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Research Article

Statistical downscaling in the TRMM satellite rainfall estimates for the Goiás state and the Federal District, Brazil[1]

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ABSTRACT

Rainfall is a fundamental component of agricultural production, and knowing its potential and variability can ensure the success of this activity. However, the number of meteorological stations is still small, even in states with agricultural aptitude, such as Goiás. Geoprocessing techniques can be used to overcome this problem. Thus, this study aimed to evaluate the products of the Tropical Rainfall Measuring Mission (TRMM) satellite to describe the annual and monthly rainfall variability in the Goiás state and the Federal District (Brazil). Interpolations were carried out to increase the spatial resolution by means of ordinary kriging and cluster analysis for spatial and temporal distribution. It was observed that the evaluated territory can be classified into three regions with differentiated water regimes up to 500 mm annually, with seasonality of accumulated precipitation from November to March. Even though the regression evaluation showed limitations for a monthly precipitation above 200 mm, the analysis of the TRMM satellite products demonstrated that this tool allows forecasts of provisional normals with a higher spatial resolution than the Brazilian National Institute of Meteorology (INMET) stations network, with known measurement errors for each evaluation period, allowing the data application in forecast models for agricultural planning involving water management.

KEYWORDS: Brazilian Midwest rainfall, Tropical Rainfall Measuring Mission satellite, spatial and temporal variability.

RESUMO

Estatística para redução de escala nas estimativas de chuva pelo satélite TRMM para o estado de Goiás e Distrito Federal, Brasil

A chuva é um componente fundamental para a produção agrícola, e conhecer seu potencial e variabilidade pode garantir o sucesso dessa atividade. Entretanto, o número de estações meteorológicas ainda é pequeno, mesmo em estados com aptidão agrícola, como Goiás. Para contornar esse problema, técnicas de geoprocessamento podem ser utilizadas. Objetivou-se avaliar os produtos do satélite Tropical Rainfall Measuring Mission (TRMM) para a descrição da variabilidade anual e mensal da precipitação pluvial no estado de Goiás e no Distrito Federal. Interpolações foram realizadas para aumentar a resolução espacial por meio de krigagem ordinária e análise de cluster para distribuição espacial e temporal. Verificou-se que o território avaliado pode ser classificado em três regiões com regimes hídricos diferenciados em até 500 mm anuais, com sazonalidade de precipitação acumulada de novembro a março. Embora a avaliação de regressão tenha mostrado limitações para precipitação mensal acima de 200 mm, a análise dos produtos do satélite TRMM demonstrou que esta ferramenta permite previsões de normais provisórias com maior resolução espacial que a rede de estações do Instituto Nacional de Meteorologia (INMET), com erros de medição conhecidos para cada período de avaliação, permitindo a aplicação dos dados em modelos de previsão para planejamento agrícola envolvendo manejo hídrico.

PALAVRAS-CHAVE: Chuvas no Centro-Oeste brasileiro, satélite Tropical Rainfall Measuring Mission, variabilidade espacial e temporal.

INTRODUCTION

Agricultural activities are highly dependent on climatic elements, especially temperature, relative air humidity, solar radiation and rainfall. Thus, they form zones where the characteristics of the environment offer the least possible risk to cultivation (Mitter et al. 2019). Rainfall is the agrometeorological variable responsible for the water supply in the soil, which is available to plants for hydration, nutrient uptake, photoassimilates transport and transpiration regulation. Moreover, it is worth noting that climate risk zoning mainly considers the water availability of a given region (Aparecido et al. 2019).

Rainfall in the Aw climate region has a seasonal distribution behavior. It shows large amounts

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concentrated in the rainy summer half of the year, with an increase in rainfall intensity and, in some regions, a trend to decrease both the precipitation period and the total amount accumulated in the period (Casaroli et al. 2018a, Pereira et al. 2018).

In the Brazilian Midwest, the temporal variability of rainfall can be divided into comparisons that show intra-annual periods (Silva et al. 2012). In these, the differences in concentration and total precipitation occur in a period of five or six months. In addition, inter-annual variability is influenced by rainfall formation events, such as the Amazonian convective systems resulting from the action of the Bolivian High (BH) and cyclonic vortex in high levels of the atmosphere, leading to rainfall of greater or lesser intensity in the region (Oliveira 1986).

