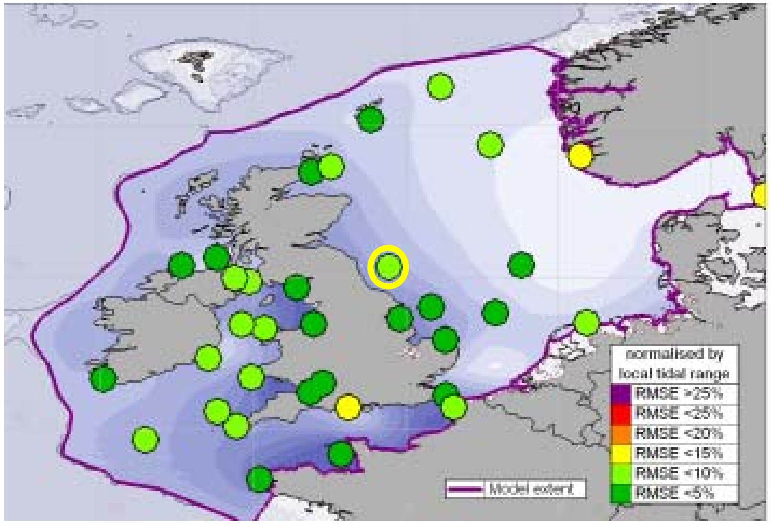
[2] Constituents from original observation period (for reference only)

Number of days: 39.65
Number of constituents: 35
MSL = 4.38 m

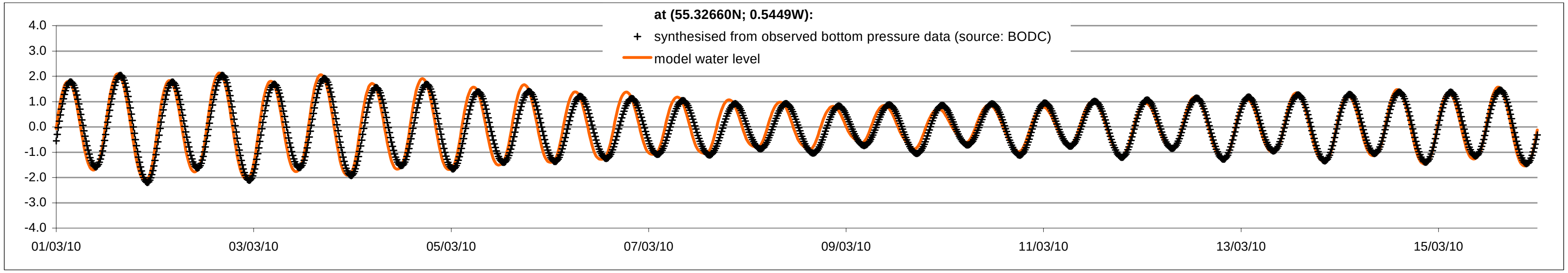
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.3187	67.9	240000
S2	12.00	0.4549	100.1	37000
N2	12.66	0.2574	39.2	13000
O1	25.82	0.1073	85.4	3400
K1	23.93	0.0985	214.3	2400
M4	6.21	0.0573	89.7	540
Q1	26.87	0.0350	21.9	290
MU2	12.87	0.0371	217.0	230

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.16 m or N-RMSE of 6% of maximum tidal range in calibration period



B 30. CCSM comparison against observed data at RL [55.3266;-0.5449]

Observed harmonic constituents

Harmonic Constituents[1] [2]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.9437	325.0	59000
N2	12.66	0.2269	297.8	5300
S2	12.00	0.2508	16.3	3700
L2	12.19	0.0970	1.6	640
K1	23.93	0.1007	201.9	630
O1	25.82	0.0837	48.4	370
MSF	354.37	0.0529	223.7	200
Q1	26.87	0.0435	355.1	87

[1] Only the first 8 constituents are listed

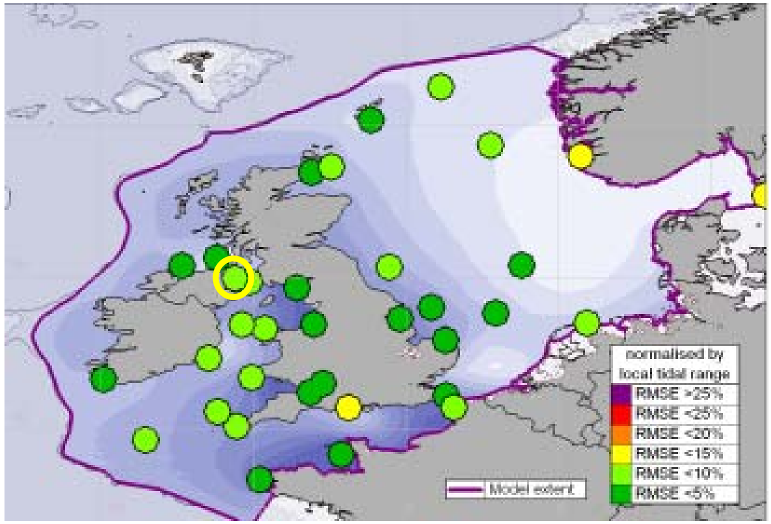
[2] Constituents from original observation period (for reference only)

Number of days: 47.99
Number of constituents: 35
MSL = -4.63 m

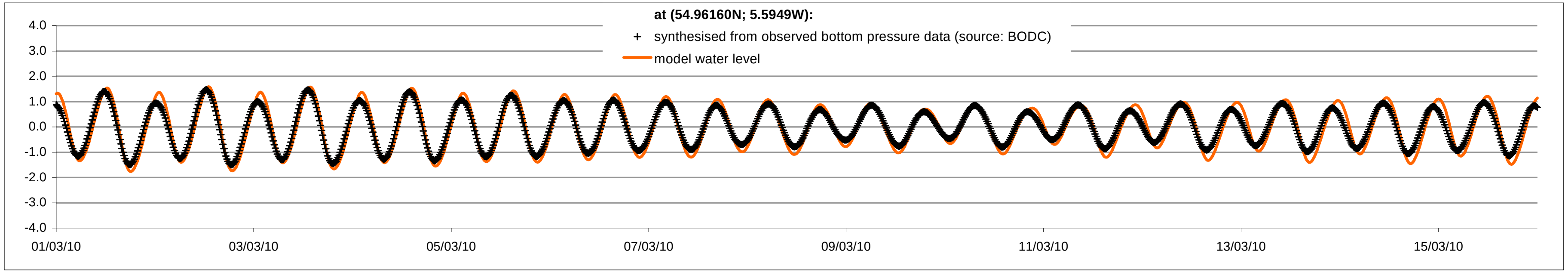
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.1668	340.6	250000
S2	12.00	0.3091	20.2	20000
N2	12.66	0.1988	311.0	14000
K1	23.93	0.1350	149.8	4300
O1	25.82	0.1076	30.7	2800
MU2	12.87	0.0832	121.3	1600
MS4	6.10	0.0582	83.4	900
Q1	26.87	0.0303	329.0	250

Number of days: 90
Number of constituents: 35
MSL = -0.03 m



MAE = 0.23 m or N-RMSE of 8% of maximum tidal range in calibration period



B 31. CCSM comparison against observed data at RB [54.9616;-5.5949]

Observed harmonic constituents

Harmonic Constituents[1] [2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.4513	139.6	120000
S2	12.00	0.4468	174.9	8700
N2	12.66	0.3318	110.8	5900
K1	23.93	0.1424	254.7	840
O1	25.82	0.1495	108.9	630
L2	12.19	0.0935	151.6	340
Q1	26.87	0.0596	59.5	160
MU2	12.87	0.0454	120.8	84

[1] Only the first 8 constituents are listed

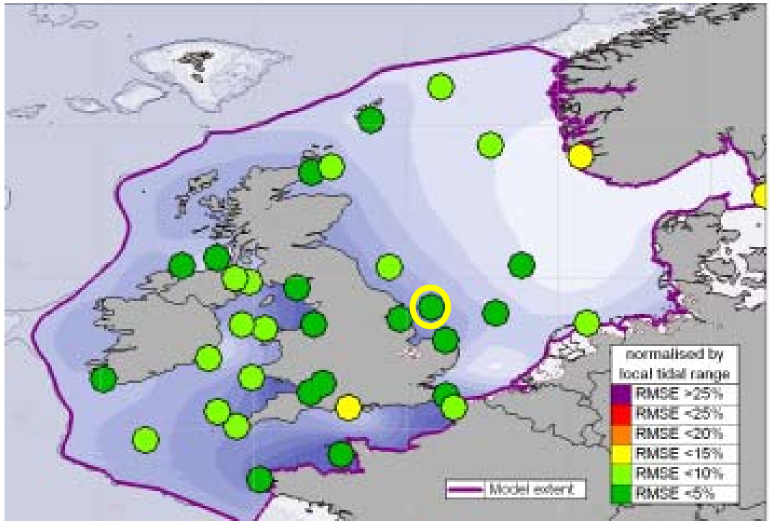
[2] Constituents from original observation period (for reference only)

Number of days: 37.42
Number of constituents: 35
MSL = 2.41 m

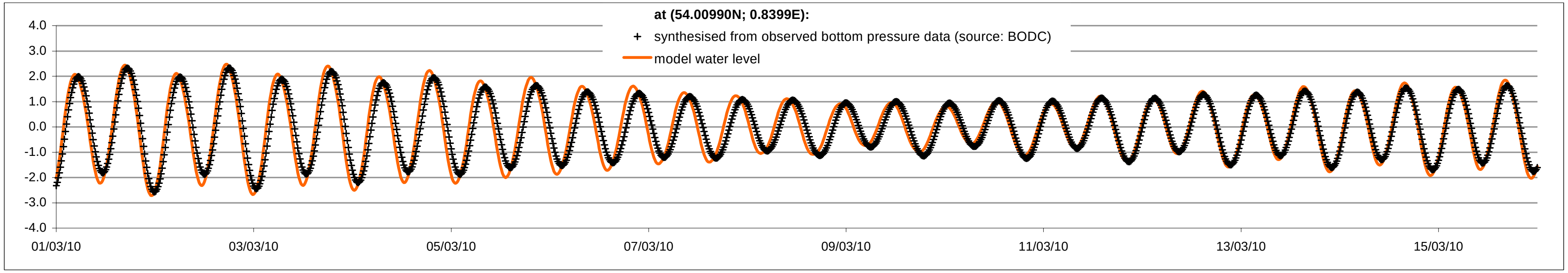
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.5809	117.2	250000
S2	12.00	0.5547	152.2	35000
N2	12.66	0.3057	89.3	14000
O1	25.82	0.1383	107.3	2600
K1	23.93	0.1274	238.7	2300
Q1	26.87	0.0442	41.6	250
MU2	12.87	0.0413	252.7	230
MS4	6.10	0.0269	119.6	110

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.19 m or N-RMSE of 5% of maximum tidal range in calibration period



B 32. CCSM comparison against observed data at RE [54.0099;0.8399]

Observed harmonic constituents

Harmonic Constituents[1,2]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.3924	309.1	61000
S2	12.00	0.5759	334.3	8000
N2	12.66	0.2583	296.8	2000
MM	661.29	0.1165	46.4	310
O1	25.82	0.1053	39.4	310
MU2	12.87	0.1070	170.8	280
K1	23.93	0.0710	188.4	190
L2	12.19	0.0634	302.6	130

[1] Only the first 8 constituents are listed

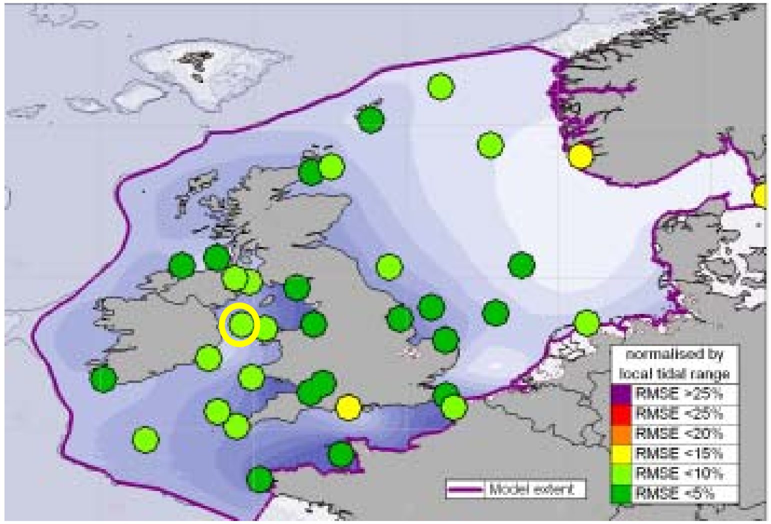
[2] Constituents from original observation period (for reference only)

Number of days: 32.53
Number of constituents: 35
MSL = 1.84 m

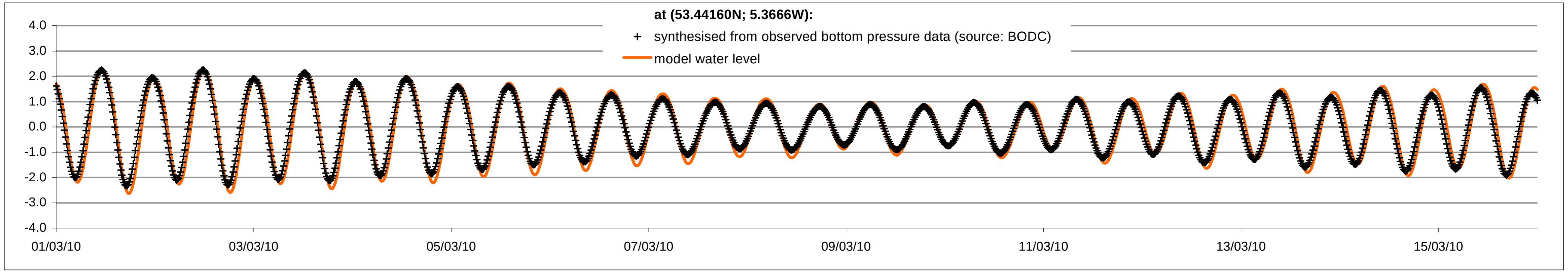
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.5499	320.0	240000
S2	12.00	0.5086	345.7	34000
N2	12.66	0.3030	291.2	15000
K1	23.93	0.1377	149.0	2600
O1	25.82	0.1156	30.2	1900
M4	6.21	0.0839	87.6	900
MU2	12.87	0.0667	132.7	500
MS4	6.10	0.0451	132.2	320

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.25 m or N-RMSE of 7% of maximum tidal range in calibration period



B 33. CCSM comparison against observed data at RGE [53.4416;-5.3666]

Observed harmonic constituents

Harmonic Constituents[1,2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.8868	141.7	380000
S2	12.00	0.5923	183.3	25000
N2	12.66	0.3803	127.8	17000
L2	12.19	0.0794	143.9	510
M4	6.21	0.0525	218.2	230
K1	23.93	0.0579	96.9	180
O1	25.82	0.0547	351.5	170
MU2	12.87	0.0383	129.7	100

[1] Only the first 8 constituents are listed

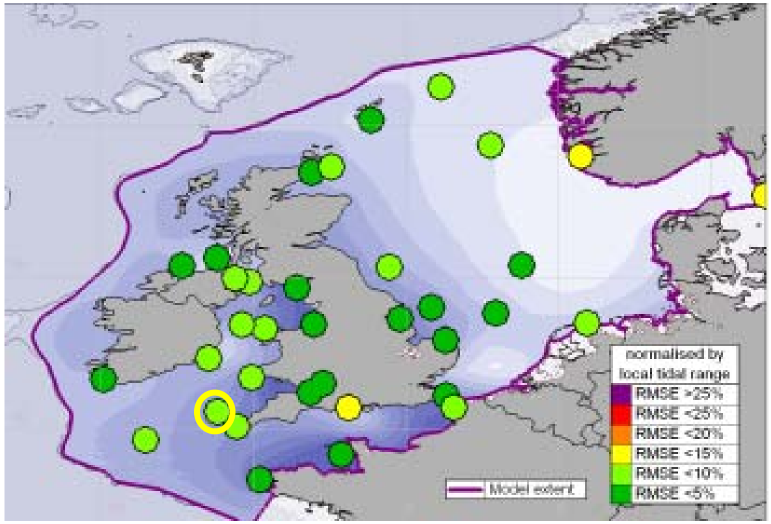
[2] Constituents from original observation period (for reference only)

Number of days: 114.84
Number of constituents: 35
MSL = 0.05 m

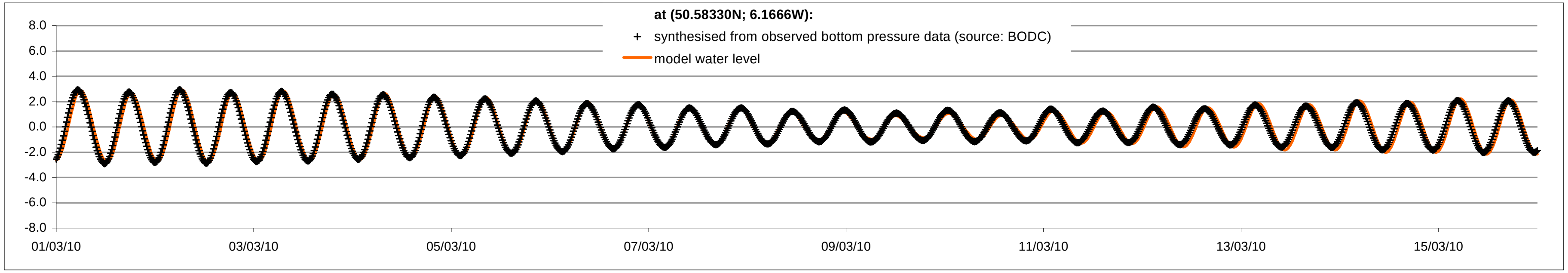
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.8212	154.3	230000
S2	12.00	0.6620	189.5	31000
N2	12.66	0.3259	135.9	14000
O1	25.82	0.0594	354.6	410
MU2	12.87	0.0733	246.1	400
M4	6.21	0.0627	260.2	340
K1	23.93	0.0613	101.5	310
MS4	6.10	0.0277	303.7	78

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.31 m or N-RMSE of 8% of maximum tidal range in calibration period



B 34. CCSM comparison against observed data at RD [50.5833;-6.1666]

Observed harmonic constituents

Harmonic Constituents[1] [2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.3646	122.9	250000
S2	12.00	0.5510	155.0	55000
N2	12.66	0.3323	106.8	26000
MU2	12.87	0.0577	80.4	540
O1	25.82	0.0541	337.4	510
L2	12.19	0.0647	128.4	460
K1	23.93	0.0467	92.5	390
M4	6.21	0.0276	232.2	130

[1] Only the first 8 constituents are listed

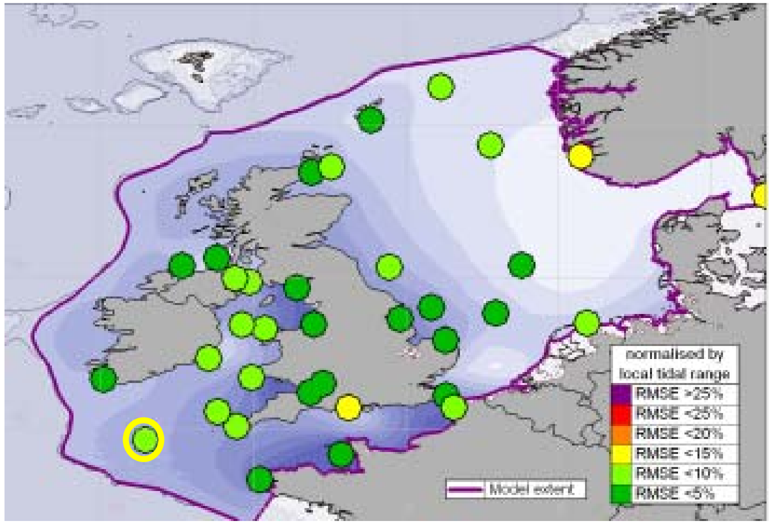
[2] Constituents from original observation period (for reference only)

Number of days: 45.52
Number of constituents: 35
MSL = -0.31 m

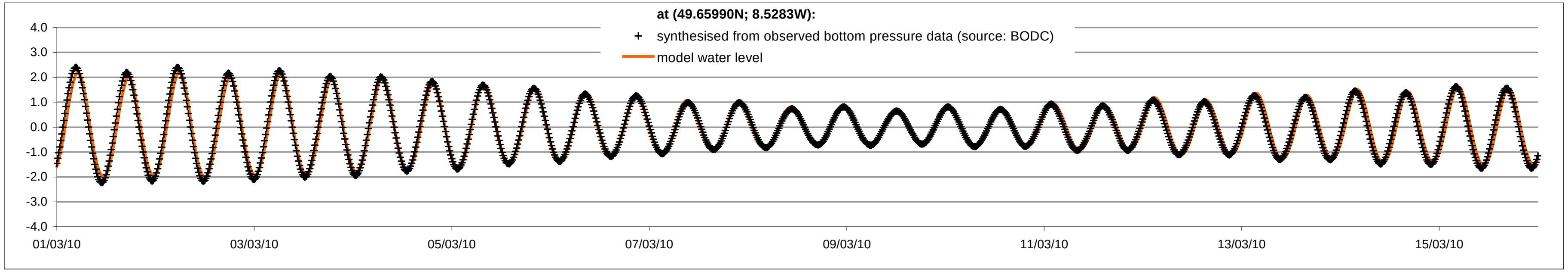
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	1.3178	132.4	230000
S2	12.00	0.4656	159.8	38000
N2	12.66	0.2554	111.1	15000
O1	25.82	0.0543	345.8	740
M4	6.21	0.0541	261.3	550
K1	23.93	0.0587	87.8	540
MS4	6.10	0.0284	309.4	180
MU2	12.87	0.0253	250.3	110

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.15 m or N-RMSE of 6% of maximum tidal range in calibration period



B 35. CCSM comparison against observed data at RG [49.6599;-8.5283]

APPENDIX C – DCSM COMPARISON AGAINST TIDAL GAUGE DATA

Calibration and validation of the DCSM followed the same methodology as that developed for the CCSM, and the results of the analysis are presented in the same form, namely:

- An inset indicating the geographical location of the observation station (yellow circle). The underlying map is a reduced version of Figures 7 and 9 combined, illustrating the DCSM performance in terms of N-RMSE values across the model area.

