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New method for coupling 1D unsteady flow hydraulic models using RST equations

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Abstract. *This paper is devoted to the presentation and evaluation of different alternatives to couple two 1D hydraulic models based on the Saint-Venant's equations. This presentation is first giving a short description of the coupling platform we use for these tests, namely the PALM coupling platform developed by Cerfacs. Then, we present 2 classical methods for this coupling: 1-way and 2-way. The 2-way method has itself different options depending on the variables exchanged at the coupling interface. Since we are using the implicit Preissmann scheme to solve numerically the Saint-Venant's equations, we can imagine another option using the so-called RST equations. This method is not very intrusive into the source code since it does not require any additional calculation, and can improve a lot the results obtained by the 2 coupled models compared to the global one. This method can be implemented in an implicit way, being equivalent to the global model, or explicitly with some degradation of the results.*

1 Introduction

The coupling of different types of models is gaining more and more attention recently. This is due, in particular, to the needs of more global model encompassing different disciplines (eg.: multi-physics) and different approaches (eg.: multi-scale, nesting, 1D-2D-3D) (see [?], [?], [?], [?], [?], [?], [?]). Also, the possibility to assemble different modeling units inside a friendly modeling software platform is an attractive solution compared to developing more and more global complex models. This coupling problem can be seen from at least 2 very different perspectives: coding or software aspects (how to put the models together, link them, run simulations and get results) and physical or algorithmic aspects (what variables must be exchanged at the coupling interfaces and how).

2 Software aspects of coupling

On the coding or software aspects of coupling there have been lots of recent developments with different alternatives and available packages.

We can, for example, quote the OpenMi European initiative defining a standard communication protocol between different softwares implementing this interface. This approach implies the development of specific routines (OpenMi API) into the model code(s). The different models can then exchange data at their interfaces without using other third party platforms. But this approach has also several limitations, for example not allowing to couple several instances of the same program. Also, since the two models are communicating directly between them, without being included into a supervisory platform, the coupled simulations cannot benefit from high level toolboxes such as optimization, sensitivity analysis or data assimilation ones.

We can also quote other approaches such as the PALM coupling platform developed by Cerfacs [?]. The original model codes have to be "Palmerized", which means slight local modifications to declare the variables that can be exchanged (input or/and output) with the other models. Then, a user friendly interface named PrePALM (Fig. **??**) allows to construct the global model by linking the different units together. PALM is the platform we use for the tests presented in this paper.

In Fig. **??** we have coupled (2-way coupling) two instances of the 1D hydraulic model SIC (or more precisely its unsteady flow module Sirene) developed by Cemagref ([?]).

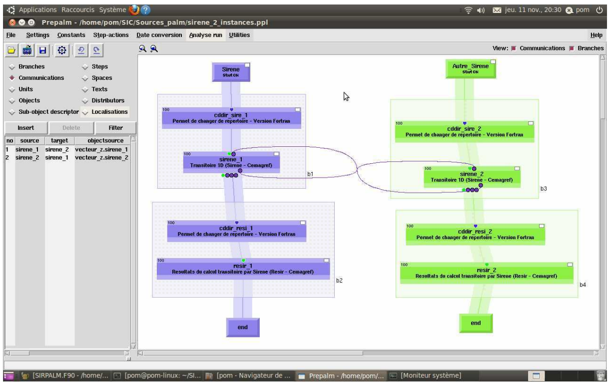

Figure 1: Coupling of models in the Palm platform

3 Algorithmic aspects of coupling

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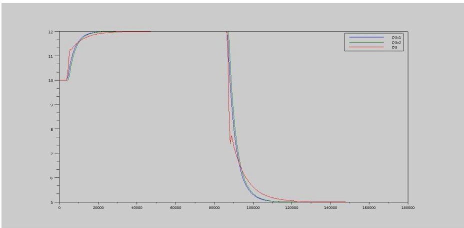
In order to illustrate different basic coupling methods and present the new one based on RST equations, we select a simple example of two reaches of a canal or river connected in series. The flow at the tail of the first upstream reach enters at the head of the second downstream reach.