The rainy season limitation affects agriculture and state revenues, while, in the dry season, water requirements can be met using irrigation systems (Hatfield & Dold 2019, Justino et al. 2019, Battisti et al. 2020, Paixão et al. 2020, Antunes Júnior et al. 2021, Caetano et al. 2021, Paixão et al. 2021, Santos et al. 2021). Furthermore, delineating homogeneous rainfall zones supports agricultural planning, especially when selecting the most adapted and technically suitable crops to be implemented (Casaroli et al. 2018b, Battisti et al. 2019, Leite-Filho et al. 2021).

Data obtained from remote sensing allow the evaluation of areas with a larger sample distribution than those obtained from conventional collection stations. Unfortunately, collection through meteorological stations is still limited for climate description in agricultural areas far from urban centers. However, there are many meteorological stations networks whose installation comprises sensors to measure and control boards that can store data (Ioannou et al. 2021).

There are still adjustments to be made and peculiarities to be studied. Examples include the interaction of the rainfall intensity and the relief (Cândido & Nunes 2008) and the limitations of prediction in daily timescales (Soares et al. 2016). The methodology for evaluating the accuracy of products is measured by dividing areas of low data dispersion, regarding the average distribution of precipitation, which is carried out through groupings by multivariate analysis in the grouping formation (Santos et al. 2017, Paixão et al. 2020).

The product obtained from the data processing of the Tropical Rainfall Measuring Mission (TRMM) satellite has isometries in the georeferencing of the pixel centers that facilitate selecting data interpolation methods. The interpolator's definition is influenced by data allocation. Thus, it avoids inducing agreed trends in data estimation unmeasured intervals (Quirino et al. 2017, Khaki & Awange 2019). Interpolation using geostatistics focuses on detailing at the micro-scale detail (radius < 100 m). It supports downscaling with regressions with known prediction errors (Teng et al. 2014).

After appropriate adjustment, the spatialization of the pluviometry data obtained by remote sensing allows the monitoring of the area's water balance, because the sensors coupled in the TRMM have a daily temporal resolution and a long program duration. Furthermore, they allow crop vegetative development monitoring due to the stimulus provided by precipitation in contrasting period areas in the Cerrado (Brazilian Savanna) (Suepa et al. 2016). According to the recommendation of the World Meteorological Organization (WMO 2018), the arrangement of the sampling points of the TRMM sensor allows the definition of a mesoscale climate (3-100 km). Moreover, it ensures the distribution between the precipitation measurements at 25 km equidistance. However, here, the TRMM satellite products have been evaluated to describe the annual and monthly rainfall variability in the Goiás state and Federal District.

MATERIAL AND METHODS

This study was carried out in the Goiás state (45.9069ºW and 12.3950ºS to 53.2486ºW and 19.4775ºS) and the Federal District (47.2657ºW and16.0850ºS to 48.3203ºW and 15.4630ºS), in Brazil, from January 2002 to December 2013. The State Geoinformation System (SIEG) platform provided the geographic data. The Giovanni - NASA and Brazilian National Institute of Meteorology (INMET) platform provided the climate data. The Köppen climate classification (Alvares et al. 2013) helped to determine the calibration points of the TRMM satellite climate products based on data collected by meteorological stations installed in the territory.

The climatic data obtained from the meteorological stations comprised filtered dates. Months with failure of meteorological observations were excluded, and the period of a provisional climatological average (≥ 10 years) was considered, since the acquisition systems of automatic stations do not have enough data to determine the climatological average (≥ 30 years). This period has prevailed due to the largest number of stations available for using geostatistics in climatic data interpolation.

After the INMET data filtering, the meteorological stations were georeferenced to use an interpolation method. Then, geostatistics was applied, if necessary. The hypothetical semivariogram showed spatial dependence.

The INMET and TRMM data interpolations used the SAGA GIS software, evaluating the semivariogram properties when observing the spatial dependence of rainfall. Then, they were divided into monthly and annual thematic maps for the area, defining the quality of the interpolations using autocorrelogram. These procedures aimed to minimize the dispersion of the estimated data regarding the real and equate the spatial scale between the stations and satellite data.

After data interpolation, the numerical values of the interpolated products were extracted to determine uniformity zones by grouping using clusters formed by the Euclidean similarity between the samples. The minimum similarity between the data was limited to 50 %. Furthermore, regions were defined for calibration regressions of the products obtained by the orbital sensors.

