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The role of Amazon river runoff on the multidecadal variability of the Atlantic ITCZ

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Abstract

Climate model projections for the 21st century predict an elongated dry season in the Amazon basin, potentially reducing the discharge into the equatorial Atlantic Ocean. In order to understand the climatic role of Amazon runoff into the ocean, sensitivity experiments were carried out using the Community Earth System Model (CESM). Without Amazon runoff, the Atlantic Meridional Overturning Circulation (AMOC) strengthens and the associated increase in northward heat transport induces a positive temperature anomaly in the North Atlantic Ocean with a spatial structure similar to the positive phase of the Atlantic Multidecadal Variability (AMV). A positive phase of AMV developed in the absence of Amazon runoff triggers a bipolar seesaw in SST across the thermal equator with warming to the north and cooling to the south. The boreal summer rainfall in the tropical Atlantic Ocean sector responds to this change in SST by displacing the intertropical convergence zone (ITCZ) to the north of its mean position. An alternate experiment by doubling the Amazon runoff shows a weakening of AMOC and AMV and a southward shift in the summer–time ITCZ. In both the experiments, we find that the largest change in rainfall is exhibited over the region where the AMV–induced decadal variability in rainfall is prominent, confirming the source of rainfall variability. Based on sensitivity experiments by varying the runoff, we propose that the Amazon discharge can affect the multidecadal variabilities, the AMOC and AMV, and thereby the low–frequency variability of rainfall over the tropical North Atlantic Ocean and West African nations and thus have an impact on the regional hydrological cycle and economy.

1. Introduction

The intertropical convergence zone (ITCZ) is characterized by a narrow band of deep convective clouds and heavy rainfall stretching zonally over the thermal equator, where the easterlies converge [1]. During boreal summer (June to September; JIAS, hereafter simply summer, for the sake of brevity) the ITCZ is located to the north of the equator [2]. The variability in the meridional position of summer ITCZ in the Atlantic sector affects the South American monsoon [3], West African monsoon [4] and the rainfall over the tropical Atlantic Ocean [5]. The West African rainfall exhibits variability ranging from seasonal to multidecadal timescales [6]. The fluctuations in large–scale meridional heat transport, the Atlantic meridional overturning circulation (AMOC), is a major source of global climate variability on decadal to multidecadal timescales [7, 8]. The variability in AMOC–driven heat transport induces a basin–wide sea surface temperature (SST) anomaly termed as the Atlantic Multidecadal Variability (AMV [9, 10]). The AMV is associated with the SST variability in the North Atlantic basin with alternate cold and warm phases occurring at a frequency of several decades. A positive phase of AMV (warm North Atlantic) favors a northward displacement of intertropical convergence zone (ITCZ), whereas, during a weaker phase, the ITCZ migrates southward [11–15]. Several studies show that the continental–scale multidecadal drought...
events in northwest Africa and the Sahel are related to the changes in AMV through its control on the meridional position of ITCZ [6, 11, 16]. Therefore, a deeper understanding of various factors affecting the low–frequency variability in ITCZ is vital for the longterm prediction of rainfall.

Seasonally, the surface salinity budget in the tropical Atlantic Ocean is regulated by a net loss of freshwater as the evaporation dominates over precipitation. But, the freshwater influx from the Amazon river partly compensates for the evaporative loss and is one of the major sources of salinity variability in the tropical Atlantic Ocean [17]. Amazon river discharges \( \sim 6.6 \times 10^3 \) km\(^2\) of freshwater into the equatorial Atlantic Ocean annually [18]. Climate projections for the 21st century predict a reduced discharge from the Amazon, owing to an elonged dry season and increased damming and diversion of river water [19–22]. However, the impact of such large–scale changes in Amazon runoff on climate remains largely unexplored. In this study, using coupled climate model simulations, we demonstrate the role of Amazon runoff in regulating the AMV that subsequently affects the multidecadal variability of summer rainfall over the tropical Atlantic sector. A climate model experiment demonstrated that the Amazon river runoff affects the oceanic heat transport and large–scale climate variabilities across the globe including the AMOC [23], North Atlantic Oscillation [23], and El Niño [24]. Studies using stand-alone ocean model [25] and coupled simulations [23] reveal that Amazon runoff influence the AMOC through changes in upper ocean salinity and density and thereby the rate of deepwater formation. In a previous study [23] we showed that the largescale climate oscillations in the Atlantic Ocean are modulated by the Amazon runoff. Using the Community Earth System Model (CESM, Version 1.0 [26]), we carried out two sensitivity experiments, one without Amazon runoff (0AMZ) and the other by doubling the runoff (2AMZ). We analyze the active role of Amazon freshwater input on the AMV and the summer–time Atlantic ITCZ by comparing the responses in 0AMZ and 2AMZ with respect to the control simulation (CR). Model configuration and experimental details are provided in the Supplementary Material (stacks.iop.org/ERL/15/054013/mmedia), section 1.

