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Assessing the Performance and Limitations of PERSIANN-CDR: A Case Study in the São Francisco River Basin

Avaliação do Desempenho e Limitações do PERSIANN-CDR: Um Estudo de Caso na Bacia do Rio São Francisco

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Resumo: Este estudo investiga o desempenho e as limitações do conjunto de estimativas de precipitação do PERSIANN-CDR em comparação com 17 estações de pluviômetros estrategicamente selecionadas na bacia do rio São Francisco entre o período de janeiro de 1989 até dezembro de 2018. Os resultados revelam padrões distintos no desempenho do PERSIANN-CDR. Notavelmente, o conjunto de dados consistentemente subestima a precipitação nas estações mais próximas do exutório, com um viés (PBIAS) de aproximadamente -20%. Por outro lado, ele tende a superestimar a precipitação em outras estações, com um viés (PBIAS) de cerca de 40%. Além disso, estimativas de precipitação do PERSIANN-CDR apresentaram variações em sua capacidade de capturar a variabilidade da precipitação, tendo um bom desempenho em estações do médio e alto São Francisco, mas ficando aquém em estações próximas do submédio e baixo São Francisco. Nós também destacamos a tendência do PERSIANN-CDR de superestimar a variabilidade da precipitação, especialmente durante períodos de chuvas intensas, como a estação chuvosa de outubro a março.

Palavras-chave: Precipitação por satélite, PERSIANN-CDR, Bacia do Rio São Francisco.

Abstract: This study investigates the performance and limitations of the PERSIANN-CDR precipitation estimates dataset in comparison to 17 strategically selected rain gauge stations within the São Francisco River Basin. The study covers the period from January 1989 to December 2018. The results reveal distinct patterns in the performance of PERSIANN-CDR. Notably, the dataset consistently underestimates precipitation at stations closest to the outlet, with a bias (PBIAS) of approximately -20%. Conversely, it tends to overestimate precipitation at other stations, with a bias (PBIAS) of around 40%. Furthermore, PERSIANN-CDR precipitation estimates exhibited variations in their ability to capture precipitation variability. They performed well at stations in the middle and upper São Francisco regions but fell short at stations near the sub-middle and lower São Francisco. Additionally, we highlight the tendency of PERSIANN-CDR to overestimate precipitation variability, especially during periods of heavy rainfall, such as the rainy season from October to March.

Keywords: Precipitation from satellite, PERSIANN-CDR, São Francisco River Basin.

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1. Introduction

Precipitation is a vital part of the Earth's climate system, and its accurate measurement is essential for a variety of applications, including weather forecasting, climate modeling, and water resources management. However, ground-based measurements of precipitation are often sparse and incomplete, especially in remote areas. Satellite-based precipitation estimates can help to fill these gaps, but they also have their limitations.

The PERSIANN (Precipitation Estimation from Remote Sensing Information using Artificial Neural Networks) family of products is one of the most widely used satellite-based precipitation estimation products. PERSIANN products are produced using a variety of satellite sensors, including passive microwave (PMW) sensors and infrared (IR) sensors. PMW sensors are sensitive to the amount of water vapor in the atmosphere, while IR sensors are sensitive to the temperature of the Earth's surface and clouds.

Despite their widespread use, PERSIANN products have a few limitations. One limitation is that they are based on indirect measurements of precipitation. PMW sensors, for example, measure the amount of microwave radiation emitted by raindrops and snow crystals. However, the relationship between microwave radiation and precipitation is not always straightforward, and this can lead to errors in the estimated precipitation amounts. Another limitation of PERSIANN products is that they are often biased. This means that the estimated precipitation amounts tend to be higher or lower than the actual precipitation amounts. The bias can vary depending on the region and the season (Sun et al., 2019; Salmani-Dehaghi et al., 2021; Sapucci et al., 2022; Baig et al., 2023).

