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COMPARISON AND VALIDATION OF TRMM SATELLITE PRECIPITATION ESTIMATES AND DATA OBSERVED IN MATO GROSSO SUL STATE, BRAZIL

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ABSTRACT: Precipitation is the most important variable in the hydrological cycle and can be estimated through remote sensing. Thus, the use of estimated satellite data has been an alternative to the absence of meteorological stations. The objective of this study was to evaluate the rainfall data of the TRMM satellite 3B43 product with observed data in the state of Mato Grosso do Sul for the period 1998 to 2019. For this purpose, it was used the regression analysis and statistical indicators: Bias, Root mean squared error (RMSE), Pearson correlation coefficient (r). For the most part, the satellite estimation data were satisfactory, especially for the months from March to November. The results indicate that the use of the estimated satellite data may be an alternative to the use of meteorological stations.

KEYWORDS: remote sensing, satellite data, rainfall.

COMPARAÇÃO E VALIDAÇÃO DAS ESTIMATIVAS DE PRECIPITAÇÃO DO SATÉLITE TRMM E DADOS OBSERVADOS NO ESTADO DE MATO GROSSO SUL, BRASIL

RESUMO: A precipitação pluvial é a variável mais importante do ciclo hidrológico e pode ser estimada através de sensoriamento remoto. Assim, a utilização de dados estimados via satélite tem sido uma alternativa frente à ausência de estações meteorológicas convencionais e automáticas. Neste estudo, objetivou-se avaliar dados de precipitação pluvial do produto 3B43 do satélite TRMM com os dados observados no estado de Mato Grosso do Sul para o período de 1998 a 2019. Para isto, utilizamos a análise de regressão e indicadores estatísticos: Bias, Raiz do quadrado médio do erro (RMSE) e coeficiente de correlação de Pearson (r). Em sua maioria, os dados de estimativas via satélite foram satisfatórios, sobretudo para os meses de março a novembro. Os resultados indicam que o uso dos dados estimados via satélite podem ser uma alternativa ao uso de estações meteorológicas.

PALAVRAS-CHAVE: sensoriamento remoto, dados de satélites, precipitação pluvial.

COMPARACIÓN Y VALIDACIÓN DE LAS ESTIMACIONES Y DATOS DE PRECIPITACIÓN DEL SATÉLITE TRMM OBSERVADOS EN EL ESTADO DE MATO GROSSO SUL, BRASIL

RESUMEN: La precipitación es la variable más importante del ciclo hidrológico y puede estimarse por teledetección. Por lo tanto, el uso de datos satelitales estimados ha sido una alternativa en ausencia de estaciones meteorológicas. El objetivo de este estudio fue evaluar los datos de lluvia del producto satelital TRMM 3B43 con los datos observados en el estado de Mato Grosso do Sul para el período de 1998 a 2013. Para esto, solíamos análisis de regresión y los siguientes indicadores estadísticos: sesgo, raíz del cuadrado medio del error (RMSE) y coeficiente de correlación de Pearson (r). La mayoría de los datos de estimaciones satelitales fueron satisfactorios, especialmente para los meses de marzo a noviembre. Los resultados indican que el uso de datos estimados por satélite puede ser una alternativa al uso de estaciones meteorológicas.

PALABRAS CLAVE: teledetección, datos satelitales, precipitaciones.

INTRODUCTION

The State of Mato Grosso do Sul is an agricultural state and is among the five largest grain producers in Brazil, with approximately three million hectares planted according to the Agribusiness Geographic Information System (SIGA-MS Program), implemented by Semagro (Secretariat Environment, Economic Development, Production and Family Farming) in cooperation with Aprosoja and Famasul (Federation of Agriculture of Mato Grosso do Sul).

However, in order to obtain better yields in the agricultural activity, there must be a good interaction between the conditions of the environment and the planted crop. Based on rainfall studies, we can seek to minimize losses to corn and soybean crop in regions that lack agroclimatic information (LONGO et al., 2006; SILVA et al., 2007; GARCIA et al. al., 2013).

Precipitation is a key component of the energy balance and water cycle and also plays a vital role in shaping the regional climate and the global climate. Thus, accurate rainfall data at high spatial and temporal resolution is extremely desirable for multiple fields of research, extreme climate, and flood forecasting (MOFFITT et al., 2011; DUAN and BASTIAANSSEN, 2013; POMBO and OLIVEIRA, 2015; ZHANG, et. al., 2016).

Although conventional rainfall gauges are considered standard precipitation gauges, their spatial limitations on point measurements and relatively insufficient networks around the world mean that they cannot reliably reflect rainfall distribution, while remote sensing has become the primary Accurate and continuous rainfall data source, potentially able to address this limitation, providing rainwater products to make alternative or supplementary estimates (JAVANMARD et al., 2010; SHRIVASTAVA et al., 2014; MANTAS et al., 2015). Therefore, the evaluation of satellite precipitation products on quality and viability is very necessary for improving product quality and researching climate change.

Rainfall monitoring in the Brazilian territory is mainly carried out through terrestrial climate stations that integrate monitoring networks of the main operational centers of the country (AIRES et al., 2016).

Rainfall monitoring of a region requires a high density of spatially well-distributed rainfall when the measurement scale of these devices is timely (KIDDER and HAAR, 1995) and does not provide representative values for large areas and often subject to failures that limit the use of this rainfall. The low density of rainfall, the irregular distribution of meteorological stations and the long distance between them, do not allow capturing the spatial variability of rainfall, generating uncertainties in the results of studies of this kind (FENSTERSEIFER, 2013; PEREIRA et al., 2013). Therefore, it is essential that rainfall estimates are closer to the real, as excessive rainfall can lead to flooding, loss of property and lives, and in the prolonged absence of drought, which directly affects crops and consumption limits Human (SILVA-FUZZO and ROCHA, 2016).

Due to the high cost and difficulty in obtaining measurements in hard to reach areas, numerical simulations and satellite data have been used for climatological and hydrological studies, contributing to increased coverage of climate data (LONGO et al., 2006; ADAMS et al., 2009). The use of satellite data has become indispensable to overcome data scarcity in regions that do not have rainfall stations or do not cover their entire territory (SANCHEZ-MORENO et al., 2014).

Among the many existing satellites for remote weather monitoring is the Tropical Rainfall Measuring Mission (TRMM) satellite, launched in November 1997, in a partnership between the National Aeronautics and Space Administration (NASA) and the Japan Aerospace Exploration Agency (JAXA), to monitor the precipitation in the tropics, and to verify its influence on the global climate (KUMMEROW et al., 2000).

TRMM provides more accurate data than indirect techniques, based on images from other satellites, and is the most equipped in terms of precipitation estimation instruments (VOLPATO et al., 2013; MAHMUD, 2014). However, to ensure that this satellite provides consistent estimates, it is necessary to validate this information with surface measurements to quantify its accuracy and precision (KUMMEROW et al., 2000; KARASEVA et al., 2011; PESSI et al., 2019).