If the flow conditions are supercritical (Froude number $F > 1$) the calculation can be done for each reach separately, in cascade from upstream to downstream. Indeed, two upstream boundary conditions are used for the calculation of either reach and no downstream boundary condition is required. In this specific case, the calculation in cascade of reach 1 and then reach 2 using a 1-way coupling (providing 2 variables at the coupling interface) would give the same results as the global calculation of the entire 2-reach river. The same remark is valid for the coupling of hydrologic and hydraulic models when there is no feedback from the hydraulic model towards the hydrologic one (see [**?**] [**?**]).

But in most cases, irrigation canals or rivers are under subcritical flow conditions, at least in most of their spatial sections, and during most of the time. In this case, we know that the hydraulic calculation of a reach needs one upstream and one downstream boundary condition. This is due to the hyperbolic nature of the equations and with two opposite directions for the characteristic lines. It is then impossible to make the calculation in cascade (in either order) of one reach after the other without simplification hypothesis and therefore degradation of the original global solution.

3.1 1-way coupling

We can first check what happens if we handle the coupling interface only 1-way. In this case, we propagate the flow at the coupling interface from upstream to downstream. For the downstream boundary condition of the first upstream reach we keep a local rating curve $Q(Z)$.



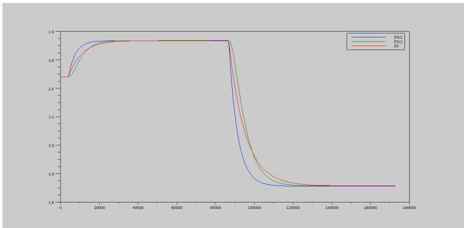


Figure 2: Discharge and Elevation at the coupling interface, 1-way coupling, $\Delta t = 600s$

We observe in this case, that the approximate solution obtained with this 1-way coupling has errors compared to the global true solution, either in terms of discharges Q and water elevations Z (Fig. **??**). This error does exist even if we reduce the calculation time step Δt since this is a physical modification of the system, and not only a numerical one. This error is plotted in Fig. **??** at the coupling interface, but also propagates further upstream and downstream.

3.2 2-way coupling

In this case we exchange two variables at the coupling interface, so as to provide one required boundary condition for each reach. The information used for one reach is coming from the other one. Eventhough we know the number and locations of the required boundary conditions to get a well-posed problem, there exist many different options for these variables. The basic option presented here (Fig. **??**) consists in providing the flow Q from reach 1 to 2 and the water elevation Z from reach 2 to 1. The physics is respected, but the exchange of coupling variables being made with one time step delay, we can observe some oscillatory behavior.

The above results can be improved by reducing the calculation time steps Δt_1 and Δt_2 of the two coupled models (Fig. **??**). But in this case we loose the advantages of using an implicit scheme such as the Preissmann scheme.

In order to overcome the problems illustrated in this section, we have again several options. The first one is to make iterations of the coupled models, until

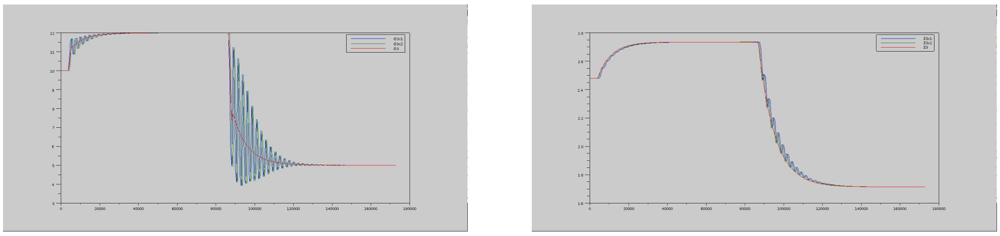


Figure 3: Discharge and Elevation at the coupling interface, 2-way coupling, $\Delta t = 600s$