The regression equations were fitted to the data to preserve a greater accuracy of the model, minimizing the sum of the squares of the deviations and determining the descriptive statistics according to Quirino et al. (2017), including the Pearson's correlation coefficient "r", agreement index "d" (Willmott et al. 1985) and confidence coefficient "c" (Camargo & Sentelhas 1997): $r = [\Sigma(xi - \overline{x})(yi - \overline{y})]/\{\sqrt{[\Sigma(xi - \overline{x})^2]}\ [\Sigma(yi - \overline{y})^2]\}$; $d = 1 - \{[\Sigma yi - xi^2]/[\Sigma(|yi - \overline{x}| + |xi - \overline{x}|)^2]\}$; $c = r \cdot d$, where: "xi" is the observed precipitation, "$\overline{x}$" the mean of the observed precipitation, "yi" the estimated precipitation and "$\overline{y}$" the mean of the observed precipitation.

RESULTS AND DISCUSSION

The interpolation adjustment model of the data extracted from the pixels obtained in the TRMM matrix file followed the Gaussian model. It presented a hypothetical semivariogram (Figure 1) showing the model adjustment ($R^2 = 0.997$) in the interpolation and spatial estimation. The nugget effect attributes were at 730 mm², and landing was at 22,560.00 mm². These attributes were spatially correlated up to the range of 305.04 km, with a higher variability range when obtained from Cunha et al. (2013) and Santos et al. (2011), estimating the range of 30 and 44 km for annual precipitation in similar climate classifications. According to the Cambardella et al. (1994) classification, the degree of spatial dependence on precipitation of 3.23 % (< 25 %) is characterized as strong, evidencing the high accuracy of the interpolation model. The distribution of the semivariogram pairs was asymmetric to the left, but with a higher volume of pairs within the range of the proposed model.

The spatial arrangement of the provisional monthly or annual rainfall average by ordinary kriging, with the Gaussian model, showed a more accurate adjustment of the rainfall dispersion in the evaluated area. That is because, in parallel with the possibility of measuring the spatial dependence of the attribute, it is also possible to perform co-kriging adjustment techniques using local factors, such as elevation and continentality, to improve the prediction (Mello & Oliveira 2016). Furthermore, the practice of orbital data interpolation is recurrently used to increase the spatial resolution (downscaling) of products, providing more sampling with known errors and allowing the use of reliable products in unsampled areas (Park 2013).

The autocorrelogram (Figure 2) between the observed and estimated data in a 0.033° grid (equivalent to ± 3,648.95 m), corresponding to

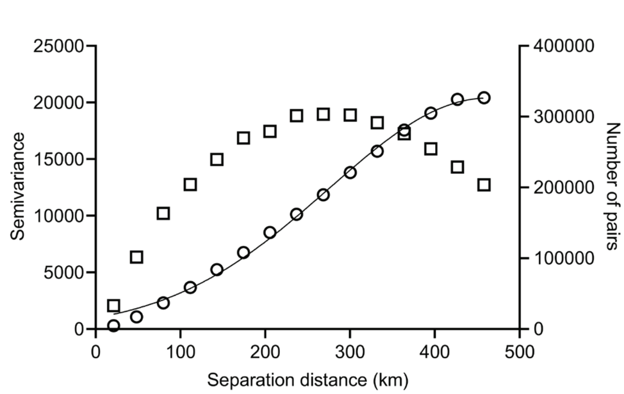

Figure 1. Theoretical semivariogram (○) of the precipitation distribution in the provisional average regime and number of interpolated equidistant pairs (□).

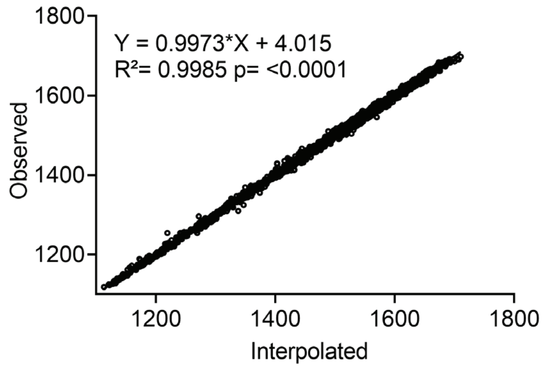

Figure 2. Autocorrelogram of rainfall distribution in the provisional average regime.