Other authors have demonstrated in their works that there is a good relation between precipitation estimates and data from the TRMM satellite, including: SILVA-FUZZO and ROCHA (2016), ALMEIDA et al. (2015), CAMPAROTTO et al. (2013), FENSTERSEIFER (2013), AS-SYAKUR et al. (2011) and KARASEVA et al. (2011).

As the TRMM satellite with the first space precipitation radar has completed more than 22 years of operation since 1997, its products have been widely applied in hydrological modeling fields (LI et al., 2012; MENG et al., 2014), meteorological drought (SAHOO et al., 2015; ZHANG and JIA, 2013), agricultural science (ARVOR et al., 2014; CASHION et al., 2005) etc., and were rated with better performance than rain gauges (DINKU, et al., 2007). In fact, in recent years, the differences between TRMM rainfall products and rainfall observations have been analyzed worldwide.

Fleming et al. (2011) compared the precipitation product 3B43 with the

Australian Bureau of Meteorology regridding dataset, which shows a correlation coefficient of 0.93 between these two datasets. Curtarelli et al. (2014) determined that there is good agreement (> 0.97) between the monthly average rainfall product TRMM 3B43 and in situ data on the Itumbiara reservoir drainage area in Central Brazil, but 3B43 tends to overestimate rainfall by approximately 1.24%. Tao et al. (2016) revealed that the best agreement of 3B43 rainfall data with observations that tend to occur in autumn (SON) and large bias can be observed during spring (NAGAOKA et al., 2009) and winter (DJF) in the Jiangsu province from, China. Nastos et al. (2016) concluded that the correlations between 3B43 rainfall and the winter terrestrial database are very high (> 0.90) for the entire Greek domain, although 3B43 overestimates precipitation over the Aegean and Ionian Sea, coastal areas, Asia Minor and Western Greece in autumn (> 60 mm). Wang et al. (2017) pointed out that 3B43 data are very consistent with autumn soil measurements and relatively stable capacity during the relatively arid and humid years in China's Qinling-Daba Mountains.

Buarque et al. (2011) emphasized that uncertainty in rainfall characteristics is underestimated after comparing four computational precipitation characteristics of the Brazilian rainfall network and the TRMM 3B42 datasets in the Amazon Basin. Chen et al. (2011) also found that TRMM 3B42 rainfall data are highly accurate and well correlated with rainfall observed in the Dongjiang River basin in the middle of the Peral Delta in China. Chen et al. (2013) showed that 3B42 has good ability to detect heavy rainfall in tropical cyclones, as well as good correlation and pattern of comparison with observations from the Comprehensive Pacific Rainfall Database. Zhao et al. (2015) reported that there is a good linear relation between monthly rainfall of 3B42 and rainfall data on the semi-wet Weihe River basin in the Yellow River basin in China.

However, the accuracy of TRMM precipitation data depends on a number of factors such as regions, seasons and spatiotemporal scales, etc. Islam and Uyeda (2007) found that data from 3B42 Version 5 overestimated rainfall before the dry monsoon season, but underestimated it during the wet monsoon season in Bangladesh. Habib, et al. (2009), evaluated that TRMM multisatellite precipitation analysis (TMPA) products track temporal evolution and surface precipitation fluctuations on a storm scale reasonably well with correlation values ranging from 0.50 to 0.80 and deviations ranging from within ± 25% in Louisiana, USA. Almazroui (2011) pointed out that TRMM 3B42 tends to overestimate rainfall in Saudi Arabia, particularly in coastal areas, although the correlation coefficient between TRMM and observation is approximately 0.90 with a significance level of 99% in monthly scale. Condom et al. (2011) found that TRMM 3B43 data overestimates in situ data between May and August, while underestimating it from October to March over the mountainous areas of the Peruvian Andes. Li et al. (2013) demonstrated that daily rainfall data from 3B42 do not accurately describe precipitation occurrence and contribution rates; however, the monthly ones have a good linear relation with the observed rainfall located in the Poyang Lake Basin from the Xinjiang watershed. Khan, et al. (2014) stated that precipitation products from 3B42 version 7 during the monsoon season are highly correlated with heavy rainfall (> 30 mm / day), whose bias is about ± 20%, overestimating light rainfall with almost 100% Bias for mountain ranges in Pakistan's Indus basin. Liu (2015) examined TRMM

3B42, versions 6 and 7 products on a global scale, whose results suggest that heavy version 6 rainfall estimates are higher than those in version 7 throughout summer and winter for land and oceans, although both versions have a good coincidence in heavy rainfall regimes.

Thus, remote sensing rainfall estimates are a useful tool that aims to improve the collection of meteorological information, besides being important in helping to fill in missing data. In this context, the objective of this work was to compare the rainfall estimates of the TRMM satellite (product 3B43) with surface data from the historical series of rainfall data from the State of Mato Grosso do Sul, obtained from the Hydrological Information System of the National Agency of Waters The data were subjected to a consistency analysis and eliminated posts whose series had less than 15 years of complete observations, resulting in 32 posts from 1998 to 2013.

METHODOLOGY

STUDY AREA CHARACTERIZATION

The study area is the state of Mato Grosso do Sul (Figure 1), which is located in the Midwest region of Brazil. The state has a total area of 357,145,320 km2, covering 79 municipalities (Figure 1).

The state of Mato Grosso do Sul has high biodiversity and comprises the area of the Pantanal Biome, considered the largest floodplain in the world. The atmospheric circulations that most affect it have a tropical and extratropical origin, being influenced by local warming, moisture transport from northern South America, Frontal Systems (FS) and dry air masses of the subtropical South Atlantic region (TEODORO et al., 2016). Major determinants of air temperature variation, with low altitude areas having higher average monthly temperature values and high altitude areas having lower average temperatures (TEODORO et al., 2015).

