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Programme Area: Marine

Project: Tidal Modelling

Title: Interface Specification for Detailed Tidal Range Model with CSM

Abstract:

The TRM project has developed and verified a set of modelling tools, and performed an initial analysis of the impact of energy extraction at various potential tidal range and tidal stream energy extraction sites from 2020 to 2050. This document describes the methodologies used to interface the Continental Shelf Model (CSM) with detailed local model(s) that represent the tidal range energy schemes in detail. The document should be used by modellers to integrate a standalone model into the CSM.

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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MA1009

Tidal Modelling

(Modelling Tidal Resource Interactions around the UK)

PM04.08

Interface Specification for Detailed Tidal Range Model with CSM

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Other Participants – Black & Veatch

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CONTENTS

1 EXECUTIVE SUMMARY

The *Energy Technologies Institute* (ETI) has proposed the development of 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 and to evaluate their impact on European coasts. The CSM was delivered to, and signed off by, the ETI as part of Milestone 2 of this *Tidal Resource Modelling* (TRM) project. *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 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.

HR Wallingford 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 HR Wallingford and other partners such as Electricité de France and the Federal Waterways Engineering and Research Institute of Germany (pertinent information related to the TELEMAC system and, in particular, to the 2D module used in this project is given in the D02 – CSM Requirements Specification document). HR Wallingford's expertise is acknowledged within the tidal modelling community as the principal entity in the UK 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 D08 deliverables. As such, it describes methodologies to interface the CSM with detailed local model(s) that include the tidal range energy schemes in sufficient detail to represent the physics of individual device outlets and intakes. It purposefully follows the interface specification detailed in PM01.05 – Interface Specification for Detailed Tidal Current Model with CSM, as the same methodology can be used for interfacing either or both, one or more Detailed Tidal Range or Detailed Tidal Current Models with the CSM.

A methodology is proposed (Section 3), which is particularly relevant to the Bristol Channel DTRM, which is being developed under D09 deliverables. In this approach, a *Modified Continental Shelf Model* (MCSM) would be developed through the substitution of the detailed local model(s) mesh into that of the CSM. It is noted that this has not been done as part of the TRM project. Detailed local model(s) set up for selected sites of interest would be integrated following internal edges and model vertices. Because of the coarser resolution of the CCSM, it is expected that detailed local models can only be substituted into the DCSM. For existing detailed local models, it is proposed that the mesh be incorporated in the DCSM where the resolution is similar between the two models. That may be far from the area of interest and may require substantial effort from the end-user. For new detailed local model(s), it is recommended that the edges in the DCSM be part of the future detailed model(s) to simplify (and automate) the substitution into the DCSM. It is noted that the time step of the resulting MCSM would be smaller than that of the DCSM because of the finer resolution introduced with the detailed local model(s). This, and the greater number of prediction points in the combined mesh, would yield increased computational run times for the MCSM compared with the DCSM.

Due to the increased run time of the MCSM, it is recommended, instead, to routinely reuse the same scenario inputs to the DTRM, but run the inputs through either the CCSM or the DCSM to predict the effect of the scenario outside of the area covered by the DTRM. Inputs to all models developed throughout the ETI’s TRM Project have purposefully been made consistent with one another and are interchangeable between models.

As was the case for the CSM, the two-dimensional module of the TELEMAC system will form the underlying methodology of the detailed local model, hence of the MCSM. It is noted that the integration of detailed model(s) into the DCSM alleviates the need to exchange information (primary variables) between models at a time step level, although the model parameters and parameterisation of the energy schemes used in the detailed local model(s) require to be transposed to those of the MCSM. The transposition of the parameterisation of the energy schemes by the end-user of the model is facilitated through the use of generic and versatile parameterisation in the continuity and momentum equations (refer to Section 2.1.4).

