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IMPACTO DAS MUDANÇAS DA COBERTURA DO SOLO DA BACIA HIDROGRÁFICA DO RIO ITACAIÚNA NO CLIMA REGIONAL

RELATÓRIO FINAL DO PROJETO TEMPO E CLIMA

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RESUMO EXECUTIVO

Este relatório contém uma análise sobre os impactos da mudança na paisagem na Bacia do Rio Itacaiúnas (BRI) nas últimas décadas sobre o clima regional. Para tanto, realizou-se uma abordagem observacional e de modelagem climática para obter a caracterização dos principais regimes sazonais na BRI, incluindo a seleção de banco de dados em pontos de grade que melhor represente os padrões espaciais da precipitação e temperatura do ar observados, que por sua vez foi utilizado para avaliar o desempenho do modelo climático regional RegCM em representar o clima e também para uma analise dos impactos de cenário de aquecimento global (cenário pessimista) e regional (mudança de cobertura do solo) sobre a bacia. Os resultados mostraram a existência de três regimes sazonais sobre a bacia: seco, pré-chuvos e chuvoso. As simulações com o RegCM revelaram que a conversão da cobertura florestal, das áreas protegidas, em pastagens impacta tanto o balanço hídrico quanto o energético da bacia. Isso reforça a importância da proteção das áreas florestais e das ações de recuperação realizadas pela VALE no IRB, garantindo a biodiversidade no bioma e gerando renda para as comunidades próximas ao projeto, contribuindo assim para uma mineração mais sustentável.

RESUMO

As florestas desempenham um papel importante na regulação do clima regional, como o balanço energético e o ciclo hidrológico. A Bacia do Rio Itacaiúnas (IRB), localizada no sudeste do estado do Pará, passou por mudanças em sua paisagem nos últimos 40 anos devido à abertura de pastagens, mineração e urbanização, que resultaram em alterações na hidroclimatologia da bacia. Uma abordagem de modelagem observacional e climática foi conduzida com o intuito de caracterizar os principais regimes sazonais da Bacia do Rio Itacaiúnas (IRB), incluindo o seleção dos melhores bancos de dados em grade para análise de padrões espaciais de precipitação e temperatura do ar observados, bem como para investigar o desempenho do RegCM para o clima atual e avaliar ainda mais os impactos dos cenários globais e regionais de um futuro próximo na sazonalidade da bacia. Nossos resultados mostraram a existência de três regimes sazonais bem configurados, os regimes seco, pré-chuvoso e chuvoso, que apresentam diferentes padrões espaciais de precipitação e temperatura do ar ao longo da bacia hidrográfica. As simulações do RegCM revelaram que a conversão da cobertura florestal em pastagens causa impactos no balanço hídrico e energético da bacia. O aumento do fluxo de calor sensível e dimunuição do fluxo de calor latente explica o aumento generalizado da temperatura do ar. A Evapotranspiração diminuída e o vento intensificado com convergência de umidade resultaram em aumento de precipitação ao longo da região. Tais evidências indicam o papel fundamental das áreas protegidas com cobertura florestal no domínio das bacias hidrográficas dentro do arco do desmatamento amazônico.

Palavras-chave: modelagem climática regional; bacia do rio Itacaiúnas; mudança de cobertura do solo.

ABSTRACT

Forests play an important role in regulating the regional climate, such as energy balance and the hydrological cycle. The Itacaiunas River Basin (IRB), located in southeastern state of Pará, has undergone changes in its landscape over the past 40 years due to the opening of pastures, mining and urbanization, have resulted in changes in the hydroclimatology of the basin. An observational and climate modeling approach was conducted with the intention of characterizing the main seasonal regimes over the Itacaiúnas River Basin (IRB), including the selection of the best gridded databases for analysis of observed precipitation and air temperature spatial patterns, as well as to investigate the RegCM's performance for the current climate and further assessing the impacts of the near-future global and regional scenarios on seasonality of the basin. Our results showed the existence of three well-configured seasonal regimes, the dry, pre-rainy and rainy regimes that present different precipitation and air temperature spatial patterns over the watershed. RegCM simulations revealed that the conversion of forest cover to pasturelands causes impacts on the water and energy balance over the basin. The increase/decrease in sensible/latent heat flux explained the widespread increase in air temperature. Decreased evapotranspiration and intensified wind with moisture convergence resulted in increased precipitation along the region. Such evidence indicates the fundamental role of protected areas with forest cover in the domain of hydrographic basins within the Amazon deforestation arc.

Keywords: regional climate modeling; Itacaiunas river basin; land cover change.

LISTA DE ILUSTRAÇÕES

SUMÁRIO

1 INTRODUCTION

In a context of climate change associated with changes in land cover, impacts on regional climate patterns are already being noted. In tropical regions such as the Amazon, for example, these impacts act directly on surface air temperature, evapotranspiration and precipitation, and in turn, the hydrological cycle (Dias et al., 2014; Souza-Filho et al., 2015 and 2016). The importance of the forest in the hydrological cycle has been studied around the world since 1970, where studies such as the one by Makarieva et al. (2013) suggest that vegetation plays a fundamental role in the regional hydrological cycle. Changes in land cover can produce notable impacts on the terrestrial energy balance and on the biogeochemical and hydrological cycles through changes in the physical properties of the terrestrial surface (Foley 2005; Van Randow et al. 2004; Bonan, 2008; Alves et al., 2017).

A study by Souza-Filho et al. (2016), sought to investigate the possible consequences of changes in land cover (forest and savannah) and land use (pastures, mining and urbanization) on the hydroclimatology of the Itacaiunas River Basin (IRB), located in southeastern Amazonia. They noted that the current scenario of land use and land cover in IRB, which has lasted since 2004, is composed of the presence of primary forest in the protected areas located in the central west portion of the basin, and of pastures/agriculture/urbanization in the rest of the basin. Transformations in the IRB landscape over the past 40 years (from 1973 to 2013) have resulted in changes in the hydroclimatology of the basin. In addition, the authors highlighted the relevant role of forest areas in IRB protected by VALE, particularly in the Carajás National Forest, where the operational mining plants are located, for the regulation of the regional climate, as well as for the conservation of biodiversity.

