FEASIBILITY ANALYSIS ON THE CONSTRUCTION OF A SOLUTION FOR MONITORING AND HYDROMETEOROLOGICAL FORECASTING

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Abstract: The management of water resources, today, is still a global challenge. Current climate models are not yet capable of satisfactorily representing interannual climate variations caused by atmospheric oscillations. Thus, the better representation of water resources issues requires data related to the variables involved with better quality, as well as the establishment of methodologies that demonstrate how these data relate to observed and expected climatic variations. In this context, the WRF-Hydro system represents the state of the art concerning water resources, and the objective of this study through exploratory research is to analyze the viability of a tool capable of monitoring and generating a predictive analysis of water bodies in the MATOPIBA region. (Maranhão-Tocantins-Piauí-Bahia). The region was geoprocessing by ArcGIS and WRF-Hydro was tested with the simulation of some hydrometeorological data for ten days. Although the WRF-Hydro system demonstrates efficiency in the region's hydrometeorological simulation, it has a range of sub-processes that make the learning curve complex. Therefore, due to the possibility of integrating the tools, it is proposed to build a web tool for greater software usability.

Keywords: Water resources, Hydrometeorological forecast, WRF-Hydro, MATOPIBA.

ANÁLISE DE VIABILIDADE NA CONSTRUÇÃO DE UMA SOLUÇÃO PARA MONITORAMENTO E PREVISÃO HIDROMETEOROLÓGICA

Resumo: A gestão dos recursos hídricos, nos dias de hoje, ainda se constitui um desafio global. Os modelos climáticos atuais ainda não têm capacidade de representar de forma satisfatória variações climáticas interanuais causadas por oscilações atmosféricas. Assim, a melhor representação das questões dos recursos hídricos requer dados relacionados às variáveis envolvidas com melhor qualidade, bem como o estabelecimento de metodologias que demonstrem como ocorre a relação destes dados com variações climáticas observadas e esperadas. Neste contexto, o sistema WRF-Hydro representa o estado da arte no que refere a recursos hídricos, sendo o objetivo deste estudo por meio da pesquisa exploratória analisar a viabilidade de uma ferramenta capaz de monitorar e gerar análise preditiva dos corpos hídricos na região do MATOPIBA (Maranhão-Tocantins-Piauí-Bahia). Foi realizado o geoprocessamento da região pelo ArcGIS e o WRF-Hydro foi testado com a simulação de alguns dados hidrometeorológicos por um período de dez dias. Apesar do sistema WRF-Hydro demonstrar eficiência na simulação hidrometeorológica da região, o mesmo possui uma gama de subprocessos que tornam a curva de aprendizado complexa. Portanto, em função da possibilidade de integração das ferramentas, propõe-se a construção de uma ferramenta web para maior usabilidade de software.

Palavras-chave: Recursos hídricos, Previsão hidrometeorológica, WRF-Hydro, MATOPIBA.

1. INTRODUCTION

The management of water resources is still a global challenge. The latest United Nations Water Development Report [1] highlights that only 10% of developing countries have monitoring systems related to water quality. Thus, the advance in the management of water bodies assists the performance of the system, consisting of a valuable tool for the economy and society. Besides, it is important to emphasize that climate variability is associated with extreme events, with the potential to generate socioeconomic damage.

Given this scenario, computational modeling emerges as a precious mechanism for decision making. However, hydrometeorological representation requires a model capable of characterizing the hydrology of the earth's surface-atmosphere, where the availability and measurements of data are fundamental for understanding the dynamics of a hydrographic basin [2].

In this context, the hydrological modeling module of the WRF (Weather Research and Forecasting) model, called the WRF-Hydro system represents the state of the art concerning water resources, which provides a coupling between an atmospheric model and a hydrological model. The WRF-Hydro system was developed by NCAR (National Center for Atmospheric Research) in partnership with NASA (National Aeronautics and Space Administration) to model and simulate rainfall, reservoir management, and flood forecasting that allow users to create, save and compare future scenarios [3].

However, it is important to have in mind that is the workflow for this system is based on preprocessing, processing, and postprocessing phases. This sequence introduces complexity to operate this solution and, consecutively, demands more computational skills for multidisciplinary teams. In this sense, this study aims to analyze the feasibility of developing a computational web tool for simplifying the integration of NCAR tools and workflow to simulate, monitoring, and predictive analysis of water bodies inserted in the MATOPIBA region (Maranhão-Tocantins-Piauí-Bahia), where the management of water resources have a strong socioeconomic interest for the Brazilian government.