PERSIANN-CDR is the product of the PERSIANN family that provides quasi-global precipitation spanning from 1982–present. While its coverage extends from 60° S–60°N and 0°–360° longitude at 0.25° spatial resolution on daily basis, it does not resolve the diurnal cycle. This means that it may not record some short-lived, intense events. Its estimates of precipitation have been used in a variety of applications, including weather forecasting, climate modeling, and water resources management (Nguyen et al., 2018). In this study, we explored the limitations of its estimates of precipitation between 1998 and 2018 over the São Francisco River basin, the largest Brazilian domestic river basin, which is home to over 20 million people.

2. Data and methods

We used precipitation data from the National Institute of Meteorology (INMET) database. The data period was from 1989 to 2018, encompassing inter-decadal rainy periods. A total of 17 rain gauge stations were included in the analysis.

The rain gauge stations were selected based on the following criteria: (1) a maximum of 20% data failure rate; a minimum of 29 years of precipitation data, and (3) a representative spatial distribution within the São Francisco River basin.

The PERSIANN-CDR estimate series were extracted for each rain gauge station, using an algorithm that identified the closest Euclidean distance to the rain gauge station. At this stage, two data series were available for each station: one observed and one PERSIANN-CDR estimate.

To assess the performance of the PERSIANN-CDR estimates, we used several statistical metrics. First, we identified if there was any bias in the estimates using the Percentage Bias (PBIAS). We also determined the volumetric efficiency (VE) and Kling-Gupta efficiency (KGE). VE provided an indication of how well precipitation volumes were being represented, while KGE gave an idea of whether the bias was correlated with precipitation variability or if it was systematic. Furthermore, we determined the thresholds at which estimates of PERSIANN-CDR were misleading using scatter plots. This allowed us to identify any potential limitations or biases in the data and improve our understanding of its performance.

The results were summarized in maps of a value of PBIAS, VE, and KGE for each rain gauge station over four parts of the São Francisco River basin: the Upper, the Middle, the Lower-Middle and the Lower (see figure 1). The division of the São Francisco River Basin into four different segments: Upper, Middle, Lower-Middle, and Lower São Francisco, is a common geographical and hydrographic approach in watershed studies for the purposes of analysis, planning, and water resource management. This subdivision is primarily based on the geographical and hydrographic characteristics of the basin, including topography, water flow, geology, and rainfall patterns, among other factors. The "Upper" São Francisco refers to the portion of the basin located in mountainous or plateau areas, typically in the higher regions of the basin. This area is often characterized by the headwaters of rivers and tributaries that contribute to the São Francisco River. The "Middle" São Francisco comprises the intermediate section of the basin, where the tributaries originating in the Upper São Francisco meet and flow together to form the São Francisco River. It is in this area that the river begins to take its main form. The "Lower-Middle" São Francisco is an extension of the middle stretch of the river as it continues to flow

northeastward through Brazil. In this region, the river may begin to widen as it receives more contributions from tributaries. The "Lower" São Francisco is the portion of the basin that approaches the river's mouth, where it flows into the Atlantic Ocean, where the river becomes broader.