- Time histories of tidal levels predicted by the DCSM (thick orange lines) compared over the calibration/validation period to those obtained by re-synthesis of observed tidal levels (black crosses). When available concurrently to the calibration period, the observations are represented by a thick light green line.

- MAE and N-RMSE values (normalised using the higher of the maximum tidal range at that location over the calibration period and 1 m). N-RMSE values below 10% are deemed to reflect a good calibration of the model at a particular site (see Section 3.2.4).

- Tables of primary harmonic constituents (first 8) resulting from tidal harmonic analysis of both the DCSM predictions and the observed data. It is noted that, for consistency, the harmonic analysis was performed on the same 90-day period (March 1st to May 30th 2010, Section 3.2.3) for both the observed and predicted datasets. There were occasions when the observed dataset did not hold 90 days of data (or any data) during that period. These instances are clearly identified in the following, and when less than 35 harmonic constituents were extracted, those derived from the full measurement period (up to a year) are repeated from Appendix A for reference although, strictly, no comparisons can be drawn between constituents extracted from a 365-day period (say) and those from a 90-day period.

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.0873	178.1	94000
S2	12.00	0.4572	200.3	20000
N2	12.66	0.2253	148.3	6000
O1	25.82	0.0826	17.7	980
K1	23.93	0.0796	148.7	650
MM	661.29	0.0583	15.1	350
MU2	12.87	0.0508	117.9	270
M3	8.28	0.0316	77.1	110

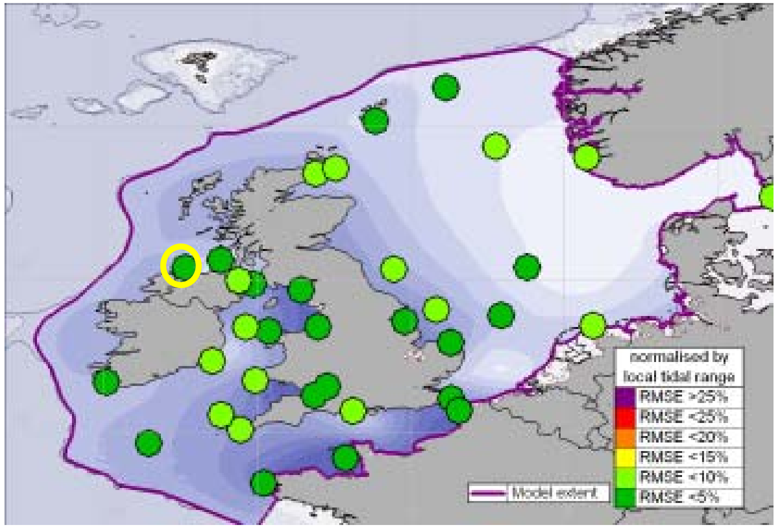
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.08 m

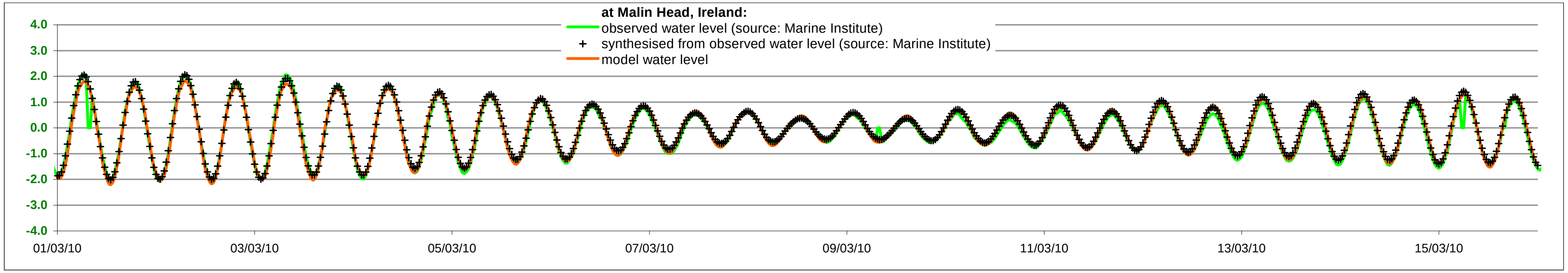
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.1305	234.8	190000
S2	12.00	0.4758	355.8	38000
N2	12.66	0.2465	113.1	12000
O1	25.82	0.0591	26.3	1000
K1	23.93	0.0636	150.0	660
M4	6.21	0.0565	271.5	530
MS4	6.10	0.0362	95.8	260
L2	12.19	0.0237	142.5	160

Number of days: 90
Number of constituents: 35
MSL = -0.06 m



MAE = 0.08 m or N-RMSE of 3% of maximum tidal range in calibration period



C 1. DCSM comparison against observed data at Malin Head, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	1.1180	130.4	120000
S2	12.00	0.3978	155.3	22000
N2	12.66	0.2211	98.8	7100
MM	661.29	0.0747	21.9	750
K1	23.93	0.0403	24.3	240
M4	6.21	0.0325	281.9	140
MS4	6.10	0.0200	347.4	63
MU2	12.87	0.0186	53.7	39

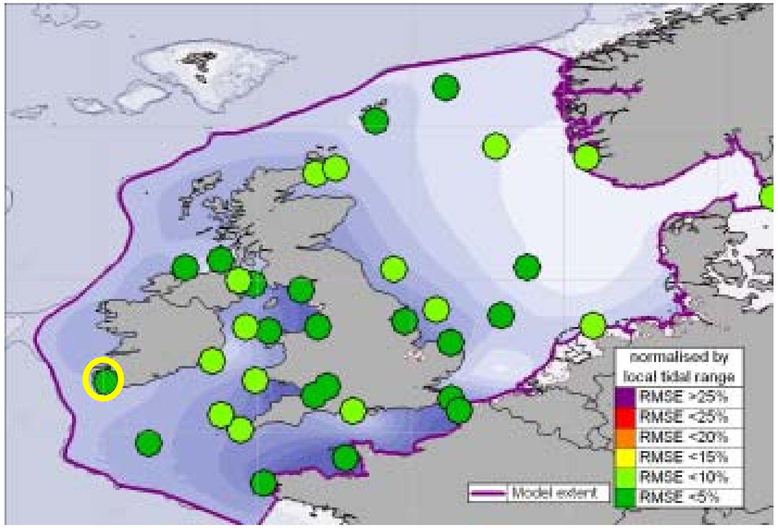
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.24 m

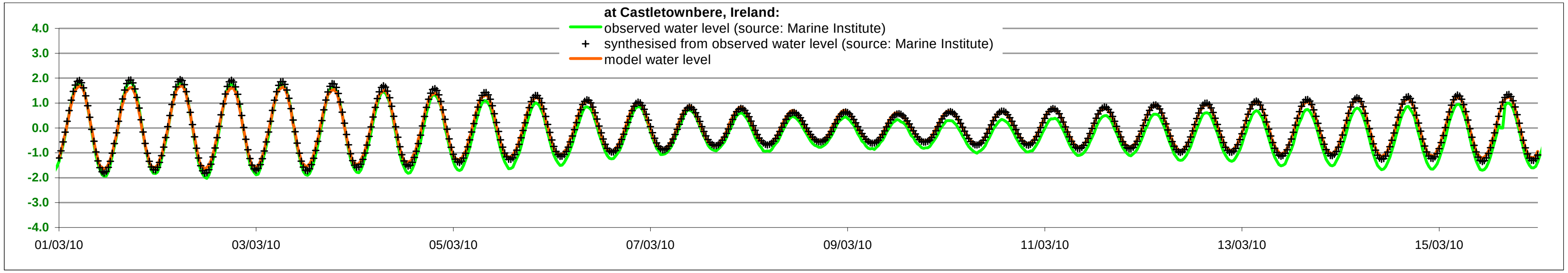
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	1.0676	184.7	230000
S2	12.00	0.3690	308.5	38000
N2	12.66	0.2160	61.9	16000
M4	6.21	0.0471	33.2	630
K1	23.93	0.0293	82.7	330
O1	25.82	0.0231	358.1	200
MS4	6.10	0.0223	206.9	140
MU2	12.87	0.0214	280.3	120

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.07 m or N-RMSE of 3% of maximum tidal range in calibration period



C 2. DCSM comparison against observed data at Castletownbere, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.4701	187.8	31000
S2	12.00	0.2159	252.5	7400
MU2	12.87	0.1059	246.9	1600
N2	12.66	0.0624	178.6	820
O1	25.82	0.0642	54.6	700
MM	661.29	0.0680	20.7	670
K1	23.93	0.0459	181.0	320
MS4	6.10	0.0401	29.7	250

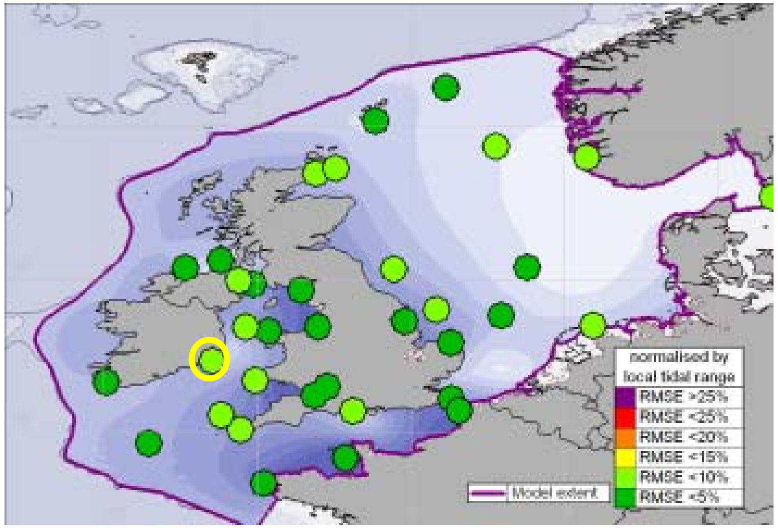
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.15 m

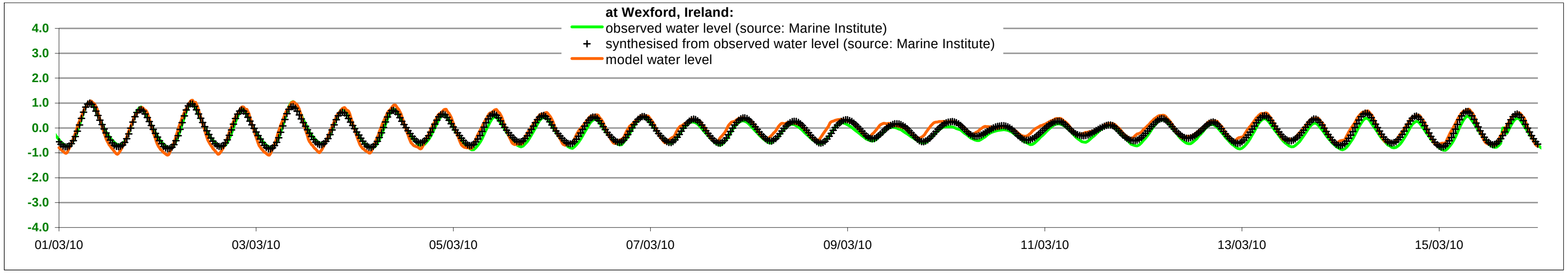
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.5208	238.2	53000
S2	12.00	0.2844	36.1	21000
N2	12.66	0.1043	157.0	2900
MU2	12.87	0.0991	179.2	2000
O1	25.82	0.0711	53.4	1300
K1	23.93	0.0702	177.7	1200
M4	6.21	0.0635	196.2	900
L2	12.19	0.0423	264.3	480

Number of days: 90
Number of constituents: 35
MSL = -0.03 m



MAE = 0.13 m or N-RMSE of 7% of maximum tidal range in calibration period



C 3. DCSM comparison against observed data at Wexford, Ireland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
S2	12.00	0.1539	147.4	1100
M2	12.42	0.1619	87.3	980
K1	23.93	0.0789	175.3	300
O1	25.82	0.0813	44.1	290
MM	661.29	0.0740	17.4	270
MU2	12.87	0.0383	117.9	67
M3	8.28	0.0391	102.1	64
2MS6	4.09	0.0319	153.5	45

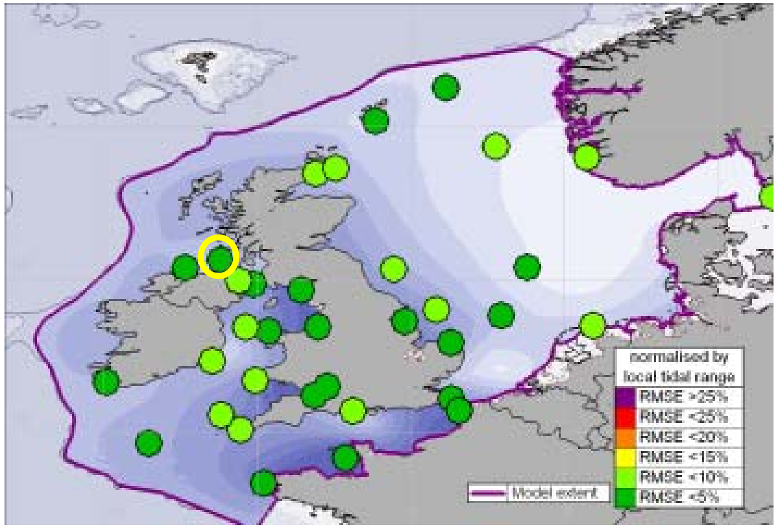
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.12 m

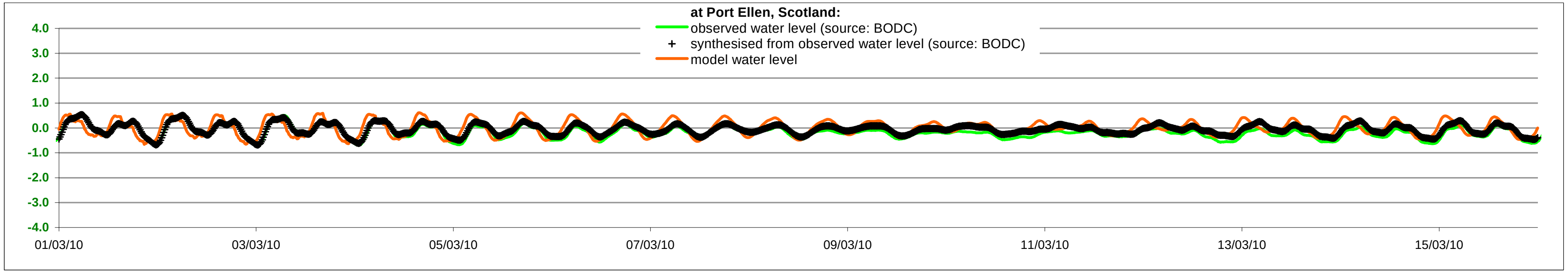
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.3670	92.1	89000
S2	12.00	0.1762	269.7	13000
K1	23.93	0.0744	183.4	4100
O1	25.82	0.0686	60.3	2900
N2	12.66	0.0480	340.7	1400
MU2	12.87	0.0481	84.5	1100
2MS6	4.09	0.0405	353.0	820
M4	6.21	0.0346	215.0	690

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.19 m or N-RMSE of 4% of maximum tidal range in calibration period



C 4. DCSM comparison against observed data at Port Ellen, Scotland

Observed harmonic constituents

Harmonic Constituents[1 2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.3480	331.6	210000
S2	12.00	0.3732	16.7	23000
N2	12.66	0.2527	304.4	8400
O1	25.82	0.0984	42.7	1700
K2	11.97	0.1094	16.7	1700
K1	23.93	0.1092	188.2	1500
L2	12.19	0.0607	4.9	880
NU2	12.63	0.0621	306.6	580

[1] Only the first 8 constituents are listed

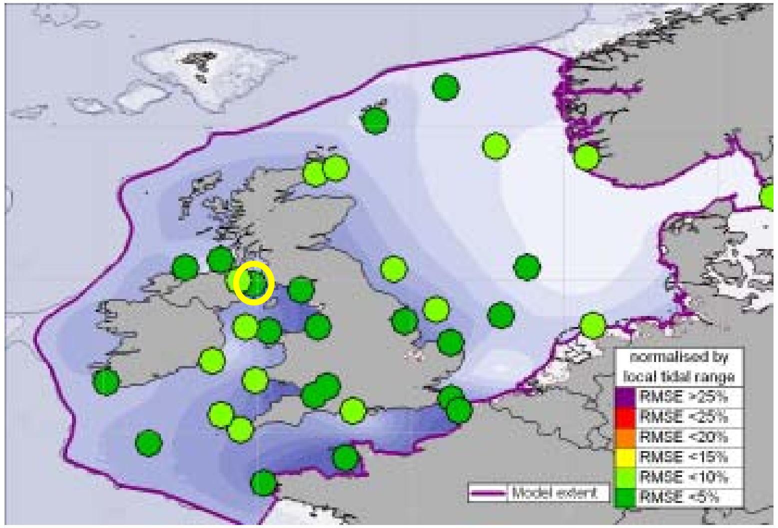
[2] Constituents from full observation period (for reference only)