Given the current changes in land cover in IRB, this work aims to investigate the impacts of land use and land cover changes on seasonal climate regimes in the Itacaiunas River Basin (IRB) in the last 20 years using simulations with a regional climate model very high resolution. The scenario of complete loss of forest by deforestation is unlikely but serves as a warning to society and decision-makers about the potential risks of deforestation under climate change land use and cover (LUC).

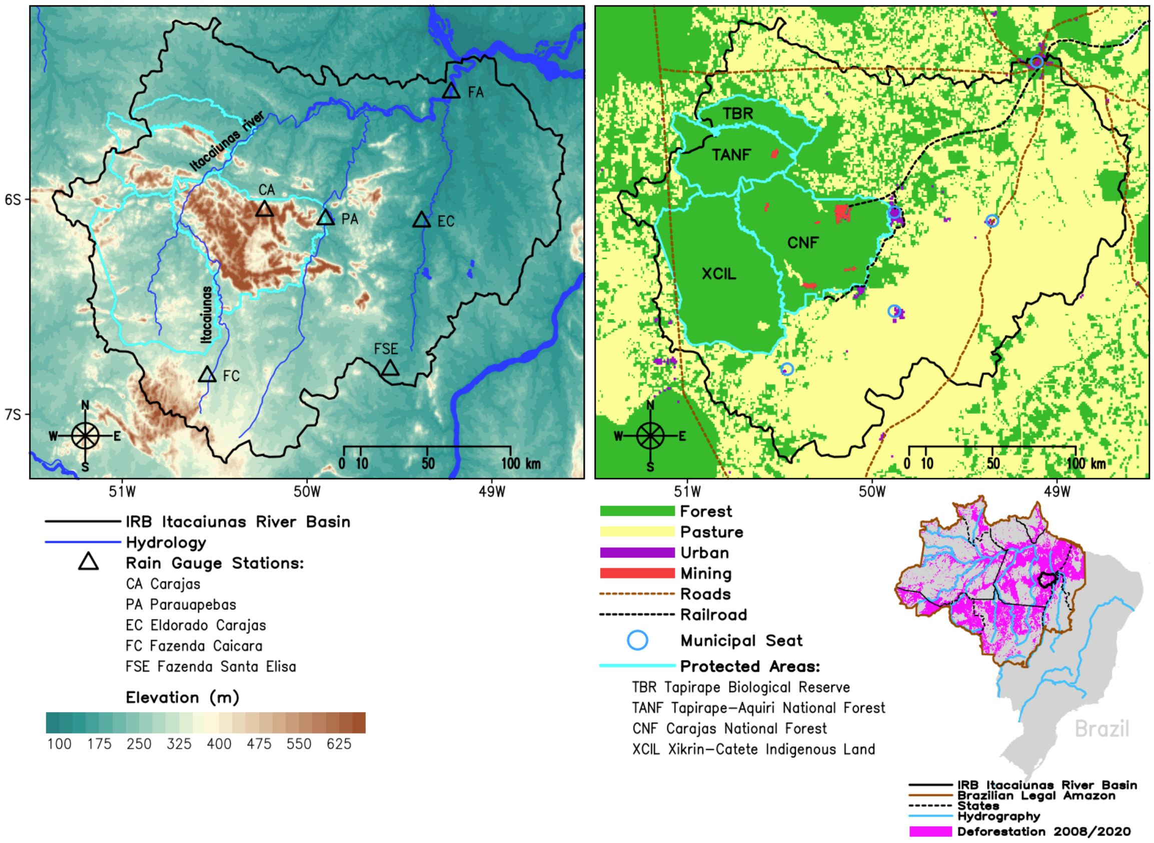
2 MATERIAL AND METHODS

An observational and climate modeling approach was conducted with the intention of characterizing the main seasonal regimes over the Itacaiúnas River Basin (IRB), including the selection of the best gridded databases for analysis of observed precipitation and air temperature spatial patterns, as well as to investigate the RegCM's performance for the current climate and further assessing the impacts of the near-future global and regional scenarios on seasonality of the basin.

2.1 STUDY AREA, OBSERVATIONAL DATASETS, AND ANALYSIS PROCEDURES

The IRB with an area of approximately 41,300 km^2 is located in eastern Brazilian Legal Amazon, southeastern state of Pará, within the well-known Amazonian Deforestation Arc (Fig. 1, bottom map). The Itacaiunas river arises in the high topography area situated in the southeast of the basin and flows northward crossing the Serra dos Carajás mountain with 400 to 700 m elevations in central/western part, then it flows through the north/northeast lowlands ranging 100 to 300 m (Fig. 1, map on the left). Souza-Filho et al. (2016) conducted a multidecadal LUC changes mapping study for the IRB region and evidenced that the human-induced deforestation over a 40-year period (1973 to 2013) resulted in significant landscape alterations, such that only ~48% of the primary tropical forest cover was conserved, while pasturelands prevail in more than half of the watershed area. In the LUC map (Fig. 1, map on the right) it is possible to identify an area around 12,000 km2 of remnant tropical forest within the mosaic of protected areas in the midwestern portion. Such protected areas are formed by indigenous lands, and integral or sustainable use conservation units, which have federal jurisdiction and are monitored by Brazilian Institute for Biodiversity Conservation (ICMBIO, in portuguese). In the rest of the basin (outside the protected areas) the predominance of pastures is noticed throughout the region with the presence of some urban centers and several small packages of fragmented vegetation especially in northeastern portion (Fig. 1, map on the right). Another importante aspect is the mining activity that occurs in the higher topographic areas of the Carajás National Forest (CNF), whose iron ore production is transported by the railroad towards the northeast of the region.

Figure 1 - Study area in the Itacaiunas River Basin (IRB) with topography, hydrology, and locations of the raingauge stations (left map); LUC map and limits of mosaic of protected áreas (right map). Bottom map shows the IRB within Brazilian Amazon including deforestation areas.



Source: Prepared by the authors (2021).

We used in situ data extracted from six raingauge stations relatively well spread across the southern, central and northeastern sectors of the IRB (see circle locations in Fig. 1, left map). Monthly precipitation (mm/day) from the Fazenda Caiçara (FC), Fazenda Santa Elisa (FSE), Parauapebas (PA), Eldorado dos Carajás (EC) and Fazenda Alegria (FA) stations were acquired from the National Water Agency of Brazil through the National Water Resources Information System (SNIRH: http://www.snirh.gov.br/hidroweb) and the Carajás (CA) station was provided by the VALE company, and this is the only one located in the mining region at the top of the mountain. Time series over a period of 25 years (1994 to 2018) are available for FC, FSE, EC and CA and 15 years (2004 to 2018) for PA and FA stations. In addition, we obtained gridded data from ten precipitation databases that have different spatial resolutions and were generated from precipitation estimates based on multiple sensors aboard geostationaryand polar-orbiting satellites, and/or from meteorological station network, whose some details are described in Table 1.

