Hydrological Rainfall-Runoff Modeling Using the WRF-Hydro Model

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This study aims to analyze the hydrological behavior of the Negro River basin, part of the greater Amazon Basin, through the simulation of rainfall and streamflow using the mesoscale Weather Research and Forecasting (WRF-Hydro) model. The premise is that streamflow simulation is a crucial tool for predicting environmental impacts, enabling timely decision-making and contributing to the sustainable management of river basins. Simulations were conducted with a spatial resolution of 1 km and a 100 m channel network, covering the period from January 1st to January 31, 2024. It was possible to evaluate rainfall and streamflow distribution, exploring the behavior of variables in the region. Furthermore, the accuracy of streamflow simulation at each river gauging station is directly influenced by the temporal distribution of rainfall simulated within the drainage network. The simulations proved satisfactory, highlighting the model's potential to support studies and environmental analyses.
Keywords: WRF-Hydro. Rainfall. Streamflow.

The Metropolitan Region of Manaus, also known as Greater Manaus, is one of the most populous and economically relevant areas in Brazil. The capital of Amazonas state, Manaus, is located on the left bank of the Negro River, covering a territorial area of 11,401 km². Situated in the Negro River Basin, in the heart of the Amazon, the municipality frequently experiences extreme rainfall events that result in floods and inundations, directly impacting urban infrastructure, mobility, and the quality of life for its population. These events, intensified by climate change and unplanned urban growth, reinforce the need for hydrometeorological monitoring and the implementation of mitigation strategies to reduce socioeconomic and environmental impacts.

One way to analyze the atmospheric events that cause severe and extreme weather conditions is to use numerical atmospheric modeling [1]. The numerical modeling proposed in this article, by coupling hydrological modeling with numerical weather prediction, aims to represent the hydrological processes of the land surface [2]. The main model of this type, the Weather Research and Forecasting Model (WRF-Hydro), which is the focus of this work, was initially designed as a coupled framework to facilitate the integration between the WRF model and terrestrial hydrological components [3].

The WRF-Hydro modeling system was developed to simulate hydrometeorological variables, floods, and the spatial distribution of water resources [4], to provide an enhanced numerical tool to address global needs in water resource planning, environmental impact assessment, risk prediction, and mitigation [5].

Within this context, the primary objective of this study is to assess the model's ability to accurately represent the hourly rainfall–runoff behavior in the Negro River basin in the Amazon, specifically in Manaus, during the period from January 1 to January 31, 2021. The simulations were conducted with a spatial resolution of 1 km and a 100 m channel network.

Materials and Methods

Simulations with the WRF model (version 3.6) were conducted to generate the initial conditions of soil moisture, soil temperature, soil water content, and atmospheric forcing, among other variables, for the WRF-Hydro model. The model

Received on 17 May 2025; revised 27 July 2025.
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Original extended abstract presented at SAPCT 2025.

J Bioeng. Tech. Health 2025;8(4):343-346

was configured with three nested grids with spatial resolutions of 9, 3, and 1 km (Figure 1). The first grid covers part of the Amazon Basin and the entire Negro River Basin (D01), while the second grid includes the Lower Negro River region (D02). Finally, the domain of interest (D03), with 1 km resolution and 50 vertical levels, encompasses the city of Manaus.

The simulations were initialized at 00 UTC on January 1, 2021, and extended until 18:00 UTC on January 31, 2021. The physics options adopted, which remained unchanged for all simulations, were: the WRF Single-Moment 6-class scheme for microphysics, the Grell-Freitas cumulus parameterization, the Mellor-Yamada Nakanishi and Niino Level 2.5 PBL scheme, the RRTMG shortwave and longwave radiation schemes, and the Noah land-surface model. The parameterization of aerosol–radiation interactions followed Ruiz-Arias and Thompson's water- and ice-friendly scheme.

Results and Discussion

Figure 2 presents the hyetograph and hydrograph for two stations located in the drainage network of each river, based on the arithmetic mean of accumulated daily rainfall at each WRF grid point and on the daily streamflows simulated by WRF-Hydro, considering the same analysis periods.