Number of days: 271
Number of constituents: 59
MSL = 0.11 m

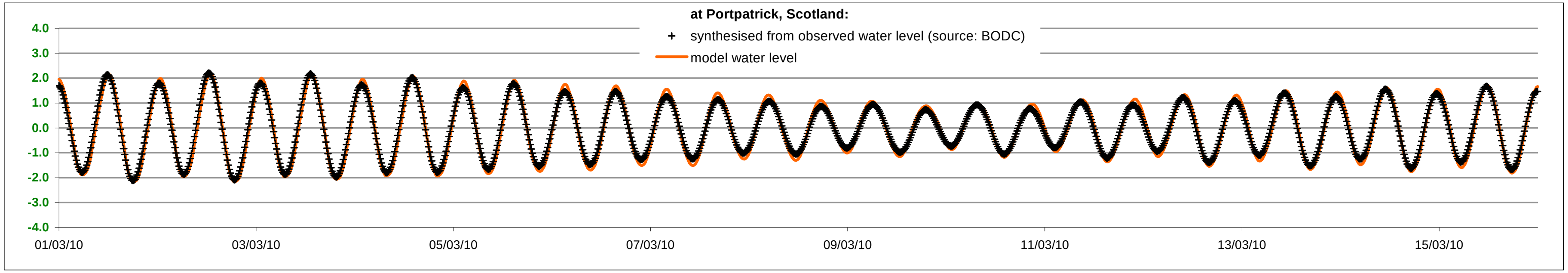
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.5412	32.8	250000
S2	12.00	0.4545	173.1	29000
N2	12.66	0.2651	267.5	11000
K1	23.93	0.0936	183.0	1700
MU2	12.87	0.0952	73.1	1400
O1	25.82	0.0863	59.7	1300
MS4	6.10	0.0383	262.3	230
L2	12.19	0.0259	177.0	150

Number of days: 90
Number of constituents: 35
MSL = -0.03 m



MAE = 0.14 m or N-RMSE of 4% of maximum tidal range in calibration period



C 5. DCSM comparison against observed data at Portpatrick, Scotland

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.7588	331.4	110000
S2	12.00	0.9475	7.7	14000
N2	12.66	0.4693	299.4	4700
M4	6.21	0.1419	255.1	360
K1	23.93	0.1043	179.6	180
O1	25.82	0.1076	47.3	170
MM	661.29	0.0875	26.9	130
MS4	6.10	0.0793	296.3	120

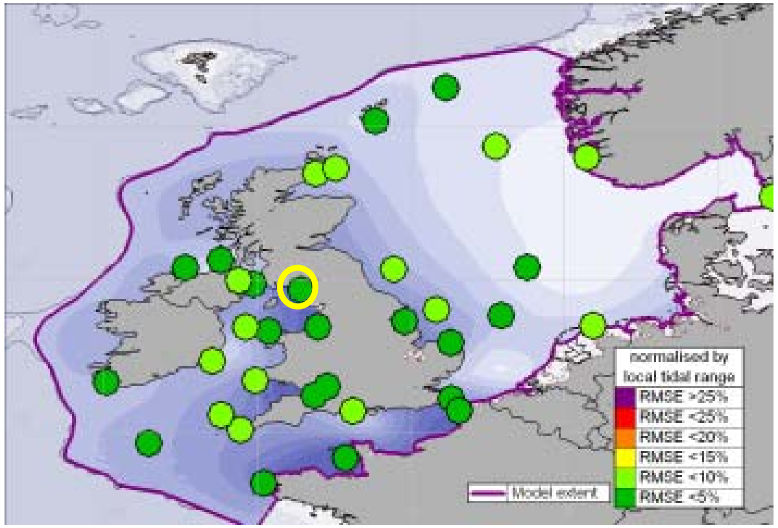
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.15 m

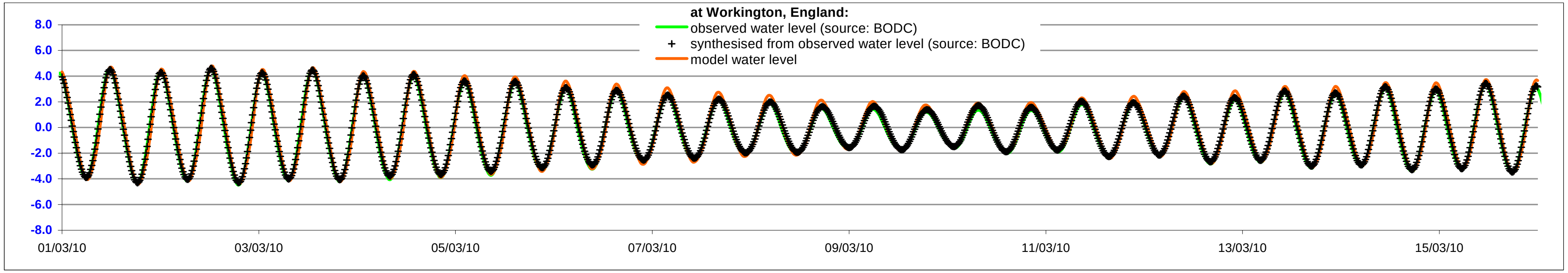
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	3.0433	33.0	240000
S2	12.00	1.0159	171.8	28000
N2	12.66	0.5349	271.6	14000
M4	6.21	0.2038	16.6	1300
MU2	12.87	0.1476	56.5	740
MS4	6.10	0.1125	154.1	490
K1	23.93	0.1119	186.8	390
O1	25.82	0.1033	63.4	360

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.27 m or N-RMSE of 4% of maximum tidal range in calibration period



C 6. DCSM comparison against observed data at Workington, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.0158	319.8	110000
S2	12.00	0.9574	352.9	13000
N2	12.66	0.4930	286.9	4200
M4	6.21	0.2752	199.5	970
MS4	6.10	0.1794	228.4	450
K1	23.93	0.1230	168.2	260
O1	25.82	0.1066	42.7	230
MM	661.29	0.1158	58.4	200

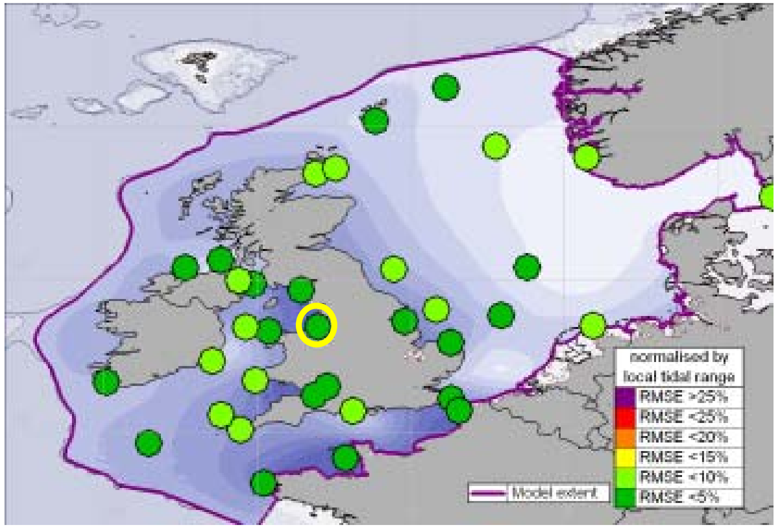
[1] Only the first 8 constituents are listed

Number of days: 67.28
Number of constituents: 35
MSL = -0.04 m

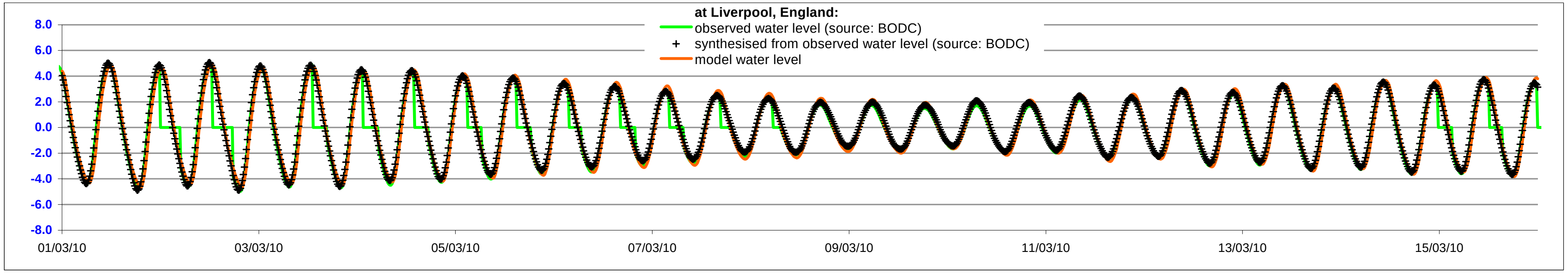
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.2770	25.8	220000
S2	12.00	1.0770	165.3	25000
N2	12.66	0.5583	265.9	13000
M4	6.21	0.2624	352.9	1500
MU2	12.87	0.1930	44.8	1100
MS4	6.10	0.1736	118.7	860
K1	23.93	0.1115	184.9	340
O1	25.82	0.1036	62.5	290

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.42 m or N-RMSE of 5% of maximum tidal range in calibration period



C 7. DCSM comparison against observed data at Liverpool, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	1.8176	291.5	110000
S2	12.00	0.7587	326.7	17000
N2	12.66	0.3931	256.5	4900
MM	661.29	0.1430	359.5	590
O1	25.82	0.1011	34.2	250
MSF	354.37	0.0836	181.8	190
K1	23.93	0.0712	167.0	190
L2	12.19	0.0730	347.4	130

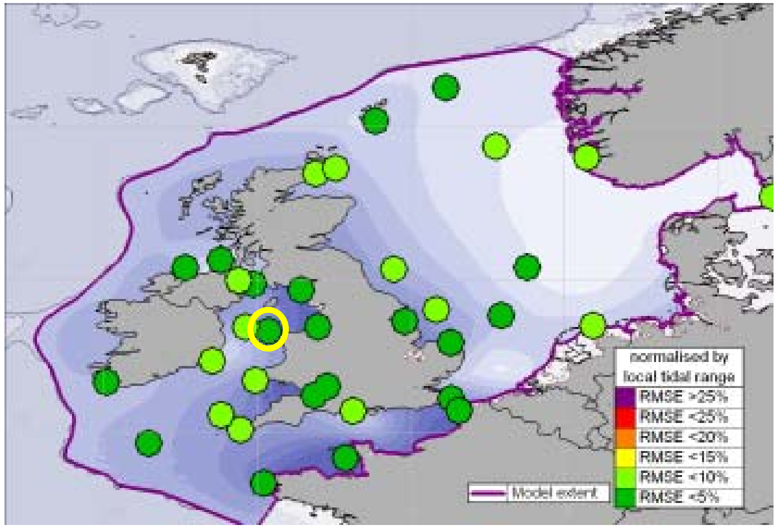
[1] Only the first 8 constituents are listed

Number of days: 46.73
Number of constituents: 35
MSL = -0.03 m

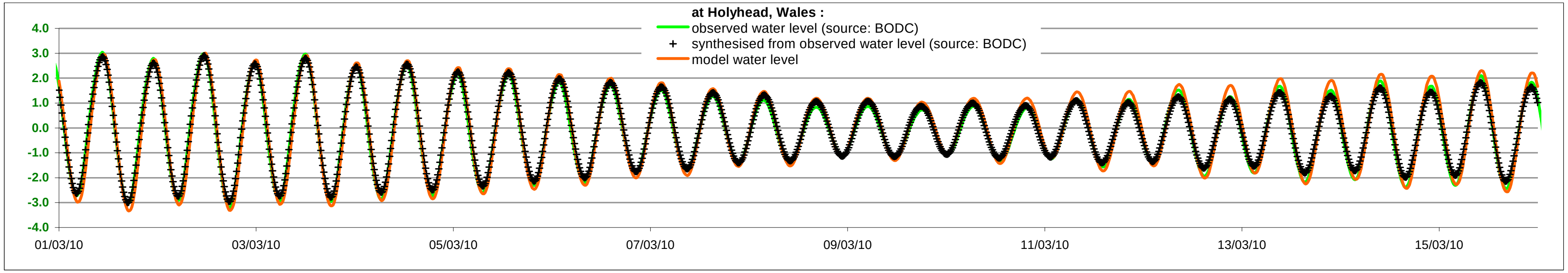
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	2.0579	353.7	250000
S2	12.00	0.7074	125.6	39000
N2	12.66	0.3896	230.6	14000
O1	25.82	0.0958	47.6	890
K1	23.93	0.1011	170.2	840
MU2	12.87	0.0723	48.2	460
MSF	354.37	0.0356	309.4	120
Q1	26.87	0.0247	256.9	65

Number of days: 90
Number of constituents: 35
MSL = -0.07 m



MAE = 0.23 m or N-RMSE of 5% of maximum tidal range in calibration period



C 8. DCSM comparison against observed data at Holyhead, Wales

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	2.2315	172.1	90000
S2	12.00	0.8743	210.1	19000
N2	12.66	0.3987	145.8	4600
MU2	12.87	0.0925	208.4	180
MM	661.29	0.0790	21.7	160
O1	25.82	0.0664	359.6	150
M4	6.21	0.0653	308.3	100
L2	12.19	0.0739	181.8	93

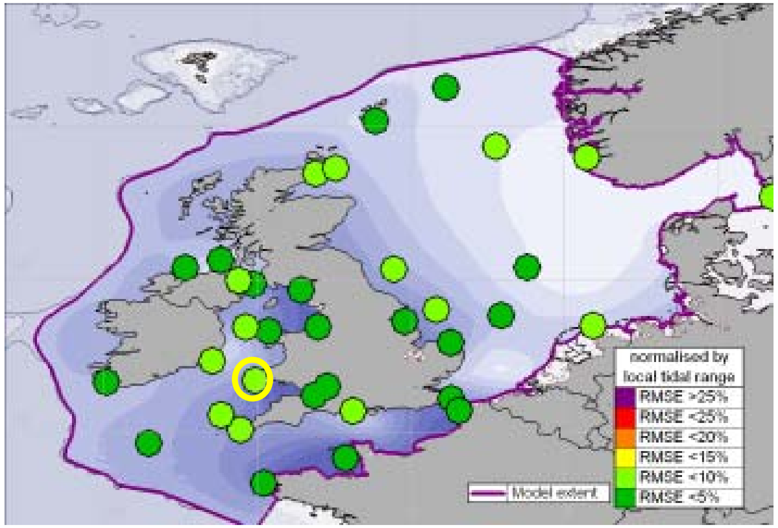
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.04 m

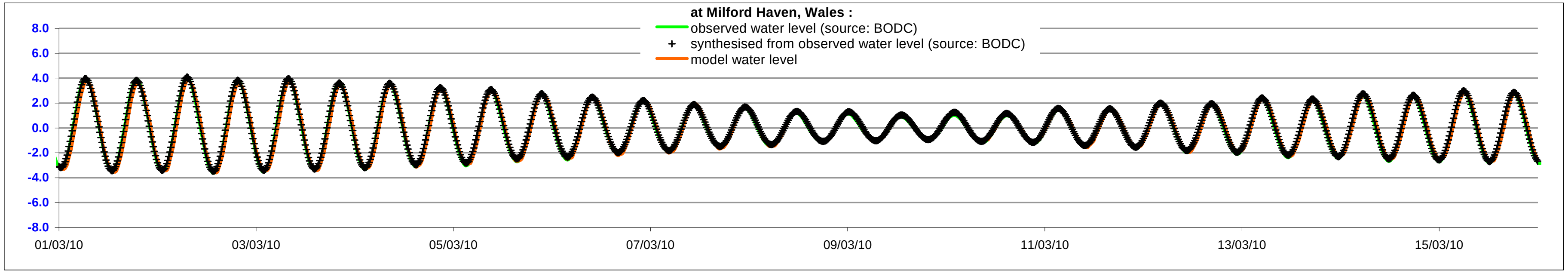
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	2.3272	238.4	190000
S2	12.00	0.9019	18.7	37000
N2	12.66	0.4237	125.5	8400
MU2	12.87	0.0978	211.5	410
O1	25.82	0.0683	20.2	320
M4	6.21	0.0829	86.8	260
K1	23.93	0.0678	137.4	200
MS4	6.10	0.0417	225.0	76

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.27 m or N-RMSE of 6% of maximum tidal range in calibration period



C 9. DCSM comparison against observed data at Milford Haven, Wales

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	3.9763	182.2	99000
S2	12.00	1.5245	229.7	17000
N2	12.66	0.6186	161.3	2900
MU2	12.87	0.3915	245.2	1000
L2	12.19	0.2288	195.6	330
M4	6.21	0.1062	20.6	81
MM	661.29	0.0954	26.9	73
O1	25.82	0.0751	0.7	64

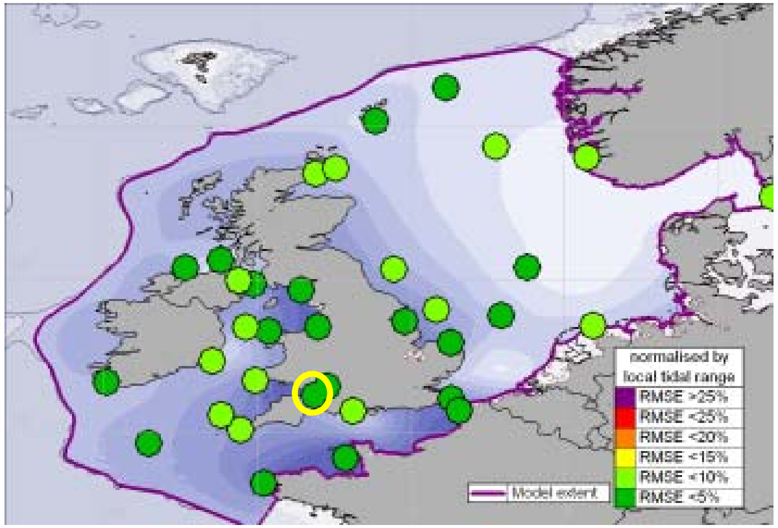
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.17 m

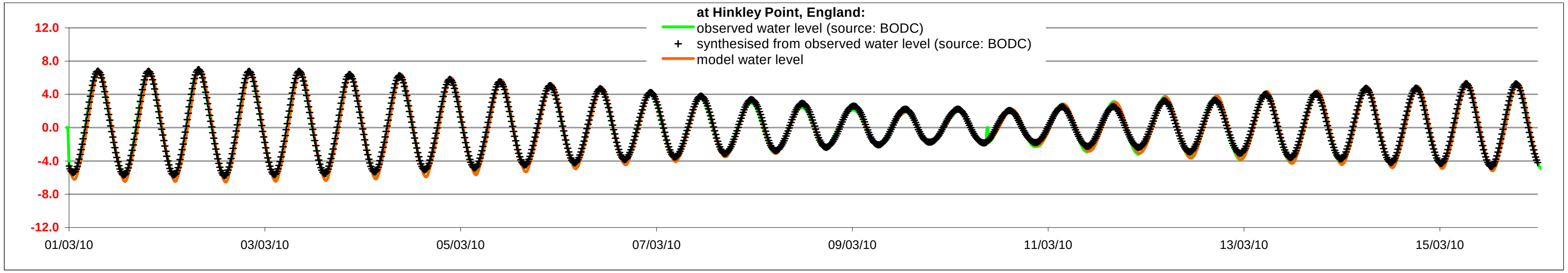
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	4.2351	244.8	170000
S2	12.00	1.6530	32.3	32000
N2	12.66	0.7151	137.8	5700
MU2	12.87	0.3618	217.8	1500
M4	6.21	0.1386	174.9	170
L2	12.19	0.1018	296.9	140
2MS6	4.09	0.0971	176.7	97
O1	25.82	0.0747	21.8	92

