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TEL2TOM: coupling TELEMAC2D and TOMAWAC on arbitrary meshes

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Abstract—In this paper, a novel approach is presented to perform coupled simulations of TELEMAC2D and TOMAWAC. In this approach different meshes are considered: a dense mesh for TELEMAC2D in order to manage fast and accurate resolution of the flow and a much coarser for TOMAWAC in order to increase the computational speed of the wave model. The communication of flow variables is implemented by means of linear interpolation. Two applications are presented utilizing the TEL2TOM functionality: the existing littoral test case from the TELEMAC2D test bank, and a real world application in the Belgian coastal zone.

I. INTRODUCTION

Currently, TELEMAC and TOMAWAC use the same computational meshes for performing coupled simulations of waves and currents. However, it would be advantageous to be able to use different meshes in TELEMAC and TOMAWAC. Then it would be possible to use a different spatial resolution in each model, which could lead to a substantial speed up in case a course mesh is used in TOMAWAC than in TELEMAC. Additionally it would be possible to use domains with different spatial extents. This could for example be used to exclude bays or rivers from TOMAWAC, where little wave action is expected. Another use would be to use a larger domain for TOMAWAC than for TELEMAC, in order to have a smoothly varying wave field at the boundary of the TELEMAC domain, which is beneficial when performing simulations of wave-current interaction. Because of the preceding examples, a very flexible coupling method is needed, that permits the use of interpolation as well as extrapolation. Moreover, in order to have fast calculation times, the coupling should be fully parallel and have little computational overhead.

The objective of the present paper is to present flexible model coupling framework developed within TELEMAC, which is applied to coupling TELEMAC2D and TOMAWAC on arbitrary grids. Further it is the objective to show examples of the application of this framework in a simplified and a real world test case.

II. DESCRIPTION OF THE CODE DEVELOPMENT

Model coupling framework

Presently, already some module coupling frameworks exist such as MCT [1] or OASIS, which served as inspiration for the present code development. However, it was chosen to use a custom module coupler, specially designed for TELEMAC, rather than a general purpose model coupler. In this way maximum advantage of TELEMAC could be taken, while minimizing the changes needed to the code.

The coupling module consists of a main module couple_mod.F whose objectives are to exchange data in parallel between two models, which may have different meshes as well as different domain compositions (though both are using the same number of processors). The module is intended to be as flexible as possible, allowing the communication of a varying number of variables between both models. Also, the module is designed to allow interpolation and extrapolation of variables in a flexible way, based on weight factors and matching node numbers specified by the user in the geometry files of each coupled model. In this way different interpolation methods can easily be defined. For example:

- Nearest neighbour interpolation can be defined, by using a single node number of the closest node, with a weight factor of one. This type of interpolation can also be used for extrapolation (for data on nodes outside of the mesh).
- Bilinear interpolation (on a triangular mesh), can be obtained using the three nodes of a triangle in the mesh of the sender with the weights for the three points determined according to the distance of the node to the tree other nodes.
- Other forms of interpolation (e.g. inverse distance interpolation or conservative interpolation) can be used using a larger number of nodes from which information is received.

It was chosen to let the user provide the information about interpolation and extrapolation in order to allow maximum flexibility. Many optimized routines are available, for example Python or Matlab, to determine these coefficients efficiently during preprocessing.

The general methodology of the coupling is as follows:

- In a model receiving information, the following information is defined for each node of the mesh:
Global node number(s) in the sending model from which information is received at a point. The number of nodes from which information is received can be varied, but is constant for all the points in the mesh. Hence one can specify for example to use information from three nodes (e.g., for linear interpolation) when sending information from TELEMAC to TOMAWAC, but only use information from one node (for nearest neighbour interpolation), when sending information from TOMAWAC to TELEMAC. However, in this example, each node in TOMAWAC needs to receive information from three different nodes in TOMAWAC. In case one wants to use information from less nodes for some specific locations (e.g., to mix nearest neighbour and linear interpolation), one has to specify some dummy node numbers, in combination with a weighting factor (described below) of zero. In case a node does not receive any information from the sending model, the number of the node from which information is received is set to zero. In that case, a default value (typically zero) is applied on the received information.

There are weighting factors specifying the weight applied to a variable on the sending process in order to determine the interpolated variable on the receiving process. This weight is specified on each node of the sending process that are used to determine the value on the receiving process. The sum of these weights should be one.

