Recent Changes in North and South America Monsoon Rainfall

Zihuai Zhao *

Park Street, P.O. Box 600, Blairstown, NJ 07825, USA

* Corresponding Author Email: johnzhao2028@gmail.com

Abstract. The North American Monsoon (NAM) and South American Monsoon (SAM) are the two dominant seasonal precipitation systems of the Western Hemisphere, yet a systematic comparison of their recent changes over the satellite era remains limited. This study investigates recent changes in NAM and SAM rainfall over the period 2001–2024 using NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) daily precipitation product, interpolated to a 1x1deg grid. Monsoon onset and demise dates are defined objectively from the minimum and maximum of the 31-day smoothed cumulative daily rainfall anomaly, with the SAM calculated on a time-converted annual cycle, and monsoon length is defined as the difference between the demise and onset dates. The results show that the recent trends of the two systems are opposite, with annual mean precipitation increasing for the NAM (0.22 mm day-1 per decade) and decreasing for the SAM (-0.19 mm day-1 per decade). The seasonal evolution is likewise distinct: the NAM onset shows an advance trend (-2.4 days per decade) while the SAM onset shows a slight delay (0.29 days per decade), and although both demise dates are delayed, the NAM extension (5.43 days per decade) far exceeds that of the SAM (1.13 days per decade). Consequently, the monsoon length shows an obvious increasing trend for the NAM (7.83 days per decade) and only a slight increasing trend for the SAM (0.84 days per decade). These contrasting changes are likely attributable to differential responses to the recent northward shift of the tropical Atlantic Intertropical Convergence Zone and to asymmetric teleconnections from Atlantic warming.

Keywords: North American Monsoon; South American Monsoon; monsoon onset and demise; precipitation trends; IMERG.

1. Introduction

The North American Monsoon (NAM) and South American Monsoon (SAM) are the two dominant seasonal precipitation systems of the Western Hemisphere, playing a critical role in regulating regional water resources, agricultural productivity, and ecosystem function across large portions of the Americas [1]. The onset of these monsoon systems marks the transition from the dry season to the major rainy season, accompanied by a fundamental reorganization of low-level winds and large-scale moisture transport. Understanding the variability and long-term trends in American monsoon characteristics, including precipitation intensity, onset timing, demise date, and seasonal duration, is therefore of considerable importance for climate adaptation and water resource planning.

The NAM is characterized by a pronounced seasonal increase in precipitation over northwestern Mexico and the southwestern United States during boreal summer, with onset typically occurring in early to mid-June and demise in late September. Previous studies have documented substantial multidecadal variability in NAM strength and timing, with two dry regimes associated with late onsets and weaker rainfall identified in 1948–1970 and 1991–2005, separated by a strong regime with early onsets and enhanced rainfall during 1971–1990 [2]. These multidecadal fluctuations have been linked to sea surface temperature (SST) variability, particularly the Atlantic Multidecadal Oscillation and long-term SST warming trends. The SAM, in contrast, develops during austral summer over tropical and subtropical South America, with convective activity intensifying over the Amazon basin and propagating southeastward.

Despite these advances, a systematic comparison of recent changes in NAM and SAM precipitation characteristics over the satellite era remains limited. In particular, whether both systems have experienced coherent or divergent trends in annual mean precipitation, onset timing, demise date, and monsoon length over the past two decades has not been thoroughly examined. Motivated

by this gap, the present study investigates recent changes in NAM and SAM rainfall over the period 2001–2024. The remainder of this paper is organized as follows. Section 2 describes the data and methods. Section 3 presents the main results.

2. Data and Methods

2.1. Data

This study uses NASA's Integrated Multi-satellitE Retrievals for GPM (IMERG) rainfall product [3], which is averaged at daily timescale and interpolated into 1x1deg. The time period we used is 2001-2024.

2.2. Definition of onset and demise dates of the NAM and SAM

We calculate the NAM and SAM rainfall, which is the spatial averages of precipitation within the domain of 0-30N and140W-60W (NAM) and 35S-0, 80W-30W (SAM), respectively (rectangles in Figure 1). We use an objective method to define the monsoon onset and demise, which is widely used. [4,5] For a specific year m, the cumulative daily rainfall anomaly of each monsoon rainfall for the day i is calculated as

$$C'_m(i) = \sum_{n=1}^{i}[D_m(n) - C] \quad (1)$$

Where $D_m(n)$ represents the daily rainfall over the monsoon regions for day n of year m, and C represents the climatological-mean (24-year daily average) monsoon rainfall. The onset (demise) date of monsoon is defined as the minimum (maximum) of the 31-day smooth cumulative daily rainfall anomaly (Figure 2). It is noteworthy that the onset and demise dates of SAM are calculated based on the time-converted cumulative daily rainfall anomaly (green dashed line in Figure 3). We first divide the whole year into two parts equally and then add the first part after the second part. The monsoon length is defined as the difference between demise date and onset date.