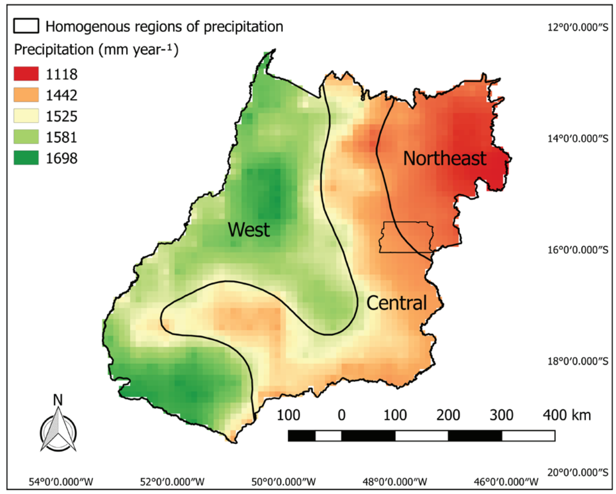

Figure 3. Thematic map of rainfall distribution in the Goiás state and the Federal District (Brazil) grouped by zones with lower average variability.

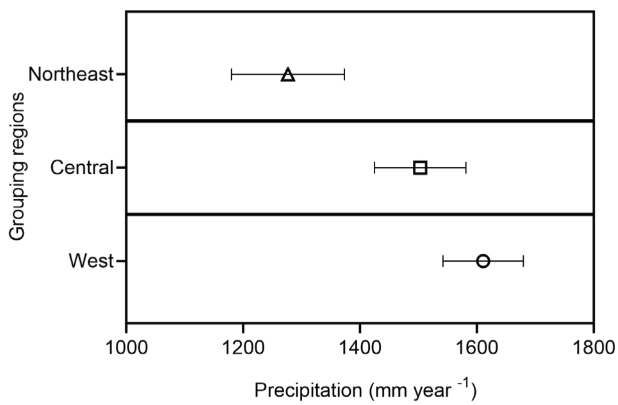

Figure 4. Averages and confidence intervals (CI = 95 %) for regions grouped by spatial clusters.

the description of the WMO Top-Scale, showed a coefficient of determination of 0.9985 and a significant regression at 1 %. The regression of the interpolated model shows a penalty in the estimate of 0.27 % and a correction factor of 4.015 mm. After adjusting the regression and semivariogram models, the georeferenced points were interpolated using ordinary kriging, since the geostatistical assumptions were met.

The clustering of regions through the formation of clusters in the Qgis 2.18.27 software, with the complement "precision agriculture tools" (PAT), highlighted three regions with the lowest dispersion of rainfall, around the local average, with normal distribution, and with a different provisional average. The western region showed the highest average annual rainfall, followed by the central and northeastern regions (Figure 3).

The calibration of the grouped zones was performed using conventional meteorological stations available in each sequence: with the possibility of defining the distribution of the provisional average rainfall ranging from 1,270 to 1,600 mm; with confidence intervals of the mean between 1,180 and 1,680 mm; and with an expected amplitude of 500 mm within the evaluated territory (Figure 4).

This study applied the grouping technique to differentiate homogeneous areas of precipitation. Santos & Souza (2012) were followed in the evaluation of homogeneous areas in the Northeast region of Brazil, outlining four groupings that explain about 97 % of the total accumulated variance. In addition, the cluster technique carefully delineates homogeneous areas. However, it depends on evaluating the power of distinction and may vary the Euclidean distance of clusters (Han & Kamber 2011).

The evaluated regions had rainfall averages compatible with what occurred in the region (Mariano 2011, Penereiro & Meschiatti 2018). They obtained values within the confidence interval of the average indicated and with no significant change in the pattern found. The municipality of Goiânia comprises the exception. Goiânia is located in the western region and shows a trend to gradually decrease the average of 3.7 mm year^{-1} (Casaroli et al. 2018a).

