EVALUATION OF THE PHYSICAL SENSITIVITY OF THE WRF-HYDRO MODEL IN THE SIMULATION OF RAINFALL IN MANAUS-AM USING DIFFERENT SETS OF PARAMETRIZATIONS

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Abstract: The main objective of the present study is to evaluate the performance of different physical parameterizations available in the Weather Research and Forecasting (WRF-Hydro) mesoscale model, in order to identify which one best represents the behavior of precipitation in the city of Manaus during an extreme event flood, which occurred on May 30, 2021, with monthly accumulated rainfall of 127.2 mm. The simulations were performed with a spatial resolution of 1 km and a channel network of 100 m for the period from April 30 to June 5, 2021. To validate the performance of the WRF-Hydro, the simulated data is compared with CPTEC's MERGE product data. The results showed a tendency for the model to underestimate the daily accumulated precipitation, reasonably reproducing some observed precipitation patterns. It is concluded that the tool presents a capacity for precipitation estimation, with potential for operational purposes.

Keywords: WRF-Hydro; precipitation, rainfall, parameterization.

AVALIAÇÃO DA SENSIBILIDADE FÍSICA DO MODELO WRF-HYDRO NA SIMULAÇÃO DA PRECIPITAÇÃO EM MANAUS-AM UTILIZANDO DIFERENTES CONJUNTOS DE PARAMETRIZAÇÕES

Resumo: O presente estudo tem como objetivo principal avaliar o desempenho de diferentes parametrizações físicas disponíveis no modelo de mesoescala *Weather Research and Forecasting* (WRF-Hydro), a fim de identificar qual delas representa melhor o comportamento da precipitação na cidade de Manaus durante um evento extremo de inundação, que ocorreu no dia 30/05/2021, com precipitação acumulada mensal de 127,2 mm. As simulações foram realizadas com resolução espacial de 1 km e rede de canais de 100 m para o período de 30/04 a 06/06. Para validar o desempenho do WRF-Hydro, os dados simulados são comparados com dados do produto MERGE do CPTEC. Os resultados mostraram uma tendência de o modelo subestimar a precipitação acumulada diária, reproduzindo razoavelmente alguns padrões de precipitação observados. Conclui-se que a ferramenta apresenta capacidade de estimativa de precipitação, com potencial para fins operacionais.

Palavras-chave: WRF-Hydro; precipitação, rainfall, parametrização.

1. INTRODUCTION

The Metropolitan Region of Manaus, or Greater Manaus, is one of the most populous and economically important cities in the country. The city of Manaus, capital of Amazonas, is located on the left bank of the Rio Negro with a territorial area of 11,401 km². The municipality of Manaus, located in the Rio Negro Basin in the Amazon, is commonly affected by extreme rainy events of a harmful nature, as was the case on May 30, 2021, in which the city of Manaus faced the biggest flood in 119 years, reaching the Rio Negro a level of 29.98 m.

One of the ways to analyze the atmospheric events that cause severe and extreme weather conditions is to use numerical modeling of the atmosphere, as performed by [1-4]. Precipitation is one of the most important meteorological variables and of difficult representation by limited area models [5,6]. In the Amazon, rainfall has a very irregular spatio-temporal distribution [7], and most of it is due to small-scale systems that interact with larger-scale systems [8]. Therefore, even with the use of regional modeling, the deficiency in the reproduction of precipitation over the Amazon, both in magnitude and in special distribution, is still very present [9].

The numerical modeling, proposed in this article, using a coupled hydrological modeling system with another numerical weather forecasting model, aims to represent the hydrological processes of the Earth's surface [9]. The main model of this type, Weather Research and Forecasting Model (WRF) – Hydro, object of this work, was originally designed as a coupled model structure to facilitate the junction between the WRF model and components of terrestrial hydrological models [10].