Table 1 – Description of ten gridded precipitation databases.

Acronym	Name and type of data source	Resolution	Period	Reference
CR	Climatic Research Unit gridded Time Series (CRU TS): only stations observations	0.05°	1994 to 2018	Harris et al. (2020)
CH	Climate Hazards group Infra-Red Precipitation with Stations (CHIRPS): satellite + gauge	0.05°	1994 to 2018	Funk et al. (2015)
ME	Combining TRMM/GPM and Surface Observations of Precipitation over South America (MERGE): satellite + gauge	0.1°	2000 to 2018	Rozante et al. (2010)
ER	ERA5 global reanalysis: model + observations	0.25°	1994 to 2018	Hersbach et al. (2020)
TR	Multi-satellite Precipitation Analysis from Tropical Rainfall Measuring Mission (TRMM): satellite + gauge	0.25°	1998 to 2017	Huffman et al. (2007)
PE	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN): satellite + gauge	0.25°	1994 to 2018	Hong et al. (2004)
XA	Gridded meteorological variables in Brazil (XAVIER): Only gauge	0.25°	1994 to 2015	Xavier et al. (2016)
CM	Climate Prediction Centre Morphing technique (CMORPH): satellite + gauge	0.25°	2000 to 2018	Xie et al. (2017)
UD	University of Delaware: only gauge	0.5°	1994 to 2018	Willmott and Matsuura (2001)
CP	Climate Prediction Center Global Unified Gauge-Based Analysis (CPC): Only gauge	0.5°	1994 to 2018	Chen et al. (2008)

Source: Prepared by the authors (2021).

Concerning near-surface air temperature data, we used two databases, the version 4 of the gridded CRUdata over all global land domains derived by the interpolation of monthly climate variables extracted from extensive networks of weather station observations (HARRIS et al. 2014), and the ERA5 global reanalysis with enhanced horizontal resolution that has been generated under significant scientific and technological upgrades on coupled modelling of the land-atmosphere processes and advanced operational techniques of multiple observational data assimilation (HERSBACH et al., 2020).

The climatological characterization of the rainfall regimes in the IRB is based on the descriptive statistical analysis employed on 25-yr monthly timeseries of the six rain gauge stations together, to obtain the box plots of annual cycle representative of in situ observational data. The monthly percentages (relative to the annual total) of climatological precipitation were calculated to delimit the months of the seasonal regimes. Then, the consecutive months that presented percentages above 10% were defined as the RAINY regime; the months with percentages below 5% were defined as the DRY regime; and a third regime named PRE-RAINY was defined in consecutive months that presented percentages varying between 5 and 10%.

Once the seasonal periods are known, the timeseries of the precipitation for RAINY, PRE-RAINY and DRY regimes in the years 1994 to 2018 were generated for the average of the six raingauge stations and also for the ten gridded precipitation databases. The Taylor diagram and corresponding statistical calculations, such as the Pearson's correlation coefficient, root mean square error (RMSE), standard deviation, and determination coefficient were applied to compare quantitatively the precipitation during the three seasonal regimes and thus to assess which gridded databases have higher degree of correspondence and consistency with the observational raingauge data. The best statistical scores in the Taylor diagram will be used to choose at least three databases, and later to generate a new blended observational database with the purpose of investigating the spatial pluviometric configuration during the RAINY, PRERAINY and DRY regimes throughout the IRB, as well as for validating the results of climate modelling.

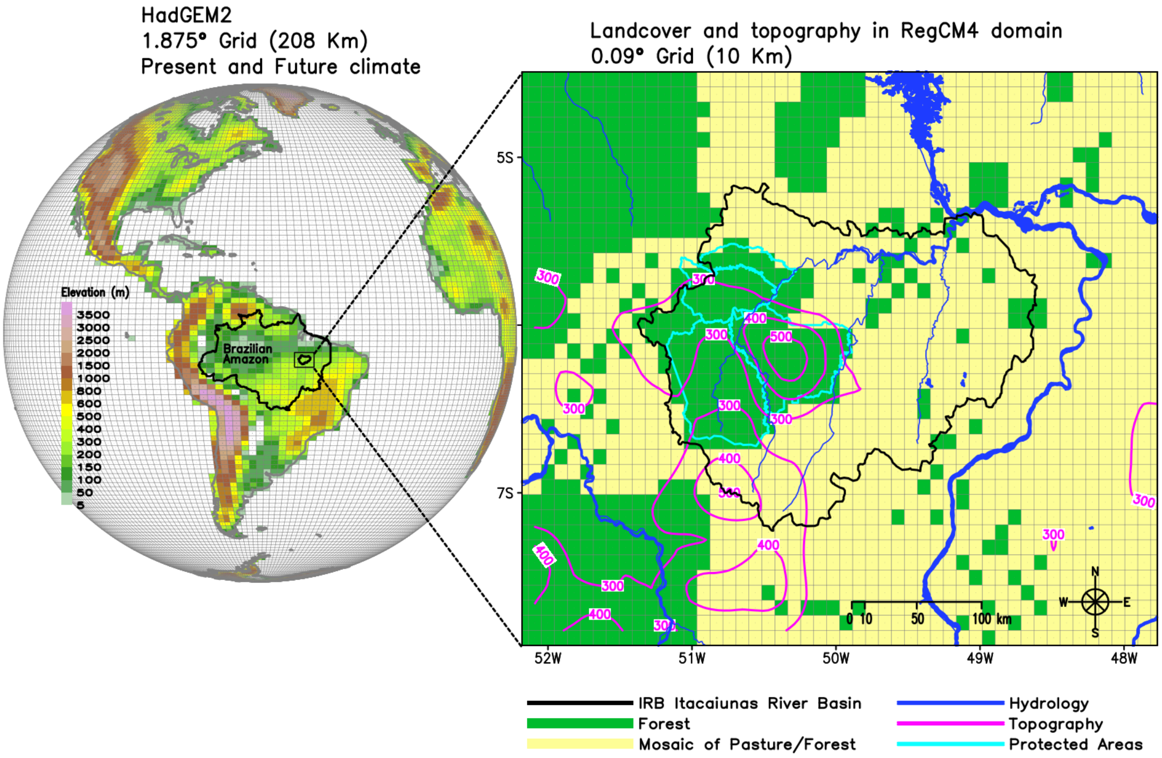
2.2 REGCM4 CONFIGURATION, EXPERIMENT DESIGN AND EVALUATION METHODS

The version 4.7.1 of RegCM4 (portable source code available at https://github.com/ictpesp/ RegCM), the fourth generation of the regional modeling system (Giorgi et al. 2012) developed at the International Center for Theoretical Physics (ICTP), was used to perform the dynamical downscaling over the IRB. This latest updated version includes the option of hydrostatic or non-hydrostatic dynamical core based on sigma-p vertical coordinates and multiple choices of different model physics and new parameterizations schemes (Giorgi et al., 2012).