2 INTRODUCTION

Both a *Coarse*- and *Detailed*-resolution versions of the *Continental Shelf Model* (CSM), the CCSM and DCSM respectively, have been setup, calibrated, validated and further verified as detailed in PM02.06B. These models may be used to assess the tidal energy potential around the UK, to inform the design of energy harnessing schemes and to evaluate their impact on European coasts. Because these models are not meant to represent the implementation of energy schemes to the level of the individual machines, the ETI has requested that the CSM be able to interface with detailed local tidal range models that do represent individual machine intakes and outlets through a tidal barrier and barrage, or at least the physics of individual device intakes and outlets.

In accordance with the acceptance criteria for Deliverable D08 – Interface Specification for Detailed Tidal Range Model with CSM, this report describes methodologies to interface the CSM with detailed local model(s) that do represent tidal energy schemes to the level of individual device intakes and outlets through a tidal barrier and barrage (or at least the physics of individual device intakes and outlets). It specifically details the interface specification with the Bristol Channel *Detailed Tidal Range Model* (Bristol Channel DTRM), presented in PM04.09 of the TRM project. It purposefully follows the same interface specification detailed in PM01.05 – Interface Specification for Detailed Tidal Current Model with CSM, as the same methodology can be used for interfacing either or both, one or more Detailed Tidal Range or Detailed Tidal Current Models with the CSM.

For clarity, the terminology of this document and of the CSM are reported in the rest of this section but the reader is referred to PM01.02 – CSM Requirements Specification document for more details.

The interface specifications are presented in Section 3.

2.1 Introduction to the CSM methodology

2.1.1 The open-source, industry-driven, TELEMAC system

The open-source, industry-driven, TELEMAC system, more specifically its two dimensional module TELEMAC-2D, forms the underlying methodology of the CSM. The TELEMAC system is a state-of-the-art free surface flow suite of solvers developed by a kernel of European organisations including HR Wallingford and other partners such as Electricité de France and the Federal Waterways Engineering and Research Institute of Germany.

The TELEMAC system is open-source software, enabling organisations to access and modify any part of its source code. The address of the official Internet website is: www.opentelemac.org. The website is managed, hosted and maintained by HR Wallingford. A number of documents can be downloaded (including manuals, tutorials, and theoretical notes) together with the entire source code and its documentation. Community-driven tools are also in place including an active discussion forum.

2.1.2 CSM primary variables

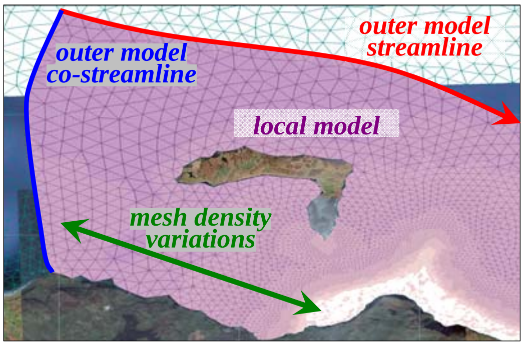
TELEMAC-2D solves the 2D depth-averaged shallow water equations, also called the St Venant equations. These comprise three equations (one equation for the conservation of the volume of water and two equations for the conservation of the water momentum) dependent on three environmental hydrodynamic variables, hereafter referred to as the CSM primary variables: the water depth h in meters and the depth-averaged current velocity components u and v in meters per second.

2.1.3 CSM parameters

In TELEMAC-2D, the user can set a number of model parameters (CSM parameters, in the case of the CSM) to improve the representation of the problem. The bottom roughness, which can be represented with a linear coefficient, a Chézy, Strickler / Manning coefficient, or using a Nikuradse roughness length, falls under this category for example. Another example would be the value used for the water density, the coefficient used for global (dynamic and turbulent) viscosity, or the choice of the numerical scheme to solve the equations. The model time step also falls into the model parameter category.

2.1.4 Boundary- and structure-fitted unstructured mesh

The TELEMAC system was designed from the outset, 20 years ago, to use the mathematically advanced finite element formulation, which is ideally suited to highly flexible unstructured meshes of triangular elements.