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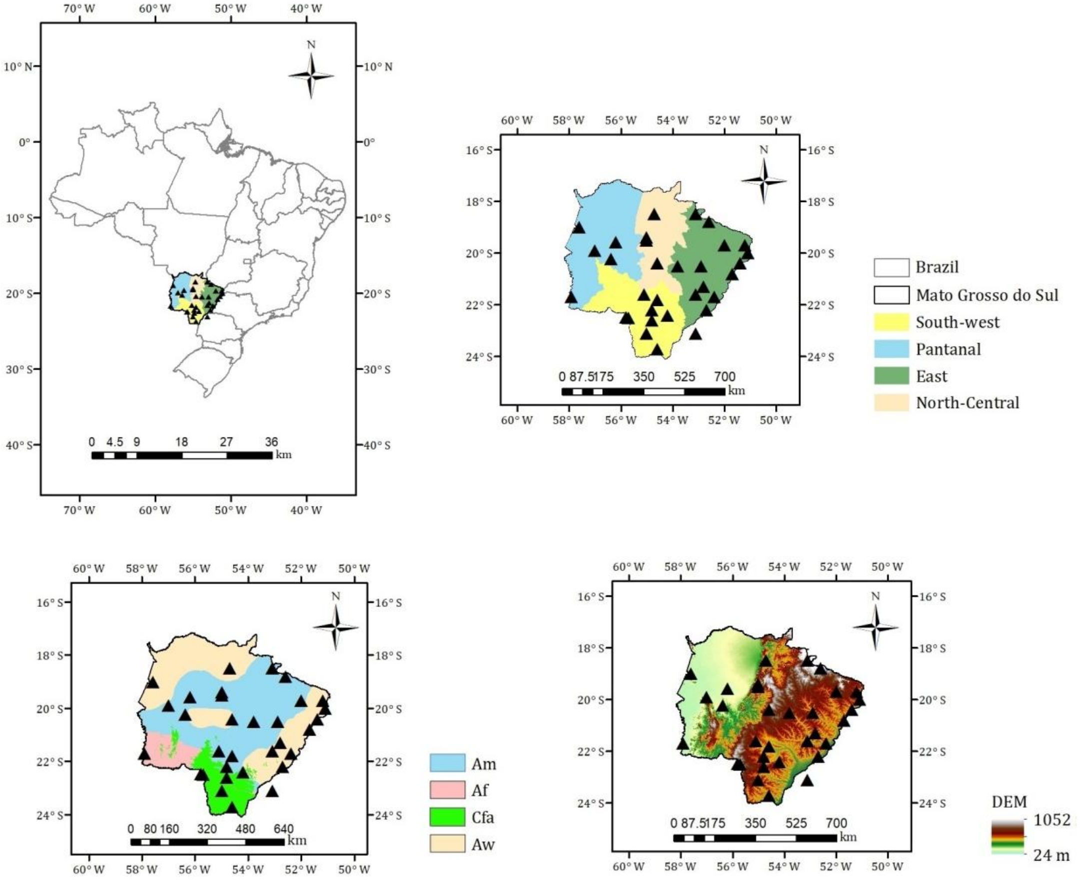

Figure 1 - Altitude map (m) of the state of Mato Grosso do Sul, separation between biomes (Savannah, Atlantic Forest and Pantanal) in the state and its location in Brazil and South America and location of weather stations and climate classification (Am, Af, Cfa e Aw). Source: The authors (2020)

The state has several edaphoclimatic characteristics distributed among three biomes with peculiar climatic attributes: Cerrado, Atlantic Forest and Pantanal. Altitudes range from 24 to 1,000 m (Figure 1).

In the state, there are three major topographic units: (a) the western Pantanal, with a unique drainage network, spread over a vast plain of modest altitudes between 80 to 200 m; (b) in the center shows a Divider Plateau or Serra de Maracaju, elongated in the Northeast-Southwest (NE-SW) direction, separating waters from the Paraguay and Paraná River basins, with altitudes ranging from 300 m (Serra de Bodoquena) to over 650 m (Amambaí Plateau); and (c) in the eastern portion, it is located on the upper Paraná River, drained by large basalt-sandstone plateau rivers, with altitudes ranging between 200 and 250 m along the valley (ZAVATTINI, 2009).

The savannah (or cerrado) is the second largest biome in South America and covers 22% of the Brazilian territory. It is in this biome that is the source of three major water sources of the South America (Amazonas / Tocantins, São Francisco and Prata), resulting in high aquifer potential and great biodiversity. Because of its latitudinal position, the region is characterized by the transition between warm low-latitude climates and temperate mid-latitude mesothermal

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climates (NIMER, 1989).

The Atlantic Forest is an environmental complex that includes mountain ranges, valleys and plateaus. It was once one of the richest and most varied sets of rainforest in South America, but is now recognized as the most uncharacterized Brazilian biome.

The Pantanal covers 25% of the state of Mato Grosso do Sul, being an almost exclusive biome of Brazil, with an area of approximately 138,183 km2. It is characterized by long-term flooding (due to low soil permeability) that occurs each year on the lowland and causes changes in the environment, wildlife and daily life of local populations (Domingues et al. 2004). The climate of the Pantanal is ''Aw'', with total rainfall between 1,000 and 2,000 mm, and two distinct seasons: one dry (May to September) and one rainy (October to April), the latter accounting for over 80% of precipitation annual total (MESQUITA et al., 2013).

HISTORICAL SERIES OF MONTHLY PRECIPITATION

The historical series used in this work are the average monthly rainfall of 32 rainfall stations in the state of Mato Grosso do Sul (Figure 1 and Table 1).

Table 1 - Identifier (ID), Altitude (m), latitude and longitude (°) and observation period of monthly precipitation of 32 municipalities in the state of Mato Grosso do Sul, Brazil.

ID	Rainfall Stations	Latitude (°S)	Longitude (°W)	Altitude (m)	Period (years)
1	Água Clara	-20.5	-52.9	303	1998-2019
2	Amambai	-23.1	-55.0	480	1998-2019
3	Anastácio	-19.6	-56.2	106	1998-2019
4	Anaurilandia	-22.2	-52.7	284	1998-2019
5	Aparecida do Tabuado	-20.0	-51.1	375	1998-2019
6	Aquidauana	-22.5	-55.8	147	1998-2019
7	Bataguassu	-21.7	-52.4	329	1998-2019
8	Bodoquena	-19.9	-57.0	133	1998-2019
9	Caarapo	-22.6	-54.8	454	1998-2019
10	Camapua	-19.5	-55.0	404	1998-2019
11	Campo Grande	-20.4	-54.6	532	1998-2019
12	Chapadao do Sul	-18.8	-52.6	790	1998-2019
13	Corumba	-19.0	-57.6	118	1998-2019
14	Costa Rica	-18.5	-53.1	641	1998-2019
15	Coxim	-18.5	-54.7	238	1998-2019
16	Dourados	-22.2	-54.8	430	1998-2019
17	Gloria de Dourados	-22.4	-54.2	422	1998-2019
18	Iguatemi	-23.7	-54.6	333	1998-2019
19	Inocencia	-19.7	-52.0	502	1998-2019
20	Maracaju	-21.6	-55.1	384	1998-2019

21	Miranda	-20.2	-56.4	125	1998-2019
22	Navirai	-23.1	-53.1	366	1998-2019
23	Nova Andradina	-21.6	-53.1	271	1998-2019
24	Paranaíba	-19.7	-51.2	374	1998-2019
25	Ponta Pora	-22.5	-55.7	655	1998-2019
26	Porto Murtinho	-21.7	-57.9	90	1998-2019
27	Ribas do Rio Pardo	-20.5	-53.8	373	1998-2019
28	Rio Brilhante	-21.8	-54.6	312	1998-2019
29	Rio Negro	-19.4	-55.0	233	1998-2019
30	Santa Rita do Pardo	-21.3	-52.8	393	1998-2019
31	Selviria	-20.4	-51.4	348	1998-2019
32	Três Lagoas	-20.8	-51.7	319	1998-2019

Observed data were obtained from the National Meteorological Water Agency (ANA) hydro-meteorological database, available at the Hidroweb - Hydrological Information System portal (http://hidroweb.ana.gov.br/) and National Institute of Meteorology (INMET). As criteria for the use of data series, we considered only the use of consistent data, with a minimum of 15 years, not being allowed years with annual failure percentage greater than 10%. To avoid discarding information, an equal data analysis period has not been established between stations. In addition, the use of series of different sizes is desirable in this type of study, since the conclusions would not be limited to the length of the series.