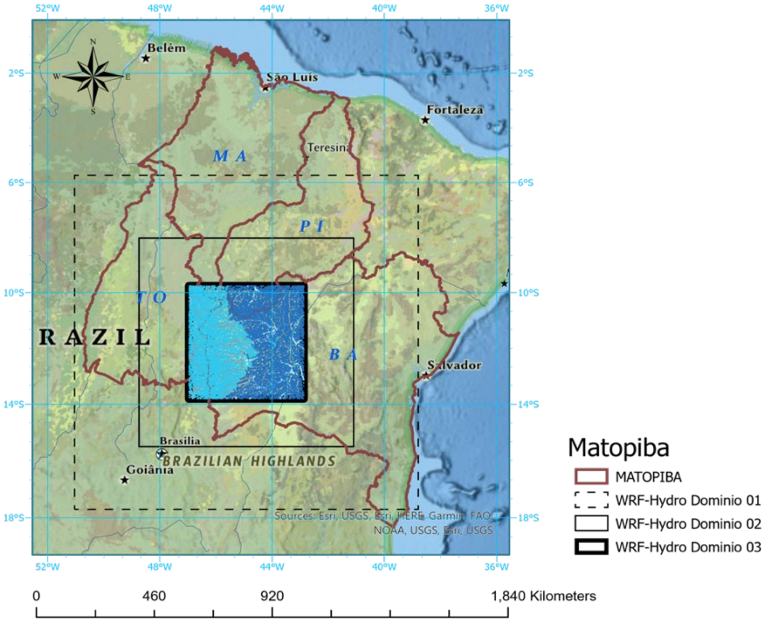
2. METHODOLOGY

2.1 Study area

The area under study is the MATOPIBA region that covers four states in Brazil, including Maranhão, Tocantins, Piauí, and Bahia, according to Figure 1. The presented scenario composes a region with great agricultural quality that demands the exploitation of land use and water resources. Therefore, it is appropriate to the objective of this study which is to evaluate the feasibility of a web tool for the monitoring and predictive analysis of water bodies.

The states that make up the MATOPIBA region have a large volume of freshwater available in Brazil, especially the basins of the Northwest Atlantic, Parnaíba, Tocantins-Araguaia, and São Francisco.

Figure 1 - Study area.