The different precipitations (Figure 3) may be due to atmospheric phenomena operating in the Brazilian Midwest, such as the Continental Equatorial Mass (CEM) and the South Atlantic

Convergence Zone (SACZ). The CEM originates in a calm region, formed by a low-pressure center, located in the Amazon Forest. It is characterized as a cyclonic atmospheric system (ascending and convergent movement). It concentrates and transmits to the upper layers of the atmosphere both the humidity generated by the vegetation and water bodies of the Amazon Forest and that originated by evaporation from the Atlantic Ocean, which is transported by the trade winds. This humid air mass moves to other Brazilian regions in the northwest-southeast direction (reaching the south coast) by the counter-trade winds. It acts in the upper layers of the atmosphere, and by the expansion of the thermal depression present in this region during the spring and summer, with repercussions on rainfall formation (Serra & Ratisbonna 1942). In the Goiás state and the Federal District, this mass enters the topographic channel formed by the Araguaia River depression, northwest and west of Goiás (Nascimento 2016).

The South Atlantic Convergence Zone (SACZ) is an elongated and persistent band of nebulosity with a northwest-southeast orientation, extending from the south of the Amazon region to the South Atlantic Ocean (Kousky 1988). This system is responsible for supplying heat and humidity from the Amazon region to higher southern latitudes through the low troposphere, causing intensification and prolonged periods (from 4 to 10 days) of rainfall in the Midwest and Southeast regions of Brazil (Nimer 1979). It can be considered one of the main atmospheric systems responsible for the rainy season in that region (Quadro 1994).

The seasonal distribution of rainfall among the months of the year has a high contribution to the adjustment of the prediction models. For the territory evaluated, about 90 % of the region has an Aw climate, followed by Am (± 6 %) and Cwa and Cwb (± 3 %) (Alvares et al. 2013). The regions have a similar seasonal rainfall: with five months of accumulated rainfall above 250 mm; seven months of lower accumulated rainfall; and confidence intervals of 68.5, 78 and 96.5 mm, respectively for the western, central and northeastern regions (Figure 5). Since the temporal dispersion of the means in the northeast region suffers from large variations, the confidence interval of the mean is compromised.

The dispersion and distribution of the monthly data influence the evaluation of the predictive and corrective potential of the TRMM product. In addition, the sensor's limitation to precisely derive the precipitation in months of greater rainfall (< 200 mm month^{-1}) also influences this evaluation.

