Estimating drought indexes from three satellite-based retrieval algorithms over the São Francisco River basin

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Abstract. The prediction of droughts in the São Francisco River Basin (SFRB) plays an imperative role for environmental and socioeconomic studies as it can provide estimates of short-, mid- and long-term water supply in the basin. However, in smaller and more remote areas, the availability of a network of rain gauges is compromised. Thus, satellite-based rainfall products become the only source of estimates of rainfall for much of the regions in the SFRB, especially the more remote and underdeveloped ones. This study presents drought indexes as calculated from estimates of rainfall from three satellite-based retrieval algorithms: TRMM, PERSIANN and CHIRPS. Drought indexes are averaged for the whole SFRB and presented as time series for as long as the estimates of rainfall from each algorithm spans. For this work, droughts were measured as a function of the SPI (Standardized Precipitation Index). Estimates of SPI values indicated that 22, 18, 10 out of 252 months were from moderate to extreme droughts from TRMM, PERSIANN and CHIRPS, respectively.

Keywords: Satellite-based estimates, Droughts, Retrieval algorithms.

1 Introduction

Droughts are the second largest geographically extensive natural risk, being the cause of the prolonged scarcity of the atmosphere, surface and water supply in the soil (see Thomas et al. [1]). They directly affect areas within the "drought polygon", which refers to the area of Northeast Brazil subject to repeated prolonged drought crises, recognized by legislation, with several geographical areas and different aridity rates (see [2]). The São Franscico River Basin (SFRB) is contained in 58% of this critical drought area.

The SFRB has seven units of the Brazilian federation - Bahia, Minas Gerais, Pernambuco, Alagoas, Sergipe, Goiás and Distrito Federal, as well as 505 municipalities - covering a drainage area of 7.5% of the whole country. In order to ease its management, the SFRB is divided into four hydrographic regions based on its altitude and direction of the course of the São Francisco River. Its waters have a great potential for urban, industrial, agro-industrial supply, fishing activities, electricity generation, transport, tourism and leisure. However, this great potential has been systematically decreased due to recent trends in drought events (see [3]).

A robust and dense rain-gauge network with high spatio-temporal resolution is extremely needed given the SFRB current developments, such as the São Francisco divertion canal, in one of the more remote and less developed areas. Recently, Santos et al. [4] showed that part of this monitoring of drought events can be carried out using satellite data, as their estimates are very close to those measured in rain-gauge stations in arid regions (see Paredes-Trejo et al. [5]).

The Standardized Precipitation Index (SPI, hereafter) is widely used to monitor drought using satellite data (see Sánchez et al. [6]). Although, droughts are a function of sother climatic factors (e.g. temperature) (see

Wu et al. [7]) the SPI stands out to identify drought severity due to its easy interpretation and applicability.

In this study, we used three data sources: (1) Tropical Rainfall Measuring Mission (TRMM) products, which have improved in recent years in applicability and precision, and are designed to offer an alternative to water resources applications, as they make up a continuous and uniformly distributed database (see Zhang et al. [8] e Elgamal et al. [9]); (2) Precipitation Estimation from Remotely Sensed Information using Artificial Neural Network (PERSIANN) data were also evaluated as Ashouri et al. [10] indicated a positive performance relative to rainfall radar data and observations; (3) the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) which, according to Funk et al. [11] is reliable because it is relatively new, has high spatial resolution and is based on several data sources; to estimate drought events using monthly precipitation obtained from three retrieval algorithms.