Number of days: 90
Number of constituents: 35
MSL = 0.03 m



MAE = 0.44 m or N-RMSE of 4% of maximum tidal range in calibration period



C 10. DCSM comparison against observed data at Hinkley Point, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	4.1981	205.1	88000
S2	12.00	1.6110	256.2	12000
N2	12.66	0.5584	186.8	1400
MU2	12.87	0.5010	269.6	1200
MS4	6.10	0.2765	16.7	330
M4	6.21	0.2568	349.7	270
L2	12.19	0.2634	209.6	260
MSF	354.37	0.1732	48.1	140

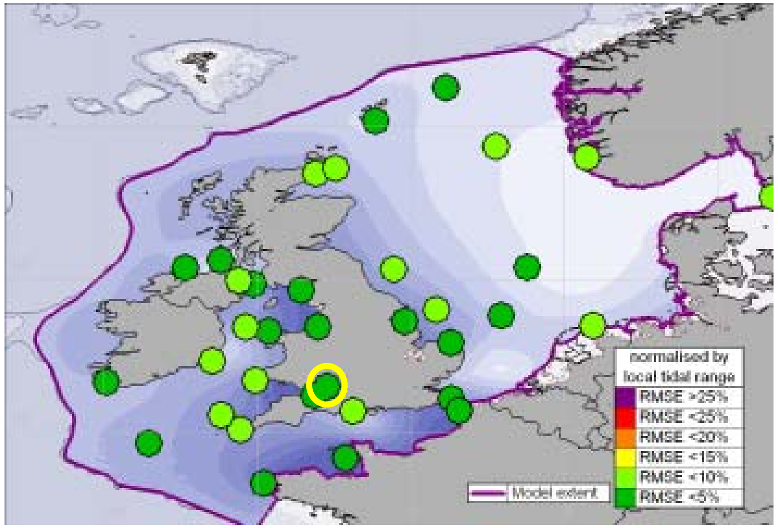
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.02 m

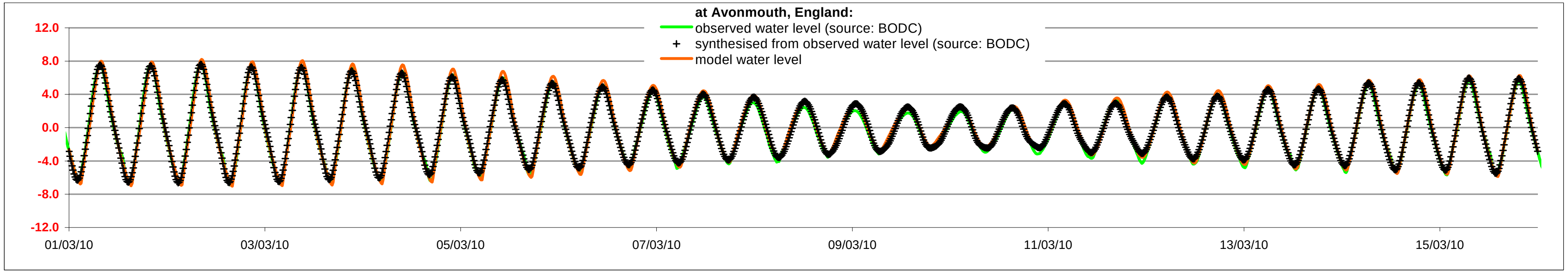
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	4.6775	261.8	160000
S2	12.00	1.7990	53.7	21000
N2	12.66	0.7607	159.0	4000
MU2	12.87	0.5246	236.0	1800
MS4	6.10	0.2573	244.6	430
M4	6.21	0.2283	125.6	310
2MS6	4.09	0.2068	255.3	290
L2	12.19	0.1393	321.2	190

Number of days: 90
Number of constituents: 35
MSL = 0.16 m



MAE = 0.37 m or N-RMSE of 3% of maximum tidal range in calibration period



C 11. DCSM comparison against observed data at Avonmouth, England

Observed harmonic constituents

Harmonic Constituents[1, 2]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.7093	133.4	140000
S2	12.00	0.5877	170.0	20000
N2	12.66	0.3256	108.5	6700
M4	6.21	0.1138	166.3	600
MS4	6.10	0.0757	210.6	350
MU2	12.87	0.0705	177.2	260
K1	23.93	0.0641	104.6	230
L2	12.19	0.0905	136.7	200

[1] Only the first 8 constituents are listed

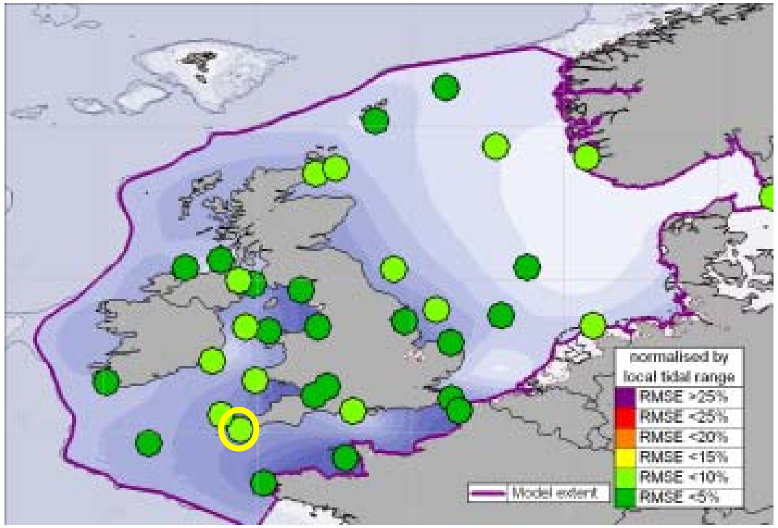
[2] Constituents from full observation period (for reference only)

Number of days: 139.39
Number of constituents: 35
MSL = 0.10 m

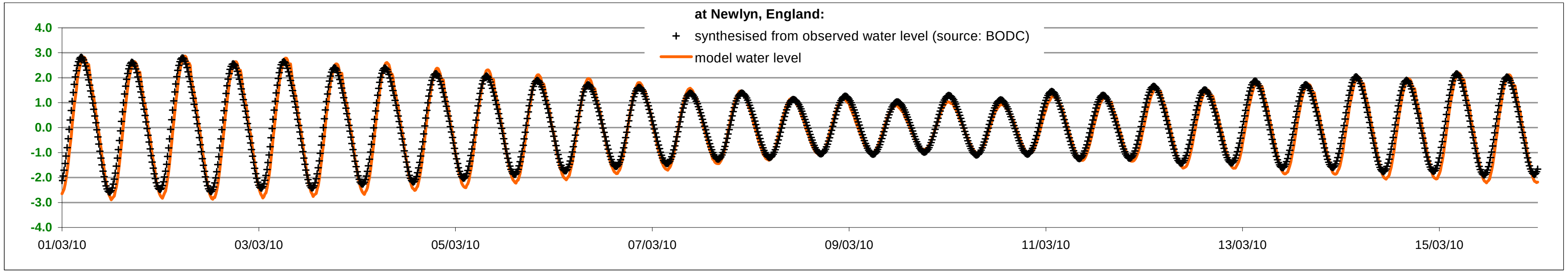
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.8301	197.2	190000
S2	12.00	0.6524	337.9	28000
N2	12.66	0.3213	83.8	12000
M4	6.21	0.1274	296.0	1200
MU2	12.87	0.1016	182.8	610
MS4	6.10	0.0847	74.3	550
O1	25.82	0.0533	4.5	310
K1	23.93	0.0556	125.0	210

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.27 m or N-RMSE of 6% of maximum tidal range in calibration period



C 12. DCSM comparison against observed data at Newlyn, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.3767	181.5	100000
S2	12.00	1.4182	224.5	21000
N2	12.66	0.6052	159.6	4000
MU2	12.87	0.2441	212.1	570
M4	6.21	0.1989	300.9	510
MS4	6.10	0.1614	348.4	280
L2	12.19	0.1561	174.1	170
O1	25.82	0.0812	341.9	99

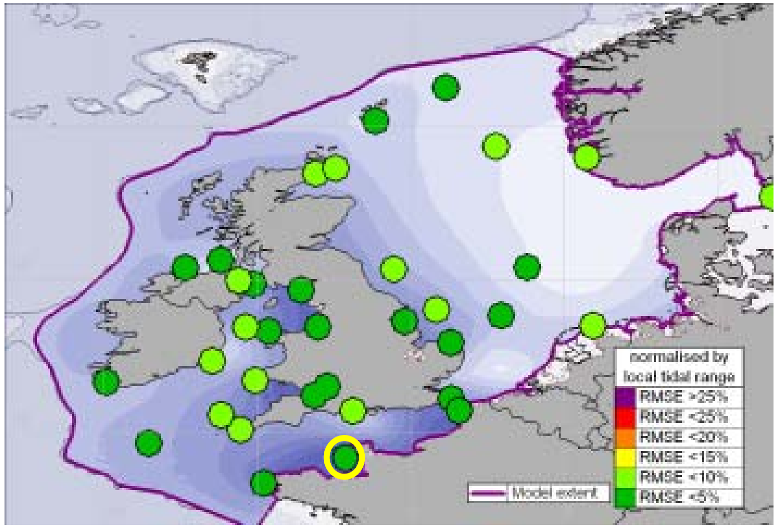
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.09 m

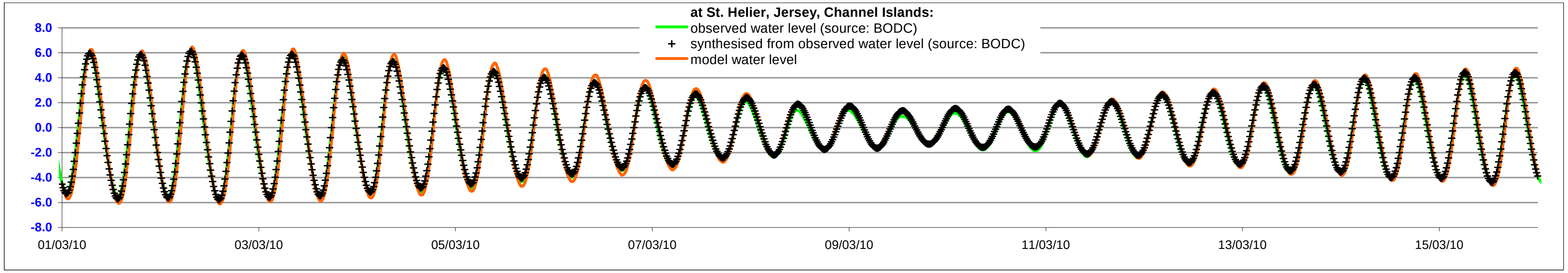
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.7959	244.1	160000
S2	12.00	1.6127	28.8	35000
N2	12.66	0.7316	136.6	7000
MU2	12.87	0.2494	188.0	710
M4	6.21	0.2230	69.4	590
MS4	6.10	0.1973	214.5	550
O1	25.82	0.0761	12.6	110
L2	12.19	0.0864	263.8	110

Number of days: 90
Number of constituents: 35
MSL = -0.06 m



MAE = 0.36 m or N-RMSE of 4% of maximum tidal range in calibration period



C 13. DCSM comparison against observed data at St. Helier, Jersey, Channel Islands

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.4089	272.7	7500
S2	12.00	0.2005	286.6	2300
M4	6.21	0.1974	22.8	2100
MS4	6.10	0.1351	68.8	1200
N2	12.66	0.1090	242.5	760
K1	23.93	0.0872	94.1	450
2MS6	4.09	0.0827	116.9	420
M6	4.14	0.0715	81.1	410

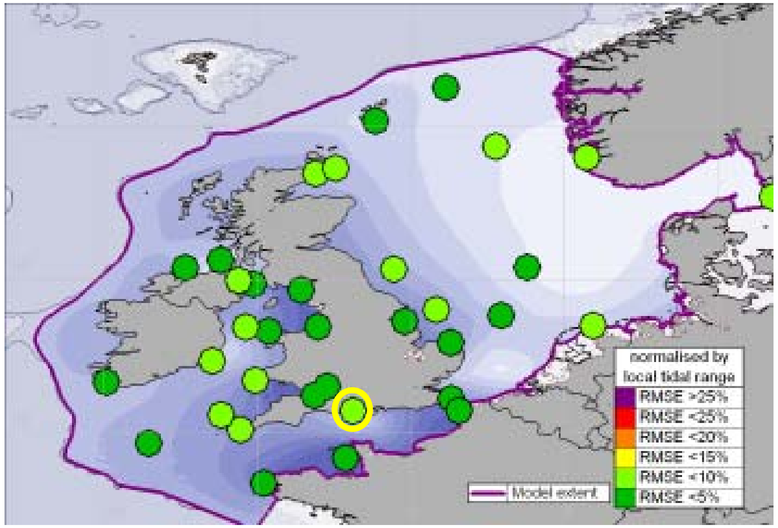
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.12 m

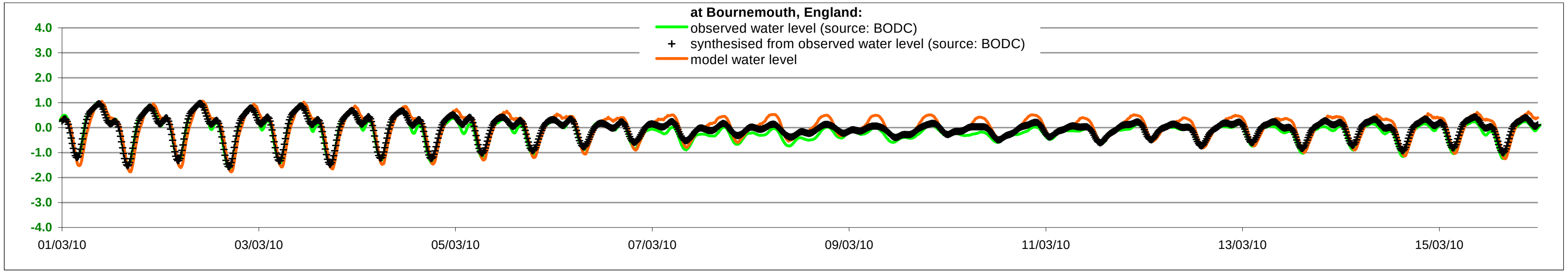
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.6218	349.6	44000
S2	12.00	0.2580	101.0	11000
M4	6.21	0.2212	145.7	6200
N2	12.66	0.1617	221.5	4700
MS4	6.10	0.1466	296.4	4000
M6	4.14	0.0696	276.8	1000
2MS6	4.09	0.0806	56.3	1000
MU2	12.87	0.0792	128.8	950

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.20 m or N-RMSE of 8% of maximum tidal range in calibration period



C 14. DCSM comparison against observed data at Bournemouth, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	2.2829	332.0	92000
S2	12.00	0.7693	16.6	11000
N2	12.66	0.3722	300.1	4500
M4	6.21	0.2695	223.5	1300
MS4	6.10	0.1868	266.8	870
MU2	12.87	0.1159	62.6	290
L2	12.19	0.1073	8.3	200
MN4	6.27	0.0854	183.3	130

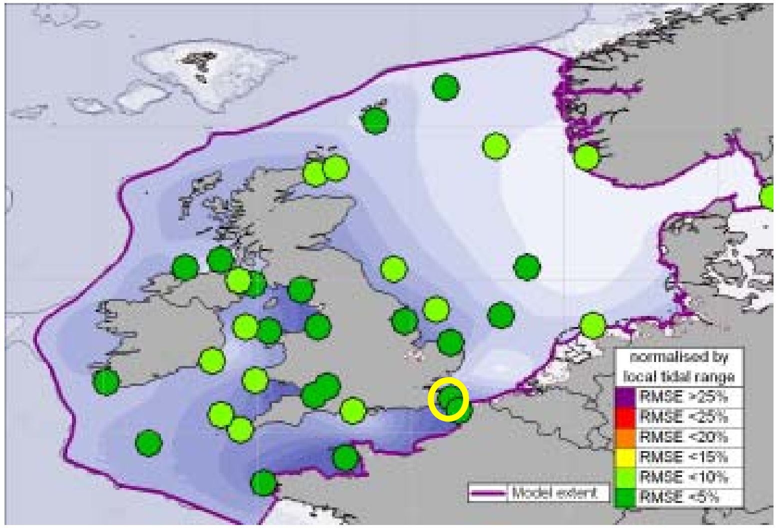
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.06 m

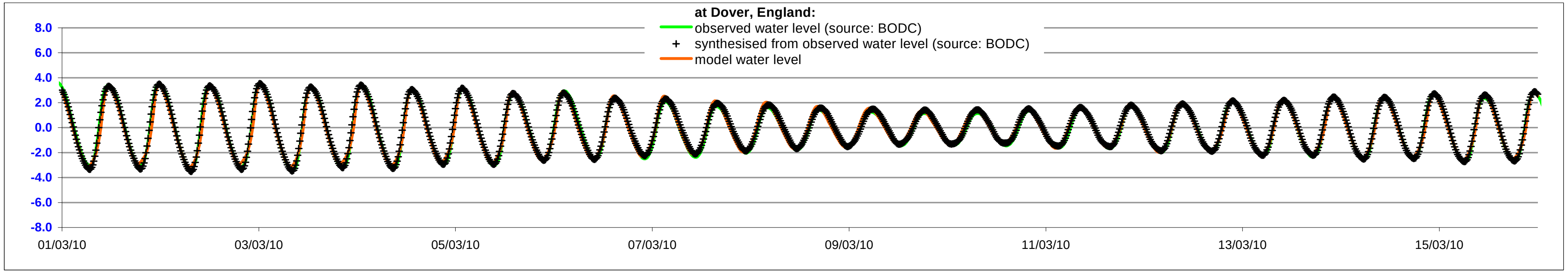
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	2.2738	26.3	140000
S2	12.00	0.7530	175.9	18000
N2	12.66	0.3544	270.0	6900
M4	6.21	0.2859	353.4	2400
MS4	6.10	0.1991	143.2	1600
MU2	12.87	0.1830	24.6	1100
2MS6	4.09	0.1014	124.4	360
MN4	6.27	0.0870	237.0	280

Number of days: 90
Number of constituents: 35
MSL = -0.09 m



MAE = 0.21 m or N-RMSE of 4% of maximum tidal range in calibration period



C 15. DCSM comparison against observed data at Dover, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.5512	188.3	53000
S2	12.00	0.5632	226.2	7800
N2	12.66	0.2819	159.6	2100
O1	25.82	0.1710	137.0	870
K1	23.93	0.1211	290.2	350
M4	6.21	0.0930	277.2	230
MS4	6.10	0.0833	316.0	180
Q1	26.87	0.0415	42.9	64

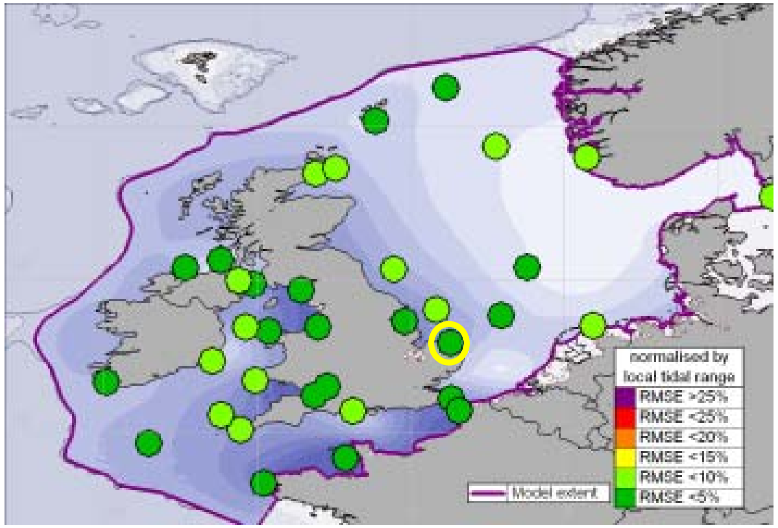
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.09 m