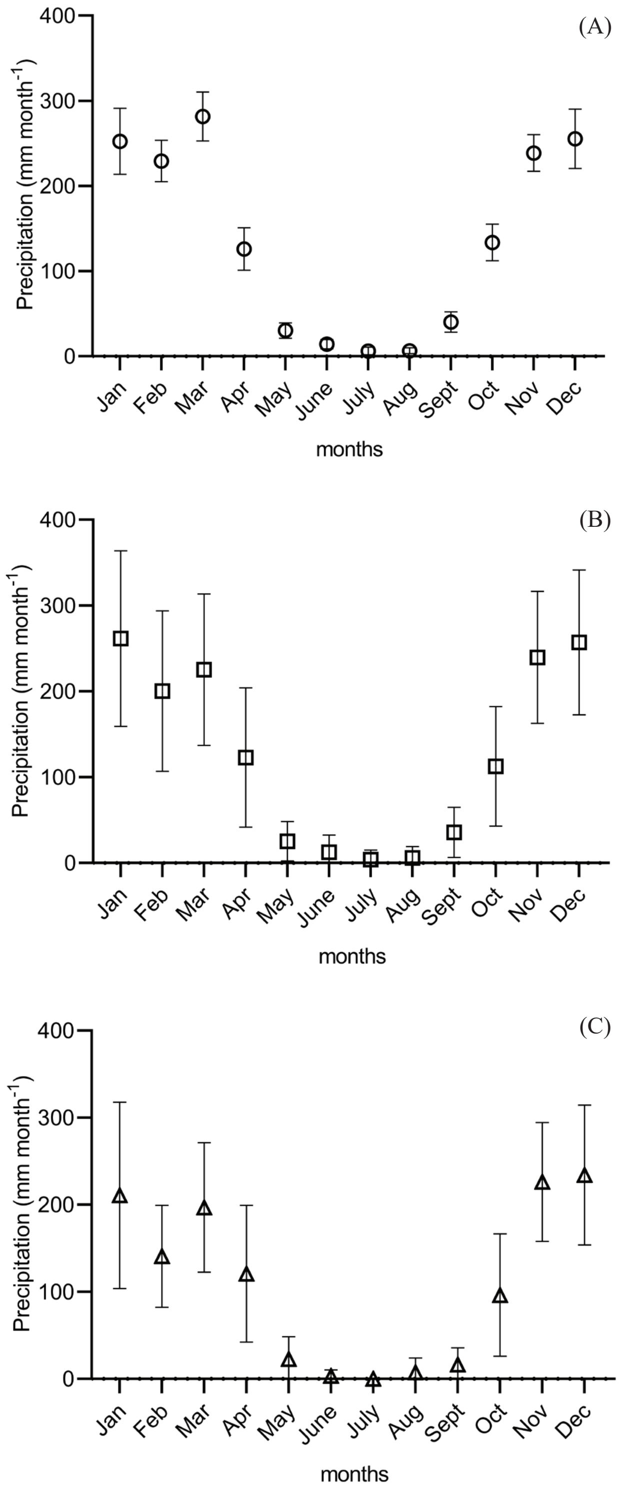

Figure 5. Temporal distribution of the monthly provisional averages for the west (A), central (B) and northeast (C) regions.

The dendogram comprises two groupings whose limit is 50 % of the similarity by the Euclidean distance (Figure 6). Groupings highlighting the two distinct periods of the Aw climate were formed, with period 1 representing the spam from November to March and period 2 from April to October.

This study estimated the averages by linear regression in all regions and periods. In the period 1, the western region showed a TRMM product overestimation trend, which was adjusted at 9.81 % by the model and intercept in 28.86 mm (R^2 = 57.57 %). For the period 2, the regression shows a slight underestimation, with 1.2 % above the observed one, with an adjustment of 2.69 mm and a coefficient of determination that fits 96.98 % of the straight line to the observed data (Figure 7).

For the central region, the linear regression model presented a low predictive power of the sensor for rainy periods. The period 1 determined an overestimation, being penalized in the order of 4.35 %, with an adjustment of 11.40 mm and R^2 = 61.69 %. For the period 2, the estimated model was underestimated by 3 %, and the straight line was adjusted by 2.053 mm, with R^2 = 97.05 % (Figure 7).

The northeast region has a greater balance between the coefficients of determination in the periods. It presents the behavior of inverse prediction in the other evaluated regions. The period 1 presented an underestimation of 0.7 % of the precipitated blade, with an adjustment of 3.297 mm, and a coefficient of determination in 83.2 % of the straight line to the observed data. For the period 2, following the contrariness when compared to the other regions, there was an overestimation of 3.84 %, but with the smallest adjustment observed, corresponding to 0.3399 mm (Figure 7).

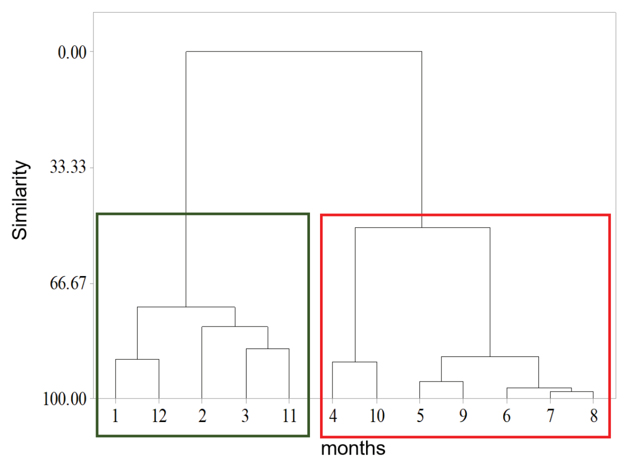

Figure 6. Dendogram of the separation of months by similarity in 50 % of the Euclidean distance. Period 1: November (11), December (12), January (1), February (2) and March (3); period 2: April (4), May (5), June (6), July (7), August (8), September (9) and October (10).