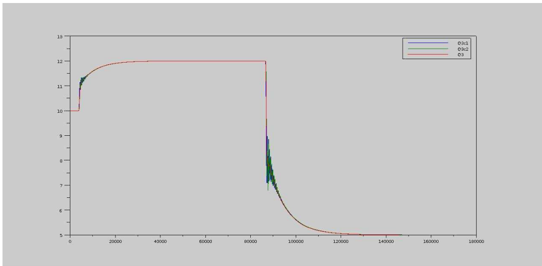


Figure 4: Discharge at the coupling interface, 2-way coupling, $\Delta t = 120s$

the variables exchanged at the interface converge towards the same values. This needs a supervision platform, such has PALM allowing the management of this type of iterations. The advantage of this method is to be non-intrusive, since this does not necessitate any further modification of the several codes involved. But there are several drawbacks. As for any iterative methods, the questions of convergence should be addressed. The required CPU time can be large, eventhough the number of iterations can be minimized for example using methods based on the Riemann invariant variables (cf. [**?**]).

4 New solution for coupling

In order to present a new method for coupling 1D models, we give some more details on the equations and numerical scheme we are using. The dynamic behavior of water in an open-channel is well described by the so-called Saint-Venant's equations:

$$\begin{cases} \frac{\partial Q}{\partial x} + \frac{\partial S}{\partial t} = 0 \\ \frac{\partial Q}{\partial t} + \frac{\partial \frac{Q^2}{S}}{\partial t} + g.S\frac{\partial Z}{\partial t} + g.S.J = 0 \end{cases} \tag{1}$$

where Q is the discharge (m^3/s), S the wetted cross-area (m^2), Z the water elevation (m), J the friction slope, x the longitudinal abscissa (m) and t the time (s). The friction slope J is usually obtained from the Manning-Strickler formula: $J = \frac{n^2Q^2}{S^2R^{\frac{4}{3}}}$, where n is the Manning's coefficient (0.02) and R is the hydraulic radius (m) ($R = \frac{S}{P}$, where P is the wetted perimeter).

The two hyperbolic, first-order, non-linear, partial-derivative equations Eq. (**??**) are discretized and linearized in time (Δt time step) and space (Δx space step) through the implicit Preissmann finite difference scheme ([**?**]). The obtained set of numerical equations are solved using the double-sweep method.

The two Saint-Venant's equations after the discretization between two sections j and $j+1$ give the following relations ([**?**]):

$$\Delta Z_j = e\Delta Z_{j+1} + d\Delta Q_{j+1} + f \tag{2}$$

$$\Delta Q_j = b\Delta Z_{j+1} + a\Delta Q_{j+1} + c \tag{3}$$

The upstream boundary condition is linearized:

$$r_1\Delta Q_1 + s_1\Delta Z_1 = t_1 \tag{4}$$

where r_1, s_1, t_1 are three known coefficients corresponding to the first section of the reach (subscript 1). This equation is named impedance relation for the section 1. The first sweep consists in triangularizing the matrix of $2n$ equations (n sections within the reach, so $2(n-1)$ Saint-Venant equations and 2 boundary conditions). That means to compute the impedance relation in each section by recurrence:

If r_j, s_j, t_j are known values at section j, the impedance relation for section j can be written as:

$$r_j\Delta Q_j + s_j\Delta Z_j = t_j \tag{5}$$

Replacing equation (**??**) by r_j (**??**) - (**??**) + s_j (**??**) gives:

$$r_{j+1}\Delta Q_{j+1} + s_{j+1}\Delta Z_{j+1} = t_{j+1} \tag{6}$$

with

$$\begin{cases} r_{j+1} = r_j a + s_j d \\ s_{j+1} = r_j b + s_j e \\ t_{j+1} = t_j - r_j c + s_j f \end{cases} \tag{7}$$

The impedance relation in the last section n is then:

$$r_n \Delta Q_n + s_n \Delta Z_n = t_n \tag{8}$$

The downstream condition is linearized, the same way as for the upstream condition:

$$r'_n \Delta Q_n + s'_n \Delta Z_n = t'_n \tag{9}$$

where r'_n, s'_n, t'_n are known values, depending on the type of downstream boundary condition.

The solution of equations **??** and **??** gives ΔZ_n and ΔQ_n. The second sweep allows calculating ΔZ_j and ΔQ_j for the $(n-1)$ remaining sections j going from downstream to upstream.