Unstructured meshes are made of triangular elements of various characteristics and sizes. The illustration opposite shows an unstructured mesh of triangles, coloured from purple to white according to triangle size. This is an arbitrary model mesh, not related to the TRM project, for demonstrative purposes only. The density variations shown along the green arrow allow small natural hydrodynamic features to be accurately modelled where the triangles are smaller, while the bigger triangles (expanding at a controlled growth rate) allow computing time savings away from the area of interest, where model results are not required with great accuracy.

Unstructured meshes of triangles control local resolution refinements, particularly in cases such as detached coastlines or underwater features including high seabed gradients. Open boundaries can also be fitted to open water lines of equal tidal phase or to streamlines (blue and red lines in this example), and include radiation.

The primary variables (water depth h and depth-averaged current velocity components u and v) are defined at the nodes of the mesh, i.e. at the vertices of triangles.

2.1.5 CSM resolution

The resolution is here defined as the distance between two prediction points (also the distance between two vertices of the unstructured mesh). It can vary across the geographical coverage of the model. In simplistic terms, the finer the resolution, the smaller the distance between prediction points, the higher the number of prediction points, the longer it takes to complete a scenario prediction.

2.2 Parameterisation of energy schemes

The CSM developed in this project is designed to be versatile. Generic parameterisation of energy schemes have been implemented in the model to allow the end-user to represent tidal range and tidal current schemes at the scale and resolution of the CSM; these cater for all types of technology, current and future. Section 2.2.1 focuses on the parameterisation of tidal range schemes. Although not directly relevant to the reader of this document, the parameterisation of tidal current schemes is presented in Section 2.2.2 for completeness.

A selection of scenarios around the UK coast (each representing a particular tidal energy extraction scheme) have been developed, designed to help the user set up specific cases (refer PM01.03 – Scenarios Modelling and PM03.07 – Interactions analysis and conclusions report).

2.2.1 Tidal range schemes

The first of three equations solved by TELEMAC-2D balances the natural variation in volume of water within the water column represented by h with a scalar term called $Srce$ (in m^3/s). This term represents intakes and outlets (negative and positive discharges respectively) such as those found on either side of tidal range structures.

The discharge through a tidal range scheme is a function of the head and energy difference across the opening and has been parameterised based on a number of turbine characteristics as both a series of intakes and outlets on either side of the tidal range structure. Turbine characteristics include the technology type, the operational procedures, the turbine capacity, the size, submergence and types of the openings and other key turbine parameters.

2.2.2 Tidal current schemes

Conversely, the other two of three equations solved by TELEMAC-2D balance the natural variation in current velocity (represented by u and v) with a vector term called F (F_x and F_y for u and v respectively). This term represents a force acting on the water momentum such as drag and energy extraction in the vicinity of tidal current devices.

The power generated by a tidal current scheme is a function of the flow field and has been parameterised based on turbine characteristics as both the structural drag and an extracted energy. Similarly to tidal range technologies, turbine characteristics include the technology type, the operational procedures, the turbine capacity, the size, blockage and other turbine parameters.

2.3 Coordinate system

The coordinate system used for the CSM is a spherical coordinate system (Latitude, Longitude), Ellipsoid WGS84. This choice is in agreement with marine maps published by The Crown Estate, even though at the UK latitude 1 degree is about 40% shorter (in m) in the North-South direction than in the East West direction. The vertical datum is Mean Sea Level. The directions are quoted with respect to True North.

3 PROJECT DESIGN/METHODOLOGY

The CSM is not designed to represent the implementation of energy schemes to the level of the individual devices. The objective of the methodologies proposed in this document is therefore to enable the end-user of the CSM to incorporate (into the CSM) results from detailed local tidal range models that do represent individual devices, or at least the physics, of individual devices. As such, input and output parameters, including primary variables (see Section 2.1.2), model parameters (see Section 2.1.3) and parameterisation of energy schemes (see Section 2.2), may be transferred between one or more detailed local models and the CSM.