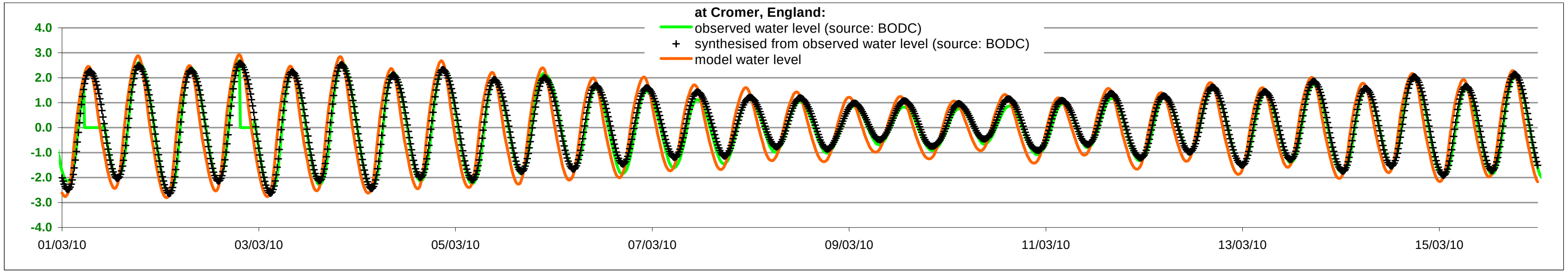
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.8504	217.1	210000
S2	12.00	0.6101	358.4	27000
N2	12.66	0.3341	92.7	13000
O1	25.82	0.1607	154.9	2200
K1	23.93	0.1404	302.7	1300
M4	6.21	0.0998	6.1	700
MU2	12.87	0.0882	239.1	590
MS4	6.10	0.0648	137.6	400

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.26 m or N-RMSE of 5% of maximum tidal range in calibration period



C 16. DCSM comparison against observed data at Cromer, England

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	2.2376	162.0	90000
S2	12.00	0.7937	205.7	13000
N2	12.66	0.3743	132.3	4800
O1	25.82	0.1844	117.5	700
K1	23.93	0.1249	272.6	320
MU2	12.87	0.1076	239.9	240
L2	12.19	0.0884	183.9	130
Q1	26.87	0.0457	30.7	48

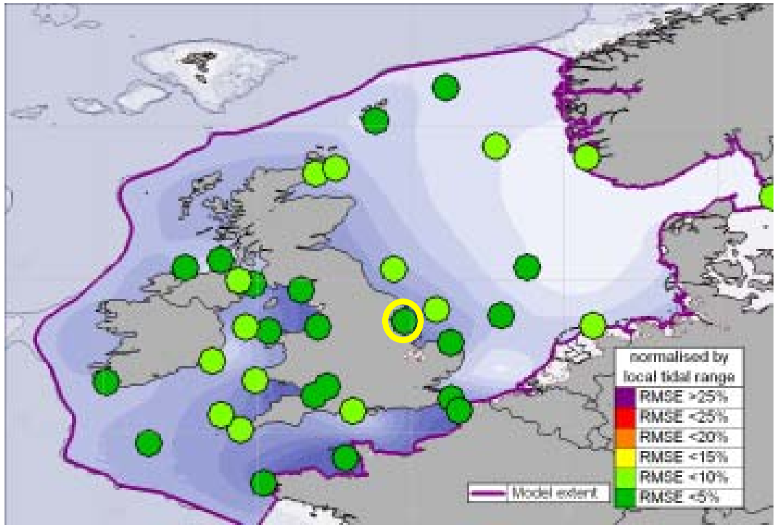
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.02 m

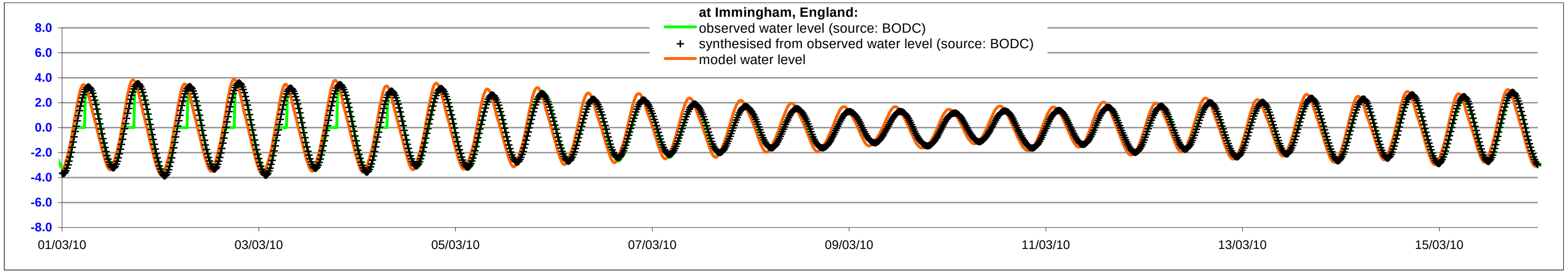
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	2.4405	189.2	180000
S2	12.00	0.7973	334.4	23000
N2	12.66	0.4214	68.5	9300
K1	23.93	0.1495	284.5	1200
O1	25.82	0.1687	136.9	1100
MU2	12.87	0.1554	192.5	980
M4	6.21	0.1316	314.6	650
MS4	6.10	0.1054	91.3	470

Number of days: 90
Number of constituents: 35
MSL = -0.05 m



MAE = 0.25 m or N-RMSE of 4% of maximum tidal range in calibration period



C 17. DCSM comparison against observed data at Immingham, England

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.0108	321.4	60000
S2	12.00	0.3144	346.6	8300
N2	12.66	0.1665	296.9	2300
O1	25.82	0.1144	27.0	1100
K1	23.93	0.1089	156.2	1100
MSF	354.37	0.0868	15.3	640
MM	661.29	0.0476	39.8	180
M4	6.21	0.0413	322.9	150

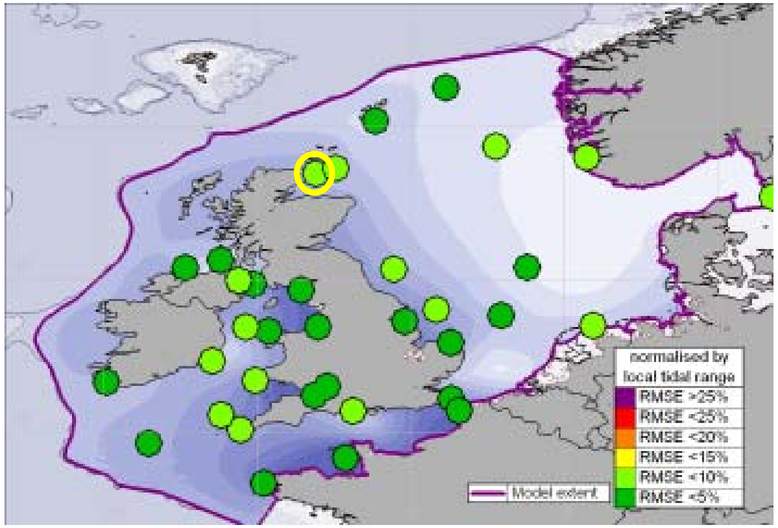
[1] Only the first 8 constituents are listed

Number of days: 44.44
Number of constituents: 35
MSL = -0.14 m

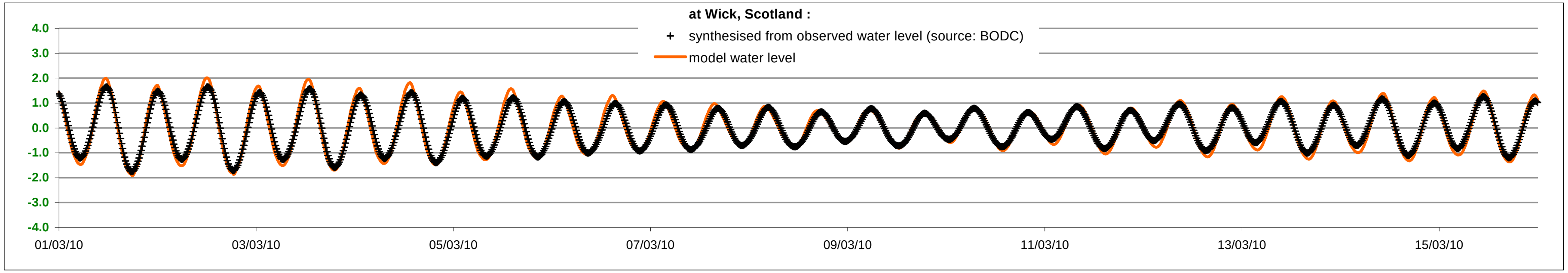
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.1348	9.7	190000
S2	12.00	0.3893	139.7	31000
N2	12.66	0.2260	247.9	13000
O1	25.82	0.1070	54.0	2600
K1	23.93	0.1003	196.1	2100
M4	6.21	0.0611	344.3	640
MS4	6.10	0.0415	167.5	390
Q1	26.87	0.0339	254.7	310

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.17 m or N-RMSE of 6% of maximum tidal range in calibration period



C 18. DCSM comparison against observed data at Wick, Scotland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.5807	312.1	25000
S2	12.00	0.2258	340.9	3800
N2	12.66	0.1141	285.3	1000
O1	25.82	0.0798	30.9	410
K1	23.93	0.0630	152.3	410
MSF	354.37	0.0312	67.2	88
MM	661.29	0.0280	6.7	53
Q1	26.87	0.0226	325.3	39

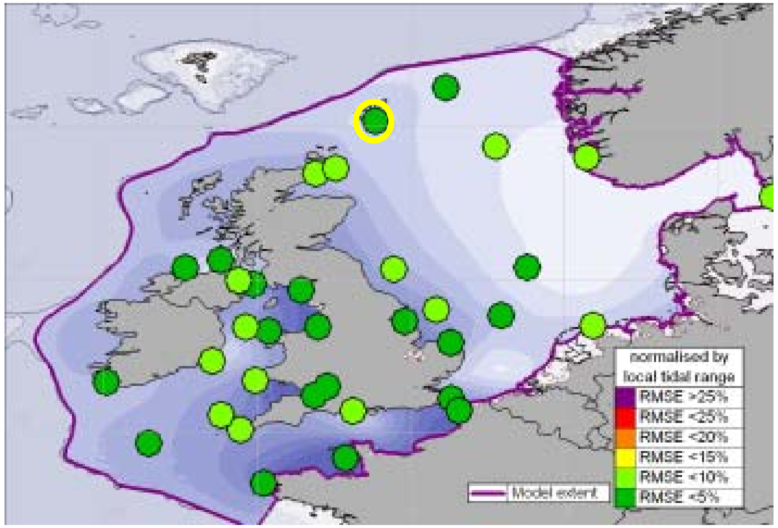
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.07 m

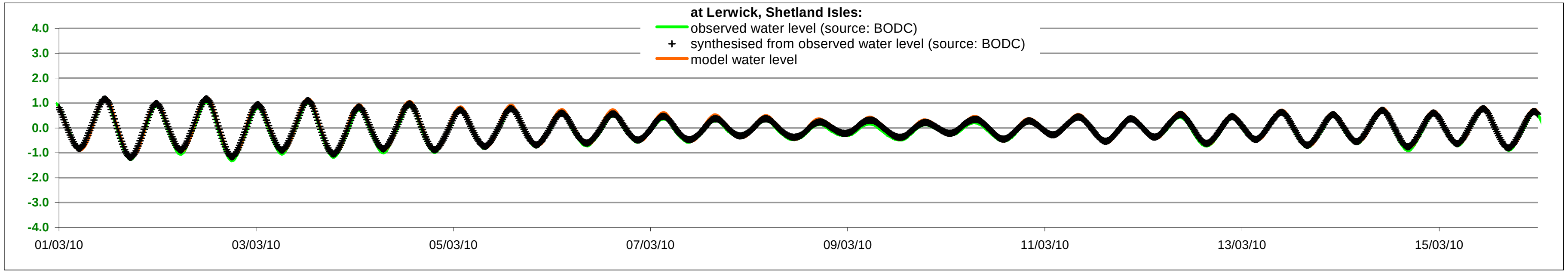
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.6550	10.2	180000
S2	12.00	0.2314	138.4	33000
N2	12.66	0.1396	247.8	13000
O1	25.82	0.0734	58.3	4200
K1	23.93	0.0714	187.9	3100
M4	6.21	0.0300	328.8	450
Q1	26.87	0.0236	262.3	410
MS4	6.10	0.0164	132.3	190

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.06 m or N-RMSE of 4% of maximum tidal range in calibration period



C 19. DCSM comparison against observed data at Lerwick, Shetland Isles

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.0712	108.5	140000
S2	12.00	0.8198	141.9	29000
N2	12.66	0.3933	83.6	7900
MU2	12.87	0.0903	125.2	360
MM	661.29	0.0836	23.9	270
O1	25.82	0.0670	326.2	190
M4	6.21	0.0578	109.8	160
K1	23.93	0.0539	57.7	110

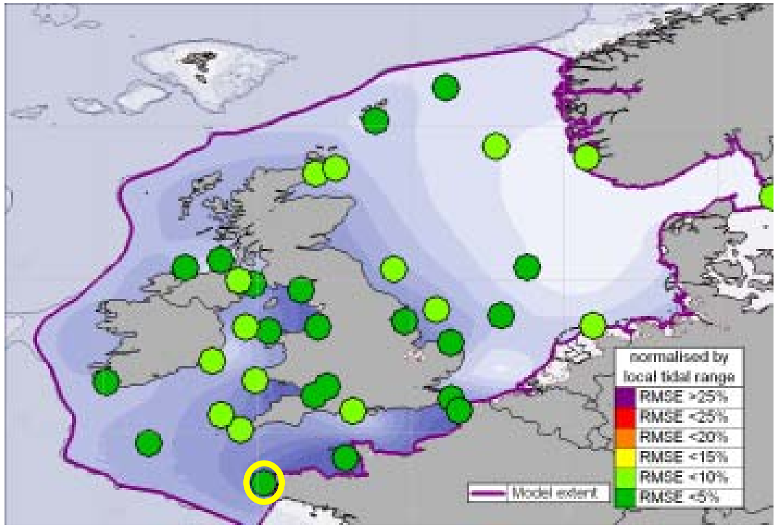
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.0 m

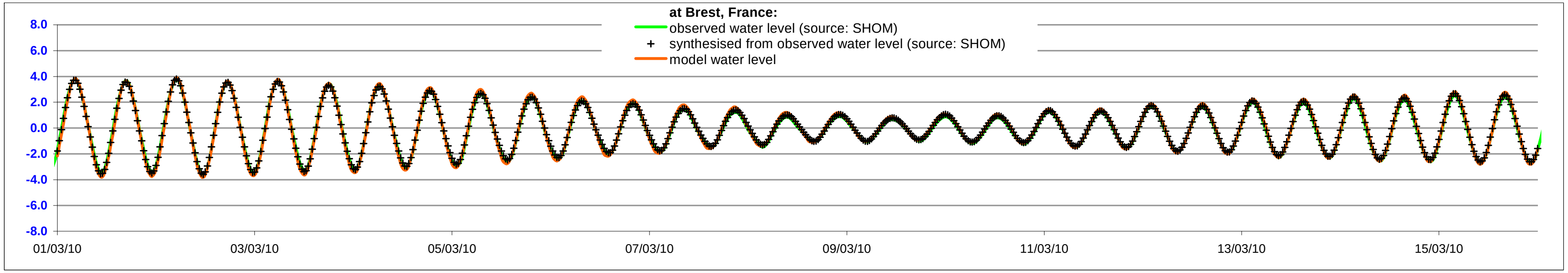
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	2.3070	164.7	160000
S2	12.00	0.9167	299.0	41000
N2	12.66	0.4592	52.5	11000
O1	25.82	0.0619	351.8	210
MU2	12.87	0.0714	121.2	210
K1	23.93	0.0593	101.1	200
M4	6.21	0.0444	227.0	99
L2	12.19	0.0262	161.7	56

Number of days: 90
Number of constituents: 35
MSL = 0.01 m



MAE = 0.14 m or N-RMSE of 3% of maximum tidal range in calibration period



C 20. DCSM comparison against observed data at Brest, France

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	2.9918	329.3	130000
S2	12.00	1.0415	13.2	24000
N2	12.66	0.4928	298.8	5600
M4	6.21	0.3484	221.4	2600
MS4	6.10	0.2435	265.8	1100
MU2	12.87	0.1407	50.8	340
MN4	6.27	0.1076	179.0	260
L2	12.19	0.1319	6.3	200

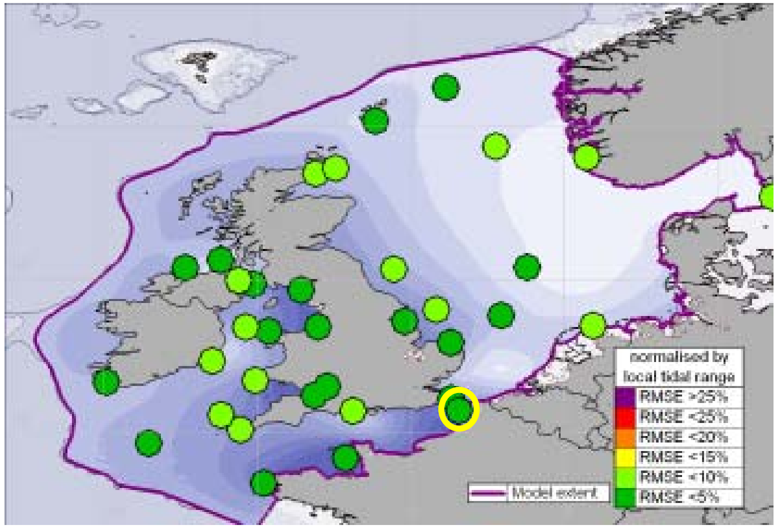
[1] Only the first 8 constituents are listed

Number of days: 88.32
Number of constituents: 35
MSL = -0.04 m

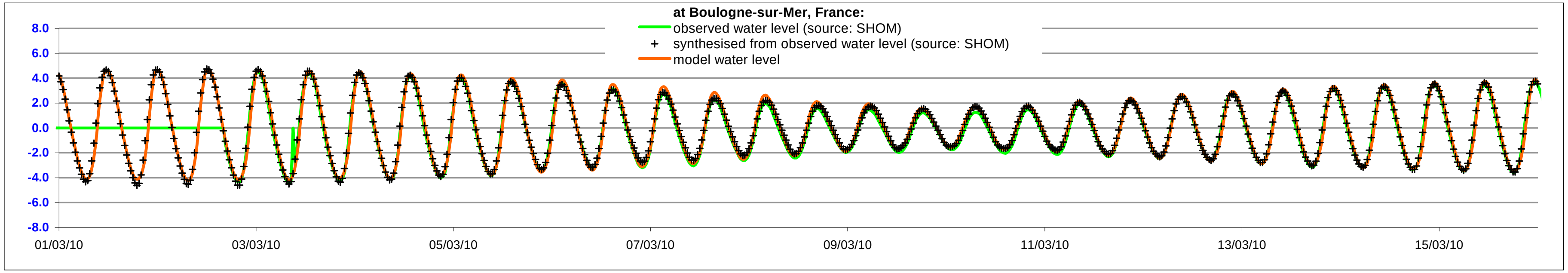
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	3.1343	30.5	170000
S2	12.00	1.0987	177.7	24000
N2	12.66	0.5209	276.1	8100
M4	6.21	0.3774	350.9	2400
MS4	6.10	0.2656	141.0	1700
MU2	12.87	0.2084	24.6	840
MN4	6.27	0.1157	234.7	300
2MS6	4.09	0.0836	92.1	140