TRMM SATELLITE DATA

Precipitation data from the TRMM 3B43 Version 7 satellite for the state of Mato Grosso do Sul were obtained from the Giovanni website (NASA, 2018) available at the link: https://giovanni.gsfc.nasa.gov/giovanni/. The files are available in ASCII format with regular grid-point. Data refer to quadrants that cover the entire limit of weather stations (Figure 1).

STATISTICAL INDICES AND VALIDATION METHOD

Of the 32 rainfall stations, four (Bataguassu, Paranaíba, Ponta Porã and Rio Brilhante) were selected due to the greater availability of data in the period of analysis (data between 1998 and 2019, without fail). The four stations were used to check the agreement (equivalence) between the observed data and the data estimated by the TRMM 3B43 and the detail performance of the TRMM 3B43 in estimating rainfall.

To verify the statistical agreement between TRMM 3B43 data versus observational values, the linear regression analysis was used by the t-tests on the coefficient ($\beta 1$). When the slope of the regression between TRMM 3B43 data versus observational values is 1, there is an agreement. Notch box-plot analysis was used to verify the behavior of the observed data in relation to those estimated by the TRMM. Notch box-plot displays the a confidence interval around the median which is normally based on the median, significance level (5%), interquartile range (IQR), square root (sqrt) of the number of observation (n):

$$(\mathrm{n}) = \mathrm{median}\ \pm 1.57\,\frac{IQR}{sqrt} \quad (1)$$

Although not a formal test the, if two boxes' notches do not overlap there is evidence their medians differ.

The performance was analyzed through the monthly averages of the data available for analysis 32 stations and TRMM estimates, meeting the criteria previously established, by statistical indices as relative BIAS, correation coefficient (r) and mean square error (RMSE):

$$\mathrm{BIAS} = \frac{\left(\sum_{i=1}^{n} \mathrm{Rf}_{\mathrm{TRMM\text{-}i}} - \sum_{i=1}^{n} \mathrm{Rf}_{\mathrm{obs\text{-}i}}\right)}{\sum_{i=1}^{n} \mathrm{Rf}_{\mathrm{obs\text{-}i}}} \quad (2)$$

$$\mathrm{CC} = \frac{\sum_{i=1}^{N}\left(\mathrm{Rf}_{\mathrm{obs\text{-}i}} - \overline{\mathrm{Rf}_{\mathrm{obs}}}\right)\cdot\left(\mathrm{Rf}_{\mathrm{TRMM\text{-}i}} - \overline{\mathrm{Rf}_{\mathrm{TRMM}}}\right)}{\sqrt{\sum_{i=1}^{N}\left(\mathrm{Rf}_{\mathrm{obs\text{-}i}} - \overline{\mathrm{Rf}_{\mathrm{obs}}}\right)^2\cdot\sum_{i=1}^{N}\left(\mathrm{Rf}_{\mathrm{TRMM\text{-}i}} - \overline{\mathrm{Rf}_{\mathrm{TRMM}}}\right)}} \quad (3)$$

$$\mathrm{RMSE} = \sqrt{\sum_{i=1}^{n} \frac{\left(\mathrm{Rf}_{\mathrm{TRMM\text{-}i}} - \mathrm{Rf}_{\mathrm{obs\text{-}i}}\right)^2}{\mathrm{n}}} \quad (4)$$

where $\mathrm{Rf}_{\mathrm{OBS\text{-}i}}$ is the observed precipitation, Rf_{TRMMi} is the precipitation value estimated by TRMM 3B43; $\overline{Rf_{OBS}}$ is the average rainfall of the observed rainfall and $\overline{\mathrm{Rf}_{\mathrm{TRMM}}}$ is the average rainfall estimatedby TRMM of 3B43; n is number of observations

When compared to pixel/grid measurements, in situ measurements are limited in point scale with uneven distribution, in fact, an in situ station usually covers about 3 ~ 4 pixels, so it is difficult to acquire accurate, high resolution data scale in the world (WANG et al., 2017), especially in inaccessible areas (mountains, for example). However, only in situ measurements can examine the accuracy of pixel / grid data, which is still an essential part of the evaluation in the TRMM 3B43 dataset. For this purpose, based on the longitude and latitude of the weather station, the nearest four pixels, which represent the general state of precipitation around each, are selected. After the mean, pixel values are used to calculate the correlation coefficient and mean square error of the annual and monthly precipitation products of 3B43 versus the observational rainfall data at the corresponding time scales, respectively.

RESULTS AND DISCUSSION

According to Nimer (1979), the Mato grosso do Sul state has a certain climate uniformity with regard to atmospheric mechanisms (mainly the circulation of air masses), which makes the regional thermal diversification due to geographical factors such as the relief, latitude and longitude (continentality). The same author states that all static climatic factors, such as relief, act on the climate of a given region in interaction with regional atmospheric circulation systems, which demonstrates the importance of knowing the circulation systems acting on the region throughout the year to understand the climate dynamics of the study area.

Regarding the seasonal and spatial distribution of rainfall, Nimer (1979) states that these are quite simple, thanks to the terrain characteristics that do not offer great barriers to the atmospheric circulation systems that define the rainfall of the Midwest.

Due to the low significance of the topography on rainfall, the average height reached by precipitation during the year over the Brazilian Midwest's regional territory presents a very simple distribution: from a rainier nucleus north of Mato Grosso do Sul, with a decrease to east and west. In the far west of Mato Grosso do Sul, the regime decreases. The Pantanal Sul-Mato-Grossense and the southern region have the highest precipitation values.

However, these precipitations are not evenly distributed throughout the year. In almost every region, more than 70% of the total rainfall accumulated during the year is precipitated from November to March, and the quarter is generally rainier, November-January (TEODORO et al., 2015).

During this quarter it rains on average 45% to 55% of the annual total. By contrast, winter is excessively dry. At this time of year the rains are very rare, with an average of 4 to 5 days of occurrence of this phenomenon per month, being rarer in the western sector of Mato Grosso do Sul, where at least one month does not even register 1 day of rain. The drought occurs in the winter quarter, ie June-July-August.

The distribution of annual and monthly rainfall averages in the region is uniform in space and time, since the highest and lowest total averages were measured in the municipalities, which leads us to believe that only topographic factors play no conditioning role in the spatial distribution of these variables, since the atmospheric circulation conditions are practically the same for the whole portion of the State of Mato Grosso do Sul.

On a macro scale, the main air masses that influence the variation and seasonal distribution of rainfall in the region are Tropical Atlantic and Polar Atlantic (in winter) and Atlantic Tropical Mass (in summer). Thus, on a more localized range, spatial variations are responsible for factors such as topography and continentality, as well as being influenced by the predominant direction of air masses.