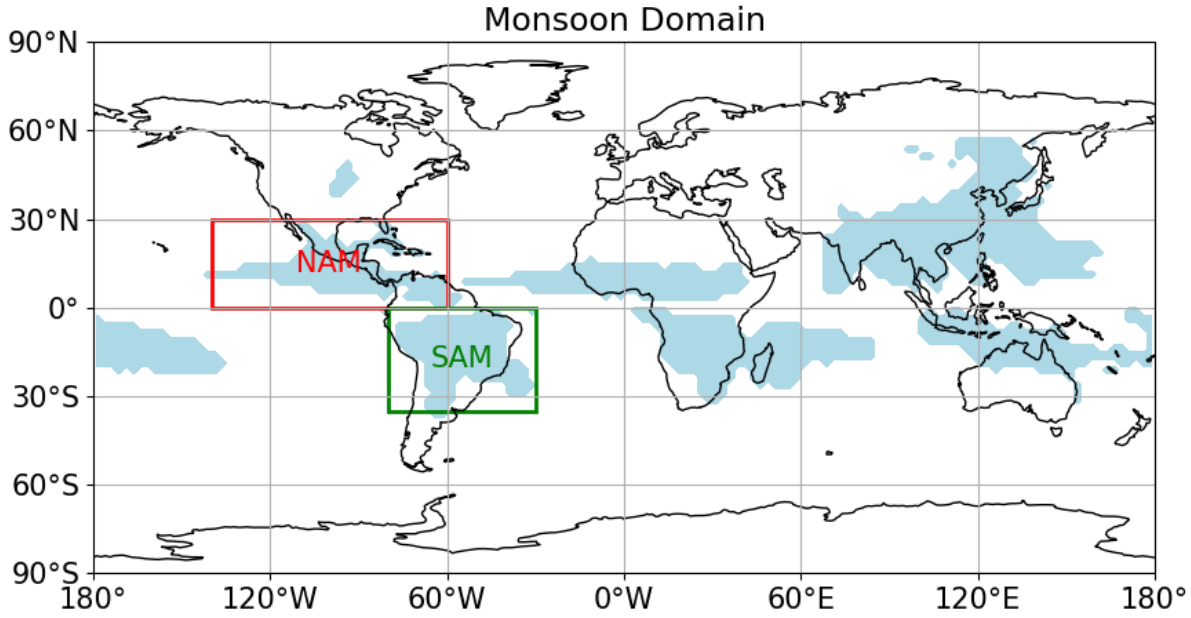


Fig 1. Map of global monsoon (shaded in blue) Two study regions are outlined: the North American Monsoon (NAM, red box) and the South American Monsoon (SAM, green box).

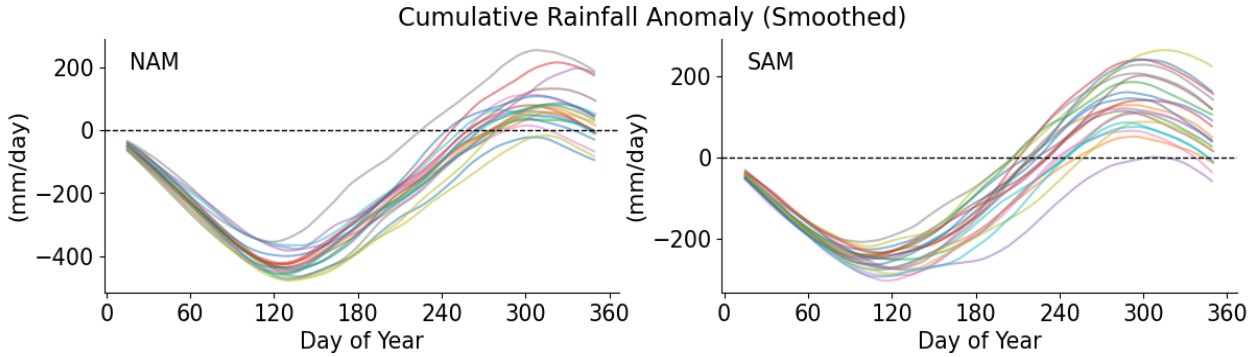


Fig 2. Smoothed cumulative rainfall anomaly (mm/day) for NAM (left) and SAM (right), with each colored line representing an individual year. The specific calculation is shown in Method section. The onset and demise dates of each monsoon are reflected in the turning points.