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.24 m or N-RMSE of 4% of maximum tidal range in calibration period



C 21. DCSM comparison against observed data at Boulogne-sur-Mer, France

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.9754	231.5	63000
S2	12.00	0.2825	283.5	4400
N2	12.66	0.1328	190.1	1100
O1	25.82	0.0907	201.3	610
M4	6.21	0.0967	319.7	510
MU2	12.87	0.0960	335.2	480
MS4	6.10	0.0710	14.5	290
MM	661.29	0.0650	16.9	270

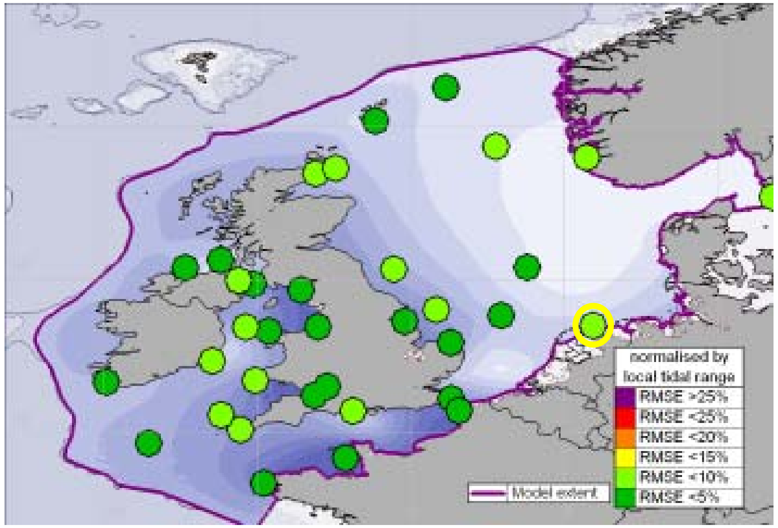
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = 0.12 m

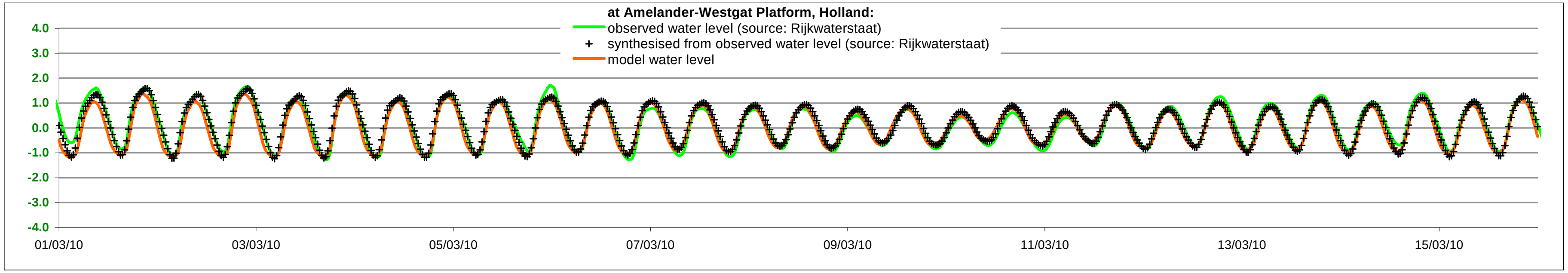
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.9718	279.7	260000
S2	12.00	0.2873	73.6	17000
N2	12.66	0.1395	157.2	4800
O1	25.82	0.0966	216.4	3100
MU2	12.87	0.0901	289.3	1600
K1	23.93	0.0769	357.0	1300
2MS6	4.09	0.0394	72.4	370
M6	4.14	0.0329	282.2	310

Number of days: 90
Number of constituents: 35
MSL = 0.01 m



MAE = 0.18 m or N-RMSE of 9% of maximum tidal range in calibration period



C 22. DCSM comparison against observed data at Amelander-Westgat Platform, Holland

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.0681	135.5	390
MM	661.29	0.0450	357.6	250
MSF	354.37	0.0445	43.5	250
O1	25.82	0.0242	299.7	63
N2	12.66	0.0206	54.7	50
MU2	12.87	0.0198	296.7	49
S2	12.00	0.0150	66.8	28
M4	6.21	0.0104	318.8	12

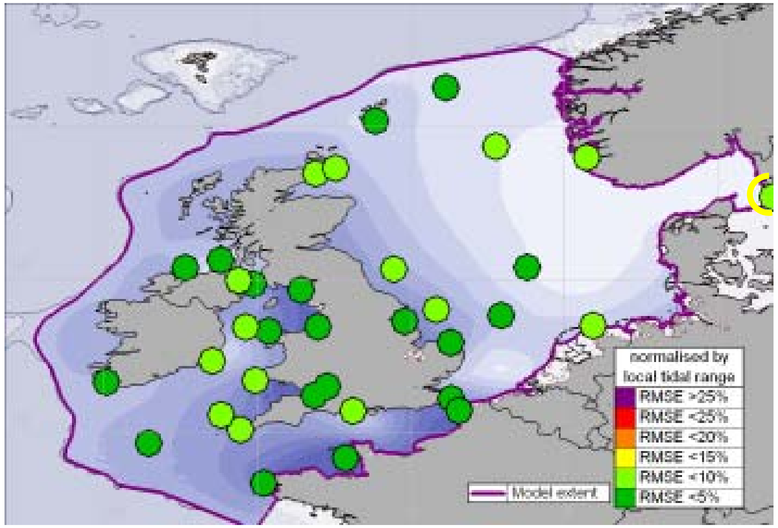
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.15 m

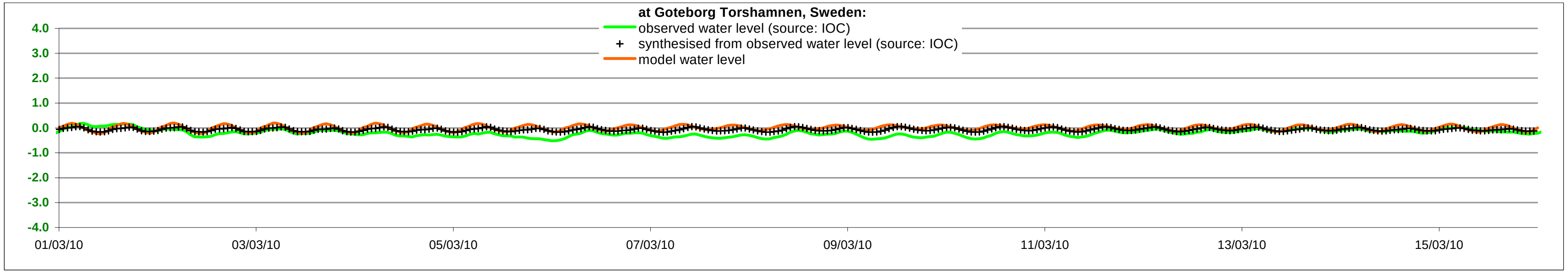
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.1314	137.3	100000
S2	12.00	0.0400	263.5	11000
N2	12.66	0.0261	9.0	5000
O1	25.82	0.0168	297.0	1800
MSF	354.37	0.0108	234.2	1000
MM	661.29	0.0088	294.1	560
K1	23.93	0.0077	51.7	480
MU2	12.87	0.0069	190.7	310

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.08 m or N-RMSE of 10% of maximum tidal range in calibration period



C 23. DCSM comparison against observed data at Goteborg Torshamnen, Sweden

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.1615	271.5	2700
S2	12.00	0.0741	317.2	880
MSF	354.37	0.0472	61.6	310
2MS6	4.09	0.0278	121.5	100
M6	4.14	0.0252	73.0	97
N2	12.66	0.0240	260.2	83
MM	661.29	0.0198	32.0	59
O1	25.82	0.0180	9.5	55

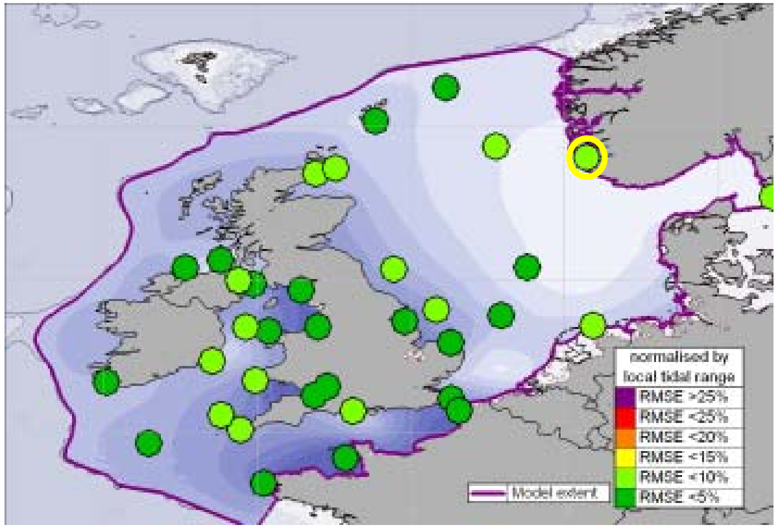
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.10 m

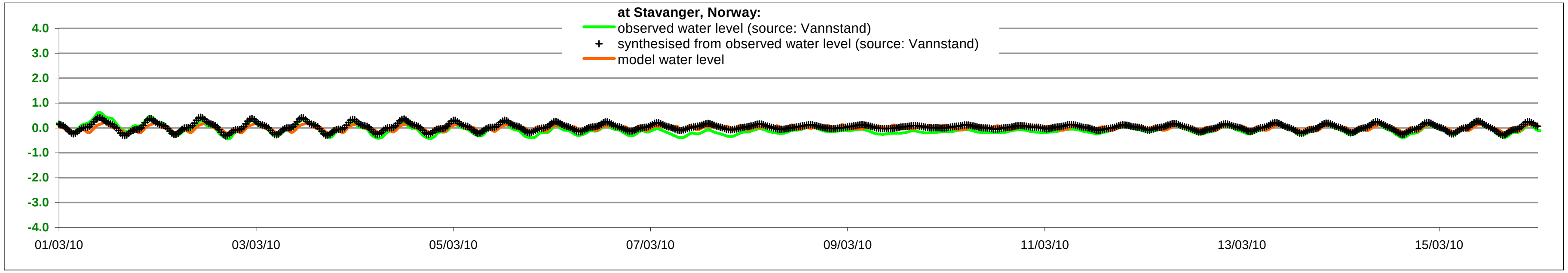
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.0670	8.8	2700
S2	12.00	0.0444	119.5	1700
M4	6.21	0.0326	14.5	870
M6	4.14	0.0276	247.4	860
2MS6	4.09	0.0313	52.0	800
N2	12.66	0.0202	264.7	550
MS4	6.10	0.0165	113.5	290
M8	3.11	0.0161	52.7	240

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.09 m or N-RMSE of 10% of maximum tidal range in calibration period



C 24. DCSM comparison against observed data at Stavanger, Norway

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.5141	287.3	27000
S2	12.00	0.1768	309.9	4100
N2	12.66	0.0865	261.6	1000
MSF	354.37	0.0637	60.0	570
K1	23.93	0.0620	150.0	440
O1	25.82	0.0573	37.5	400
MM	661.29	0.0526	82.0	360
Q1	26.87	0.0126	329.3	32

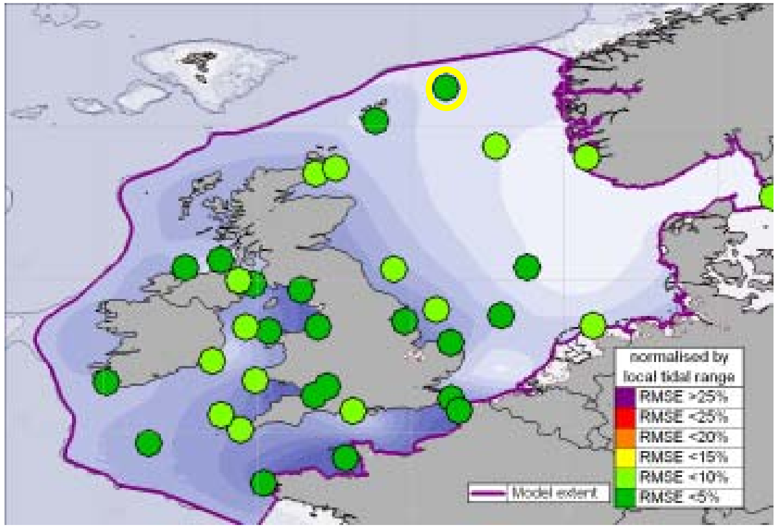
[1] Only the first 8 constituents are listed

Number of days: 55.98
Number of constituents: 35
MSL = 0.11 m

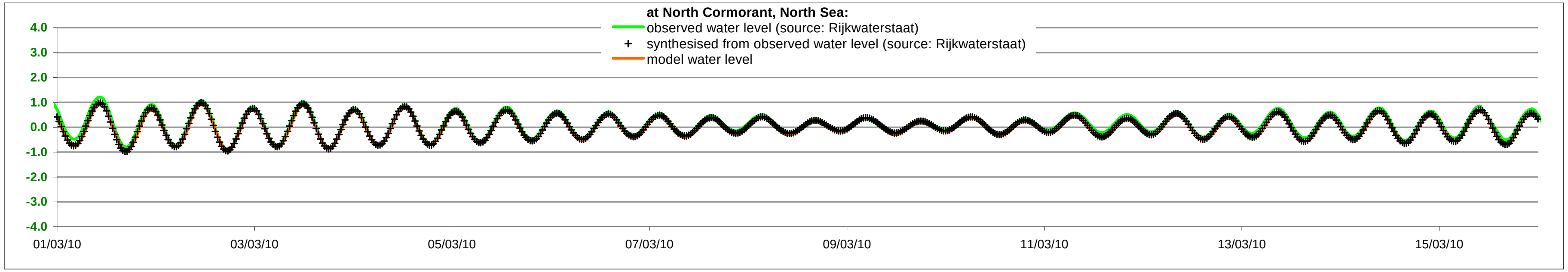
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.4990	345.9	120000
S2	12.00	0.1881	115.1	29000
N2	12.66	0.1015	224.6	8800
O1	25.82	0.0584	69.1	2700
K1	23.93	0.0568	194.3	2500
Q1	26.87	0.0186	266.5	360
MSF	354.37	0.0177	239.8	260
MM	661.29	0.0102	329.6	73

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.07 m or N-RMSE of 5% of maximum tidal range in calibration period



C 25. CCSM comparison against (offshore) observed data at North Cormorant

Observed harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.2729	132.3	6700
S2	12.00	0.0819	164.5	850
N2	12.66	0.0501	91.3	360
O1	25.82	0.0419	160.0	290
M4	6.21	0.0396	0.7	200
K1	23.93	0.0294	287.1	99
MM	661.29	0.0220	16.9	64
MSF	354.37	0.0216	78.4	58

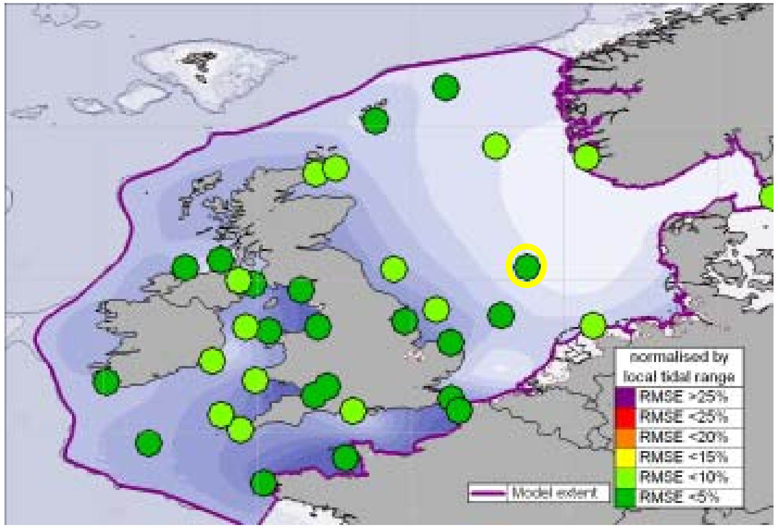
[1] Only the first 8 constituents are listed

Number of days: 90
Number of constituents: 35
MSL = -0.08 m

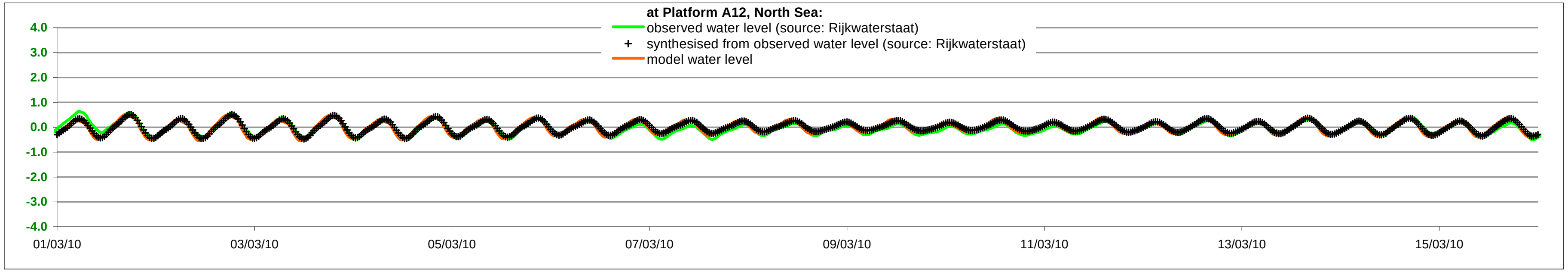
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	0.3119	168.8	100000
S2	12.00	0.0918	304.2	13000
N2	12.66	0.0562	38.1	5000
O1	25.82	0.0508	173.1	4800
M4	6.21	0.0478	77.3	3300
K1	23.93	0.0420	316.3	2700
MS4	6.10	0.0235	242.7	900
Q1	26.87	0.0175	10.2	650

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.04 m or N-RMSE of 5% of maximum tidal range in calibration period



C 26. CCSM comparison against (offshore) observed data at Platform A12

Observed harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	0.6960	170.3	41000
S2	12.00	0.2467	214.5	6800
N2	12.66	0.1157	141.0	1400
O1	25.82	0.0962	157.3	890
K1	23.93	0.0685	305.5	460
MU2	12.87	0.0341	233.0	110
Q1	26.87	0.0273	69.3	80
L2	12.19	0.0318	190.1	68