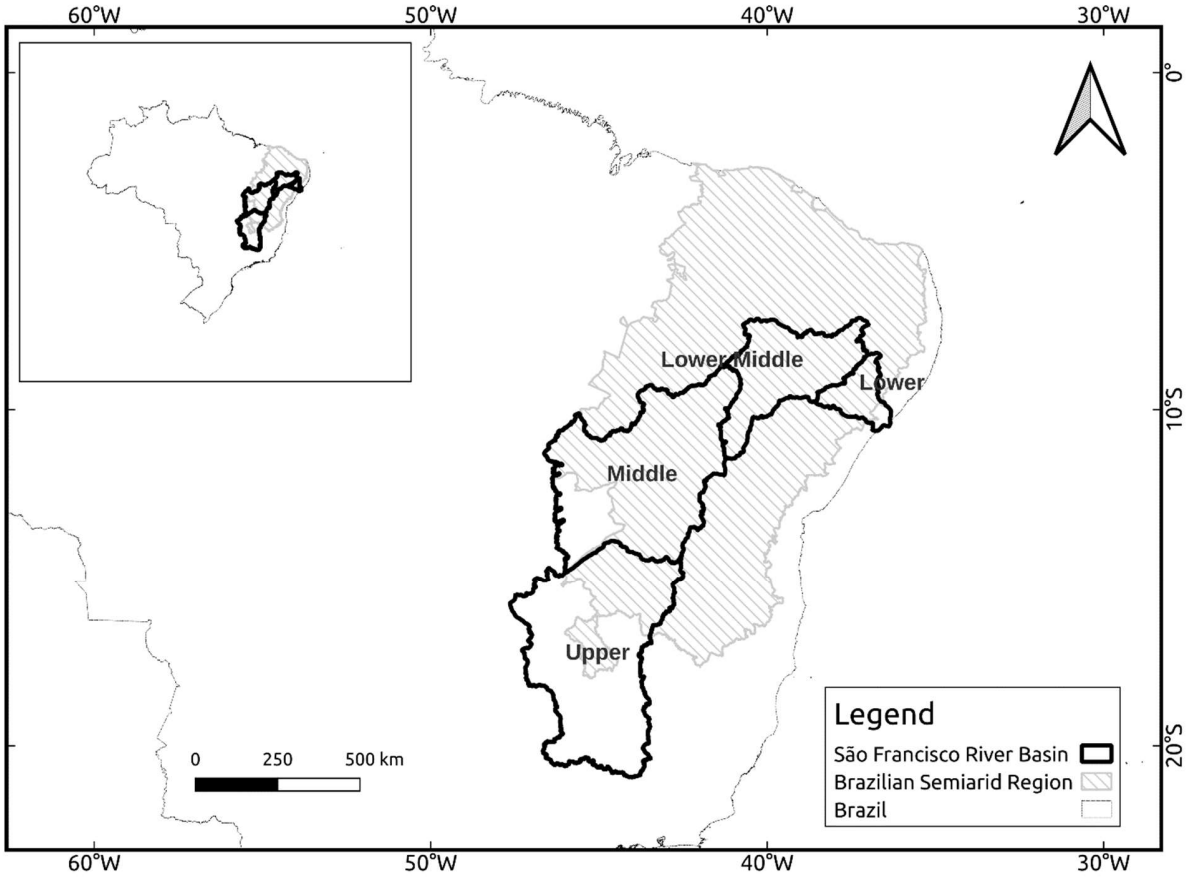

Figure 1 – The division of the São Francisco River Basin into four different segments: Upper, Middle, Lower-Middle, and Lower São Francisco. This subdivision is primarily based on the geographical and hydrographic characteristics of the basin, including topography, water flow, geology, and rainfall patterns, among other factors.
Font: Authors (2023).

3. Results and discussion

In our assessment of PERSIANN-CDR's performance, focusing on PBIAS (Percentage Bias), distinctive patterns emerge across the monitoring stations. Notably, the model consistently reveals an underestimation of precipitation at the two stations nearest to the outlet, with a PBIAS of approximately -20. Conversely, at two other stations, there is a consistent overestimation of precipitation, with a PBIAS of about 40. For the remaining stations, PERSIANN-CDR tends to exhibit a relatively neutral bias (Figure 2).

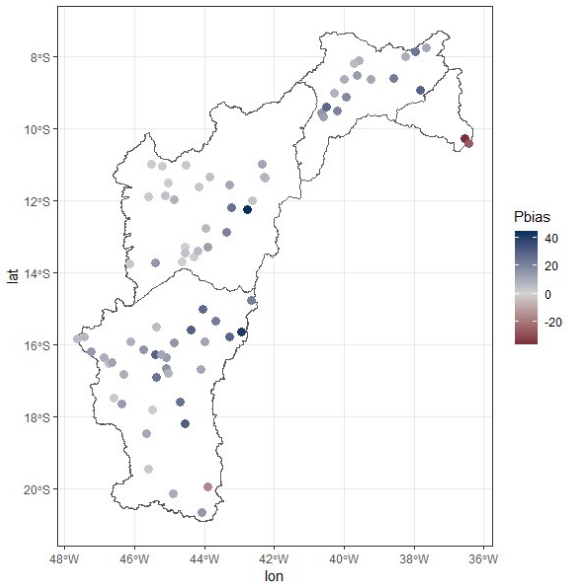

Figure 2 – Percentage Bias (PBIAS) Distribution Across the São Francisco River Basin.
Font: Authors (2023).