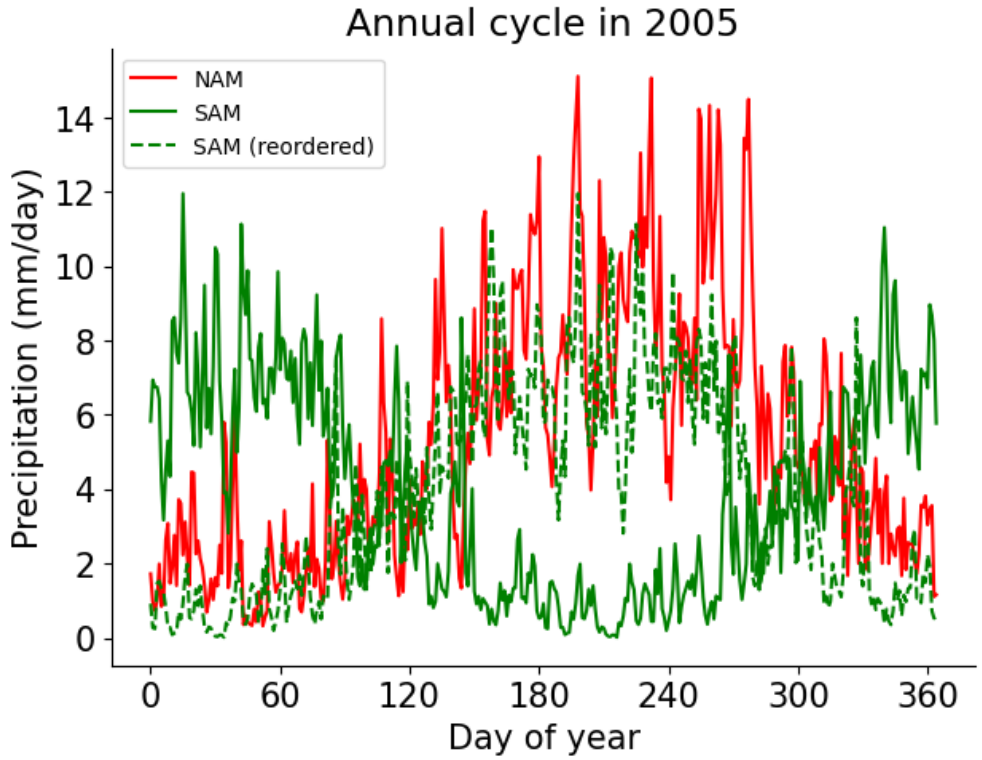


Fig 3. Annual cycle of daily precipitation (mm/day) in 2005 for the NAM (red solid), SAM (green solid) and time-converted SAM (green, dashed).

3. Results

As shown in Figure 4, the recent trends of NAM and SAM are opposite, with increasing for NAM and decreasing for SAM (Figure 4), which is likely related to the recent northward shift of the tropical Atlantic Intertropical convergence zone [6]. The changing rates for NAM and SAM are 0.22 mm day-1 per decade and -0.19 mm day-1 per decade, respectively. Apart from the recent trends of annual-mean precipitation, some monsoon characteristics are quite distinct from NAM and SAM as well (Figure 5). Specifically, the NAM onset shows an advance trend (-2.4 days per decade) during recent decades, while SAM onset shows a slight delay trend (0.29 days per decade). Conversely, the NAM demise date shows a trend of delay (5.43 days per decade), while the SAM demise date shows a slight delay trend as well (1.13 days per decade). Therefore, the monsoon length, defined as the difference between demise date and onset date, shows an obvious increasing trend for the NAM (7.83 days per decade) and slight increasing trend for the SAM (0.84 days per decade).