2. Materials and Methods

We used the Standardized Precipitation Index (SPI, hereafter) to identify the periods with abnormal precipitation deficit in the SFRB. Based on the range at which values of SPI varied, we were also able to categorize the drought severity as: (1) mild, (2) moderate, (3) severe and (4) extreme. The values of SPI were computed using estimates of monthly precipitation obtained from (1) the TRMM 3B43 and (2) the PERSIANN-CDR and (3) CHIRPS retrieval algorithms. The TRMM 3B43 (TRMM, hereafter) algorithm merges daily data from passive microwave and precipitation radar sensors on board the Tropical Rainfall Measuring Mission (TRMM) satellite at a spatial resolution of 0.25 degrees. The PERSIANN-CDR algorithm combines data from infrared and passive microwave from multiple geostationary satellites from the International Satellite Cloud Climatology Project (ISCCP) at a spatial resolution of 0.25 degrees (PERSIANN-CDR, hereafter). The CHIRPS algorithm retrieves its estimates of precipitation from global infrared Cold Cloud Duration observations at a spatial resolution of 0.05 degrees. It is important to note that CHIRPS estimates of precipitation were calibrated with one of the Tropical Rainfall Measuring Mission (TRMM) products, the TRMM 3B42 algorithm.

Estimates of monthly precipitation from each of the retrieval algorithms were averaged over the SFRB for a 21-year period, spanning from January 1998 to December 2018. The values of SPI as calculated in this study were obtained by fitting a gamma distribution. Because we intend to focus our results on the impact of drought on the availability of surface water, we will investigate precipitation deficit on a relatively short timescale. So, precipitation deficit was measured in terms of 3-month SPI. Note that, for hydrologic drought analysis on groundwater, streamflow or reservoir storage applications, 6-month up to 48-month SPI are recommended instead (see McKee *et al.* [12]). The flowchart presented in Figure 1 summarizes the steps undertaken in this work to calculate the values of 3-month SPI.

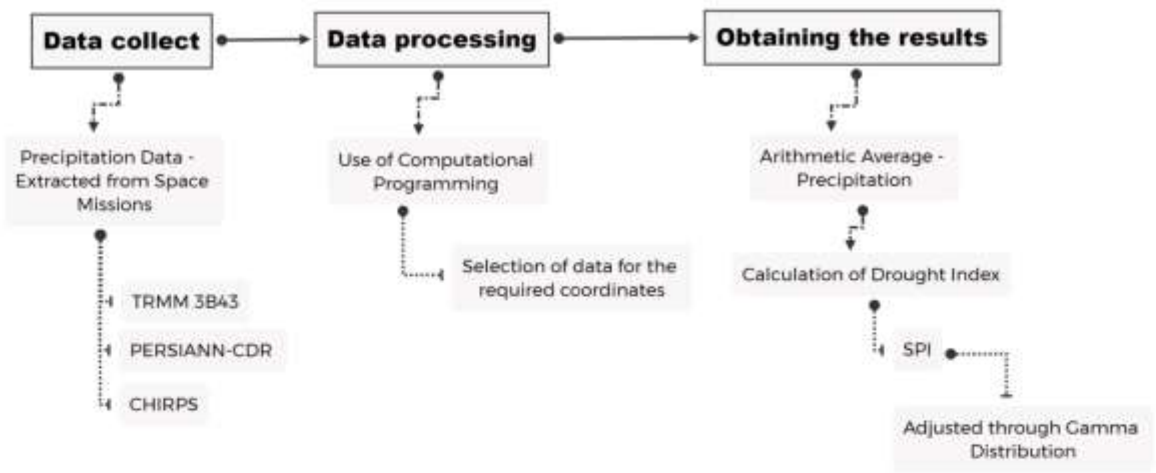

Figure 1. Summary of the steps undertaken in this study to determine the values of 3-month SPI. Source: Authors.

3. Results and discussions

Based on estimates of monthly precipitation obtained from each of the retrieval algorithm investigated here, we calculated 252 values of 3-month SPI for the period ranging from January 1998 to December 2018. As defined in McKee *et al.* [12], a drought event occurs anytime the SPI is continuously negative and reaches an intensity of less than -1.0. Based on this criteria, Table 1 summarizes the frequency of drought events occurred in the SFRB. We could note that, from CHIRPS to TRMM and PERSIANN-CDR, the frequency of drought events varied a lot. While CHIRPS had 10 drought events, TRMM and PERSIANN-CDR had more than doubled over the same period and for the same domain. This difference could be a response to the effects of interpolation techniques used by CHIRPS to increase its spatial resolution, which could lead to smoother transitions in precipitation gradients over the SFRB. Other reasons for why estimates of precipitation from CHIRPS may difer from the other two retrieval algorithms were explored in Gao *et al.* [13] and Zhong et al. [14].