The two selected stations present distinct characteristics in terms of streamflow behavior [6,7]. For both stations, rainfall values fluctuate throughout the month, with notable peaks in specific periods. In the Rio Preto da Eva station graph, streamflow peaks are more pronounced and occur shortly after rainfall events. In contrast, the Novo Airão station exhibits a more gradual streamflow behavior, suggesting a dampened hydrological response to rainfall events.

At Rio Preto da Eva, streamflow peaks mostly ranged between 125 and 150 m³/s, reaching a maximum above 150 m³/s. In contrast, Novo Airão

Figure 1. Location of the domains.

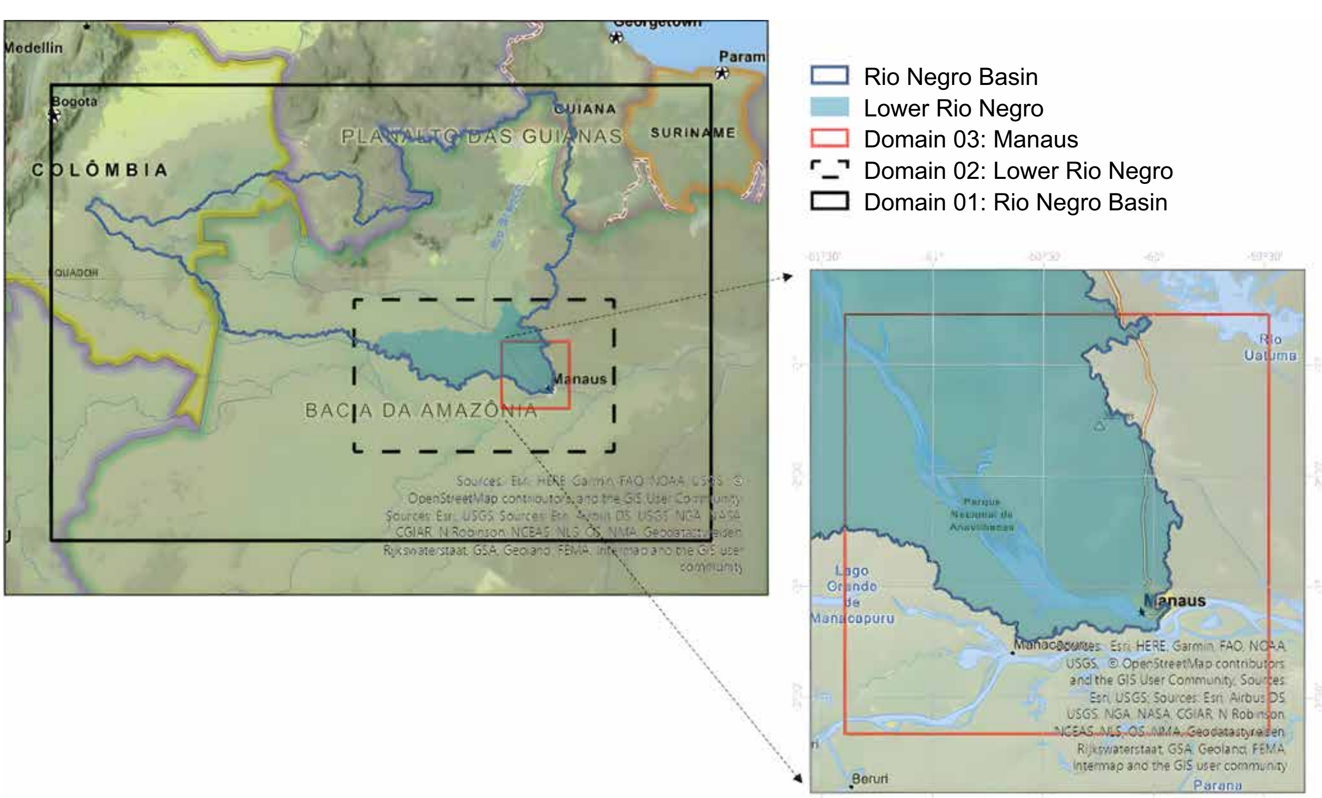
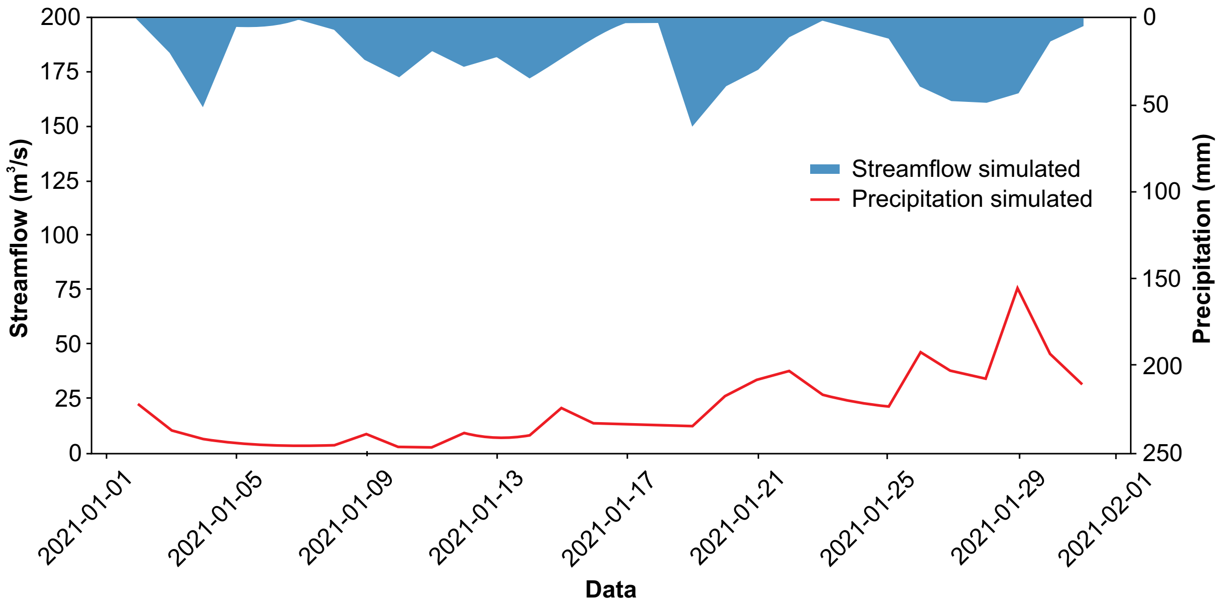
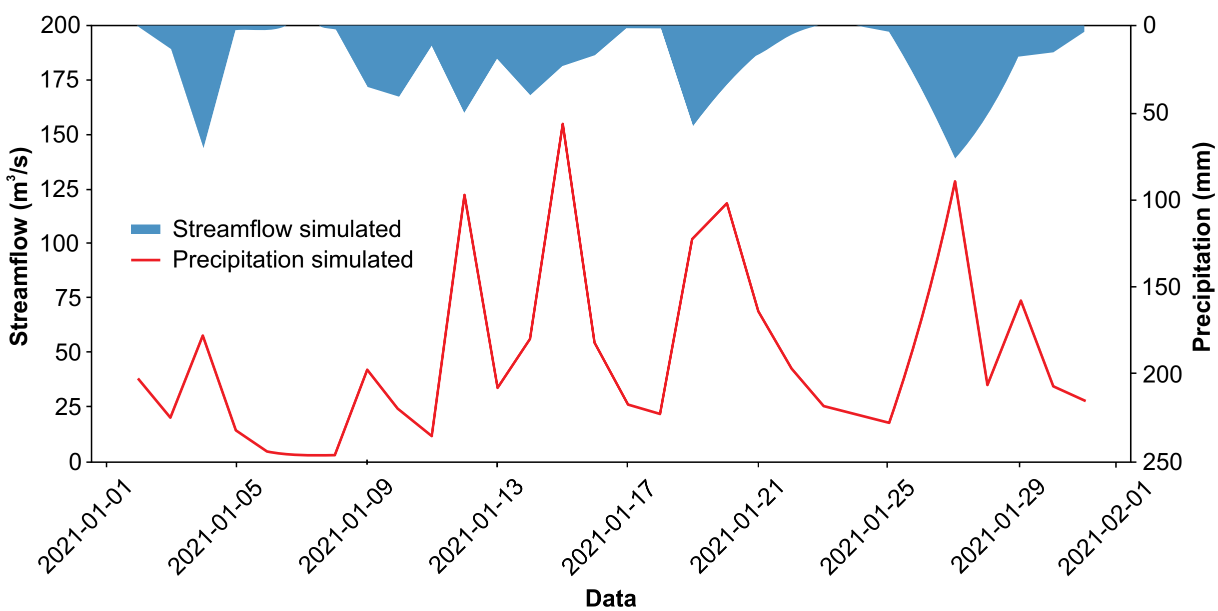