Regarding the Volumetric Efficiency (VE), we observe a variation in PERSIANN-CDR's ability to capture precipitation variability across different station categories (Figure 3). Impressively, PERSIANN-CDR closely mirrors observed precipitation in the Upper and Middle sections of the basin (VE > 0.6), exhibiting similar amplitudes of rise and fall. However, its performance diminishes when attempting to capture the actual volumes of precipitation in the Lower Middle and Lower parts of the basin, near the outlet (VE < 0.6). Through the utilization of box plots, we discern a propensity of PERSIANN-CDR to overestimate the actual volumes of precipitation, especially during periods of heavier precipitation, such as the wet season spanning from October to March. Furthermore, a scatter plot reveals that this inclination to overestimate precipitation variability becomes more pronounced when monthly precipitation volumes exceed 200 mm (Figure 4).

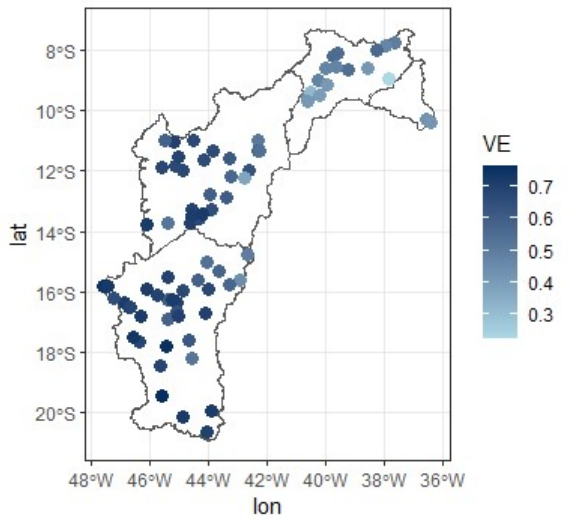

Figure 3 – Variability in Volumetric Efficiency (VE) across the São Francisco River Basin.
Font: Authors (2023).

