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► **To cite this version:**

Sleimane Hariri, Sylvain Weill, Jens Gustedt, Isabelle Charpentier. Pairing GIS and Distributed Hydrological Models Using MATLAB. 2nd Conference of the Arabian Journal of Geosciences (CAJG 2019), Nov 2019, Sousse, Tunisia. pp.257-259, 10.1007/978-3-030-72543-3_103 . hal-02333260

HAL Id: hal-02333260

<https://hal.science/hal-02333260>

Submitted on 25 Oct 2019

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Pairing GIS and distributed hydrological models using Matlab

Sleimane Hariri¹, Sylvain Weill², Jens Gustedt^{1,3}, Isabelle Charpentier¹

¹ ICube UMR 7357, Université de Strasbourg&CNRS, 67412 Illkirch, France

² LHyGeS UMR 7517, Université de Strasbourg&CNRS, 67000 Strasbourg, France

³ INRIA, France

shariri@unistra.fr

Abstract. Observed data are required to carry out hydrological simulations in a watershed for use by policy makers. Hydrological simulations thus require a large interdisciplinary knowledge about modeling, computer sciences, databases, GIS. A Matlab preprocess prior to the hydrological modeling is presented for educational purposes and an easy uptake by non-GIS users. Moreover, this allows for parallel computing. This pre-process builds on two renowned and freely available Matlab toolboxes providing GIS and mesh functionalities. Additional functionalities allow for a decomposition of watersheds with respect to parameterized constraints, including the meshing of the subdomains and the construction of an oriented flow graph. The method is exemplified on a sub-basin of the Saar River.

Keywords: Hydrology, Domain decomposition method, GIS modelling.

1 Introduction

Data – topography, climate, land cover, soil properties – are required to carry out hydrological simulations in a watershed for use by policy makers. These data are of different nature and usually provided with their own standard data format. Topography and land cover are freely available from national agencies or transnational projects like Copernicus or CORINE Land Cover. Climate data are scarcer in both time and resolution. Fortunately, simulations can be performed using reanalyzes [1]. Soil and geology parameters are usually unknowns and calibrated using climate data, discharge data and hydrological models.

Digital Elevation Models (DEM) store projected topographic information in a gridded format and constitute fundamental data to hydrological studies [2]. Spatial heterogeneities can be accounted by mean of a decomposition of the watershed into smaller geographical units. Conceptual models preferably deal with sub-watersheds to facilitate routing. River analyses are carried out using a one- or two-dimensional partial differential model discretized by meshing the major bed and splitting it longitudi-

35 nally. Watershed simulations, surface and underground flows, involve more complex
36 meshes and numerical methods. Domain decomposition has another major advantage
37 since it offers the opportunity to run simulations on a parallel platform.

38 Only basic interdisciplinary knowledge in GIS, hydrology or computer sciences is
39 usually insufficient to carry out numerical simulations because pairing GIS tools,
40 database and computer models is not an easy task. QGIS and GMSH are loosely inter-
41 faced by means of Python and shapefiles read/write. The Python-based open-source
42 framework PIHMgis [3] goes one step further by managing the coupling of GIS tools,
43 data and distributed hydrological modeling through pre- and post-processes. Although
44 a user interface exists and the program code is available, further developments require
45 a good knowledge of GIS tools, Python, and the programming language of the hydro-
46 logical model under study.

47 To overcome this shortfall, Matlab is chosen as a framework for pairing GIS and
48 parallel/distributed hydrological models. Thereby, it enable to take advantage of exist-
49 ing toolboxes [4,5]. This short paper presents a pre-processor written in Matlab that
50 allows for the management of DEMs with regards to hydrological structures, hydro-
51 logical modeling and parallel computing.

52 **2 Methods**

53 The approach is to propose a user-friendly upgradeable open-source interface imple-
54 mented in a classical language in sciences and educational communities. Matlab
55 meets these requirements and, additionally, it provides visualization functionalities. A
56 number of free toolboxes, namely TopoToolbox [4] and mSim[5], offer particular GIS
57 operations and mesh generation (through GMSH), respectively. Working in a non-
58 GIS scientific computing framework rather than in a GIS or Python environment may
59 facilitate the uptake by engineering students.

60 The pre-process workflow ranges from the DEM read to watershed decomposition
61 and sub-mesh generation, carried out with respect to user's constraints.