The node numbers from which information is received and their corresponding weights are used to determine the parallel communication pattern between the two models.

At each coupling period step, information is exchanged in parallel between the two models. In order to interpolate, the weighting factors are used.

The module consists of the following subroutines:

**INIT_COUPLE:** initialisation of the coupling module, which allocates memory for the data structures used in the coupling.

**ADD_SENDER:** Every model that sends information to another module calls this routine once, in order to let the coupler know that it will send information to another model. In this routine, some memory allocations are done, and the list of global node numbers from the sender is sent to all processes of the receiving model.

**ADD_RECEIVER:** Every model that receives information will call this module once. First the list of global node numbers is received from the sending model. Then, the node numbers of the sending model from which information is expected are read from the geometry file (in a separate subroutine READ_RECV). Also the weighting factors related to these are read. The list of node numbers from which information is expected, in combination with the received global node numbers of the sending model are used to determine how to communicate data from the sender to the receiver by making lists of data to send, and data to receive, i.e., a mapping between the sender and the receiver. The lists of node numbers from which information is expected, is communicated to the right processor of the sender model.

**SEND_COUPLE:** this routine is called by the sender at every coupling period time step. This routine sends the necessary variables to the correct process of the receiver, using the mapping defined in ADD_RECEIVER.

**RECEIVE_COUPLE:** this routine is called by the receiver at every coupling period time step. It receives the data sent by SEND_COUPLE, and performs the interpolation using the stored weighting factors.

**END_COUPLE:** Deallociation of the memory used for the coupling.

**Application for coupling TELEMAC and TOMAWAC**

The implementation is made in the cookiecuttershark branch, which is based on TELEMAC v7p2r1. In order to apply the coupling module for coupling TELEMAC and TOMAWAC, the following modifications of the code are made:

- Two new variables are added (type bief_obj; object of objects), namely TEL2TOM and TOM2TEL. Through POINT_TELEMAC2D and POINT_TOMAWAC, the subroutine ADDBLO is called to set pointers to the coupled variables. The number of variables being communicated is stored in the new variables NVARTOM2TEL and NVARTEL2TOM.
- The variables that can currently be communicated are:
  - Water depth, U velocity and V velocity (from TELEMAC to TOMAWAC)
  - Significant wave height, Peak period, Wave radiation forces (in x and y directions), Wind velocity (in x and y directions), orbital wave velocity and mean wave direction (from TOMAWAC to TELEMAC).
- The variables that are communicated (for example water depth), need to be defined
Each model (TELEMAC and TOMAWAC) have already dedicated variables to define the mesh (defined in declarations_telemac2d.f and declarations_tomawac.f). Nevertheless both variables are used in the subroutine homere_telemac2d.f, and hence it was necessary to define in the latter an alias for the TOMAWAC mesh. Moreover, there is one variable related to the mesh in parallel, which is not in the variable MESH, but in the variable NPTIR. Therefore, it is necessary to update this variable by calling the subroutine GET_MESH_NPTIR in the subroutines WAC and TELEMAC2D.

Note also that PARTEL splits each geometry file separately by default. Hence no changes to PARTEL or the PYTHON scripts were necessary for the coupling of TELEMAC and TOMAWAC with different meshes. Also GRETEL correctly merges the meshes in case different meshes are used. Hence changes to GRETEL were also not needed.

Some function calls to the coupling routines need to be made. The routines ADD_SENDER and ADD RECEIVER are called twice in HOMERE_TELEMAC2D, once for sending information from TELEMAC to TOMAWAC and once for sending information from TOMAWAC to TELEMAC. The functions SEND_COUPLE and RECEIVE_COUPLE are used to exchange data between the modules during the initialisation and at every coupling period time step.

Finally, some default values were needed in the initialisation (for example the radiation forces were set to zero in the initialisation).

**Limitations**

Presently there are some limitations, when using the coupling:

- The coupling currently only works in parallel (using more than one processor for each coupled model). This stems from the fact that in the present implementation, the global node numbering (in the variable MESH%KNOLG) is used to determine the communication between the two processes. This variable does not exist for one processor. In principle, this limitation can be overcome quite easily.

- The number of processors needs to be the same for each coupled model, as there is currently. This limitation stems from the fact that TELEMAC2D and TOMAWAC use the same variable NCSIZE to specify the number of processors that is used.

- No special treatment of dry nodes is currently implemented.