Figure 2. Hydrographs simulated by WRF-Hydro at the stations (a) Novo Airão and (b) Rio Preto da Eva, along with their respective hyetographs simulated within the Negro River drainage network.-





showed a more gradual pattern, with only one peak of 75 m³/s at the end of the period, despite similar rainfall volumes.

This behavior may indicate differences in infiltration and surface runoff modeling, suggesting that the terrain may have a lower water absorption capacity or that the basin has characteristics that favor rapid responses to intense rainfall.

Conclusion

This study aimed to analyze the temporal distribution of rainfall and streamflow in the Negro River basin, highlighting the model's potential to support environmental studies and analyses in the region. The results confirmed the correlation between rainfall and streamflow.

The comparison between hydrographs and their corresponding hyetographs illustrates rainfall as the most important factor for streamflow simulation. Furthermore, simulating streamflow behavior in a given region is a crucial tool for predicting environmental impacts, enabling timely decision-making and contributing to the sustainable management of river basins. Future research should encompass more extended periods of analysis and incorporate observational data to assess model accuracy.

Acknowledgments

The authors thank the SENAI CIMATEC Supercomputing Center for the computational infrastructure required to run the model and the Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB) for financial support.

References

1. Da Cunha Luz Barcellos P, Cataldi M. Flash flood and extreme rainfall forecast through one-way coupling of WRF-SMAP models: natural hazards in Rio de Janeiro state. Atmosphere. 2020;11(8):834.
2. Liu Y, Li H, Tian F, Zhang Q, Xu Y, Yang L, et al. Parameter sensitivity analysis of the WRF-Hydro modeling system for streamflow simulation: a case study in semi-humid and semi-arid catchments of northern China. Asia Pac J Atmos Sci. 2020;1–16.
3. Gochis DJ, Barlage M, Dugger A, FitzGerald K, Karsten L, McAllister M, et al. Coupled WRF/WRFHydro V5 test case user guide (version 5.0). NCAR Technical Note. 2018. 107 p.
4. Sun M, Liu Z, Guo Y, Wang C, Ma J, Chen X. Evaluation of flood prediction capability of the WRFHydro model based on multiple forcing scenarios. Water. 2020;12(3):874.
5. Maciel JSC, Faria S, Bentes C, de Souza EB, Ramos AM, Mota MAM, et al. Flood forecast in Manaus, Amazonas, Brazil. WIT Trans Built Environ. 2020;194:63–72.
6. Dantas da Silva Júnior JR et al. Feasibility analysis on the construction of a web solution for hydrometeorological forecasting considering water body management and indicators for the SARS-COV-2 pandemic. AI Perspectives. 2021; v. 3, n. 1, p. 4.
7. Silva DG et al. WRF-Hydro for Streamflow Simulation in the MATOPIBA Region within the Tocantins/Araguaia River Basin—Brazil: Implications for Water Resource Management. Water. 2023; v. 15, n. 22, p. 3902.