In this work, the RegCM4 was compiled with the hydrostatic core by using the Biosphere Atmosphere Transfer Scheme (BATS, Dickinson et al., 1993) to describe land surface processes. Three RegCM4 experiments with different convective precipitation parameterisations were conducted, the Emanuel (EMA) scheme (Emanuel, 1994), Kain-Fritsch (KFR) scheme (Anderson et al., 2007), and Tiedtke (TIE) scheme (Tiedtke, 1989). For global terrain and landuse, we used the 30s resolution global land cover characteristics (GLCC) by Loveland et al. (2000) and GTOPO topography data taken from the USGS.

The RegCM4 domain was set over the IRB region (central point at 52.0°W and 6.2°S) considering a horizontal 0.09° grid spacing (10 km), 18 sigma-pressure vertical levels with top pressure in 5 hPa. The Fig. 2 (right map) depicts the spatial patterns of the topography and the LUC characteristics at 10 km resolution that was properly updated to be consistent with recent data from IBGE (as in Fig. 1). The LUC map in Fig. 2 shows forest cover (green grids) mainly over protected areas in the central/western portion and a pasture/forest mosaic (yellow grids) predominating in the rest of the basin. Also is possible to visualize in the Fig. 2 (left map) the 1.875° HadGEM2 global grid, including the location of the IRB in eastern Amazon, whose data was used to force RegCM4 for current and near-future climate simulations. So, The UK Met Office Hadley Centre (HadGEM2-ES) Global Circulation Model (Collins et al. 2011) outputs at 6 hourly intervals have been used as the initial and boundary conditions for RegCM4 simulations with BATS scheme. We selected the HadGEM-ES ensemble from Coupled Model Inter-comparison Project Phase 5 (CMIP5) under the RCP8.5 scenario that is considered the most extreme future global climate change. All simulations were performed for a continuous integration starting on 01 January 2005 and ending on 31 December 2045. The first year is considered as a spin-up period and is not included in the analysis, so that the model results will be evaluated for a period of 15 years (2006 to 2020) considered as present-climate and next 25 years (2021 to 2045) are defined as near-future climate.

Figure 2 - RegCM4 domain (right map) showing the topography (m) and landcover patterns over the IRB at 10 km resolution. The 1.875° HadGEM2 global grid is presented on the left map.



Source: Prepared by the authors (2021).

The seasonal means of precipitation and air temperature during the RAINY, PRE-RAINY and DRY regimes were calculated for the three RegCM4 simulations (EMA, KFR and TIE convective schemes) in the years 2006 to 2020. The new blended observational databases for precipitation and air temperature (compiled in the present study) are adopted to validate the performance of seasonal spatial patterns predicted by RegCM. To enable statistical comparisons, observed and simulated data were spatially remapped to a common 0.09° (10 km) horizontal grid by using bilinear interpolation. As quantitative measurements of overall model performance, we consider relative bias [(model – observations) / observations], and the spatial correlation [covariance (model, observations) / **s**model × **s**observations], so that both metrics were employed across all grid points over IRB region.

We performed two RegCM4 experiments driven by HadGEM2-ES covering the period 2005-2045, in which the first one considers the recent LUC map over the basin (as in Fig. 2), and the second one contemplates LUC changes with the forest cover

over protected areas being modified to the pasture/forest mosaic and in the rest of the basin being altered for short grass surface cover. In the BATS model code, the leaf area index (LAI, in m2/m2) in the forest cover varies between 5 and 6, the pasture/forest mosaic between 1 and 6 and the grass between 0.5 and 2 (Giorgi et al., 2012). Thus, we assume that the first simulation depicts only the impacts of global climate change, hereafter referred as the GCC experiment, while the second expresses the regional impacts related to the LUC changes in combination with the GCC, referred as the GCC+LUC experiment. The impacts of the GCC and GCC+LUC experiments on precipitation and air temperature seasonal patterns over the IRB region will be evaluated by the physical interpretation of the atmospheric variables of the water balance, considering the differences between the near-future climate (means of the next 25 yr periods, 2021/2045) and the current climate (mean of the last 15-yr period, 2006/2020). In these comparative analyses, the two-tailed T-test with 5% level (p-value below 0.05) will be considered in order to investigate the statistical difference between the means of the future and present RegCM experiments.

The interpretation of near-future changes obtained from RegCM experiments was conducted analyzing the water budget components in terms of simplified equation $P = E + C$, so that P is precipitation, E is evapotranspiration and C is vertically integrated moisture flux convergence. Thus, the results can discriminate whether the precipitation change signal is affected by land-atmosphere feedback (modulation of variable E) or by the large-scale circulation patterns (modulation of variable C), or even if both processes act to explain the sign of changes.