The methodology presented in this document is equivalent to the so-called alternative methodology in the case of the interface for Detailed Tidal Current Model (see PM01.05). It fulfils the ETI's objective, is based on common modelling practices and is also applicable to other modelling systems with similar characteristics. However, in the specific case of the Bristol Channel DTRM (detailed in PM04.09), it will only be applicable to the DCSM because of the inappropriately large differences in mesh resolution with the CCSM.

3.1 Assumptions

The proposed methodology relies on a profound alteration to the CSM mesh to fully integrate the detailed local models and make one *Modified Continental Shelf Model* (MCSM). The operation of the MCSM as one model based on TELEMAC-2D is the principal assumption of the methodology. This restricts the type of detailed local models that can be merged as these will have to be based either on the TELEMAC system or on another unstructured mesh solver.

In order to complete the integration of the detailed local model(s) into one MCSM, three further assumptions are made:

1. At the geographical interface between the CSM and the detailed local model(s), the triangles and vertices of the unstructured meshes should align and superimpose. In particular, the mesh resolution should be similar along the geographical interface (see Section 3.2).

2. The parameterisation of the energy scheme implemented in the detailed local model(s) should be transposed or transferred, where appropriate, into a parameterisation suitable for the MCSM (e.g. as defined in the D02 – CSM Requirements Specification document for the CSM, see also Section 2.1.4).

3. The model parameters (see Section 2.1.3) used when developing the detailed local model(s) should also be transposed to model parameters suitable for the MCSM. This applies to the friction maps for example.

Care should be taken to ensure that the transpositions made in (2) and (3) are as intended, as the implementation of the same model parameters in different solvers for example can yield different results, and therefore a different measure of the impact of the energy scheme. This is not an issue for users of the DTRM as it is based on the TELEMAC system under the same assumptions and parameterisations.

3.2 Construction of the MCSM

For illustrative purposes, Figure 1 shows the unstructured mesh for the interface between the DCSM and the Bristol Channel DTRM (see PM04.09). The Bristol Channel DTRM extends to the mouth of the Bristol Channel, from Milford Haven in Wales to Padstow in England, as illustrated in Figure 2. In order for the DTRM to interface with the DCSM, the tidal boundary follows the element orientation (and exact node locations) of the DCSM. The node-to-node boundary fitting is evident in Figure 1, where the DCSM mesh (up to the interface) is displayed in orange and the DTRM mesh in blue.

The Bristol Channel DTRM resolution is also shown in Figure 2, in comparison to that of the DCSM. It is apparent that the mesh resolution varies smoothly (without shocks) at the interface between the two models.