The rainy season (October to March/April) concentrates over 85% of annual rainfall, with December and January contributing more than 35% of annual rainfall. The dry season, which begins in April and extends to the beginning of October, is characterized by a significant reduction in rainfall. In the driest quarter of the year (June-August), rainfall represents, on average, less than 2% of the annual total.

During the dry season it is possible to observe long periods without rainfall and/ or with insignificant rainfall, well below the daily evapotranspiration (PET) and that does not change the dryness of the environment. These periods often exceed 100 days. During the analysis period, the number of years and the average number of days in a row that such prolonged dry periods occurred do not exceed 75 consecutive days.

It was also observed that the average days, in the years in which long dry periods occurred above the minimum research limit were 105 days, and the average days without significant rainfall (less than 2.5 mm) is 110 days and that Almost half of the years have a long period without rainfall exceeding 75 uninterrupted days (SOUZA et al, 2010). This period coincides with the time of year of the dry season, being more common in June, July and August, and may arrive until mid-September.

EQUIVALENCE BETWEEN OBSERVED AND ESTIMATED RAINFALL DATA BY TRMM

The Figure 2 shows the regression analysis between observed and estimated data, for the four stations with complete series between 1998 and 2018. It is possible to observe that there is a slight tendency to underestimate the TRMM, especially in months with rainfall greater than 150mm. The angular coefficient of regression between data observed on the surface and TRMM data was different from 1, which indicates that there is no equivalence between the methods of obtaining monthly rainfall. The Figure 3 shows the analysis of notch box-plot in which the notch overlap between the observed rainfall and estimated by TRMM are observed. The Notch displays the confidence interval around the median and the notches of the overlap, which normally, there is evidence their medians equals (95% confidence).

Equivalence between observed and estimated data, regardless of the methodology, is scarce (PEREIRA et al., 2013). Most studies attest to the reliability of the estimates through adjustment statistics that indicate precision and accuracy (POMBO and OLIVEIRA, 2015; COSTA et al., 2019). However, equivalence indicates that, although alternative methodologies can supply needs for hydrological information, they should be used with reservations. To compose this work, for example, of the 32 rainfall stations, only four presented series without time commitment and with a minimum of failures for analysis. The failures were also observed in the series obtained by the TRMM. The medians of the observed and estimated data, in turn, showed greater similarity through the analysis of the notch box-plot. This analysis indicates that TRMM satellite data can more effectively estimate long-term averages or Climate Normals

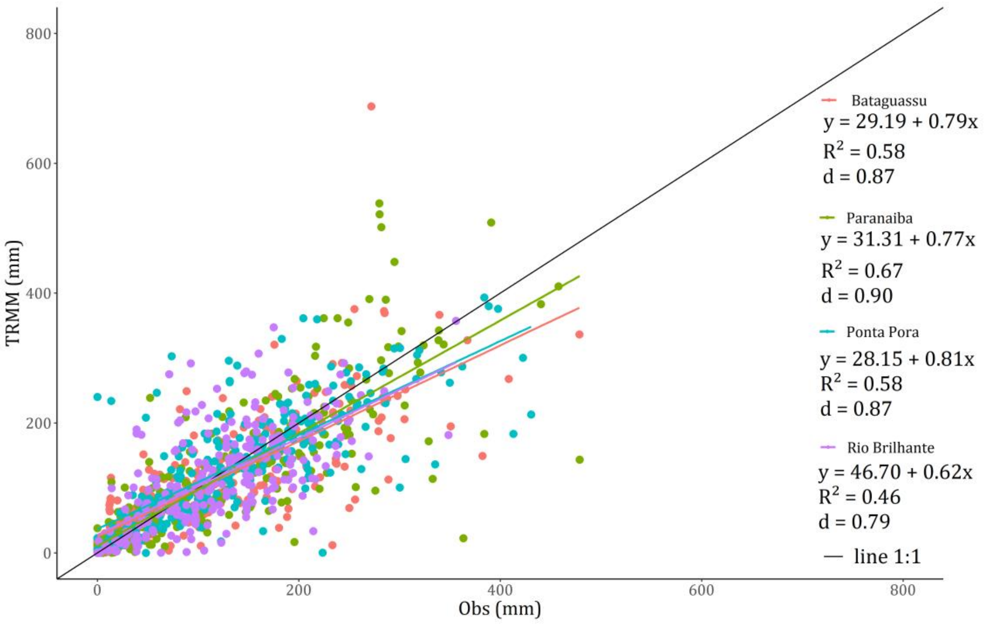

Figure 2 - Relation of observed rainfall (mm) and estimated rainfall by TRMM 3B43 (mm) and the regression analisys in the state of Mato Grosso do Sul between 1998 and 2019.

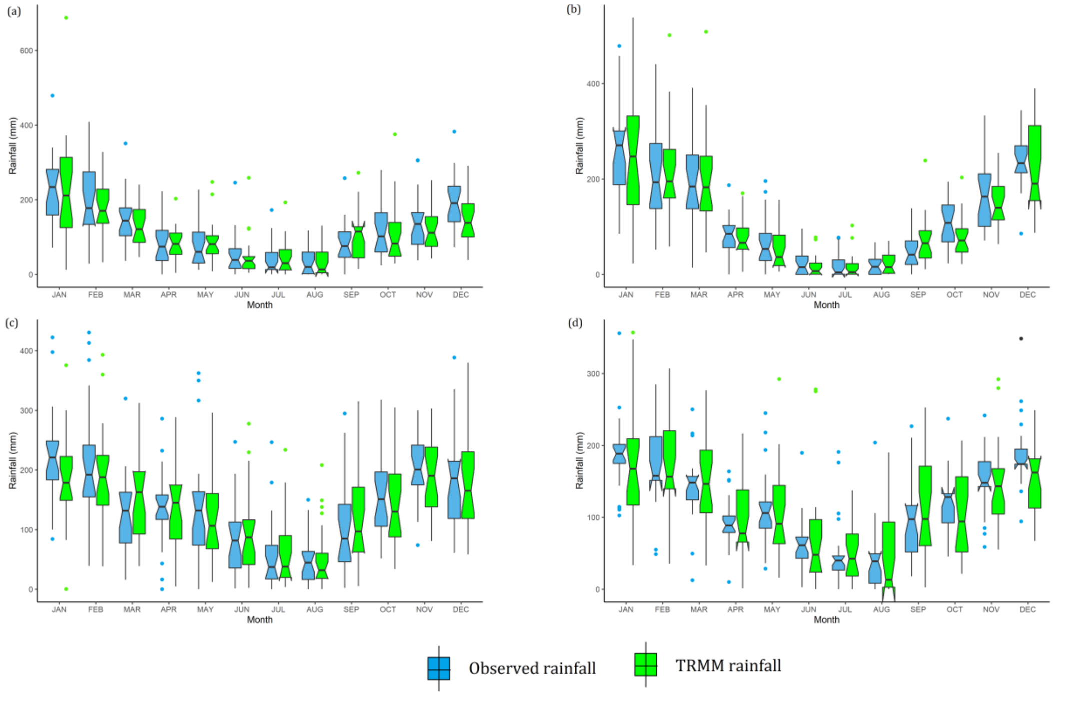

Figure 3 - Notch box-plot of observed rainfall (mm) and estimated rainfall by TRMM 3B43 (mm) for Bataguassu (a), Paranaíba (b), Ponta Porã (c) and Rio Brilhante (d), in the state of Mato Grosso do Sul between 1998 and 2019.