The WRF-Hydro modeling system was developed by NCAR (National Center for Atmospheric Research) in partnership with the American space agency NASA (National Aeronautics and Space Administration) to simulate hydrometeorological variables, floods, spatial distribution of water resources [11], with the objective of providing an improved numerical tool to meet the world's needs in water resources planning, environmental impact assessment, risk forecasting and mitigation. More details regarding the numerical and computational structure of the model can be obtained in [12].

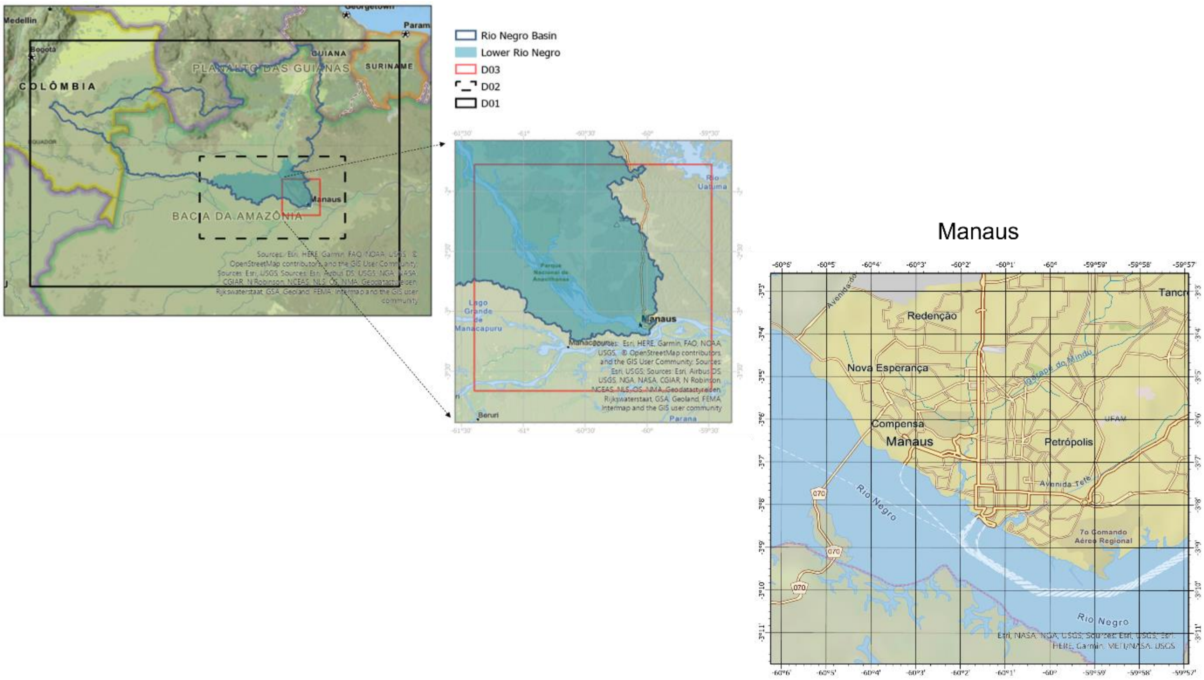
Given this context, the main objective of this study is to evaluate the model's ability to represent precipitation in the Rio Negro watershed in the Amazon, with the domain of interest in the city of Manaus. For this, eight high resolution (1 km) simulations using different combinations of four cumulus (CU), two planetary boundary layer (PBL) and two surface layer (LS) schemes were conducted to elucidate the physical parameterization schemes most suitable for this extreme rain event over the city of Manaus. Furthermore, to validate the WRF-Hydro capability, the simulated data are compared with the MERGE product data, proposed by [13]. There are few studies that have evaluated the parameterizations used in the WRF model in extreme rainfall conditions over the Manaus region.

2. METHODOLOGY

2.1 WRF-Hydro physical parameterization schemes and modeling setup

The simulations with the WRF model (version 3.6), described by [17], were performed to generate the initial conditions of soil moisture, soil temperature, soil water content, atmospheric forcing, among other variables to run the WRF model -Hydro. The model was configured with three nested grids with special resolution of 9, 3 and 1 km (Figure 1). The first grid covers part of the Amazon basin and the entire Rio Negro basin (D01), while the second grid includes the lower Rio Negro region (D02) and, finally, the domain of interest (D03) with 1 km resolution and 50 vertical levels, encompasses the city of Manaus.