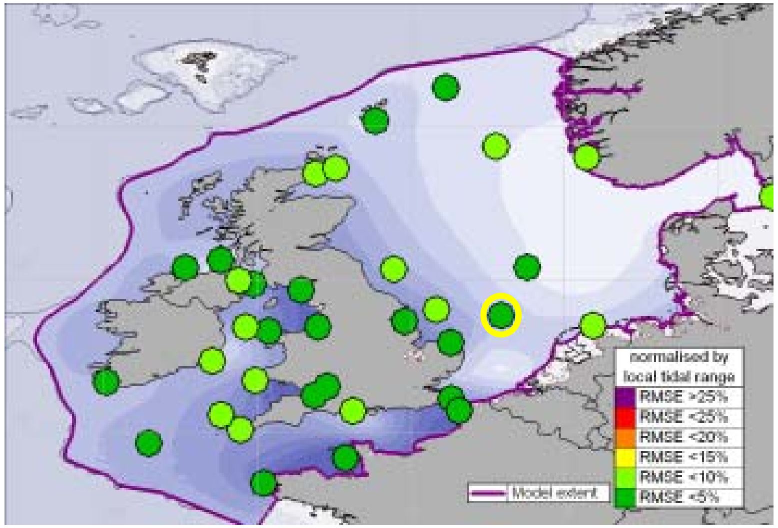
[1] Only the first 8 constituents are listed

Number of days: 89.76
Number of constituents: 35
MSL = -0.13 m

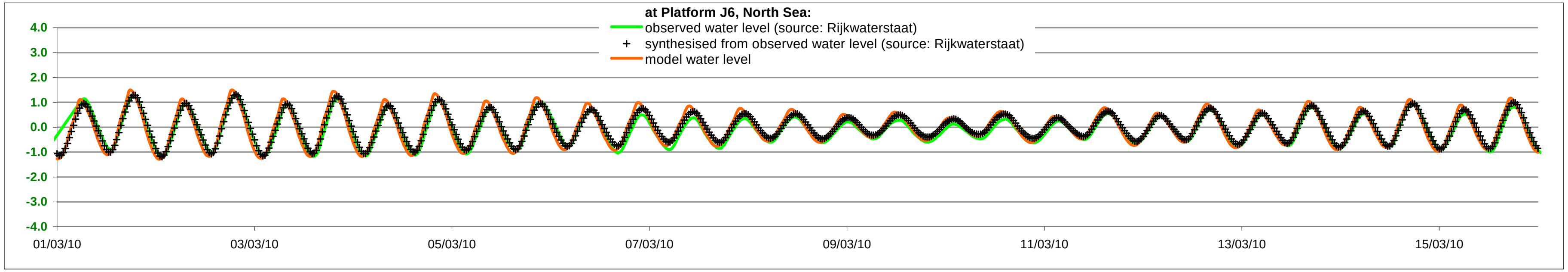
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(°)	(-)
M2	12.42	0.8353	209.4	160000
S2	12.00	0.2809	352.1	20000
N2	12.66	0.1504	88.4	10000
O1	25.82	0.1022	172.9	3700
K1	23.93	0.0858	319.5	2100
M4	6.21	0.0480	12.7	650
MU2	12.87	0.0382	216.0	450
Q1	26.87	0.0321	8.7	420

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.11 m or N-RMSE of 5% of maximum tidal range in calibration period



C 27. CCSM comparison against (offshore) observed data at Platform J6

Observed harmonic constituents

Harmonic Constituents[1 2]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.3165	309.0	4800
S2	12.00	0.1486	341.4	1100
N2	12.66	0.0731	288.8	330
MSF	354.37	0.0305	269.1	57
O1	25.82	0.0362	54.4	50
MU2	12.87	0.0266	264.9	42
K1	23.93	0.0208	172.3	21
MM	661.29	0.0179	185.6	19

[1] Only the first 8 constituents are listed

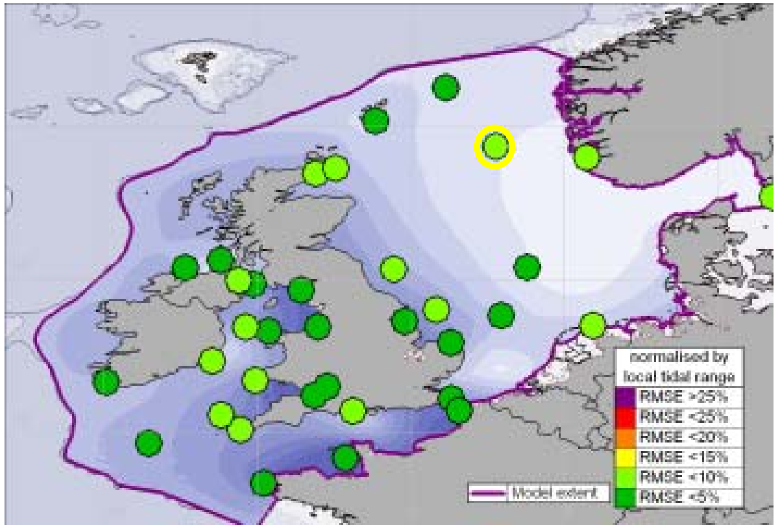
[2] Constituents from original observation period (for reference only)

Number of days: 33.64
Number of constituents: 35
MSL = -0.91 m

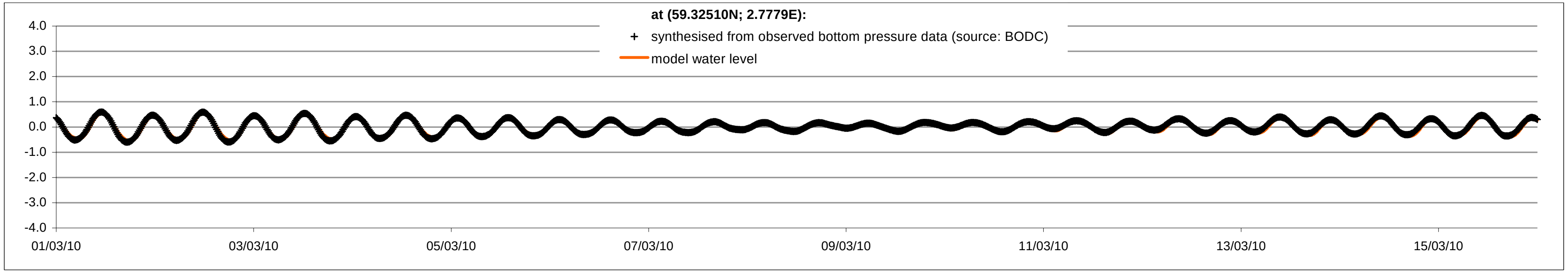
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.3006	12.5	81000
S2	12.00	0.1172	137.5	17000
N2	12.66	0.0648	252.5	5900
K1	23.93	0.0287	210.0	1100
O1	25.82	0.0301	79.0	990
M4	6.21	0.0257	344.0	800
MSF	354.37	0.0133	252.4	240
MS4	6.10	0.0123	101.2	180

Number of days: 90
Number of constituents: 35
MSL = 0.0 m



MAE = 0.05 m or N-RMSE of 6% of maximum tidal range in calibration period



C 28. CCSM comparison against (offshore) observed data at PJONSDAP, R56 [59.3251;2.7779]

Observed harmonic constituents

Harmonic Constituents[1,2]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.7527	326.0	30000
S2	12.00	0.3199	0.9	6600
N2	12.66	0.1836	306.1	2400
O1	25.82	0.0939	31.0	350
MM	661.29	0.0675	136.0	330
MU2	12.87	0.0489	282.0	160
K1	23.93	0.0512	179.3	150
MSF	354.37	0.0362	252.9	95

[1] Only the first 8 constituents are listed

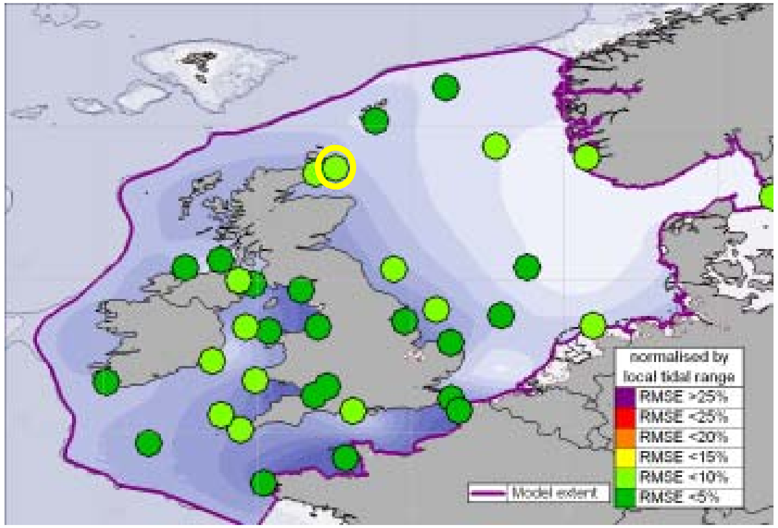
[2] Constituents from original observation period (for reference only)

Number of days: 36.90
Number of constituents: 35
MSL = 0.16 m

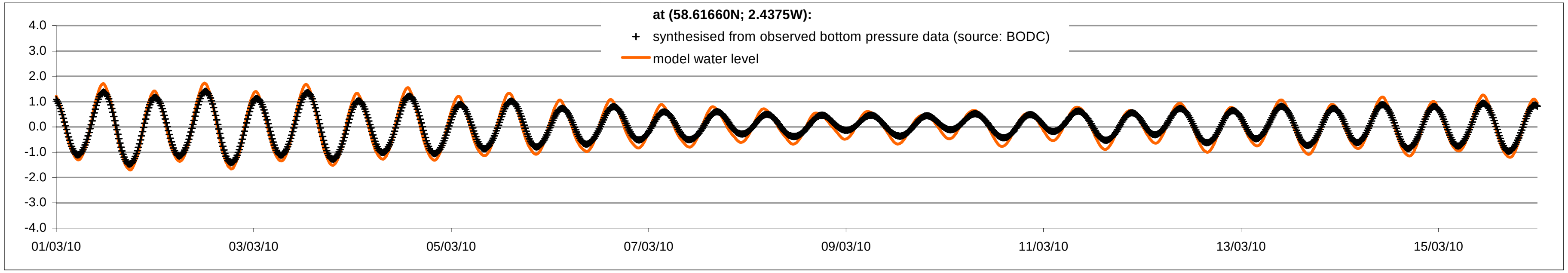
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (°)	S/N Ratio (-)
M2	12.42	0.9640	14.4	190000
S2	12.00	0.3356	144.2	30000
N2	12.66	0.1978	252.5	16000
O1	25.82	0.0986	58.2	3000
K1	23.93	0.0913	199.5	2600
M4	6.21	0.0491	337.8	600
Q1	26.87	0.0316	259.1	400
MS4	6.10	0.0296	158.7	310

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.19 m or N-RMSE of 7% of maximum tidal range in calibration period



C 29. CCSM comparison against observed data at PJONSDAP, R53 [58.6166;-2.4375]

Observed harmonic constituents

Harmonic Constituents[1] [2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.2671	87.5	100000
S2	12.00	0.3757	119.0	12000
N2	12.66	0.2905	58.8	9000
K1	23.93	0.1111	226.2	1100
O1	25.82	0.1161	81.4	680
L2	12.19	0.0790	106.1	530
Q1	26.87	0.0457	36.8	180
MSF	354.37	0.0382	6.5	120

[1] Only the first 8 constituents are listed

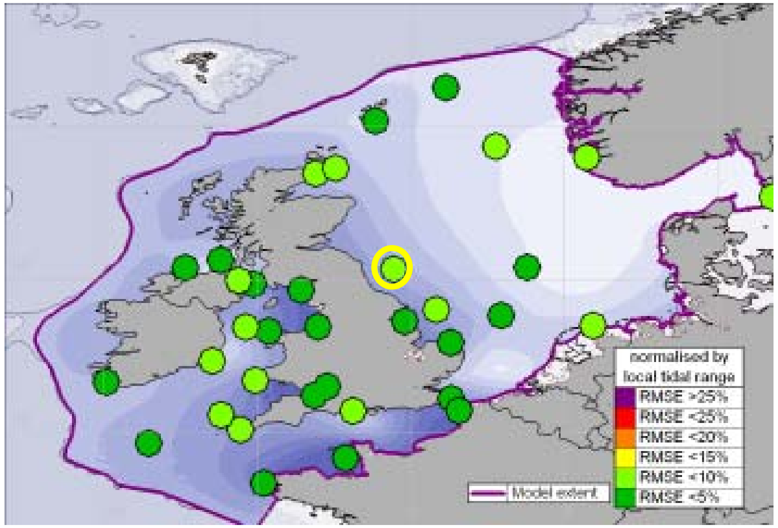
[2] Constituents from original observation period (for reference only)

Number of days: 39.65
Number of constituents: 35
MSL = 4.38 m

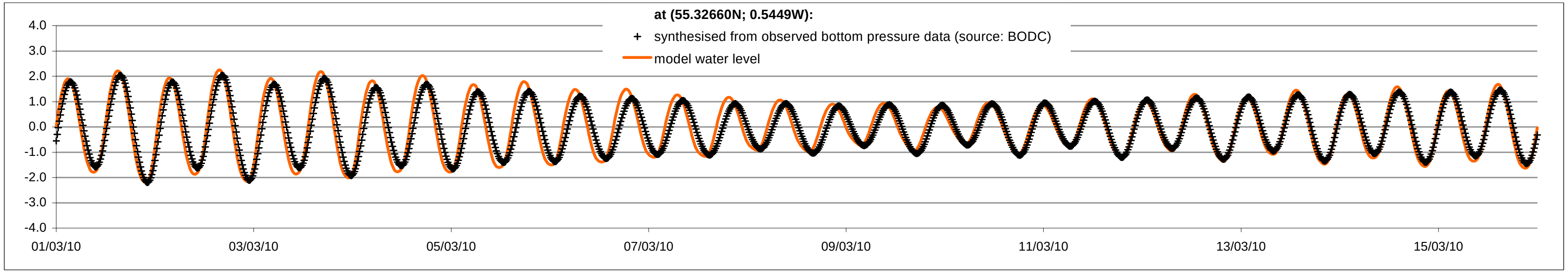
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.3968	120.3	380000
S2	12.00	0.4698	255.8	32000
N2	12.66	0.2685	353.9	14000
K1	23.93	0.1016	252.8	2500
O1	25.82	0.1130	108.3	1900
M4	6.21	0.0612	192.1	580
MU2	12.87	0.0420	166.1	260
Q1	26.87	0.0360	306.7	220

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.18 m or N-RMSE of 6% of maximum tidal range in calibration period



C 30. CCSM comparison against observed data at RL [55.3266;-0.5449]

Observed harmonic constituents

Harmonic Constituents[1 2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	0.9437	325.0	59000
N2	12.66	0.2269	297.8	5300
S2	12.00	0.2508	16.3	3700
L2	12.19	0.0970	1.6	640
K1	23.93	0.1007	201.9	630
O1	25.82	0.0837	48.4	370
MSF	354.37	0.0529	223.7	200
Q1	26.87	0.0435	355.1	87

[1] Only the first 8 constituents are listed

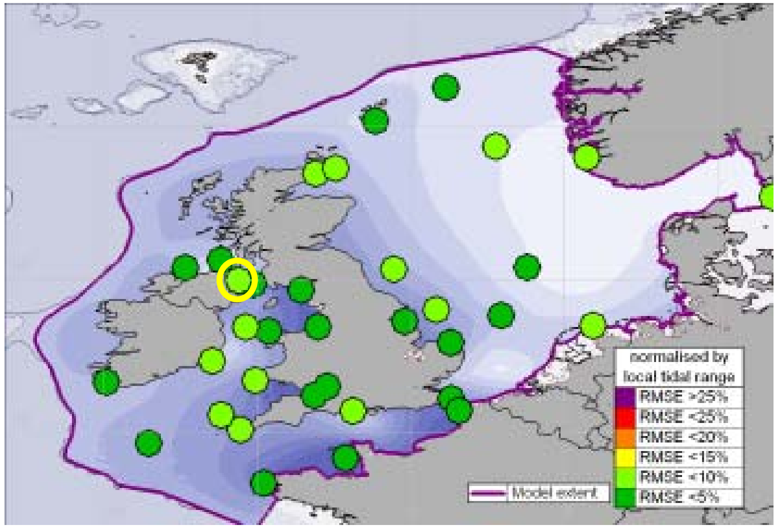
[2] Constituents from original observation period (for reference only)

Number of days: 47.99
Number of constituents: 35
MSL = -4.63 m

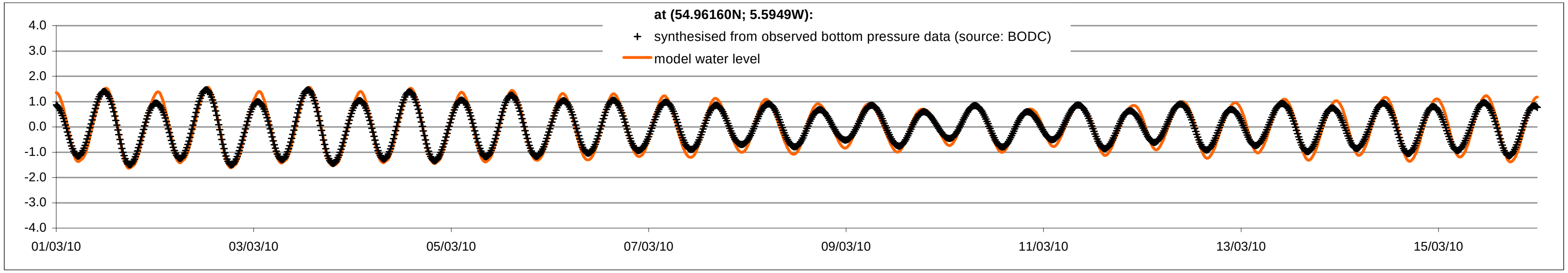
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.1747	28.1	270000
S2	12.00	0.3093	171.6	19000
N2	12.66	0.1945	261.5	14000
MU2	12.87	0.0887	67.5	2100
K1	23.93	0.0885	179.9	1800
O1	25.82	0.0813	56.5	1700
MS4	6.10	0.0490	269.4	570
L2	12.19	0.0263	165.9	280

Number of days: 90
Number of constituents: 35
MSL = -0.03 m



MAE = 0.18 m or N-RMSE of 7% of maximum tidal range in calibration period



C 31. CCSM comparison against observed data at RB [54.9616;-5.5949]

Observed harmonic constituents

Harmonic Constituents[1 2]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.4513	139.6	120000
S2	12.00	0.4468	174.9	8700
N2	12.66	0.3318	110.8	5900
K1	23.93	0.1424	254.7	840
O1	25.82	0.1495	108.9	630
L2	12.19	0.0935	151.6	340
Q1	26.87	0.0596	59.5	160
MU2	12.87	0.0454	120.8	84

[1] Only the first 8 constituents are listed

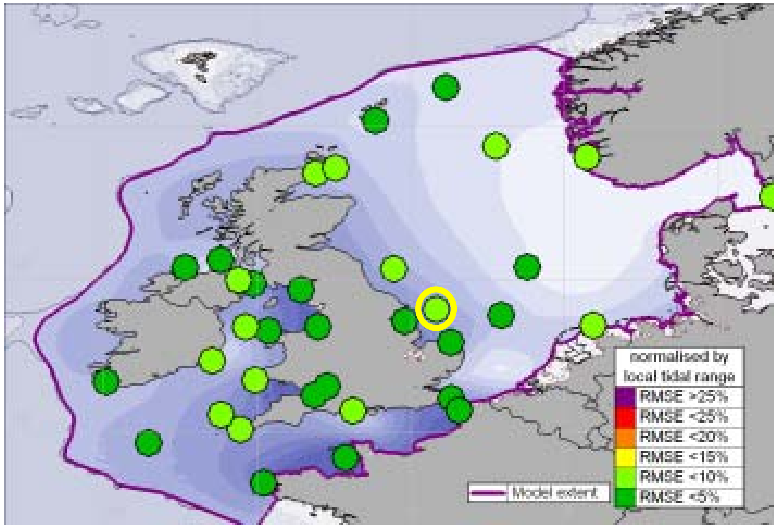
[2] Constituents from original observation period (for reference only)