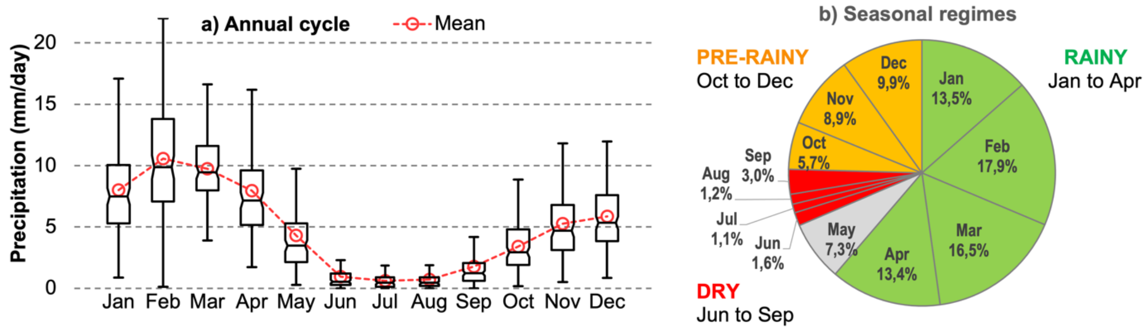
3 RESULTS

3.1 OBSERVED PATTERNS IN THE SEASONAL REGIMES

The Fig. 3 illustrates the box-plot graphics of annual cycle of the climatological precipitation (mm/day) based on series of meteorological stations for the period 1994 to 2018 in IRB and pie chart of the monthly percentages (relative to the annual total) of precipitation. The rainfall cycle in IRB is very pronounced throughout the year, with maximum values reaching an average of 297 mm in February and 310 mm in March, while minimum values reach 20 mm in June and 23 mm in August. Based on the monthly percentages relative to the annual total (pie chart), the seasonal climate regimes in the region stand out:

- Dry regime (monthly percentages < 5%) between June and September;
- Pre-rainy regime (monthly percentages >5% and <10%) occurs between the months of October and December;
- Rainy season (monthly percentages >10%) takes place between January and April.

Figure 3 - a) Annual cycle of the climatological (1994/2018) precipitation (mm/day) based on six gauge stations, b) corresponding pie chart of the monthly percentages (relative to the annual total) of precipitation, including the selection of the three seasonal regimes.



Source: Prepared by the authors (2021).

Table 2 and Figure 4 (Taylor's diagram) show the descriptive statistics of the different gridded precipitation databases with reference to observational data on the basin. To build the new precipitation database (NB-New Blended) over the basin in the three seasonal regimes, the 3 that presented the highest scores were selected as the correlation. For the dry regime, the best databases on the basin are TRMM, ERA5 and

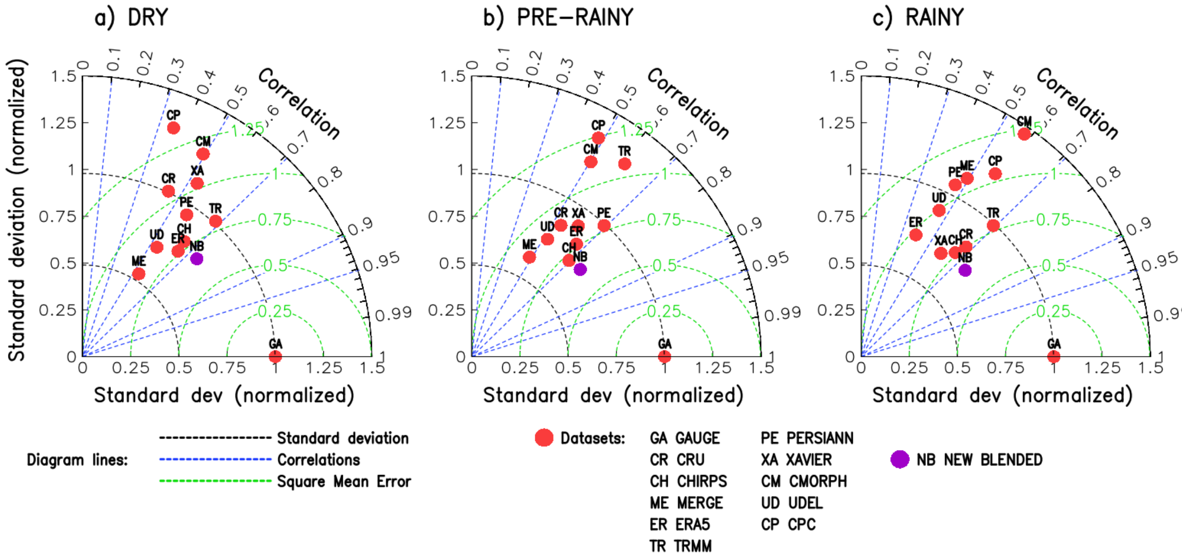
CHIRPS, while for the rainy are TRMM, CRU and CHIRPS. For pre-rainy the recommended are CHIRPS, PERSIANN and ERA5.

Table 2 - Standard deviation normalized (sn), correlation coefficient (r), determination coeficiente (R2) and root mean square error (RMSE) corresponding to the ten precipitation databases for DRY, PRERAINY and RAINY regimes. Values in bold indicate the three databases used to generate the new blended data.

	DRY				PRE-RAINY				RAINY			
	sn	r	R^2	RMSE	sn	r	R^2	RMSE	sn	r	R^2	RMSE
CRU	0.99	0.45	0.20	0.46	0.84	0.55	0.31	3.25	0.80	**0.68**	0.46	1.06
CHIRPS	0.81	**0.63**	0.40	0.16	0.72	**0.70**	0.49	2.39	0.74	**0.66**	0.43	1.07
MERGE	0.53	0.59	0.35	0.49	0.61	0.49	0.24	3.37	1.10	0.50	0.25	9.85
ERA5	0.77	**0.65**	0.43	0.52	0.81	**0.67**	0.45	1.07	0.71	0.40	0.16	3.17
TRMM	1.12	**0.70**	0.49	0.18	1.30	0.61	0.37	3.33	0.98	**0.70**	0.49	1.66
PERSIANN	0.93	0.58	0.34	0.28	0.98	**0.70**	0.49	5.06	1.04	0.47	0.22	2.02
XAVIER	1.10	0.54	0.29	0.24	0.89	0.62	0.38	1.62	0.69	0.60	0.36	2.30
CMORPH	1.25	0.50	0.25	0.31	1.26	0.51	0.26	4.93	1.46	0.58	0.33	5.83
UDEL	0.70	0.55	0.30	1.52	0.74	0.53	0.28	3.77	0.88	0.46	0.21	1.89
CPC	1.31	0.36	0.13	0.47	1.34	0.49	0.24	2.19	1.20	0.58	0.33	3.42
BLENDED	0.80	0.76	0.58	0.12	0.75	0.77	0.59	2.27	0.72	0.75	0.57	0.88

Source: Prepared by the authors (2021).