2. Low-frequency variability of the Atlantic summer ITCZ

The climatological mean rainfall and winds from the observation as well the CESM control (CR) simulation show that the summer–time (June–August; JJAS) ITCZ is located to the north of the equator, roughly centered around 8°N, where the low–level easterly winds converge (figures 1(a) and (b)). In both the observation and CR, the Sahel region (10°N–20°N, 18°W–15°E [6]) receives relatively less rainfall over the northern half compared to the south (figures 1(a) and (b)). In the past decades, this region experienced severe and prolonged drought events that resulted in large–scale human migrations [27, 28]. This is because there exists a strong multidecadal–scale variability in rainfall over this region, overlying the interannual variability (Supplementary figures 1(a)–(d)). Several studies have shown that these extreme events are associated with the low–frequency SST variability in the Atlantic, the AMV [11, 13, 29]. Paleoclimate studies of the past millennia also signify the active role of AMV on the multidecadal droughts in the Sahel region [16]. Observed anomalies in SST during a positive AMV event coincide with a positive rainfall anomaly over the southern half of the Sahel, demarcated by the blue box between 10° N and 15° N in figures 1(c) and (e), suggesting a northward shift in the mean ITCZ. The SST anomaly associated with a positive AMV shows warming to the north of 10° N and cooling to the south of it, creating a meridional SST gradient across the thermal equator (figure 1(d)). On the other hand, when the observed AMV is in a cooler phase, the rainfall anomaly is negative over the region enclosed by the box in figure 1(e), with a southward shift in the mean ITCZ position and the associated meridional gradient in SST reverses (figure 1(f)). Below we focus on the role of Amazon runoff on the aforementioned variability of rainfall over the tropical Atlantic region and West Africa that has a significant impact on the regional economy and hydrological cycle.

The decadal variance in JJAS rainfall (variance of 10–year running average) shows that the CESM CR simulation is able to pick up the high variability (> 1 mm day\(^{-1}\)) along the coasts of West Africa, with some difference in magnitude (figures 2(a) and (b)). The observed and simulated decadal variance (figures 2(a) and (b)) in the summer rainfall is confined to the north of the equator exhibiting significant variability in the southern Sahel (blue box). However, the variance of inland rainfall, away from the coast, is not well reproduced in the CR when compared to the observation (figures 2(a) and (b)) and we are unable to present the observed decadal rainfall variability over the ocean since the CRU dataset [32] is land–based. A comparison of simulated rainfall variability over the selected box in figure 2(b) with and without oceanic grid points is shown in Supplementary figure 2(a) and (b). Further, the decadal variance of longterm rainfall over the tropical North Atlantic Ocean and Sahel region is unrealistically large in the reanalysis datasets and therefore not shown.

Though there are some disagreements in the magnitude and spatial extent of the decadal variance between observed and simulated rainfall, we use the CESM model simulations to qualitatively show the Amazon runoff–induced longterm variability of the Atlantic ITCZ. From figures 1(c) and (e), it is clear that the AMV–related rainfall variability over the
Sahel region is mostly confined to the southern half (box encompassing the region $10^\circ$ S–$15^\circ$ N, $18^\circ$ W–$15^\circ$ E). Further, the decadal variance in summer rainfall to the north of $10^\circ$ S is largely contributed by the July, August, and September months (JAS; Supplementary figures 1(b)–(d)). Therefore, we focus our further analysis on the JAS rainfall variability in the model and its response to Amazon runoff over the southern half of the Sahel and northern tropical Atlantic Ocean.