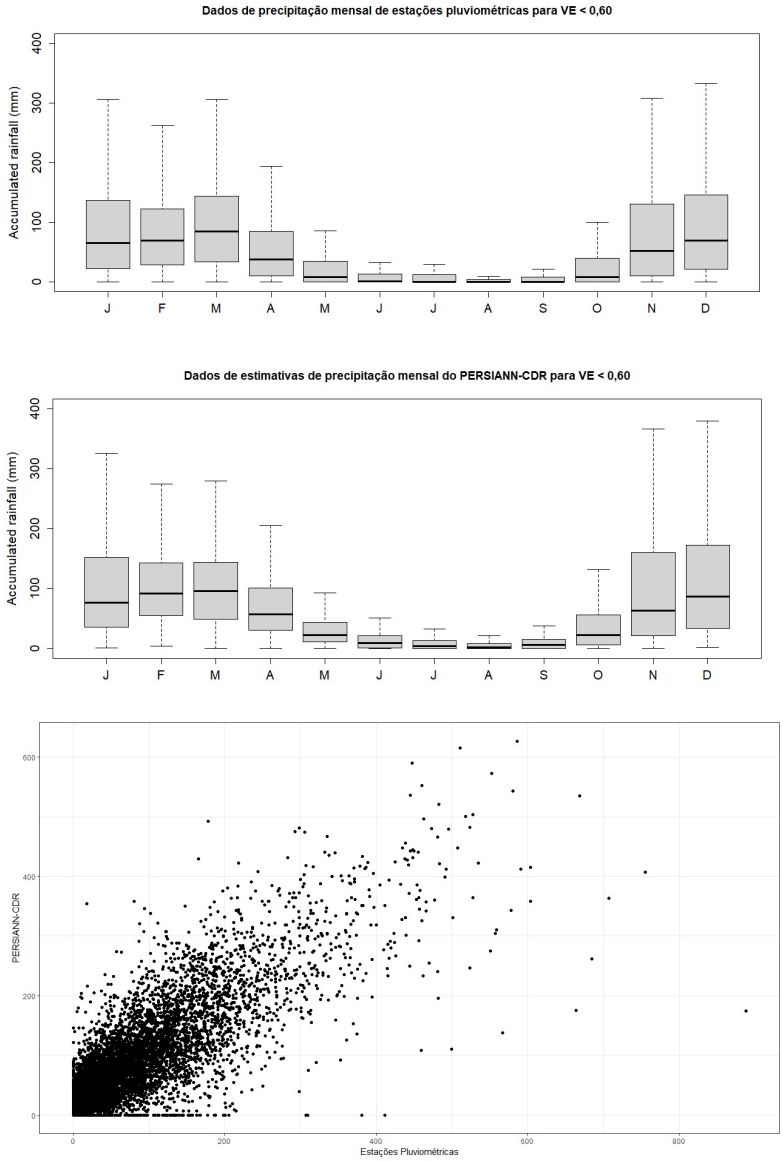

Figure 4 – Panel with box plots and a scatter plot: PERSIANN-CDR overestimation of actual volume of precipitation during heavy rainfall periods, with scatter plot emphasizing the discrepancy in high precipitation totals (>200 mm). Font: Authors (2023).

Kling-Gupta Efficiency (KGE) offers a comprehensive evaluation of PERSIANN-CDR's performance. Notably, KGE trends closely align with those observed in VE, implying that the underrepresentation of variability (amplitudes) at stations near the outlet significantly impacts PERSIANN-CDR's overall performance for these proximal stations (Figure 5). Performance is notably poorer at the two stations closest to the outlet, primarily because PERSIANN-CDR consistently underestimates precipitation in this region (PBIAS < -20).

These findings underscore several limitations inherent to PERSIANN-CDR over the past three decades of precipitation estimation for the São Francisco River Basin. Notably, its spatial variability struggles to accurately represent precipitation at stations near the outlet, which holds significant implications for closing the water budget within downstream regions of

the São Francisco River Basin. Additionally, PERSIANN-CDR tends to exaggerate amplitude variations, particularly during periods of heightened precipitation, potentially leading to skewed assessments of extreme weather events.

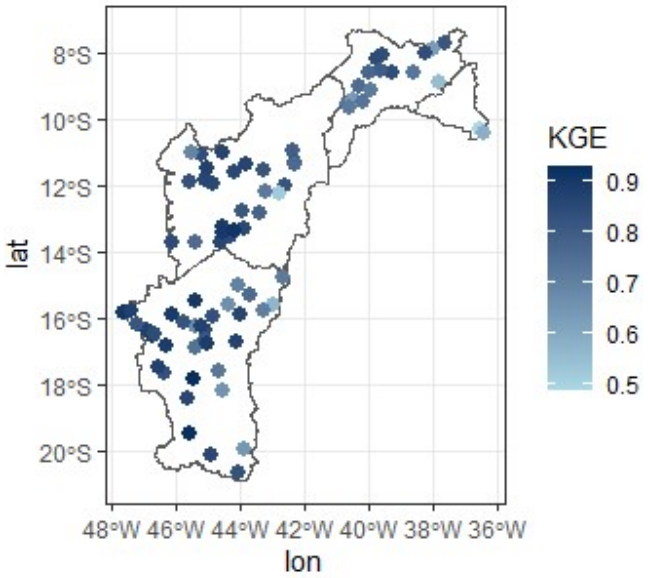

Figure 5 – Kling-Gupta Efficiency (KGE) Assessment: Underrepresentation on PERSIANN-CDR's Performance, with Emphasis on Stations Near the Outlet.
Fonte: Authors (2023).

4. Final considerations

While estimates of precipitation from PERSIANN-CDR offers valuable insights into precipitation patterns, it should be used cautiously, especially in regions with proximity to outlets, during periods of heavy rainfall, and when precise precipitation amplitude measurements are essential for decision-making processes. Understanding these limitations is essential for maximizing the utility of PERSIANN-CDR data.

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