Source: From the authors

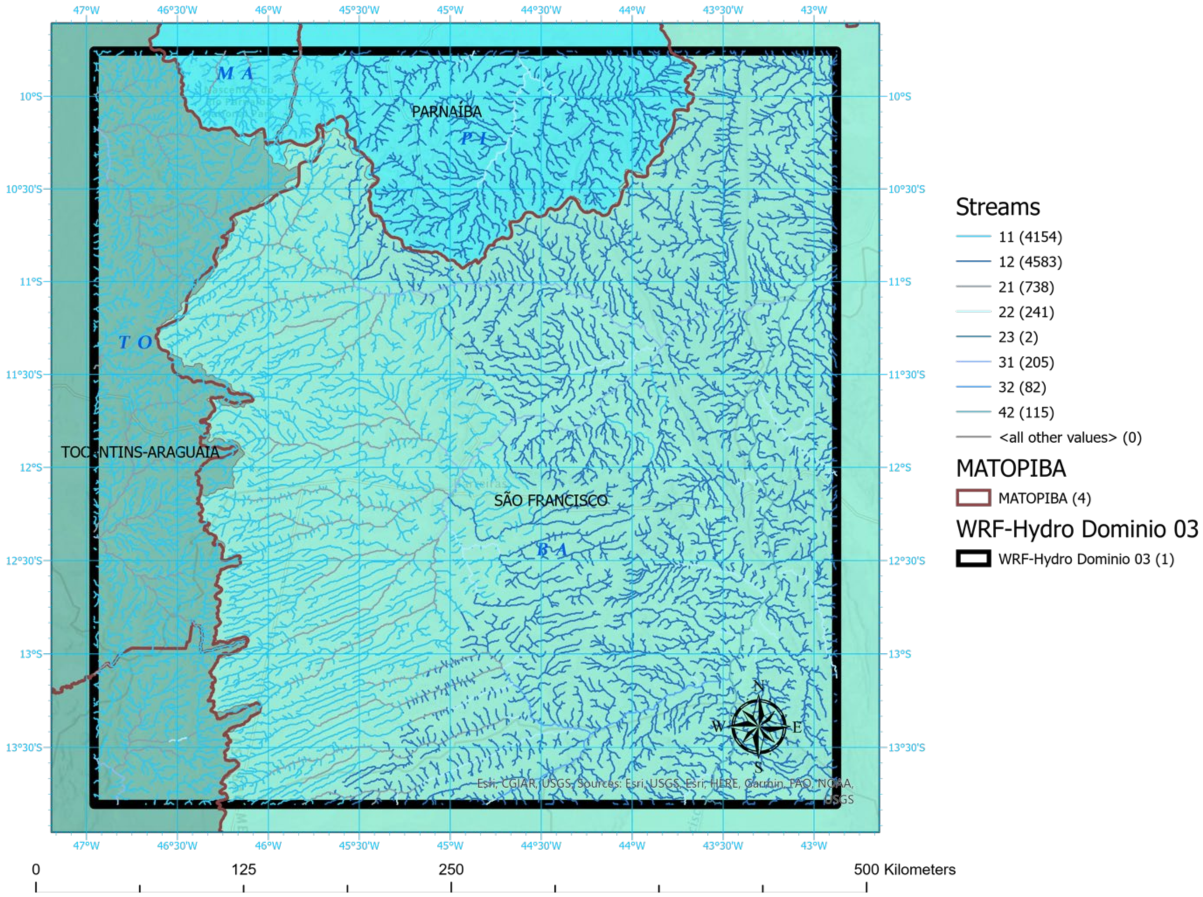
Maranhão is in northeastern Brazil and its vegetation covers the amazon rainforest, cerrado, and caatinga. The Tocantins is in central Brazil, being bounded to the west by the Araguaia River and in the center by the Tocantins River, with an economy consisting basically of agriculture [4]. Piauí is inserted in the Northeast of Brazil, and its economy is directed to industry (chemical, textile, beverage, agriculture, and livestock). Bahia is also in the Brazilian Northeast and its economy consists of agriculture, industry, mining, tourism, energy (oil & gas, and renewable), and services [4].

2.2 Hydrometeorological modeling with WRF-Hydro system

The simulations were performed using the hydrometeorological modeling system WRF-Hydro. Modeling couples the high-resolution hydrological model to a thin-scale meteorological model within a single system. This allows us to reduce the uncertainties associated with the spatial distribution and precipitation volume, demonstrating the adequate predictive potential of surface runoff, flow prediction, and flooding.

The modeling was divided into two parts (meteorological and hydrological). The meteorological model was configured in three nested grids with a resolution of 9 km, 3 km, and 1 km, according to Figure 2.

Figure 2 - Location of the domain of interest with water flows.



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The domain of interest (D03) has a horizontal resolution of 1 km in a grid of 448 x 454, using geoprocessing tools for grid resizing to 250m in the hydric scope. An overview of spatial configurations is shown in Table1.

Table 1 - Configuration of domains.

Domain	**D01**	**D02**	**D03**
Horizontal Resolution	9 km	2.5 miles	1 km
Number of cells	150x150	280x280	448x454
Domain size	1350x1350 km	840x840 km	448x454 km

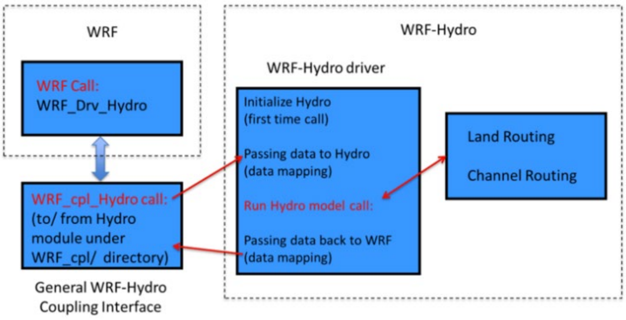
The simulation was performed using the WRF-ARW core, version 3.9.1, with initialization at 12 h (UTC)) on March 10, 2019, extending until 18 h (UTC)) on March 20, 2019 (246h of the simulation).