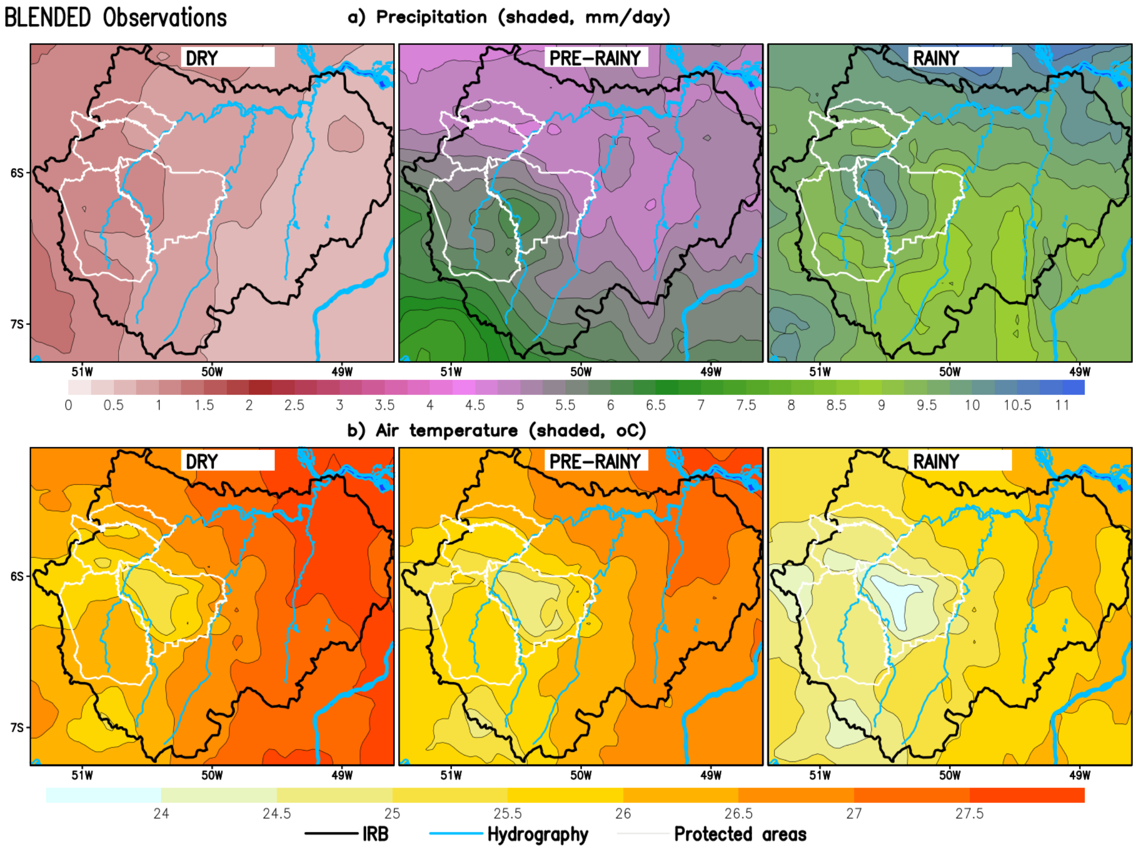
Figure 4 - Taylor diagrams of the IRB area-averaged climatological precipitation considering the ten databases for a) DRY, b) PRE-RAINY and c) RAINY regimes.



Source: Prepared by the authors (2021).

The figure 5 refers to the climatology of precipitation (a) and temperature (b) in the basin from the new database created, New Blended in the 3 climate regimes. Note that the new dataset is able to represent the main patterns of these variables. In the dry regime (upper and lower left panels) the lowest rainfall levels, less than 0.5mm/day, are located to the east of the basin, and with high temperatures, on average, above 27°C, the highest throughout the year. In the period of the year when the rainy season begins in the basin (pre-rainy, middle panels, the new dataset represents the highest rainfall volumes in the southwest of the basin, above 5mm/day, representative of the rains caused by the South Atlantic Convergence Zone. In the rainy season (upper and lower right panels), rainfall volumes in the entire basin are above, on average, 9mm/day, with emphasis on the protected areas in the Flona de Carajás, with an average daily rainfall exceeding 10.5mm. It is also observed that in this period of the year, the average temperature can be below 24°C over the protected areas, coinciding where there is forest.

Figure 5 - Climatological spatial patterns (1994/2018) of the new BLENDED data for a) precipitation (mm/day) and b) near surface air temperature (°C) during DRY, PRE-RAINY and RAINY regimes. Magnitudes are indicated by the colorbars.



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3.2 SIMULATIONS OF REGIONAL AND GLOBAL CHANGES IMPACTS

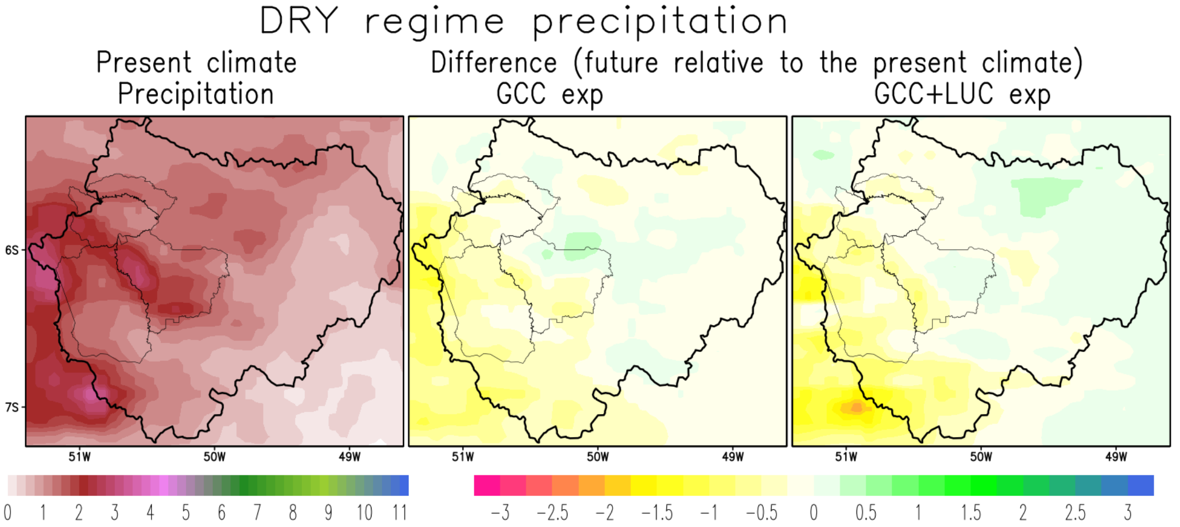
The results of the RegCM4 simulations for the present climate and the changes obtained in the GCC and GCC+LUC experiments in terms of the difference between the near-future climate relative to the present climate during the DRY, PRE-RAINY and RAiNY regimes are shown in Figs. 6, 7 and 8, respectively.