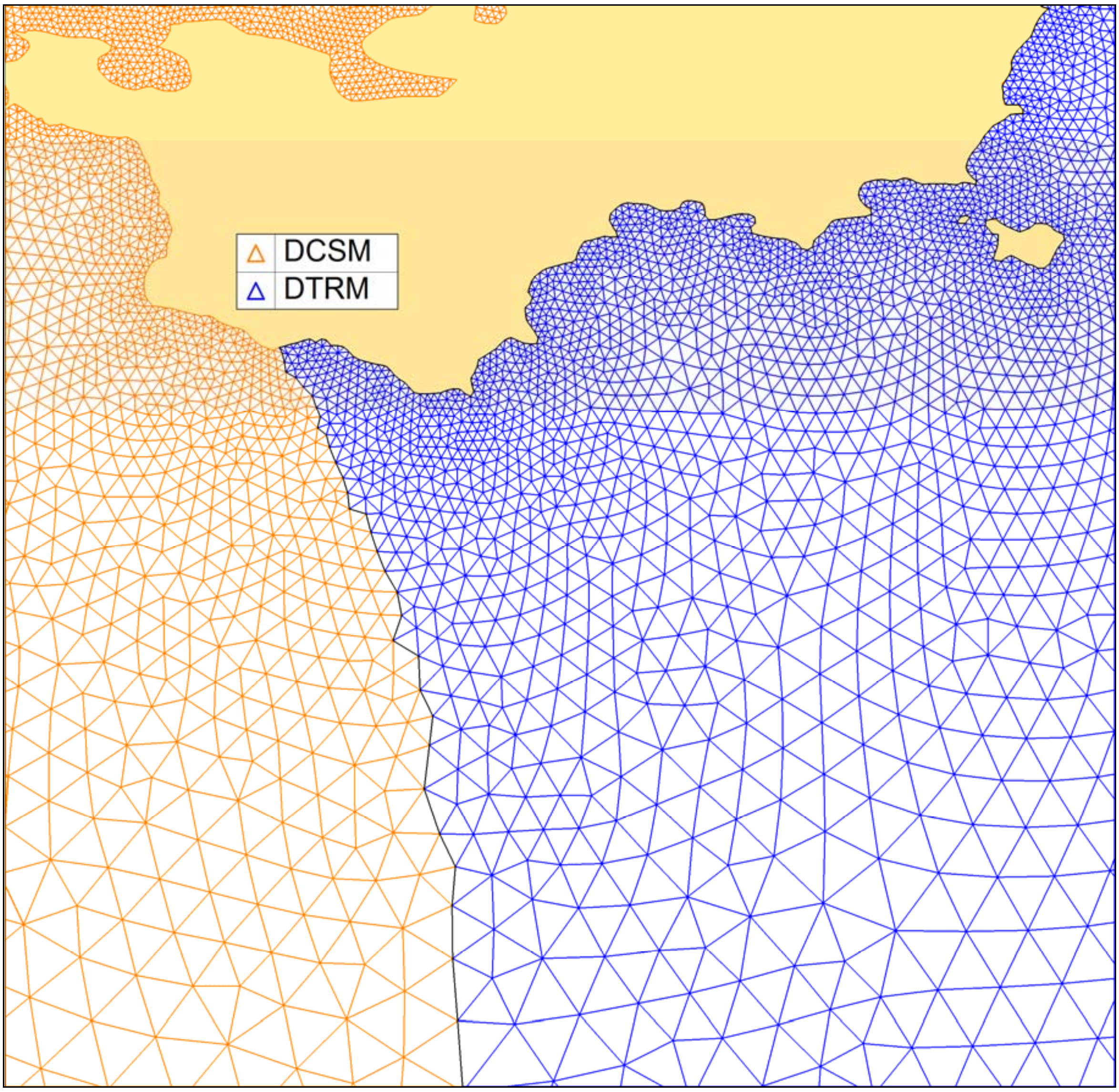


Figure 1 Tidal boundary of the Bristol Channel DTRM illustrating node-to-node boundary fitting