Figure 1. Location of the three nested domains in Rio Negro Basin



Source: Author, 2022.

Held pre-processing the data to generate the domain of interest (D03), a geoprocessing tool based on Geographic Information System - GIS was used to create the file with the routing data of the hydrographic channel network for D03 with resolution of 100 meters. This tool creates high resolution fields in routing grids such as flow direction, underground flow and channel routing processes needed to be used as input data in the WRF-Hydro model.

The WRF-Hydro mainly integrates a Land Surface Model (LSM) module and a hydrological module that provides a framework that includes surface, groundwater and channel flows. In this study, WRF-Hydro version 5.2.1 was configured in its fully coupled mode to run with WRF. The main hydrological configurations of the model are shown in Table 1.

Table 1. The parameterizations of coupled WRF-Hydro model

Category	Parameterization Selected
NWP model	WRF model
Land surface model	Noah LSM
Subsurface flow	Distributed hydrology soil and vegetation model
Overland flow	D8 method
Baseflow	Exponential storage-discharge function
Channel routing	Diffusive wave-gridded

Source: Author, 2022.

In order to evaluate the model's sensitivity to represent the precipitation front the event under study, eight tests were performed, varying combinations of cumulus (CU), planetary boundary layer (PBL) and surface layer (SL) schemes. The PBL and CU parameterization schemes influence the magnitude of precipitation in the WRF model [2]. The other physical parameterizations such as longwave radiation, shortwave radiation, microphysics and terrestrial surface remained unchanged for all simulations. The physical parameterization schemes were selected based on the studies in [1, 2, 5,15,16]. Table 2 shows the physical parameterizations used. References for each option available in the WRF model can be found in its manual and in [17].

Table 2. Summary of the parameterizations used in the simulations

Test	Microphysical	Cumulus	PBL	LW/SW Radiation	Surface Layer	Land Surface
T-01	WSM6	Grell Freitas (GF)	MYNN 2.5	RRTMG	MYNN	Noah LSM
T-02	WSM6	Grell Freitas (GF)	YSU PBL	RRTMG	MM5	Noah LSM
T-03	WSM6	New Tiedtke (NT)	MYNN 2.5	RRTMG	MYNN	Noah LSM
T-04	WSM6	New Tiedtke (NT)	YSU PBL	RRTMG	MM5	Noah LSM
T-05	WSM6	Betts-Miller-Janjic (BMJ)	MYNN 2.5	RRTMG	MYNN	Noah LSM
T-06	WSM6	Betts-Miller-Janjic (BMJ)	YSU PBL	RRTMG	MM5	Noah LSM
T-07	WSM6	Grell 3D (G3D)	MYNN 2.5	RRTMG	MYNN	Noah LSM
T-08	WSM6	Grell 3D (G3D)	YSU PBL	RRTMG	MM5	Noah LSM

Source: Author, 2022.

The simulations were started from 00 UTC on May 1, 2021 and extended to 1800 UTC on June 6, 2021. In order to obtain more realistic initial conditions, 480 h of spin-up was used, model adjustment time and excluded from the evaluations. To initialize the model, data from the NCEP-FNL (National Centers for Environmental

Prediction – Final Analysis), with a spatial resolution of 0.25° x 0.25°, were operationally prepared every six hours. Land use and occupation data were provided by the USGS (United States Geological Survey), with a resolution of 2' for domains 1 and 2 and 30” for domain 3.

To evaluate the performance of the WRF-Hydro model regarding the variable accumulated daily precipitation, data from the MERGE product, proposed by [13], were used, which consists of combining surface data with satellite estimation data. This technique presents precipitation values throughout the grid of the domain under study, which allows a more assertive comparison with the simulated data, since the model also has values in grid points of the mesh [18]. For this evaluation, it was necessary that the grids of the simulated and observed data had the same domain and the same special resolution. Thus, bilinear interpolation and clipping methods were applied to the MERGE and WRF data through the shell script, using the CDO (Climate Data Operators) code [19].