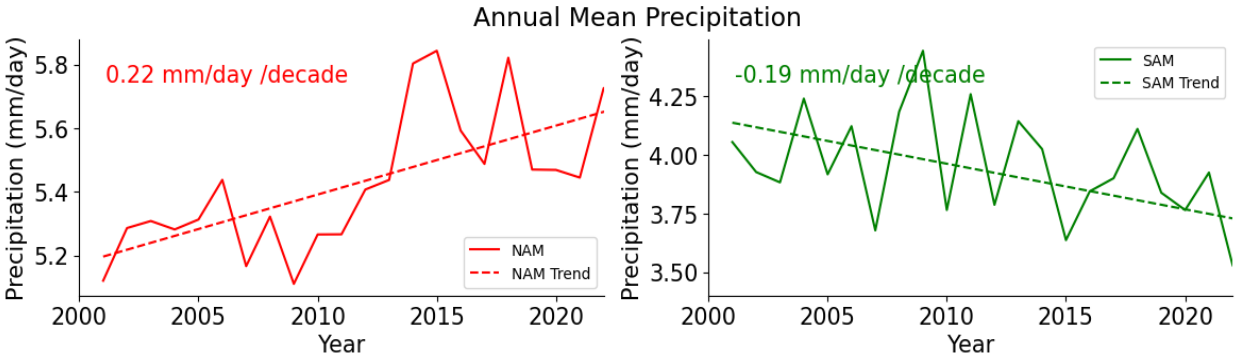


Fig 4. Annual mean precipitation (mm/day) from 2001 to 2024 for NAM (left panel) and SAM (right panel). Dashed lines indicate the linear trends for each region, with the change rate shown in the top-left corner of each figure.

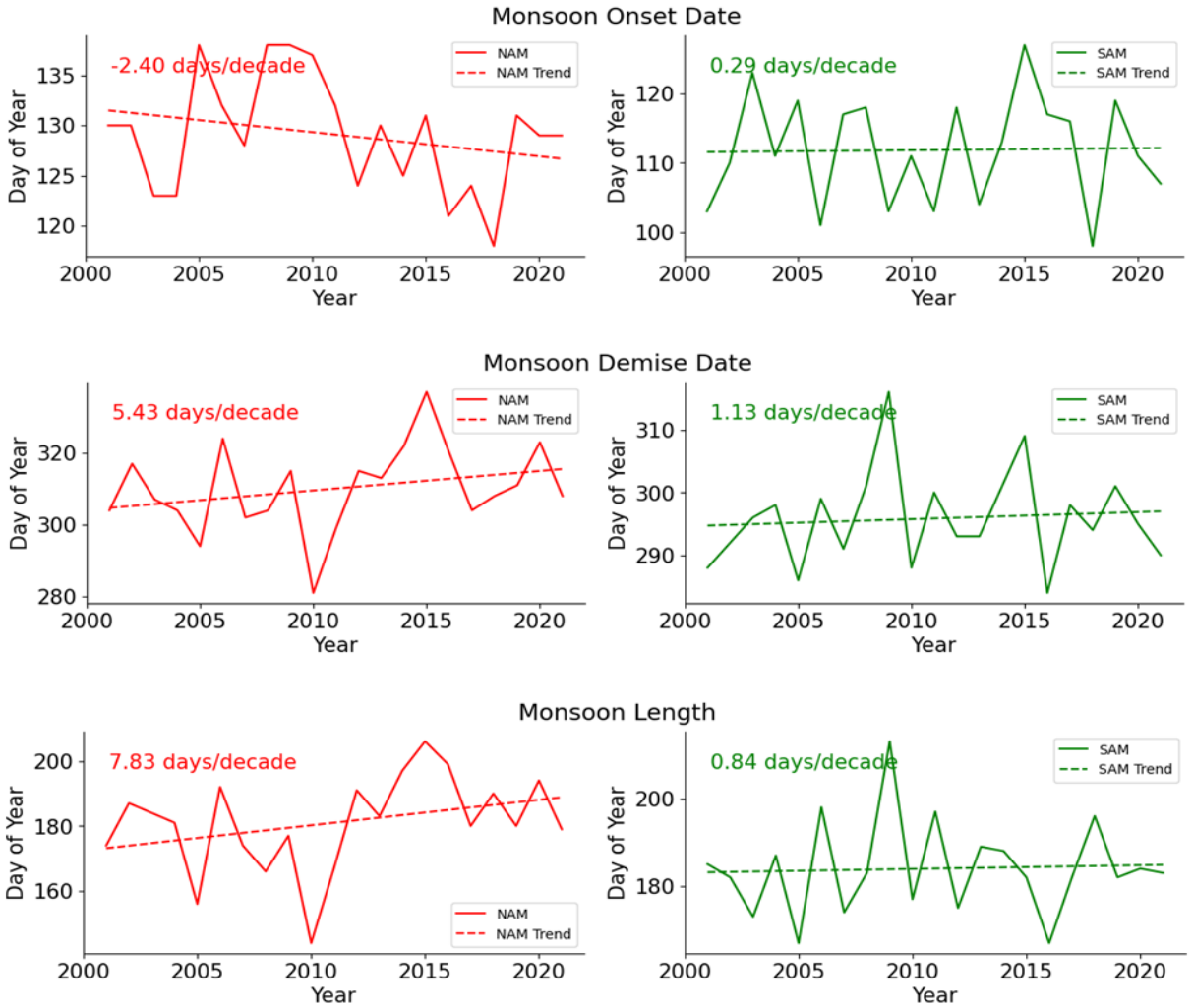


Fig 5. Interannual variability of monsoon characteristics from 2001 to 2024 for NAM (red) and SAM (green), including onset date (top panels), demise date (middle panels), and monsoon length (bottom panels), with dashed lines indicating the linear trend for each region and its changing rate shown in the top-left corner of each figure.