MONTHLY RAINFALL

The remote sensing data, although they do not accurately represent the monthly rainfall of each year, perform well in representing the average monthly rainfall (average from 1998 to 2019), as can be seen in Figure 4. In general, the correlation coefficients range from 0.48 to 0.94, BIAS range from -2.42 to 5.56 and the RMSE range from 7.13 to 29.14 mm. Considering the monthly rainfall, the estimates by the TRMM were satisfactory. The worst estimates occurred between October and December. These are months with considerable precipitous totals, with a large standard deviation and the number of extreme hundreds (OLIVEIRA et al., 2020) and convective rainfall (PESSI et al., 2019). But in general, the statistical indices were similar to those found in other regions, when satellite rain estimates were compared and observed, such as Mato Grosso (PESSI et al., 2019) and Amazon (ALMEIDA et al., 2015).

In the winter months, the r/RMSE values were higher/lower, while the BIAS was higher, indicating precision and not accuracy (tendencies to under/overestimation), as observed by Pessi et al. (2019). Rainfall is of low intensity, often caused by the entry of cold air masses, which cover a large region of the State of Mato Grosso Sul, which may contribute to the better performance of TRMM in estimating rainfall. According to Almeida et al. (2015), the reason for this performance is the variations in seasonal rainfall trends.

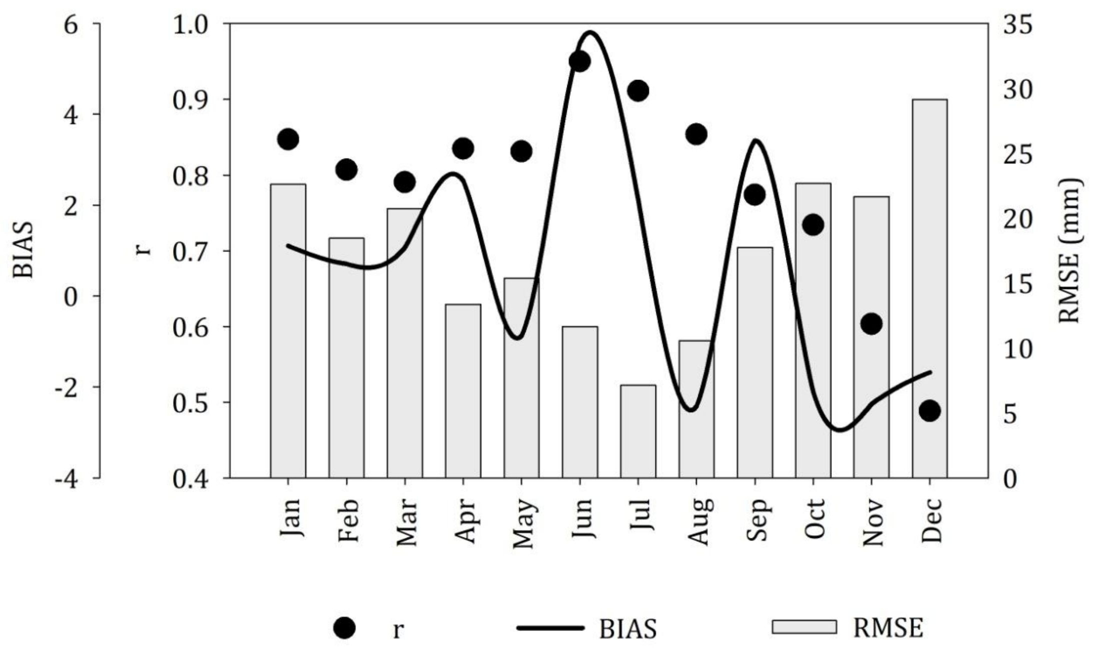

Figure 4 - Correlation (r), BIAS and root mean squared error (RMSE, mm) between rainfall data (mm) observed and estimated by TRMM 3B43 (mm) in the state of Mato Grosso do Sul between 1998 and 2019.

In the context of the statistical correlation of precipitated totals as a function of months, it is verified that the average total precipitated from December to February presented a low and non-significant correlation coefficient. According to Ferreira (2005), low and little significant correlation coefficients may influence the fit of the models reducing their statistical qualities. In the context of precipitation, they provide high and, in some cases, highly significant coefficients, showing that it is possible to adequately model precipitation totals, a reflection of climatic characteristics and orographic influence on rainfall behavior in regions of the state where, under higher latitudes, there is a predominance of colder climates, of the “Cwb”/”Cwa” type by the Köppen classification (ANTUNES, 1986); These regions are influenced by more intense FS, which weaken whenever they enter the state toward lower latitudes, meaning that more frequent frontal winter rain events are more significant and important for larger regions. Latitudes, showing their importance in the total precipitation of the dry period (VIANELLO and ALVES, 2000).

In general, although TRMM 3B43 overestimates monthly precipitation, deviating from observed data, except for may, September, October, November and December. TRMM 3B43 overestimates monthly precipitation to the largest extent of 22.6 mm by RMSE in january, while the largest underestimation by RMSE was in december (29 mm). This could also explain why monthly TRMM-derived precipitation averages agree well with observational data, while the Bias distributed between positive ranges in Figure 2 has overwhelming percentages in a few months.

Figure 5 shows the variation of the monthly average precipitation for the observational data (OBS) and TRMM 3B43 in the state of Mato Grosso do Sul between 1998 and 2019 and the Table 2 shows the regression coefficients for the linear regression between average rainfall observed and average rainfall estimated by TRMM. The 1: 1 ratio considering all months showed equivalence, as well as that for the rainy period and for most months. The dry period showed underestimations of the TRMM, as well as the months of February, March, June and December, in all cases, not equivalent to the observed data.