Let's suppose we want to couple 2 unsteady flow 1D models at some interface section k. The idea of the RST coupling method we propose in this paper is to exchange the r_k, s_k, t_k variables of the impedance relation for section k. This can be done explicitly with a one time step delay. But this can also be done keeping the implicit feature of the double sweep method. In this case the procedure is the following:

- run the first sweep on reach 1
- provide the 3 r_k, s_k, t_k scalar variables of the impedance relation though the coupling interface, from reach 1 to reach 2
- run the first sweep on reach 2
- run the second sweep on reach 2
- provide the 3 r_k, s_k, t_k scalar variables of the impedance relation though the coupling interface from reach 2 to reach 1
- run the second sweep on reach 1

This method does not require any additional calculation, since the impedance equations are already computed. It just needs exchange of 3 scalar variables through the coupling interface, upward and downward. It is equivalent to the global calculation, but allowing modularity of different instances of 1D hydraulic model to be coupled.

5 Conclusion

A new method for coupling different instances of 1D hydraulic models has been presented, based on RST equations. This is equivalent to the global calculation in simple cases (2 reaches in cascade). But at the same time, the modularity offered by handling such coupling method allows many interesting applications, using a coupling platform such as PALM. For example, coupling 1D models with other types of models (handling supercritical flows, open channel 1D and sewer 1D models, etc). We can also imagine extensions of this method for the coupling of 1D-2D models since the RST method is providing a boundary condition at the interface.

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REFERENCES

[1] R. E. Beighley, K. G. Eggert, R. L. Ray, C. J. Wilson, M. K. Greene, G. L. Altman, J. C. Rowland, B. J. Travis, and D. M. Lawrence, Coupling hydrologic and hydraulic models in the Mackenzie Basin to quantify the spatial and temporal distribution of surface and subsurface water storages, American Geophysical Union, Fall Meeting (2010)

[2] L. Yanqing, I-C. Chan, J. Singh, M. Demissie, V. Knapp and X. Hua, Coupling of hydrologic and hydraulic models for the Illinois River Basin, Journal of hydrology, **344**(3–4) (2007) 210–222

[3] E. Blayo, Méthodes de couplage de modèles, Invited Presentation, SimHydro 2010 conference, Sophia-Antopolis, Nice, 2-4 Juin 2010.

[4] J. Leandro, A. S. Chen, S. Djordjevic, D. A. Savic, Comparison of 1D/1D and 1 D/2D Coupled (Sewer/Surface) Hydraulic Models for Urban Flood Simulation, Journal of hydraulic engineering, **135** (6) (2009) 495–504

[5] Finaud-Guyot P., Delenne C., Guinot V. Coupling of 1D and 2D models for river flow modelling, SimHydro 2010: Hydraulic modeling and uncertainty, 2-4 juin 2010, Sophia-Antipolis Nice (France)

[6] E.D. Fernández-Nietoa, J. Marinb and J. Monnier, Coupling superposed 1D and 2D shallowwater models: Source terms in finite volume schemes, Computers and Fluids, **39** (6), June 2010, 1070–1082

[7] A. Ambroso, C. Chalons, F. Coquel, E. Godlewski, F. Lagoutire, P.-A. Raviart and N. Seguin, The coupling problem of different thermal-hydraulic models arising in two-phase flow codes for nuclear reactors, Int. Conf. on Computational Methods for Coupled Problems in Science and Engineering, (2009) CIMNE, Barcelona

[8] Baume Jean-Pierre, Malaterre Pierre-Olivier, Belaud Gilles, Le Guennec Benoit, "SIC: a 1D Hydrodynamic Model for River and Irrigation Canal Modeling and Regulation", in Métodos Numéricos em Recursos Hidricos 7, ABRH (Associacao Brasileira de Recursos Hidricos), Coppetec Fundacao, Editor Rui Carlos Vieira da Silva, 1–81, (2005) ISBN 85-88686-14-7

[9] A. Piacentini, The PALM Group, PALM: A Dynamic Parallel Coupler, Lecture Notes In Computer Science, High Performance Computing for Computational Science, **2565**, (2003), 479–492