4. Conclusions

The NAM and SAM exhibit opposing precipitation trends, with NAM increasing and SAM decreasing, and they also show distinct seasonal evolution, as NAM onset advances while SAM onset delays, and although both demises are delayed, the NAM's much greater demise extension results in a far more pronounced lengthening of its rainy season compared to that of the SAM.

The opposing precipitation trends between NAM and SAM, along with their distinct seasonal evolution, are likely attributable to differential responses to the northward shift of the tropical Atlantic ITCZ and asymmetric teleconnections from Atlantic warming [7]. The northward ITCZ displacement may enhance moisture convergence and convective instability over the NAM region [6], particularly during its early season, thereby advancing onset and prolonging the rainy season through persistent low-level convergence. In contrast, the SAM region, located farther south and influenced more by Pacific decadal variability [8] and the South Atlantic Subtropical High [9,10], may experience reduced moisture supply, leading to a slight delay in onset and only marginal lengthening.

References

[1] Bombardi, Rodrigo J., et al. “Detection, Variability, and Predictability of Monsoon Onset and Withdrawal Dates: A Review.” International Journal of Climatology, vol. 40, no. 2, 11 Sept. 2019, pp. 641–667, doi:10.1002/joc.6264. Fangfang. Research on power load forecasting based on Improved BP neural network. Harbin Institute of Technology, 2011.

[2] Arias, Paola A., et al. “Decadal Variation of Rainfall Seasonality in the North American Monsoon Region and Its Potential Causes.” Journal of Climate, vol. 25, no. 12, 15 June 2012, pp. 4258–4274, doi:10.1175/jcli-d-11-00140.1.

[3] Huffman, George J., et al. “Integrated Multi-Satellite Retrievals for the Global Precipitation Measurement (GPM) Mission (IMERG).” Advances in Global Change Research, 2020, pp. 343–353, doi:10.1007/978-3-030-24568-9_19.

[4] Dunning, Caroline M., et al. “Later Wet Seasons with More Intense Rainfall over Africa under Future Climate Change.” Journal of Climate, vol. 31, no. 23, 1 Dec. 2018, pp. 9719–9738, doi:10.1175/jcli-d-18-0102.1.

[5] Noska, Ryne, and Vasubandhu Misra. “Characterizing the Onset and Demise of the Indian Summer Monsoon.” Geophysical Research Letters, vol. 43, no. 9, 7 May 2016, pp. 4547–4554, doi:10.1002/2016gl068409.

[6] Zhou, Wenyu, et al. “Contrasting Recent and Future ITCZ Changes from Distinct Tropical Warming Patterns.” Geophysical Research Letters, vol. 47, no. 22, 20 Nov. 2020, doi:10.1029/2020gl089846.

[7] Kucharski, F., et al. “Tropical Pacific Response to 20th Century Atlantic Warming.” Geophysical Research Letters, vol. 38, no. 3, Feb. 2011, doi:10.1029/2010gl046248.

[8] Ogata, Tomomichi, et al. “Interdecadal Amplitude Modulation of El Niño–Southern Oscillation and Its Impact on Tropical Pacific Decadal Variability*.” Journal of Climate, vol. 26, no. 18, 9 Sept. 2013, pp. 7280–7297, doi:10.1175/jcli-d-12-00415.1.

[9] Fahad, Abdullah Al, et al. “How Will Southern Hemisphere Subtropical Anticyclones Respond to Global Warming? Mechanisms and Seasonality in CMIP5 and CMIP6 Model Projections.” Climate Dynamics, vol. 55, no. 3–4, 10 May 2020, pp. 703–718, doi:10.1007/s00382-020-05290-7.

[10] He, Chao, et al. “Responses of the Summertime Subtropical Anticyclones to Global Warming.” Journal of Climate, vol. 30, no. 16, Aug. 2017, pp. 6465–6479, doi:10.1175/jcli-d-16-0529.1.