The performance of the WRF-Hydro model follows the statistical evaluation procedure recommended by [20] and defined as follows: mean bias (MB), Fractional Bias (FB), root mean-square-error (RMSE), mean absolute gross error (MAGE), correlation coefficient (*r*) and index of agreement (IOA). The MB, RMSE, and MAGE are indices related to the errors and deviations of the model. Therefore, high-quality simulations have values closer to zero. The R and IOA are indices of association and agreement between modeled and observed data, with zero indicating an absence of correlation and values closer to 1 indicating a strong correlation.

3. RESULTS AND DISCUSSION

The analysis applied to evaluate the precipitation variable consisted of reducing the field of accumulated daily precipitation, of the simulation and the MERGE product. This reduction was made in D03, concentrating this field in the municipality of Manaus, as illustrated in Figure 1. The results of the simulations carried out with the WRF-Hydro model during the extreme rainfall event in Manaus are presented to evaluate the capacity of the mesoscale model to represent precipitation. Table 3 shows the performance of the parameterization schemes through the aforementioned statistical indices.

Table 3. Statistical comparison between observed and simulated data

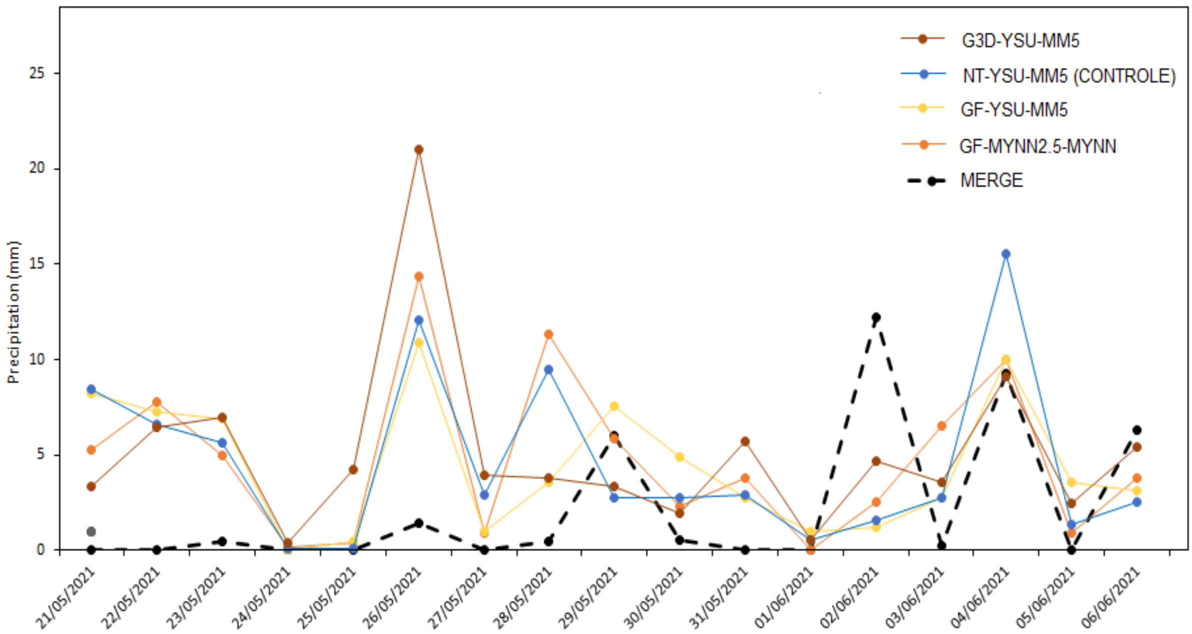
TEST	MB	FB	MAGE	RMSE	r	IOA
T-01	2.59	1.22	3.81	5.54	0.15	0.42
T-02	2.25	1.21	3.70	4.96	0.16	0.46
T-03	2.21	1.07	4.20	6.15	0.06	0.33
T-04	2.42	1.16	4.24	5.49	0.19	0.45
T-05	3.16	0.99	5.11	7.16	0.03	0.31
T-06	4.89	1.23	6.19	7.58	-0.16	0.27
T-07	2.94	1.23	4.02	5.96	0.16	0.38
T-08	5.43	1.35	6.09	7.69	0.06	0.34

Source: Author, 2022.