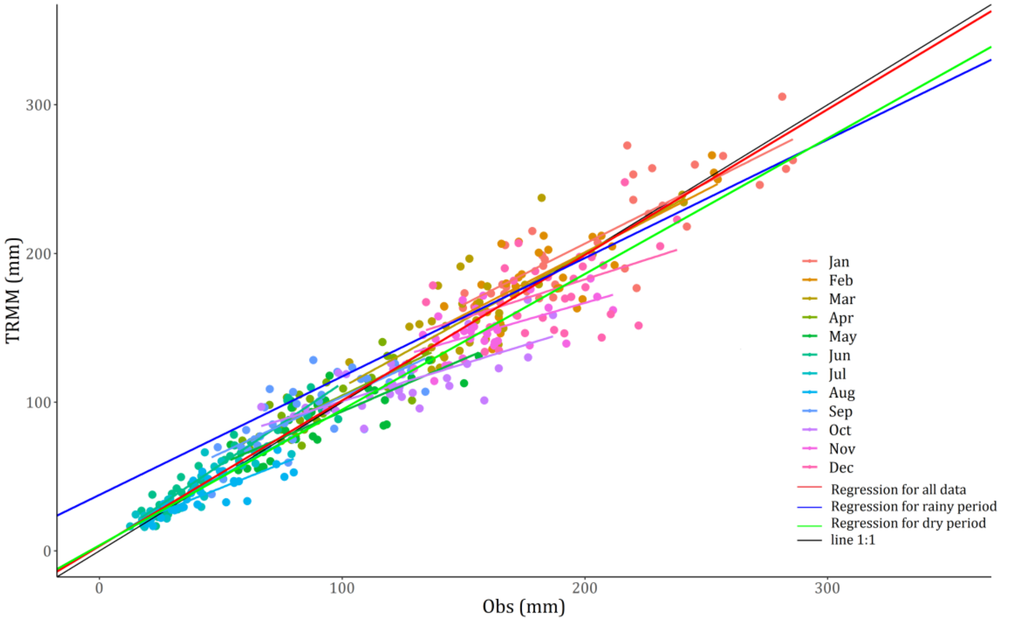

Figure 5 - Relation of monthly average rainfall for TRMM 3B43 (mm) and observational data (mm) in the state of Mato Grosso do Sul between 1998 and 2019 for each month, dry and rainy period.

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Table 2 - Coefficients of linear regression and correlation between average rainfall observed and average rainfall estimated by TRMM.

Months	β_0	β_1	r	p-value for H_0: $\beta_1 = 1$
Jan	20.736	0.876	0.847	0.226^{ns}
Feb	39.135	0.774	0.807	0.037
Mar	44.743	0.693	0.79	0.004
Apr	5.245	0.886	0.835	0.293^{ns}
May	5.943	0.979	0.831	0.859^{ns}
Jun	1.908	0.824	0.95	0.001
Jul	1.751	0.919	0.911	0.297^{ns}
Aug	0.246	1.119	0.854	0.346^{ns}
Sep	11.915	0.793	0.774	0.090
Oct	3.062	1.074	0.734	0.687^{ns}
Nov	46.645	0.7751	0.603	0.239^{ns}
Dec	107.29	0.457	0.489	0.001
All data	**3.188**	**0.979**	**0.957**	**0.176**^{ns}
Dry period	**3.667**	**0.913**	**0.924**	**0.000**
Rainy period	**37.597**	**0.797**	**0.851**	**0.176**^{ns}

ns = not significant at 5% significance for the Studant t test for null hypothesis (H0): β1 = 1.

Costa et al. (2019) analyzed rainfall data from the INMET/CPTEC and Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) from the Midwest and North regions and found that they stood out with the lowest coefficients of determination, being 78% (Midwest) and 77% (North), considerably below the other regions, which have an average coefficient of determination of 94% between the data sets. The Midwest stood out with an overestimate of average error of 10 mm.

In the winter months the observed values were lower, being the lowest observed in Campo Grande with an average of 43 mm. At this time of the year, rainfall is of low intensity, often caused by the entry of cold air masses, which cover a large region of the state of Mato Grosso do Sul.

According to Almeida et al. (2015), when variations in seasonal precipitation trends occur, this anomaly is mainly due to the satellite overestimating or underestimating the values in relation to observed data.

Other studies have also reported these differences (COLLISCHONN et al., 2007; NÓBREGA et al., 2008; ROZANTE et al., 2010; ALMEIDA et al., 2015; SILVA-FUZZO and ROCHA, 2016) and explain that there is a tendency to overestimate rainfall over the continent, as well as report on the ability of TRMM to estimate dry and rainy periods. According to these authors, this factor has not yet been fully explained and may be related to some processing error, both in reading rain gauges and in generating satellite estimates.

Rozante et al. (2010) analyzed and showed that the product 3B42 tends to overestimate the precipitation around 7% and this fact is associated with the product's inability to estimate clouds over the region. It has also been found that an apparent relation between latitude is possible, showing that this trend increases with latitude (VIANA et al., 2010).

In this sense, the differences between data derived from the TRMM satellite and obtained from weather stations (OBS) may be a consequence of the differences in scale between them, as the rain gauge is a point estimate, while the satellite represents an average pixel estimate (ALMEIDA et al., 2015).

Considering watersheds, Collischonn et al. (2007), assessed that the rainfall estimates provided by the TRMM are consistent and fairly accurately reproduce the rainfall regime, confirming that satellite-based rainfall data can be an efficient and inexpensive alternative when compared to soil instruments, like rainfall stations.

For Nobrega et al. (2008), the TRMM can analyze seasonal variability, satisfactorily representing dry and rainy periods. Still, according to the authors, the TRMM data correlate satisfactorily with the denser rainfall network. Similarly, the analysis of the 3B43 algorithm showed a high degree of reliability in the studied areas (OLIVEIRA and ANGELIS, 2010; VIANA, 2010; FLEMING et al., 2011), including in relation to the presence of convective clouds over deforested regions.

Figures 6 and 7 show the results of the temporal distribution of monthly rainfall from 1998 to 2019 for both data sources (TRMM-3B43 and observational, respectively) in the state of Mato Grosso do Sul. The rainfall patterns provided by the TRMM estimates and the observed data were similar. Both methods were able to represent the monthly patterns. The highest rainfall occurred between January and March and between October and December (rainy period), and the lowest occurred between May and August (dry period). In the driest months of the year, rainfall is higher in the lower latitudes, while in the rainy months, the highest rainfall is observed in the eastern region of the state, influenced by the orography (Figure 1).

The lowest rainfall rates for the TRMM satellite are located in the northwest of the state, in the Pantanal, with values ranging from 0 to 25 mm and ranging from 0 to 100 mm considering all Mato Grosso do Sul state, in the driest month. In the southwest of the state the TRMM identified highest rainfall values between 0 and 150 mm in dry period (between May and August). The highest rates were found in the north/northeast region, with values between 225 and 300 mm in rainy period. Considering all year, the largest precipitation occurred in the municipalities of East region and the lowest in the municipalities of Pantanal region. There is a coincidence in the regions with the lowest and highest monthly precipitation, although TRMM data underestimate these precipitations in relation to the observed data. According to data from the ANA and INMET website (OBS data) the lowest rainfall rates values are ranging from 0 to 175 mm, in dry period and the highest rates values ranging from 150 to 300 mm/month. The spatial pattern corroborates with the statistical analyzes that demonstrated greater ability of the TRMM to estimate monthly precipitation in the rainy period.

The northeast of Mato Grosso do Sul receives moisture from the Amazon coming from the South Atlantic Convergence Zone (SACZ) phenomenon, and the southwest receives FS. These are the regions of the state that have the highest rainfall rates during the analyzed period, influenced by these SACZ and those FS that reach these regions (TEODORO et al., 2015).