In the CR, there are two zonally distinguishable bands of high decadal variability over the northern tropical Atlantic Ocean (figure 2(b)). When the AMV is positive, the northern band experience higher than normal rainfall (over the box in figure 2(b)), whereas the rainfall over the southern band reduces. We present the variability over the northern band for the JAS season as the response over the southern counterpart is almost opposite in sign (as seen in figures 1(c) and (e)). The mean rainfall over the southern half of the Sahel (averaged over $10^\circ$ S–$15^\circ$ N, $18^\circ$ W–$15^\circ$ E) shows a clear seasonality, with the highest rainfall in the month of August ($8.2 \text{ mm day}^{-1}$) with significant contribution during July and September months as well [6, 34], in both observation and CR (figure 2(c)). The timeseries of interannual (black curve) and decadal (10–year running average; red and blue shades) rainfall during peak months of JAS in the box enclosed in figures 2(a) and (b) are shown in figures 2(d) and (e), respectively. From observation, it is evident that the southern Sahel experienced prolonged wet (from 1930 to 1960) and dry periods (from 1970 to 1990) that sustained for more than a decade (figure 2(d)) before its recovery.
Figure 2. Low–frequency variability of rainfall. Decadal rainfall variability in CRU (a) and CR (b) estimated as the variance (in (mm day$^{-1}$)$^2$) of the 10–year running average of JJAS rainfall. The blue box in (a) encloses the southern Sahel region where the low–frequency rainfall variability is high, whereas the box in (b) encloses the same latitude but by including the high rainfall variability over the oceanic region as well. Since the CRU dataset lacks rainfall over ocean grid points, the comparison of the annual cycle of rainfall (c) is presented over the southern Sahel region (10$^\circ$N–15$^\circ$N, 18$^\circ$W–15$^\circ$E; for the box shown in (a)) from the observation (black curve) and the CR (red curve). Note that the southern half of the Sahel receives its largest share of rainfall during the summer months of July, August, and September (JAS) as seen in (c). The observed interannual (black curve) and 10–year average (red and blue shades) timeseries of rainfall over the southern Sahel during peak months (JAS) is presented in (d). (e) shows the timeseries of interannual and decadal rainfall variability in the CR run including the ocean points (10$^\circ$N–15$^\circ$N, 40$^\circ$W–15$^\circ$E) for JAS months (for the box shown in (b)).

since 2000. Though the simulated interannual variability of rainfall is comparable to the observation (~0.2 mm day$^{-1}$), the decadal variance is relatively weaker (figures 2(d) and (e)). A similar analysis was performed for the CR simulation by selecting the same box over the southern Sahel region as in observation (Supplementary figures 2(a) and (b)). Though there exist large differences in interannual rainfall, the decadal rainfall variability in the CR run over the land region (blue box in figure 2(a)) and the region that includes the ocean rainfall (blue box in figure 2(b)) exhibits a striking similarity (Supplementary figures 2(a) and (b)). This suggests that the source of multi–decadal rainfall variability over the demarcated land and ocean region is of the same origin (Supplementary figures 2(a) and (b)). Keeping this in mind, we explore the impact of runoff on AMV and summer ITCZ using CESM1.0 CR run and sensitivity experiments by shutting off (0AMZ) and doubling (2AMZ) the Amazon runoff. The model simulations were carried out for 200 years and the results from the last 100 years are used for our analysis (for more details on model configuration and experiments see Supplementary section 1).