Table 1. Frequency of drought events based on the values of 3-month SPI from CHIRPS, TRMM and PERSIANN-CDR. Source: Authors.

Dataset	Amount of Severe and Extreme Drought in 252 months.
TRMM	22
PERSIANN-CDR	18
CHIRPS	10

We also evaluated the drought events in terms of temporal mismatching. Figure 2 shows the time series of values of 3-month SPI for each of the retrieval algorithm. Despite the differences in frequency of drought events, we note a good correlation between the three retrieval algorithms with respect to the overall timing of dry periods.

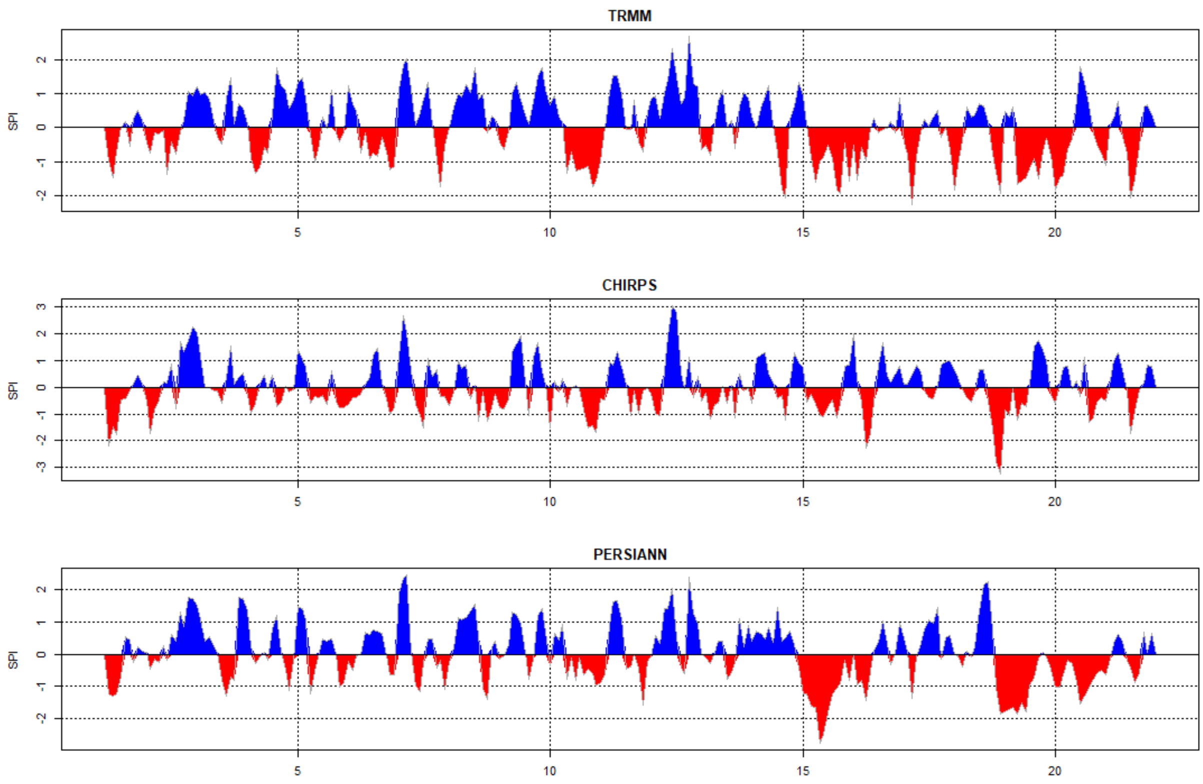

Figure 2. Values of 3-month SPI as calculated from estimates of monthly precipitation from the three retrieval algorithms: a) PERSSIAN; b) TRMM; c) CHIRPS. Source: authors.