- No special interpolation method is used for interpolating wave directions, which may give inaccurate results for a wave direction close to 0 degrees. In principle this limitation could be easily resolved by sending the sine and cosine of the wave direction, rather than the wave direction, which can be interpolated without any problem. The wave direction can then

- The coupling is currently only implemented between TELEMAC2D and TOMAWAC, not yet between TELEMAC3D and TOMAWAC. In principle, this extension to TELEMAC3D is straightforward, especially when the exchange is limited to two-dimensional variables (as it is the case in TELEMAC v7p2). In that case, the changes that need to be made are limited to a number of function calls to the coupling routines within TOMAWAC-3D, and the definition of some separate variables in TELEMAC3D for the coupling. The flexibility of the coupling module, also allows three-dimensional information to be sent, for example by specifying each vertical layer as a separate two-dimensional variable, defined as a pointer to a part of a three-dimensional variable.

**III. TEST CASES**

**Schematic test (Littoral)**

In order to test the TEL2TOM functionality, an existing TELEMAC test (littoral) was executed. In this test case, the three-way coupling between TELEMAC2D, TOMAWAC and SISYPHE is tested. The test case describes a beach with a slope of 1:5, on which waves (significant wave height 1.0 m, peak period 8.0 s, wave direction 30°) propagate toward the coast. The waves generate a longshore current in the breaker zone, which on its turn induces sediment transport (calculated using the equation of Bijker). On the lateral boundaries of the TELEMAC model, a custom FORTRAN code is used to calculate the lateral velocity from the radiation stresses calculated in TOMAWAC. Note that in principle, it would have been possible to use the Neumann boundary conditions developed by [2] to calculate the velocity at the boundary, but it was chosen to keep the test case as close as possible to the original one. For the test case, two different setups were tested (Figure III-1):

- Settings comparable to the original test case setup (further referred to as fine). The same mesh is used for TELEMAC2D as for TOMAWAC. In order to have a fully developed wave profile at the lateral boundaries the wave
spectra at the centreline of the model are applied to the lateral boundaries using a custom boundary condition. The settings for TEL2TOM were defined such that data was directly applied at each node (without any interpolation).

- A setup with different meshes (further referred to as coarse). The mesh for TELEMAC2D and SISYPHE was kept the same as in the original test case. However, the mesh for TOMAWAC was coarsened by a factor 2. Further, the TOMAWAC domain was extended laterally to make sure that a correctly developed wave profile forms at the lateral boundary of the TELEMAC model (Figure III-1). On the lateral boundaries, a wave height of 1.0 m was applied.

Hence the custom FORTRAN code for transferring wave conditions from the centre to the boundary was not used any longer. The weighting factors were set such that linear interpolation was used to exchange information between the two meshes. The extrapolation used on the extended TOMAWAC domain, outside TELEMAC2D mesh, was the nearest neighbour method.

Each case was run on two parallel processors (the minimum number of processors to use in TEL2TOM).

The results from the first case in TELEMAC v7p2 (using TEL2TOM), not shown, and from the original test case in TELEMAC v7p3 are similar. Nevertheless some small changes existed in the spin-up period, because of changes in the application of the boundary conditions in TOMAWAC between v7p2 and v7p3.

Results of the wave height, velocity profile and free surface elevation on a profile perpendicular to the beach in the centre of the domain, using TEL2TOM with the same and with different meshes, are shown in Figure III-2 to Figure III-4. In general the results are very similar. The wave height has the same maximum in both cases, but the profile is slightly different around the breaker zone, due to the differences in mesh resolution between TOMAWAC and TELEMAC2D. This leads to a wave driven current, with a slightly broader profile (but the same peak velocity) as in the case with the same meshes. The current profile is slightly broader in the case with the coarse TOMAWAC mesh, with a slight change of the location of the peak. This is presumably, because the force due to radiation stresses is very non-linear, but is interpolated using linear interpolation, such that the force profile is slightly different between the two cases. Also the calculated wave setup is very similar between the two models. With respect to the calculation time, the coarse case with two different meshes is about two times faster than the original case.