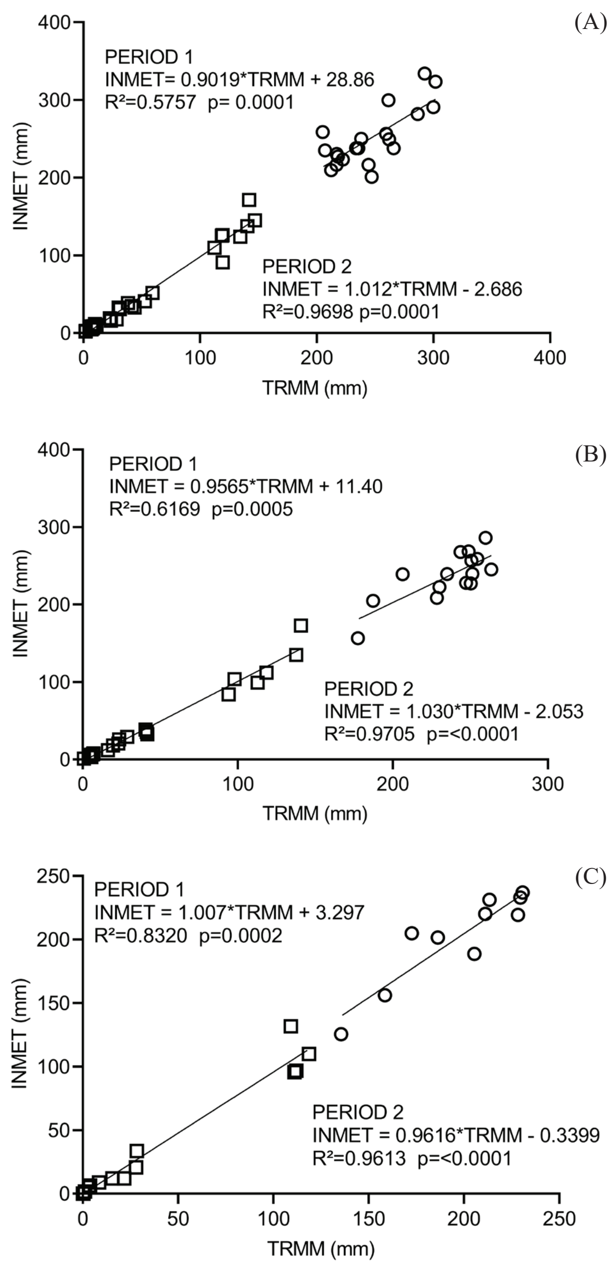

Figure 7. Spatial and temporal adjustment regressions of the monthly provisional average for the west (A), central (B) and northeast (C) regions for the periods 1 (○) and 2 (□). TRMM: Tropical Rainfall Measuring Mission satellite; INMET: Brazilian National Institute of Meteorology.

Table 1. Statistical coefficients for provisional average rainfall between observed data and predicted by the regression model for regions and periods.

Region	West		Central		Northeast	
Period	1	2	1	2	1	2
r	0.76	0.98	0.79	0.98	0.91	0.98
d	0.85	0.99	0.87	0.99	0.95	0.99
c	0.64	0.97	0.68	0.97	0.87	0.97

Coefficient "c": > 0.85 - good; 0.76 to 0.85 - very good; 0.66 to 0.75 - good; 0.61 to 0.65 - fair; 0.51 to 0.60 - acceptable; 0.41 to 0.50 - bad; ≤ 0.40 - terrible. Period 1: November to March; period 2: April to October.

The statistical coefficients, which measure the quality of the models in describing the data observed by the estimates, highlight the strong linear Pearson's correlation among all the regions and periods. The correlations ranged from 0.76 to 0.98 (Table 1).

The index "d" of Willmott et al. (1985) showed an adjustment of results above 85 % for all the periods and regions. For the coefficient "c" proposed by Camargo & Sentelhas (1997), it classified the adjustments as reasonable for the period 1 of the western region, good for the period 1 of the central region and optimal for the period 2 of the west region, for the period 2 of the central region and for the periods 1 and 2 of the northeast region.

CONCLUSIONS

1. According to the World Meteorological Organization (WMO) classification, it is possible to downsize the Tropical Rainfall Measuring Mission (TRMM) observation scale from mesoscale (0.01-3 km) to toposcale (3-100 km) with high accuracy using statistical techniques;
2. The downscaling technique for the TRMM sensor in the Goiás state and the Federal District (Brazil) requires regional adjustments to predict climatic average rainfall, divided into adjustments from November to March and from April to October;
3. The TRMM sensor has limitations in measuring monthly precipitations above 200 mm in the evaluated region, and the minor deviations comprise precipitation below this limit;
4. The Goiás state and the Federal District have a distinct hydrological regime in their extension, divided into three homogeneous rainfall regions, with an amplitude of about 500 mm.

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