4. Conclusion

This work presented estimates of drought events using monthly precipitation obtained from three retrieval algorithms. Comparisons between the estimates of drought events were made in terms of values of 3-month SPI for drought severity and temporal mismatching of dry periods. While the timing of dry periods showed no much discrepancies from one retrieval algorithm to another, the frequency of moderate drought events was much higher for TRMM and PERSIANN-CDR than for CHIRPS. We suggested that this could be an effect of the interpolation techniques used by CHIRPS. In either cases, drought events showed to be very consistent in the SFRB, as it presented at least 10 moderate drought events over about two decades.

References

[1] T. Thomas, R. K. Jaiswal, R. Galkate, P. C. Nayak, and N. C. Ghosh, "Drought indicators-based integrated assessment of drought vulnerability: a case study of Bundelkhand droughts in central India," *Nat. Hazards*, vol. 81, no. 3, pp. 1627–1652, 2016.

[2] "SEI - Polígono das Secas." [Online]. Available: https://www.sei.ba.gov.br/index.php?option=com_content&view=article&id=2603&Itemid=664. [Accessed: 27-Jul-2020].

[3] "A Bacia - CBHSF : CBHSF – Comitê da Bacia Hidrográfica do Rio São Francisco." [Online]. Available: https://cbhsaofrancisco.org.br/a-bacia/. [Accessed: 27-Jul-2020].

[4] C. A. G. Santos, R. M. Brasil Neto, J. S. A. Passos, and R. M. da Silva, "Drought assessment using a TRMM-derived standardized precipitation index for the upper São Francisco River basin, Brazil," *Environ. Monit. Assess.*, vol. 189, no. 6, 2017.

[5] F. J. Paredes-Trejo, H. A. Barbosa, and T. V. Lakshmi Kumar, "Validating CHIRPS-based satellite precipitation estimates in Northeast Brazil," *J. Arid Environ.*, vol. 139, pp. 26–40, 2017.

[6] N. Sánchez, Á. González-Zamora, J. Martínez-Fernández, M. Piles, and M. Pablos, "Integrated remote sensing approach to global agricultural drought monitoring," *Agric. For. Meteorol.*, vol. 259, no. July 2017, pp. 141–153, 2018.

[7] J. Wu, L. Zhou, X. Mo, H. Zhou, J. Zhang, and R. Jia, "Drought monitoring and analysis in China based on the Integrated Surface Drought Index (ISDI)," *Int. J. Appl. Earth Obs. Geoinf.*, vol. 41, pp. 23–33, 2015.

[8] L. Zhang, W. Jiao, H. Zhang, C. Huang, and Q. Tong, "Studying drought phenomena in the Continental United States in 2011 and 2012 using various drought indices," *Remote Sens. Environ.*, vol. 190, pp. 96–106, 2017.

[9] A. Elgamal, P. Reggiani, and A. Jonoski, "Impact analysis of satellite rainfall products on flow simulations in the Magdalena River Basin, Colombia," *J. Hydrol. Reg. Stud.*, vol. 9, pp. 85–103, 2017.

[10] H. Ashouri, "Daily Precipitation Climate Data Record from Multisatellite Observations for Hydrological and Climate Studies," no. January, pp. 69–84, 2015.

[11] C. C. Funk *et al.*, "A Quasi-Global Precipitation Time Series for Drought Monitoring," *U.S. Geol. Surv. Data Ser.*, vol. 832, p. 4, 2014.

[12] McKee, T. B., Doesken, N. J., & Kleist, J. (1993, January). The relationship of drought frequency and duration to time scales. In *Proceedings of the 8th Conference on Applied Climatology* (Vol. 17, No. 22, pp. 179-183).

[13] Gao, F., Zhang, Y., Ren, X., Yao, Y., Hao, Z., & Cai, W. (2018). Evaluation of CHIRPS and its application for drought monitoring over the Haihe River Basin, China. *Natural Hazards*, *92*(1), 155-172.

[14] Zhong, R., Chen, X., Lai, C., Wang, Z., Lian, Y., Yu, H., & Wu, X. (2019). Drought monitoring utility of satellite-based precipitation products across mainland China. *Journal of hydrology*, *568*, 343-359.