This simulation aimed to generate the preliminary data that is required for geoprocessing in the ArcGIS application. The initial and contour conditions used in the simulations come from the global atmospheric model GDAS-FNL (Global Data Assimilation System Final analysis) of NCEP (National Center for Environmental Prediction), with a horizontal resolution of 0.25° x 0.25° and temporal resolution of 6 hours. Land use and occupation topography data are provided by the USGS (United States Geological Survey) with a resolution of 30s [5]. This model was used instead of

GDAS-GFS cause with NFL we can get almost ~10% more observational data, also GDAS was selected based on NCAR experience, considering that we are receiving support from them and this model makes this processes more suitable to improve this research with agility and quality.

There is a growing trend to use one-way or two-way hydrometeorological modeling systems, indicating the importance of integrated atmospheric, soil, and hydrologic modeling tools. Typical studies use the WRF (Meteorological Research and Forecasting) model and hydrological models, such as the WRF-Hydro model [6]. Due to its robust architecture, WRF-Hydro represents the state of the art in hydrometeorological modeling, whether in uncoupled or coupled mode. Figure 3 has the representation of how the models (meteorological and hydrological) are integrated.

Figure 3 - Structure of the WRF-Hydro system in the face of the physical aspects related to meteorology and the type of coupling.



Source: Figure from [3]

After preprocessing with WRF, as shown in Figure 3, the intermediate files required for data processing with ArcGIS are obtained. It is important to highlight that ArcGIS was also developed for the characterization of drainage systems (stream networks, hydrographic basins, holms characteristics) and model integration. The framework is implemented as a set of free, open-source Python tools, and is based on the core functionality of ArcGIS, the proprietary tool, which uses geoprocessing capabilities to ensure extensibility.

ESRI (Environmental Systems Research Institute) ArcGIS is a software package for the development and manipulation of vector and matrix information for the use and management of thematic bases. ArcGIS provides in a GIS (Geographic Information System) environment a range of tools in an integrated and user-friendly way. Geoprocessing can be understood as the technical and conceptual link of tools for capturing, storing, processing data, and the presentation of georeferenced spatial information.

The WRF-Hydro *GIS Pre-processing Toolkit* is designed to facilitate the process of derivation of input files and WRF-Hydro parameters from commonly available geospatial data products, such as hydrologically processed digital elevation models. Many input and water parameter files can be generated by these tools, as well as a geospatial metadata file to support georeferencing of WRF-Hydro model output files and relevant shapefiles to help visualize model components.

WRF-Hydro GIS preprocessing tools are designed to function as an additional *Arc Toolbox* in the Esri ArcGIS software. Specific operating system and software requirements are covered in the complete documentation of the WRF-Hydro GIS Preprocessing Toolkit.

As described in the previous paragraphs, it is noticed that working with WRF-Hydro requires a series of steps that may present some complexity for researchers from different areas, but which are fundamental in the study of hydrological aspects of a river basin, such as agrarian, biological or engineering science professionals. These professionals need water information for decision-making in several studies, which are often scarce, preventing the realization of adequate water resources management, as mentioned in the Hydrological Atlas of the Rio Grande hydrographic basin [7].

Thus, the construction of a web tool, which minimizes the need to write and prepare specific computational codes, capable of integrating the execution stages of WRF-Hydro intuitively, proves to be an interesting alternative for engineers, scientists, and other professionals related to the hydrometeorology area. This will allow them to develop their studies with quality equivalent to the conventional work of WRF-Hydro, without the need for possible assistance from a computer professional, thus stimulating the increase of research in this area and rewarding possible failures of hydrological monitoring of hydrographic basins.

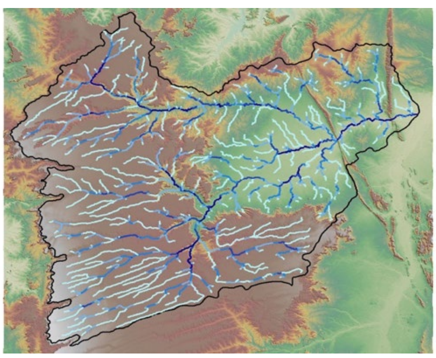
3. RESULTS AND DISCUSSION

Based on the analyses performed in a multidisciplinary research environment, it was possible to obtain information, as shown in Figure 4 and Video 1 on the quality, accuracy, and integration of WRF-Hydro tools with respective integration modules in an HPC (High-Performance Computing) environment, ESRI ArcGIS in an independent layer, as well as the web interface.

From the non-intuitive processes in which this information was obtained, it is considered the proposal of the web interface, in which some authors are highlighting the important usability characteristics that it offers, associating the ease with which new users can initiate an effective interaction and achieve maximum performance in tasks, which are included in the context of GIS [8].