This model study on the climatic impacts of Amazon runoff have the following limitations. The sensitivity experiments were conducted by shutting down or doubling the Amazon discharge, which is not realistic. In reality, the natural variability in runoff is relatively small and, therefore, a complete shutdown of freshwater would result in pile up of water over the land, submerging a huge area and affecting the local hydrology and ecosystem. These feedbacks in the real world will not be captured in our study as it is an idealized experiment that does not account for the water that is stopped from reaching the ocean. Further, the simulated longterm impacts of shutting off/doubling of Amazon runoff cannot be segregated from the observation since the observed runoff does not show a consistent increase/reduction in longer timescales [22]. Moreover, the observed AMOC record from the Rapid Climate Change–Meridional Overturning Circulation and Heatflux Array (RAPID/MOCHA) covers only the last 2 decades; which is insufficient to analyze the longterm impacts.

3. Oceanic response to Amazon runoff

The summer–time (JAS) response of sea surface salinity (SSS) to the blocking of Amazon runoff into the ocean (0AMZ) is shown in figure 3(a). The difference (0AMZ–CR) in JAS surface salinity for the 100–200 year period (figure 3(a)) shows that the effect of runoff can be found even thousands of kilometers far away from the river mouth [23, 24]. In the absence of Amazon discharge (0AMZ), the North
Atlantic turns saltier (figure 3(a)) and the salinity anomalies from the river mouth (~2 psu) reach the northern extratropics via strong and prevailing northward boundary currents [23–25]. The western boundary currents carry anomalous SSS from the Amazon mouth along the coast (till ~40°N) and then directed to the open ocean by the offshore currents (Supplementary figure 3). However, there exists a huge interannual variability in the northward advection of the positive SSS in the 0AMZ (Supplementary figures 3(b) and (c)). The Amazon runoff–induced changes in air–sea interaction also contributes to the SSS anomalies in the 0AMZ (positive P minus E leads to freshening in Supplementary figures 3(b) and (c)).

The direct impact of runoff on SSS (positive difference) is negligible to the south of the equator, highlighting the predominant role of northward surface currents in the salinity distribution in the Atlantic Ocean. An increase in SSS in the northern Atlantic Ocean has a significant effect on the mixed layer depth (MLD) and the deepwater formation, especially during northern winter (December to January; DJF) as the exchange of heat fluxes between atmosphere and ocean is strongest during that period of time.

The runoff–induced changes in MLD in the northern extratropics are not significant in the summer months and therefore not shown. During DJF, the mean MLD in the 0AMZ deepens over the extratropical North Atlantic, north of 40°N. A significant increase in MLD (by more than 20 m) in the extratropics (over the deepwater formation sites including the Labrador Sea region) in the DJF months is considered as a fingerprint of enhanced deepwater formation and intensification of AMOC (briefly explained in [23]). Earlier studies on Amazon runoff proposed that a significant change in tropical freshwater input can influence the AMOC [23, 25] through salinity-induced changes in the rate of deepwater formation. Consistent with an increase in SSS and deepening of MLD in the extratropics, the AMOC strengthens in the absence of Amazon runoff (maximum increase of ~5% at around 2000 m along 30°N; figure 3(e)). Though the magnitude of increase in AMOC in the 0AMZ in figure 3(e) is weak compared to the mean AMOC strength of the CR (figure 3(d)), the upper ocean temperature response to this change in circulation is significant. One of the robust responses to an intensification of AMOC is the development of meridional SST dipole with cooling to the south and warming to the north of the thermal equator [35, 36]. Consistent with the earlier studies (e.g. [37]), a reinforced AMOC (in the absence of Amazon input) warms the upper ocean (top 50 m) of the North Atlantic and cools the southern part (by ~0.3° C) via changes in meridional heat transport and enhanced upwelling in the southern latitudes (figure 3(c); for more details see [23]). On the other hand, when the runoff from the Amazon is doubled, we get a contrasting response, with fresher and cooler North Atlantic and a suppressed deepwater formation and AMOC (Supplementary figure 4).
In the absence of Amazon runoff, a tripole pattern of temperature anomaly emerges in the North Atlantic with a cool anomaly centered around 40° N and 2 warm anomalies surrounding it to the north (centered around 55° N) and south (15° N), respectively (figure 3(c)). This tripole pattern off SST difference in the 0AMZ over the North Atlantic Ocean resembles the SST anomaly induced by a negative NAO. In an earlier study, we have found that the absence of Amazon runoff leads to a negative NAO–like atmospheric response over the North Atlantic sector during winter [23]. Typically, the AMV is characterized by a basin-wide warming/cooling of the North Atlantic Ocean. In our study, the monopolar SST pattern in the North Atlantic Ocean associated with AMV is embedded with the tripolar SST associated with NAO. However, we find that the rainfall and SST changes in the tropical Atlantic are coherent with the phase of AMV rather than NAO. Further, the effects of NAO are limited to the extratropical Atlantic Ocean, and thus the changes in the tropical Atlantic sector are driven by the positive AMV–like SST pattern. Therefore, in the rest of the study, we analyse the response of rainfall over the tropical Atlantic Ocean in relation to the AMV–like SST pattern.