62

63 **2.1 Domain decomposition**

64 The watershed decomposition can be organized such that it fulfills parameterized
65 user-defined constraints:

- 66 1. the account for important hydrological structures (dams/ponds/discharge station)
67 or bridges that can create logjams. are "primary checkpoints";
- 68 2. the partition of the domain into more sub-watersheds by placing "secondary
69 checkpoints" on the stream;
- 70 3. the design of sub-watersheds with similar areas, typically a few km². The inter-
71 est is threefold: (i) assigning homogeneous data (soil and climate) at the sub-
72 watershed level to account for spatio-temporal variability, (ii) dealing with hydro-

73 logical sub-models of similar size, (iii) balancing the computational load on a parallel platform.
 74

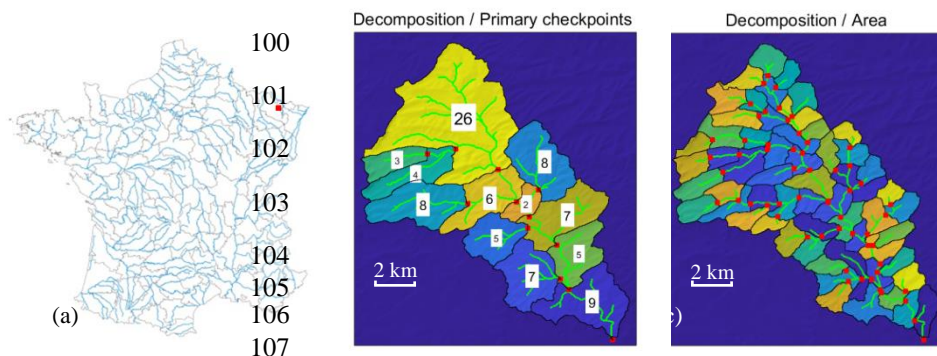
75 All these checkpoints are inlets or outlets of the sub-watershed they delineate. At
 76 surface level, these flow interfaces are located on the stream. Domain decomposition
 77 functionalities are implemented by building on [4, 5] and Matlab.
 78

79 2.2 Preprocess workflow

80 A graphical user interface (not shown here) articulates GIS and meshing operations as
 81 follows: (1) read the DEM [4], (2a) define user outlets as suggested by the first constraint,
 82 (2b) automatically insert additional outlets to satisfy the third constraint, (3)
 83 partition the watershed by delineating drainage basins with respect to these outlets [4],
 84 (4) format the partition as a shapefile for plotting purposes (*shapewrite* and *shaperead*
 85 of the “mapping Matlab toolbox”), (5) mesh the subdomains [5], (6) determine inlet
 86 and outlet faces, (7) order subdomains to build an upstream to downstream graph.
 87 The files generated (sub-domain mesh and oriented flow graph) are used as input file
 88 for the hydrological model.

89 3 Results

90 For the sake of clarity in the figures, the small watershed (89 km²) of the Mutterbach
 91 stream near to the city of Sarralbe (Région Grand-Est, France) is used. To serve as a
 92 defense waterline in 1940, 6 ponds and 5 dams were built to supply water and to control
 93 the floods in the valley. These constitute a set of 11 primary checkpoints allowing
 94 for water management. In Figure 1.b, the decomposition is carried out with respect to
 95 these hydrological structures (marked with red squares). To anticipate parallel computing,
 96 secondary checkpoints have been added to fulfill the third constraint. Figure 1.c
 97 displays a decomposition into 58 subdomains, the areas of which range from 1 km² to
 98 2.5 km² with an average value of 1.54 km². The numbers of nodes/elements in the
 99 sub-meshes are equal to 1260/2200 on average, respectively.



108 **Fig. 1.** (a): Location in France (red point); (b): Decomposition/checkpoints; (b) Load-
 109 balanced refined decomposition.

110 **4 Discussion**

111 Hydrological simulations require a large interdisciplinary knowledge about modeling,
112 computer sciences, databases, GIS... For educational purposes and an easy uptake by
113 non-GIS users, our interdisciplinary team (hydrologists, computer scientists and
114 mathematicians) work on Matlab pre- and post-processes to the hydrological model-
115 ing. These build on two renowned and freely available Matlab toolboxes [4,5] provid-
116 ing GIS and mesh functionalities, respectively. Note that both were designed in a
117 hydrological context and come with user guides.

118 For the sake of reproducibility, proposed domain decomposition functionalities
119 (parameterized constraints, watershed decomposition and oriented flow graph) will be
120 exhaustively described and documented in a future work. Then, Matlab codes will be
121 made freely available to serve as a basis to implement other decomposition con-
122 straints. Complementary tests were performed on the Saar watershed partly located in
123 France and Germany.

124 This hydrology-targeted Matlab-GIS framework is intended to be useful not only
125 for education purposes or for a first contact with GIS tools for hydrology modeling,
126 but also as a common basis for interdisciplinary studies with non GIS users. Moreo-
127 ver, it benefits from the numerous toolboxes already developed in and for Matlab.

128 **5 Conclusion**

129 The Matlab-GIS interface builds on two renowned and freely available Matlab
130 toolboxes providing GIS and mesh functionalities. It has been designed for an easy
131 uptake by non-GIS users and modelers in hydrology. Resulting watershed decomposi-
132 tion can be interfaced with a conceptual model or with a parallelized finite element
133 model for watershed simulations by using the oriented flow graph for routing.

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