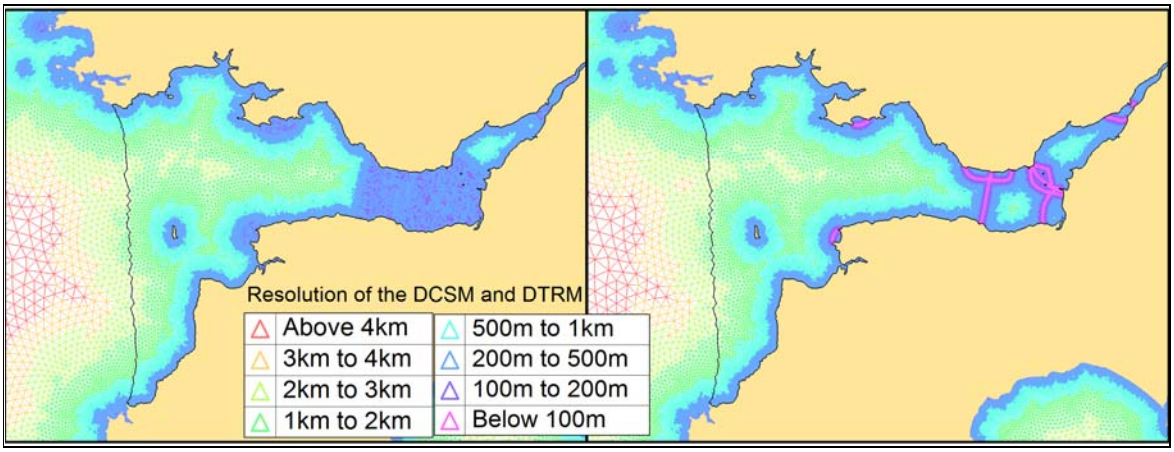


Figure 2 Extent and resolution of the DTRM in comparison to the DCSM

3.3 Exchange of primary variables between models

Should the DCSM and the detailed model(s) be run separately but dynamically coupled concurrently, the DCSM primary variables (as defined in Section 2.1.2) would need to be exchanged on a time step basis. Having chosen to build one MCSM from the two models, the exchange of primary variables between the detailed local model(s) and the outer DCSM is trivial: this methodology calls for only one TELEMAC-2D computation throughout.

3.4 Computing time of the MCSM based on the Bristol Channel DTRM

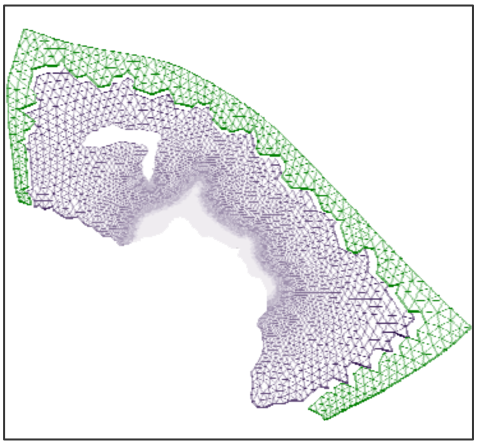
In the specific case of the Bristol Channel DTRM, because the corresponding MCSM would include the DCSM with more than a million calculation points, it should be run on a super computer. In addition, because the MCSM would include the Bristol Channel DTRM with a time step 6 times smaller than that of the DCSM, simulations of the MCSM would be expected to take 5 to 10 times longer (or utilise 5 to 10 times more of the super computing resources) than the DCSM on its own. It is reminded that construction of the MCSM was not part of the TRM project. As such, the runtimes and considerations given in this document are only indicative.

In view of the increased runtime and/or CPU demand, should far-field effects also be of interest, it is recommended, instead, to reuse the same scenario inputs to the DTRM, but run the inputs through either the CCSM or the DCSM to predict the effect of the scenario outside of the area covered by the DTRM. Inputs to all models developed throughout the ETI’s TRM Project have purposefully been made consistent with one another and are interchangeable between models.

3.5 Extension to the construction of the MCSM

Similarly to the methodology detailed in PM01.05 – Interface Specification for Detailed Tidal Current Model with CSM, an extension to the above methodology has been considered that provides further flexibility for those detailed local models where the unstructured mesh cannot be aligned directly to the internal edges of the CSM.

The underlying premise is to extract a portion of the mesh from the detailed local model well within the internal edges of the CSM (blue triangles in the illustration next page) having identified a boxing area where the resolution of the detailed local model is similar to that of the CSM. The modeller will then have to fill in the gap created between the sub-mesh of the detailed local model and the internal edges / vertices with an intermediate mesh (green triangles) to join with the outer CSM. Again, this shows an arbitrary model mesh, not related to the TRM project, for demonstrative purposes only.



It is recommended that the use of the extended methodology be limited where possible and that future models comply with the procedure outlined in Section 3.2 as mesh generation of the gap requires the modeller's input and is therefore a process that cannot be automated.