Hence this test case shows that, using TEL2TOM, similar results can be obtained with the same or different meshes, but that substantial calculation time (as well as storage space for output) can be saved. Also this test case shows that using extrapolation of water depths and velocities outside the TELEMAC2D domain, a more flexible modelling approach is possible, which can be for example advantageous in determining boundary conditions for TOMAWAC on the boundary of a TELEMAC domain.
The TEL2TOM functionality has also been implemented within the Scaldis-Coast model for simulating tidal flow, wave flow and sediment transport within the Belgian coast. The computational meshes for TELEMAC2D and TOMAWAC are presented in Figure III-6. In this application, both TELEMAC2D and TOMAWAC have the same offshore boundary, but, within the TOMAWAC domain, the inner ports, the Eastern Scheldt and Western Scheldt regions have been excluded in order to reduce number of elements in the mesh. Furthermore, the minimum resolution of TOMAWAC is substantially coarser (using elements of 50 m resolution) than the resolution of the TELEMAC2D mesh in the coastal zone (using elements of 25 m). This resulted in the reduction of the number of nodes for TOMAWAC down to 137,752 from the initial number of 258,390 (46.6% reduction). Linear interpolation is used for exchanging information between TELEMAC2D and TOMAWAC.

The coupled model simulated a period of 8 days starting from 16 Nov 2015 and the wave boundary conditions came from Westhinder station (code name WHIDW1, Figure III-5). The model results are compared with the dataset collected at stationary measurement points in the Broersbank project ([3]).

The TEL2TOM model results are given in Figure III-7 and Figure III-8 in terms of significant wave height and mean period, respectively. The results demonstrate a very good agreement with the observations (and comparable to results obtained using the same mesh for TELEMAC2D and TOMAWAC, not shown). However, the simulation time is reduced significantly, more or less by a factor 2.
Figure III-6: Computational domains and meshes for TOMAWAC (upper figure) and TELEMAC2D (lower figure) for the TEL2TOM simulation of the Scaldis-Coast model.
Figure III-7: Comparison of significant wave height between the observed data and modelled results at measurement stations, for a coupled TELEMAC2D-TOMAWAC case using TEL2TOM with a coarser TOMAWAC mesh.
Figure III-8: Comparison of mean wave period between the observed data and modelled results at measurement stations, for coupled a TELEMAC2D-TOMAWAC case using TEL2TOM with a coarser TOMAWAC mesh.
IV. USER MANUAL

In order to use different meshes on TELEMAC2D and TOMAWAC coupling the following should be done:

1.) Generate separate GEOMETRY FILES for TELEMAC2D and TOMAWAC (with a different mesh). Add these on each respective .cas model file.

2.) Add to the TOMAWAC GEOMETRY file the following variables:
   a. TEL2TOM01: This variable contains, for each node in the TOMAWAC mesh, the number of the first node in TELEMAC from which TOMAWAC receives information. In case the node does not need to receive information, set this number to zero.
   b. TEL2TOMWTS01. The weight factor applied to the information received from the node specified in TEL2TOM01.
   c. Optionally add information from additional nodes in variables TEL2TOM02 to TEL2TOMNN, where NN is the number of nodes from which information is received.
   d. For each of these additional variables TEL2TOM02 to TEL2TOMNN add the corresponding weights TEL2TOMWTS02 to TEL2TOMWTSNN. For each receiving node, the sum of the weights of the sending nodes must be equal to one.

An example of the above procedure is shown in Figure IV-1, for a simple mesh consisting of one TOMAWAC element and two TELEMAC2D elements.

3.) Add to the TELEMAC2D GEOMETRY file the following variables:
   a. TOM2TEL01 to TOM2TELNN: for each node in TELEMAC mesh, it has the node number in TOMAWAC from which TELEMAC receives information. It works in a similar way as explained above for TEL2TOM.
   b. TOM2TELWTS01 to TOM2TELWTSNN: the corresponding weights to send information from TOMAWAC to TELEMAC.

4.) Specify the keyword PARALLEL PROCESSORS in TELEMAC and TOMAWAC .cas files. Use the same number of processors in both models. The minimum number of processors that can be used is currently 2.

V. SUMMARY AND CONCLUSIONS

In this paper, the TEL2TOM functionality has been presented. Through this novel approach, TELEMAC and TOMAWAC meshes and domains can be different. The TEL2TOM has been firstly applied in a schematic case through the Littoral tutorial and then in a real application within the Belgian coast using the Scaldis-Coast model for tidal flow and waves. The use of TEL2TOM resulted in significant computational speed-up (to a factor of 2) while showing similar accuracy against field measurements for waves in the Belgian coast.

REFERENCES