For the DRY regime (Fig. 6), the model well captures the spatial distribution of rainfall observed in the present climate. Analyzing future climate changes, the GCC experiment indicates a pattern alternating between negative in the center-south and positive in the eastnortheast of the region. The GCC+LUC experiment points out a trend of increased precipitation throughout the region.

For the pre-rainy regime (Fig. 7), the RegCM4 is able to reproduce the spatial pattern of rainfall observed in the present climate, except in the southeastern portion. The future climate changes simulated by the GCC experiment indicate areas of increase in the south and negative areas in the central portion, while the GCC+LUC experiment points out a change of precipitation intensification configuring throughout the entire region, mainly in the southern portion.

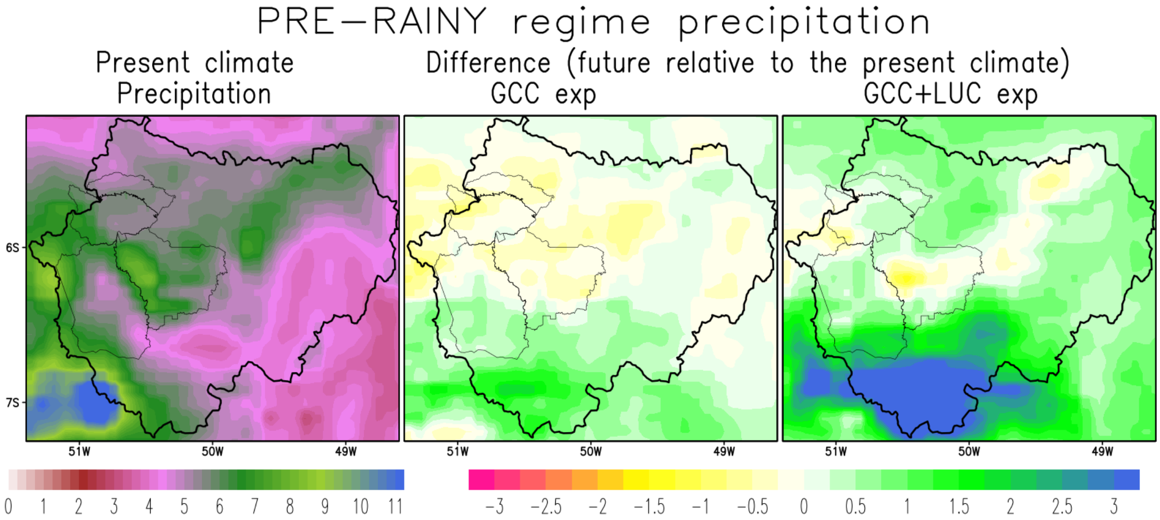
In the RAINY regime (Fig. 8), the spatial pattern of precipitation in the present climate is very well simulated by the regional model. In terms of future climate changes, the GCC experiment exhibits alternating positive and negative values across the region. The GCC+LUC experiment shows more significant changes in precipitation increase over most of the region.

Figure 6 - Precipitation in the present climate (left) and the changes obtained in the GCC and GCC+LUC experiments (middle and right) in terms of the difference between the near-future climate relative to the present climate during the DRY regime.



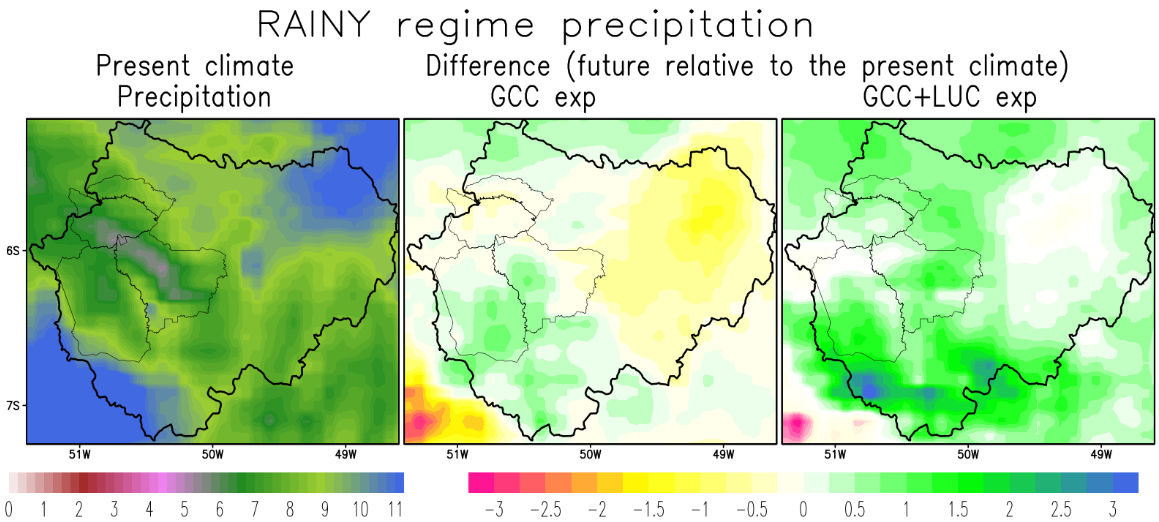
Source: Prepared by the authors (2021).

Figure 7 - As in Fig. 7, but for the PRE-RAINY regime.



Source: Prepared by the authors (2021).

Figure 8 - As in Fig. 7, but for the RAINY regime.



Source: Prepared by the authors (2021).