4 KEY FINDINGS

- A methodology is proposed which is identical to the methodology detailed for the interface with Detailed Tidal Current Models. The use of this methodology has been illustrated with the example of the Bristol Channel DTRM (see PM04.09). In this methodology, the detailed local model mesh is substituted into that of the CSM and the energy schemes fully parameterised.

- For this methodology, the detailed local model has to be based on an unstructured mesh so that it can be substituted adequately into the CSM. It is noted that this is not an issue for the Bristol Channel DTRM.

- Because of restrictions in the CCSM resolution, the Bristol DTRM mesh could only be substituted into the DCSM to yield a MCSM.

- Parameters and the parameterisation of the energy schemes used in the detailed local model(s) have to be transposed to those used in the MCSM.

- The computational run time of the MCSM proposed will increase in proportion to the combined number of prediction points (the DCSM has more than a million calculation points) and to the smaller time step (for example, the Bristol Channel DTRM has a time step 6 times smaller than the DCSM).

- In the case of the Bristol Channel DTRM, it is expected that computation time would increase by a factor between 5 and 10 (indicative only since construction of the MCSM was not part of the TRM project). For this reason, should far-field effects also be of interest, it is recommended, instead, to reuse the same scenario inputs to the DTRM, but run the inputs through either the CCSM or the DCSM to predict the effect of the scenario outside of the area covered by the DTRM. Inputs to all models developed throughout the ETI’s TRM Project have purposefully been made consistent with one another and are interchangeable between models.

- An extension to the above methodology has been considered that provides further flexibility for those detailed local models where the unstructured mesh cannot be aligned directly to the internal edges of the CSM.

5 CONCLUSIONS AND RECOMMENDATIONS

The *Energy Technologies Institute* (ETI) has proposed the development of 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 and to evaluate their impact on European coasts. The CSM was delivered to, and signed off by, the ETI as part of Milestone 2 of this *Tidal Resource Modelling* (TRM) project. *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 TRM scope of work delivered by B&V as prime contractor.

This specification document fulfils the ETI's objectives and requirements, and forms the D08 deliverable (PM04.08). It describes methodologies to interface the CSM with external detailed local model(s) that represent the tidal range energy schemes in detail, to the level of individual device intakes and outlets through the barriers or barrages, or at least represent the physics of individual devices.

A methodology is proposed (Section 3), which is illustrated with the example of the Bristol Channel DTRM (see PM04.09). In this approach, a *Modified Continental Shelf Model* (MCSM) is to be developed through the substitution of the detailed local model(s) mesh into that of the CSM. Detailed local model(s) set up for selected sites of interest would be integrated following internal edges and model vertices. Because of the coarser resolution of the CCSM, it is expected that detailed local models can only be substituted into the DCSM. For existing detailed local models, it is proposed that the mesh be incorporated in the DCSM where the resolution is similar between the two models. That may be far from the area of interest and may require substantial effort from the end-user. For new detailed local model(s), it is recommended that the edges in the DCSM be part of the future detailed model(s) to simplify (and automate) the substitution into the DCSM. It is noted that the time step of the MCSM will be smaller than that of the DCSM because of the finer resolution introduced with the detailed local model(s). This, and the greater number of prediction points in the combined mesh, will yield increased computational run times for the MCSM compared to the DCSM.

These methodologies and procedures are essentially the same as for detailed tidal current models, which were discussed at a workshop held on November 2nd, 2011, and attended by the management and modelling teams of the ETI's PerAWaT project. The consensus was that the methodology (so called the alternative methodology in PM01.05) offered a suitably generic geographical interface, and a suitably standard parameterisation of the energy schemes that it can be transposed from the detailed local model(s) to the MCSM.

Finally, despite the methodology presented, due to the increased run time of the MCSM, it is recommended, instead, to routinely reuse the same scenario inputs to the DTRM, but run the inputs through either the CCSM or the DCSM to predict the effect of the scenario outside of the area covered by the DTRM. Inputs to all models developed throughout the ETI's TRM Project have purposefully been made consistent with one another and are interchangeable between models.