To analyze the temporal distribution of precipitation during the study period by the TRMM satellite, aiming to identify possible variations over the years, which shows the cumulative total precipitation values, ranging from 1195 mm/year (in 2010) to 1663 mm/year (in the year 2001) and an average of 1415 mm/year. The highest averages were observed in 1998, 2001, 2009 and 2014. The lowest was observed in 2010; Observational data from the ANA website show cumulative total precipitation values, averaging 1380 mm/year, ranging from 1172 in 2002 to 1600 mm/year in 2009.

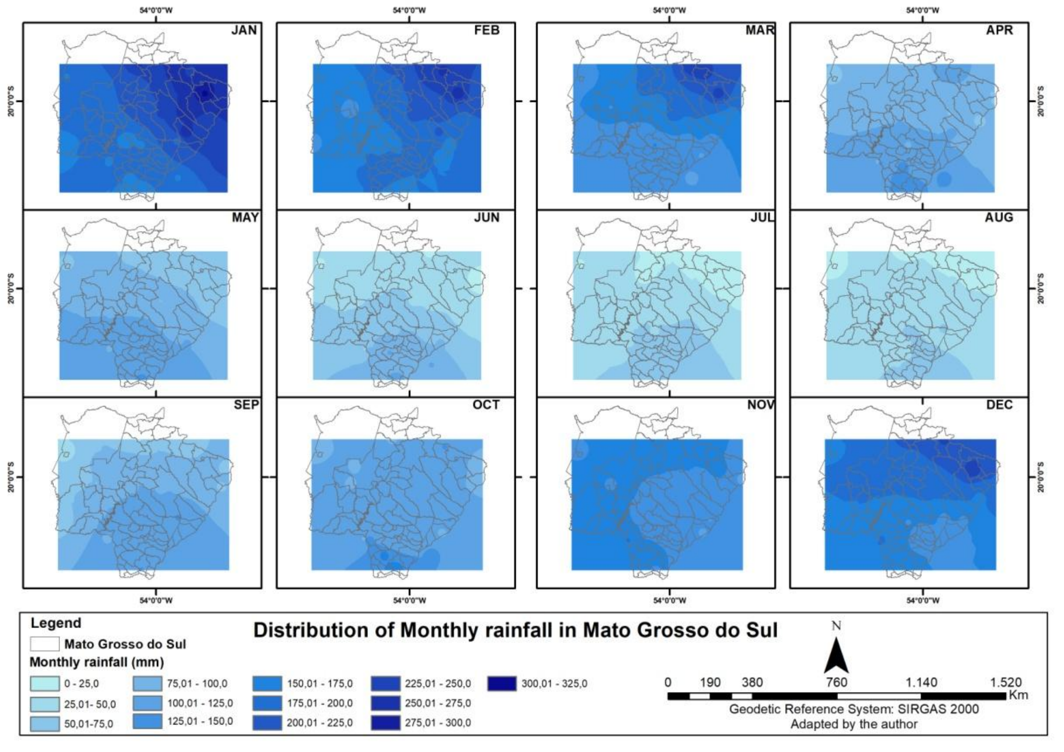

Figure 6 - Spatial distribution of the average monthly rainfall (mm) of the TRMM 3B43 versão 7 from January to December between 1998 and 2019.

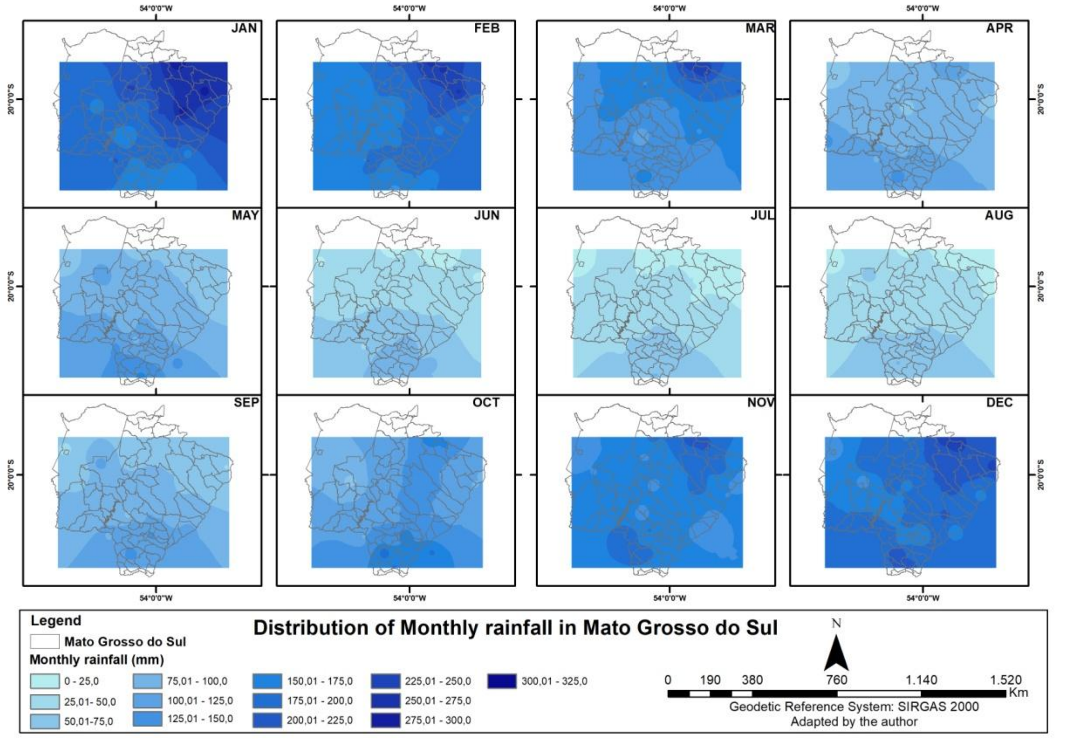

Figure 7 - Spatial distribution of observational monthly (mm) average precipitation (OBS) – (mm) from January to December between 1998 and 2019. Source: The authors (2020)

CONCLUSION

A strong correlation was found between precipitation estimates using the satellite product TRMM 3B43 and observations from the network of conventional rain stations (OBS) for the entire region of the State of Mato Grosso do Sul, especially for the dry season/months. The monthly correlations varied widely, and in the months of the rainy season these correlations were lower than in dry months. Despite this, due to the consistency between the databases, with due care, it is possible to make use of the satellite in situations where there are no conventional weather stations for some months of the year (especially the months of the dry season) and for the annual period. There is a tendency of underestimation of rainfall by the TRMM. The TRMM 3B43 product can be used in the study of climatology, water resources and, mainly, in filling gaps in the rainfall time series for the state of Mato Grosso do Sul.

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Database declaration / Data availability: The weather database is in the public domain and available at: https://giovanni.gsfc.nasa.gov/giovanni/> and ftp: // ana: agencia @ ftp2. ana.gov.br/Upload/SGH/GEINF/PluMS.zip

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