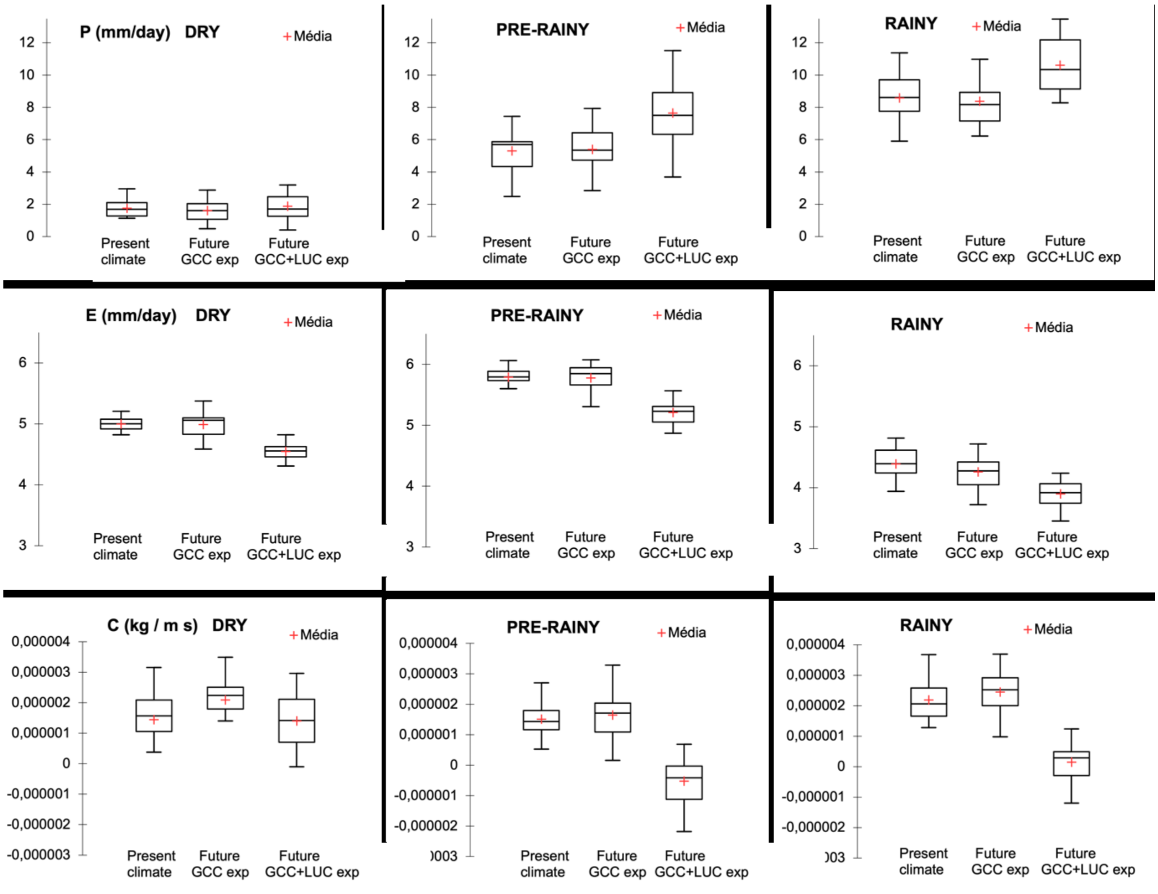
To better understand the changes simulated by the RegCM experiments, the values of water budget components (P – precipitation, E – evapotranspiration and C – convergence of moisture flux) were calculated for IRB area-averaged considering the present climate (2006 to 2020) and near-future climate (2021 to 2045) and then the boxplots were plotted in Fig. 9. The Table 3 also help to understand such results considering the area-averaged values for the whole IRB region.

For the DRY season, the comparison of the boxplots (Fig. 9, left panel) and the values in Table 3 indicates that the GCC experiment for near-future climate, P decreases, E is stable and C with a positive value indicates an increase in the divergence of the moisture flow. In the GCC+LUC experiment, P increases, E decreases and negative C shows increasing moisture convergence.

For the PRE-RAINY season (Fig. 9, middle panel, and Table 3), the GCC experimente for near-future climate shows P increasing slightly, E becoming relatively negative and C with a positive value indicating some decrease in moisture flow divergence. In the GCC+LUC experiment, the values of P and E are much higher and negative C indicates an increase in the convergence of the moisture flow.

In the RAINY regime (Fig. 9, right panel, and Table 3), the GCC experiment for nearfuture climate shows a decrease in P and E and an increase in moisture divergence, while the GCC+LUC experiment points out signs of an increase in P, a decrease in E and an increase in the convergence of the moisture flow.

Figure 9 - Boxplots of P precipitation, E evapotranspiration and C convergence of moisture flux) corresponding to the IRB area-averaged for the present climate (2006 to 2020) and near-future climate (2021 to 2045) in the RegCM4 experiments for the DRY, PRE-RAINY and RAINY regimes.



Source: Prepared by the authors (2021).

Table 3 - Differences between near-future climate relative to present climate for RegCM4 experiments during the DRY, PRE-RAINY and RAINY regmes.

Variables	RegCM Experiments	DRY	PRE-RAINY	RAINY
T	GCC exp	0,99	0,83	0,58
	GCC+LUC exp	1,45	1,41	1,05
P	GCC exp	-0,15	0,05	-0,21
	GCC+LUC exp	0,12	2,30	2,00
E	GCC exp	0,00	-0,02	-0,13
	GCC+LUC exp	-0,45	-0,60	-0,50
C	GCC exp	6,45E-07	1,29E-07	2,63E-07
	GCC+LUC exp	-4,32E-08	-2,03E-06	-2,04E-06

Source: Prepared by the authors (2021).

4 DISCUSSION AND CONCLUDING REMARKS

Based on analysis of precipitation data from in situ stations and from several gridded databases for the period 1990 to 2020, our results evidenced the existence of three well configured seasonal regimes occurring in the IRB region, the DRY, PRE-RAINY and RAINY that present different precipitation and air temperature spatial patterns over the watershed.

The results obtained in two sets of experiments using RegCM4 driven by HadGEM2-ES revealed that the combined effects of global climate change (RCP 8.5 scenario) and the conversion of forest cover to pasturelands cause impacts on the water and energy balance over the IRB. The impacts are evident in the three seasonal regimes, DRY, PRE-RAINY and RAINY. Such evidence indicates the fundamental role of protected areas with forest cover in the domain of hydrographic basins, like the IRB, within the Amazon deforestation arc.

The forests protected by VALE in the IRB, as well as actions to recover degraded areas, are essential to maintain regional climate regulation and mitigate the effects of global warming. In addition, they ensure biodiversity in the biome and generate income for communities close to the project, thus contributing to a more sustainable mining industry.

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