In this perspective, a structure of integration of WRF-Hydro and ArcGIS is presented through a web tool of usability suitable for researchers or potential customers, through visualization and operation of simulation processes, to monitor and make predictive analyses of a hydrometeorological character of a given region.

Figure 4 – Rio Grande DEM Streamflow. Video 01 – Rio Grande DEM 3D.



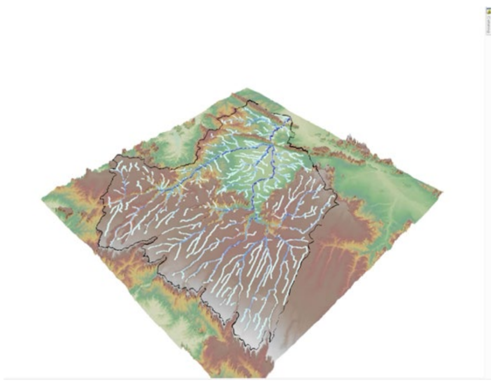


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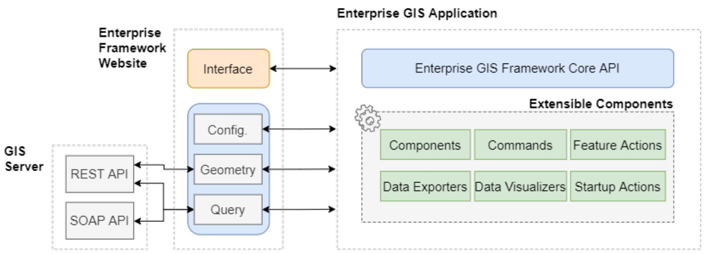
Figure 4 represents a DEM (Digital Elevation Model) in RGB with river flows in a superior view. This Video 01 represents a DEM in RGB with river flows in an animation exposing more details about this micro basin. To access this animation please click at the animation hyperlink or access this URL (https://youtu.be/oQiw9nHedtg).

These results were generated with a multidisciplinary team with distinct roles and knowledge area but could be simplified in a single GIS web tool, providing a single panel view designed based in software usability, using native integration as an exhibit in Figure 5, through REST (*Representational State Transfer*) and SOAP (*Simple Object Access Protocol*) API (*Application Programming Interface*) developing in programming languages like Java, .NET or Python.

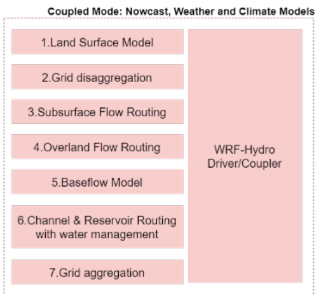
Figure 5 – ArcGIS Framework.



Source: Adapted from [9]

Figure 6 display WRF-Hydro Coupled Model Framework, that is loaded commonly in an HPC environment that could be operated by Python.

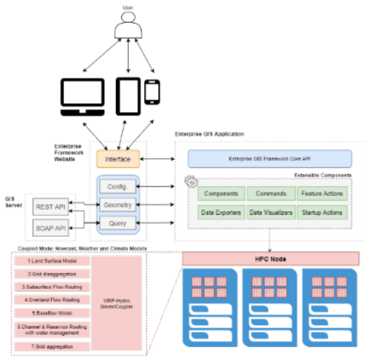
Figure 6 – WRF-Hydro Framework.



Source: Adapted from [3]

Figure 7 shows a representation of the logical integration of solutions through a GIS web tool.

Figure 7 - Integration structure of WRF-Hydro and ArcGIS.



Source: Adapted from [3,9]

4. CONCLUSION

The research, still exploratory, is being developed by an interdisciplinary group of researchers who are working on the execution of all the steps considered necessary in the hydrometeorological simulation of the MATOPIBA region. The geoprocessing of the region was completed through ArcGIS, as presented, bringing as partial results the detailed information of the region, important for the next stages of the study. Besides, flow, precipitation, and other variables have already been obtained, proving WRF-Hydro as an efficient hydrometeorological simulation model. Although the data obtained are sufficient, the group is still working on some steps to seek improvements in simulation accuracy through automated and efficient data calibration.

Therefore, with the consolidation of the described processes, we seek the implementation of the proposed solution, considered feasible to be implemented, given the significant number of steps necessary in the monitoring and hydrometeorological forecasting carried out, in large part, by scholars unrelated to the area of computing.

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