It is observed that for all tests, the statistical indicator FB was positive, indicating the model's tendency to underestimate the MERGE data of precipitation. The best results for this indicator were achieved by the NT-MYNN2.5-MYNN and BMJ-MYNN2.5-MYNN schemes. When analyzing the agreement indices, they obtained low values of IOA, with the set GF-YSU-MM5 reaching the highest value of 0.46 (r=0.16), followed by NT-YSU-MM5 with IOA of 0.45 and r of 0.19. In the analysis of the MB and MAGE indices, NT-MYNN2.5-MYNN presented the best indices (2.21 and 1.07), and the worst was for G3D-YSU-MM5 (5.43 and 1.35). In general, the RMSE expressed similar and high results for all schemes. The BMJ-MYNN2.5-MYNN combinations; BMJ-YSU-MM5 and G3D-YSU-MM5 had the highest deviations and the lowest correlations on most metrics.

To evaluate the time series of precipitation, Figure 2 presents the behavior of the precipitation variable of the four sensitivity tests that achieved the best results in most metrics. Therefore, Figure 2 compares the accumulated daily precipitation of the GF-MYNN2.5-MYNN (T-01) combinations only; GF-YSU-MMF (T-02); NT-YSU-MM5 (T-04) and G3D-YSU-MMG (T-07). Since the other simulations did not produce significant results.

Figure 2. Daily behavior of simulated and observed accumulated precipitation



Source: Author, 2022.

Figure 2 shows that the MERGE product recorded 6 mm, 12.2 mm and 9.2 mm on May 29, June 2 and June 4, respectively. The analysis reveals that the GF-YSU-MM5 and GF-MYNN2.5-MYNN schemes were able to produce values closer to these peaks, except for June 02, although all sets represent the trend of rainfall. The GF-YSU-MM5 set generated values of 5.9 mm, 2.6 mm and 10 mm, and GF-MYNN2.5-MYNN, values of 7.5 mm, 1.2 mm and 10.03 mm. Thus, it can be seen how the GF-YSU-MM5 and GF-MYNN2.5-MYNN configurations showed the most adequate agreement with the MERGE precipitation data.

4. CONCLUSION

The present work is characterized as an initial study to evaluate the performance of the WRF-Hydro model in the simulation of precipitation during an extreme flood event in the Amazon region. Eight simulations combining different CU, PBL and SL schemes were tested in this study. The GF-MYNN2.5-MYNN (T-01) schemes; GF-YSU-MMF (T-02); NT-YSU-MM5 (T-04) and G3D-YSU-MMG (T-07) were selected to generate time series graphs, as these combinations presented statistical indicators with lower deviations and higher agreements.

The performance of the mesoscale model has a strong influence of lateral and initial boundary conditions, from the NCEP-FNL (National Centers for Environmental Prediction – Final Analysis). The results of the sensitivity tests show that the model underestimates the observed values and the schemes that had results that were closest to the observed were the GF-YSU-MM5 and GF-MYNN2.5-MYNN combinations. It is important to highlight that the Grell Freitas cumulus scheme, parameterization adapted for South America [21], presented a better performance in both combinations.

For the next steps, simulated river level and flow data will be analyzed. Finally, the WRF-Hydro model proves to be a computational tool with great potential in the management of water resources and in the estimation and mitigation of risks.

Acknowledgments

The authors thank the Supercomputing Center for Industrial Innovation of the SENAI CIMATEC for providing the computational infrastructure needed to run the models, and the Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB) for the financial support.

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