Number of days: 37.42
Number of constituents: 35
MSL = 2.41 m

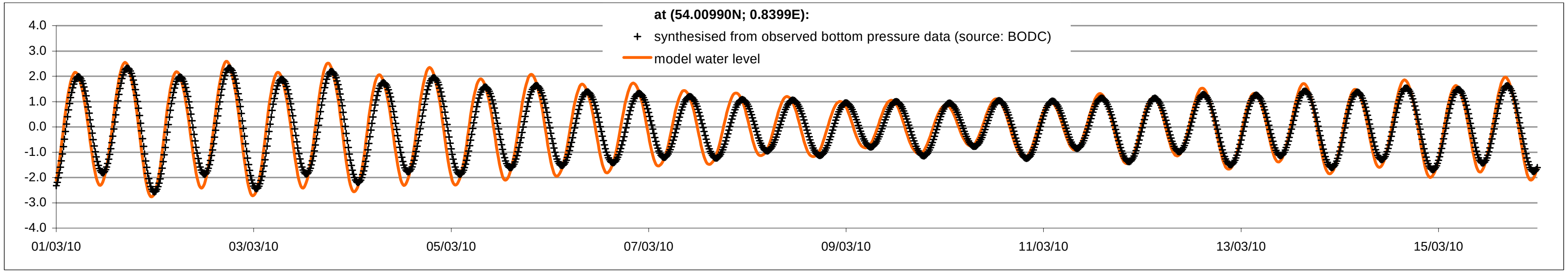
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.6548	171.7	230000
S2	12.00	0.5649	310.3	35000
N2	12.66	0.3140	46.2	13000
K1	23.93	0.1310	279.2	2500
O1	25.82	0.1457	132.0	2300
Q1	26.87	0.0457	328.0	330
MU2	12.87	0.0494	203.0	270
MS4	6.10	0.0222	314.3	67

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.22 m or N-RMSE of 6% of maximum tidal range in calibration period



C 32. **CCSM comparison against observed data at RE [54.0099;0.8399]**

Observed harmonic constituents

Harmonic Constituents[1] [2]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.3924	309.1	61000
S2	12.00	0.5759	334.3	8000
N2	12.66	0.2583	296.8	2000
MM	661.29	0.1165	46.4	310
O1	25.82	0.1053	39.4	310
MU2	12.87	0.1070	170.8	280
K1	23.93	0.0710	188.4	190
L2	12.19	0.0634	302.6	130

[1] Only the first 8 constituents are listed

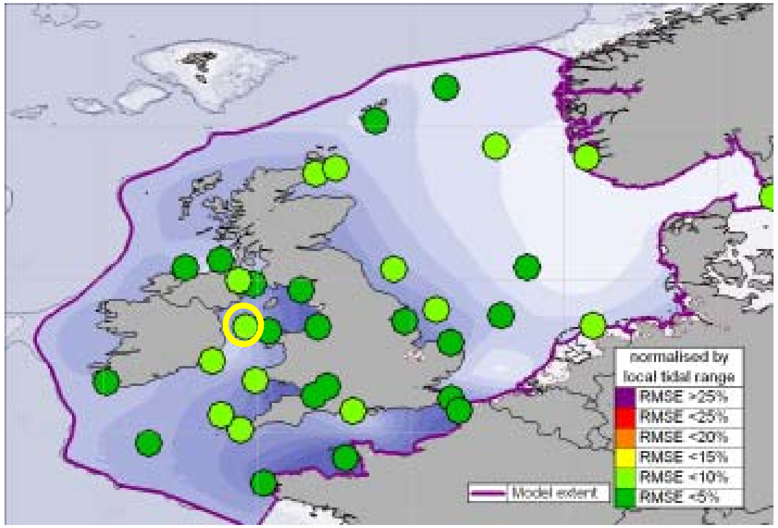
[2] Constituents from original observation period (for reference only)

Number of days: 32.53
Number of constituents: 35
MSL = 1.84 m

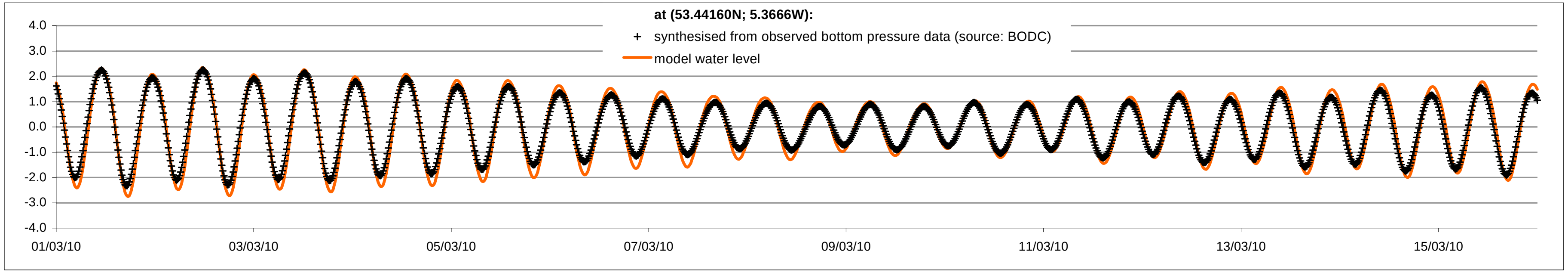
Predicted harmonic constituents

Harmonic Constituents[1]	Period (hrs)	Amplitude (m)	Greenwich Phase (º)	S/N Ratio (-)
M2	12.42	1.6564	7.6	240000
S2	12.00	0.5465	136.5	35000
N2	12.66	0.3201	241.6	16000
K1	23.93	0.0966	176.9	1200
O1	25.82	0.0909	53.4	1100
M4	6.21	0.0968	187.7	1100
MU2	12.87	0.0725	78.5	650
MS4	6.10	0.0562	338.3	470

Number of days: 90
Number of constituents: 35
MSL = -0.02 m



MAE = 0.22 m or N-RMSE of 6% of maximum tidal range in calibration period



C 33. CCSM comparison against observed data at RGE [53.4416;-5.3666]

Observed harmonic constituents

Harmonic Constituents[1,2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.8868	141.7	380000
S2	12.00	0.5923	183.3	25000
N2	12.66	0.3803	127.8	17000
L2	12.19	0.0794	143.9	510
M4	6.21	0.0525	218.2	230
K1	23.93	0.0579	96.9	180
O1	25.82	0.0547	351.5	170
MU2	12.87	0.0383	129.7	100

[1] Only the first 8 constituents are listed

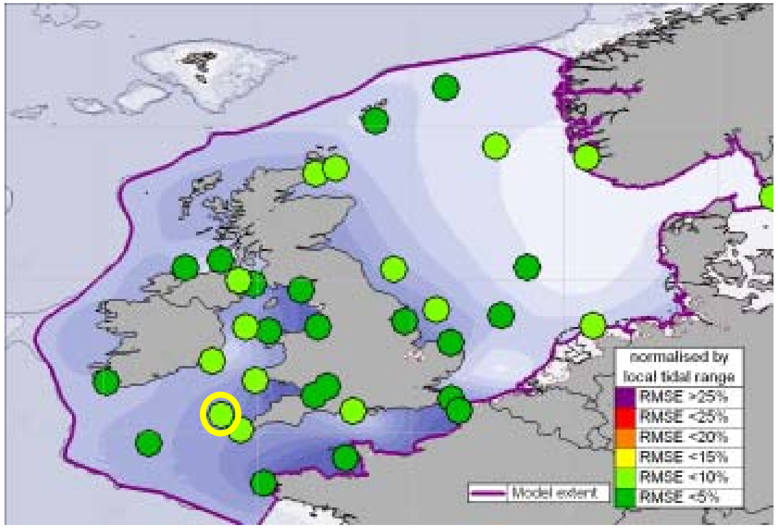
[2] Constituents from original observation period (for reference only)

Number of days: 114.84
Number of constituents: 35
MSL = 0.05 m

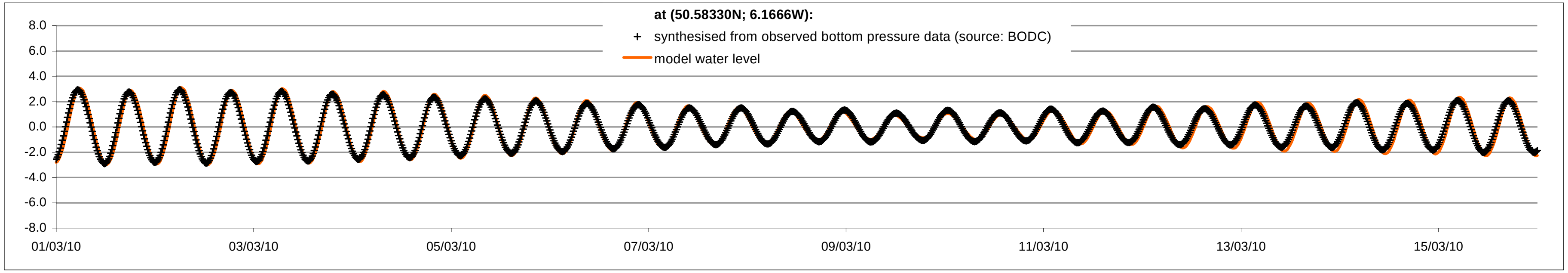
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.9387	205.4	350000
S2	12.00	0.7178	344.5	34000
N2	12.66	0.3473	91.5	9400
MU2	12.87	0.0843	188.4	520
M4	6.21	0.0712	359.5	320
K1	23.93	0.0543	128.4	240
O1	25.82	0.0551	13.1	210
MS4	6.10	0.0324	149.5	83

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.28 m or N-RMSE of 7% of maximum tidal range in calibration period



C 34. CCSM comparison against observed data at RD [50.5833;-6.1666]

Observed harmonic constituents

Harmonic Constituents[1 2]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.3646	122.9	250000
S2	12.00	0.5510	155.0	55000
N2	12.66	0.3323	106.8	26000
MU2	12.87	0.0577	80.4	540
O1	25.82	0.0541	337.4	510
L2	12.19	0.0647	128.4	460
K1	23.93	0.0467	92.5	390
M4	6.21	0.0276	232.2	130

[1] Only the first 8 constituents are listed

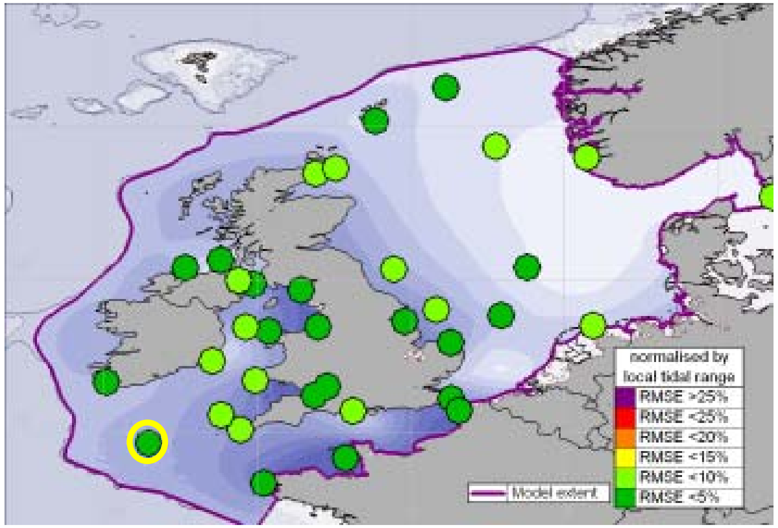
[2] Constituents from original observation period (for reference only)

Number of days: 45.52
Number of constituents: 35
MSL = -0.31 m

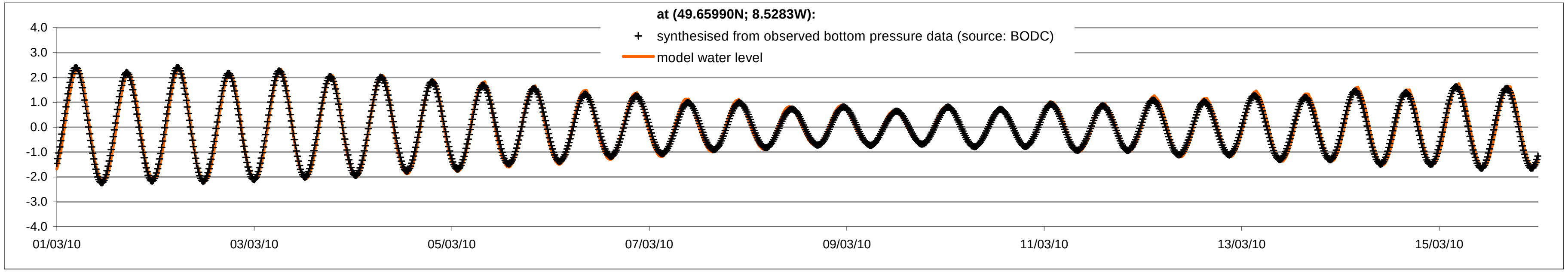
Predicted harmonic constituents

Harmonic Constituents[1]	Period	Amplitude	Greenwich Phase	S/N Ratio
	(hrs)	(m)	(º)	(-)
M2	12.42	1.4174	182.6	230000
S2	12.00	0.5105	313.8	37000
N2	12.66	0.2735	65.2	15000
O1	25.82	0.0531	2.1	620
K1	23.93	0.0588	114.3	550
M4	6.21	0.0535	357.0	390
MS4	6.10	0.0262	153.1	120
MU2	12.87	0.0283	185.0	100

Number of days: 90
Number of constituents: 35
MSL = -0.01 m



MAE = 0.12 m or N-RMSE of 4% of maximum tidal range in calibration period



C 35. CCSM comparison against observed data at RG [49.6599;-8.5283]

APPENDIX D – CCSM VS. DCSM

The following tables summarise the results of the CCSM and DCSM calibration and validation exercise side by side, such that users can make informed decisions as to which resolution of the CSM model to use, and with what consequence to performance.

- Presentation of error statistics includes all of RMSE and MAE in their raw (dimensional) and normalised forms (i.e. all of N-RMSE, RMSE, N-MAE & MAE).

- Differences in maximum tidal range (raw and normalised) between computed and re-synthesised data is summarised at areas of interest for tidal range schemes.

- Phase being a potential source of error (and used as a correction in some instances), phase differences between computed and re-synthesised data are also summarised in the following tables.

CCSM	**Sites**	**RMSE (m)**	**N-RMSE**	**MAE (m)**	**N-MAE**	**Differences**		
						Range (spring)	**N-Range (spring)**	**Phase**
Celtic Sea and Severn Estuary	Castletownbere – Ireland	0.15	5%	0.12	4%			--
	Wexford – Ireland	0.16	8%	0.12	6%			--
	Milford Haven – Wales	0.42	7%	0.33	5%			--
	Hinkley Point – England	0.53	4%	0.42	3%	-0.21	2%	--
	Avonmouth – England	0.32	2%	0.25	2%	0.14	1%	--
	RG	0.20	6%	0.15	4%			--
	RD	0.39	8%	0.31	6%			--
Irish Sea, North Channel, Malin Sea	Malin Head – Ireland	0.11	3%	0.08	2%			--
	Port Ellen – Scotland	0.28	5%	0.24	4%			--
	Portpatrick – Scotland	0.25	6%	0.22	5%			--
	Workington – England	0.42	5%	0.35	4%	0.10	1%	--
	Liverpool – England	0.37	4%	0.29	3%	-0.44	4%	--
	Holyhead – Wales	0.34	6%	0.27	5%			--
	RB	0.27	8%	0.23	7%			--
	RGE	0.31	7%	0.25	5%			--
Firths of Scotland	Wick – Scotland	0.16	5%	0.13	4%			--
	Lerwick – Shetland Isles	0.05	3%	0.05	2%			--
English Channel and Channel Islands	Newlyn – England	0.41	8%	0.32	6%			--
	Bournemouth – England	0.26	11%	0.22	9%			--
	Dover – England	0.30	4%	0.19	3%	-0.19	3%	--
	Boulogne-sur-Mer – France	0.48	6%	0.33	4%			--
	St. Helier, Jersey	0.54	5%	0.41	3%			--
	Brest – France	0.13	2%	0.10	2%			--
North Sea	Amelander-Westgat– Holland	0.24	9%	0.19	7%			--
	Cromer – England	0.20	4%	0.16	3%	-0.01	0%	45min
	Immingham – England	0.23	3%	0.18	3%	-0.35	5%	45min
	Goteborg Torshamnen – Sweden	0.12	12%	0.10	10%			--
	Stavanger – Norway	0.13	13%	0.10	10%			--
	Platform A12	0.04	4%	0.04	4%			30min
	North Cormorant	0.10	7%	0.09	6%			--
	Platform J6	0.09	4%	0.07	3%			30min
	PJONSDAP,R53	0.17	6%	0.15	5%			--
	RL	0.20	6%	0.16	4%			45min
	RE	0.23	5%	0.19	4%			45min
	PJONSDAP,R56	0.07	7%	0.06	6%			--

DCSM	Sites	RMSE (m)	N-RMSE	MAE (m)	N-MAE	Differences		
						Range (spring)	N-Range (spring)	Phase
Celtic Sea and Severn Estuary	Castletownbere – Ireland	0.09	3%	0.07	2%			--
	Wexford – Ireland	0.16	7%	0.13	6%			--
	Milford Haven – Wales	0.35	6%	0.27	4%			--
	Hinkley Point – England	0.53	4%	0.44	3%	0.77	6%	--
	Avonmouth – England	0.48	3%	0.37	2%	1.01	7%	--
	RG	0.15	4%	0.12	3%			--
	RD	0.35	7%	0.28	6%			--
Irish Sea, North Channel, Malin Sea	Malin Head – Ireland	0.10	3%	0.08	2%			--
	Port Ellen – Scotland	0.23	4%	0.19	3%			--
	Portpatrick – Scotland	0.17	4%	0.14	4%			--
	Workington – England	0.33	4%	0.27	3%	0.29	3%	--
	Liverpool – England	0.51	5%	0.42	4%	-0.38	4%	--
	Holyhead – Wales	0.29	5%	0.23	4%			--
	RB	0.21	7%	0.18	6%			--
	RGE	0.27	6%	0.22	5%			--
Firths of Scotland	Wick – Scotland	0.21	6%	0.17	5%			--
	Lerwick – Shetland Isles	0.07	4%	0.06	3%			--
English Channel and Channel Islands	Newlyn – England	0.34	6%	0.27	5%			--
	Bournemouth – England	0.24	8%	0.20	7%			--
	Dover – England	0.28	4%	0.21	3%	-0.38	5%	--
	Boulogne-sur-Mer – France	0.34	4%	0.24	3%			--
	St. Helier, Jersey	0.47	4%	0.36	3%			--
	Brest – France	0.17	3%	0.14	2%			--
North Sea	Amelander-Westgat– Holland	0.23	9%	0.18	7%			--
	Cromer – England	0.31	5%	0.26	5%	0.51	10%	45min
	Immingham – England	0.30	4%	0.25	3%	0.21	3%	45min
	Goteborg Torshamnen – Sweden	0.10	10%	0.08	8%			--
	Stavanger – Norway	0.10	10%	0.09	9%			--
	Platform A12	0.05	5%	0.04	4%			30min
	North Cormorant	0.08	5%	0.07	4%			--
	Platform J6	0.13	5%	0.11	4%			30min
	PJONSDAP,R53	0.21	7%	0.19	7%			--
	RL	0.23	6%	0.18	5%			45min
	RE	0.27	6%	0.22	5%			45min
	PJONSDAP,R56	0.06	6%	0.05	5%			--