During the JAS season, the atmospheric feedback on the SST is relatively weak (Supplementary figure 5). We also find that the equatorial cold–tongue in the top 50 m of the upper ocean, stretching off the coast of the Gulf of Guinea, intensifies (0.35°C cooling along the coast), generating a meridional dipole in SST (figure 3(c)). Several studies have focussed on the inverse relationship between AMOC and meridional SST dipole (for e.g. [36, 38, 39]) and suggested that this can be used as a fingerprint of AMOC strength. The enhancement of the cold tongue in the equatorial Atlantic (in figure 3(c)) further confirms the intensification of AMOC in the absence of runoff. On the other hand, when the Amazon runoff is doubled, the anomaly over the cold tongue becomes warmer and the meridional dipole reverses its sign (Supplementary figure 4(c)). Earlier studies suggest that the occurrence of meridional see–saw in SST anomaly over the tropical Atlantic Ocean is largely driven by the wind–evaporation–SST (WES) feedback in the tropical Atlantic Ocean [10]. However,
in the absence of Amazon river input, the contribution of atmospheric feedback to the cooling in the southern tropical Atlantic Ocean in the 0AMZ is not significant (Supplementary figures 5(a) and (b)). From figure 3(c) and Supplementary figure 4(c)), it is evident that the upper 50 m of the tropical North Atlantic Ocean turns warmer (cooler) in the absence (doubling) of Amazon runoff. How does this runoff–induced temperature change in the Atlantic Ocean affect the summer–time ITCZ?

The AMV index used in the study is calculated as the area–average upper ocean (top 50 m) temperature in the North Atlantic Ocean over region 0°–60° N, 70° W–10° W. Most of the earlier studies opted basin–wide SST instead of top 50 m [37, 40, 41]. However, we find that the simulated multidecadal variability of rainfall in the CR and sensitivity (0AMZ and 2AMZ) is better correlated with mean temperature in the upper 50 m than the SST. The upper–ocean temperature shows mean warming in the North Atlantic without Amazon runoff, favoring a positive phase of AMV (figure 3(c)) whereas, with a doubling of Amazon runoff, the mean SST shows a cooling to the north (Supplementary figure 4(c)). But, the typical SST pattern associated with a positive AMV is a basin–wide warming in the North Atlantic and cooling to the south [10]. The tripolar SST pattern (figure 3(c)) found in the North Atlantic Ocean is suggested to be induced by a negative NAO at interannual timescales [42] as proposed by [23]. During a negative phase of NAO, the winds over the extratropical North Atlantic Ocean turn weaker and thereby reduces the rate of deepwater formation [23]. Thus the atmospheric response to the suppression of Amazon runoff tends to weaken the AMOC. But, we find that the AMOC turns stronger in the absence of runoff, underlining the dominance of oceanic processes. The strengthening of AMOC, despite a negative NAO, signifies the importance of oceanic processes in the low–frequency variability of the Atlantic Ocean. Further, we find that the rainfall response in the tropical Atlantic is closely associated with the AMV rather than NAO (a detailed analysis of the relative roles of NAO and AMV on the Atlantic ITCZ is beyond the scope of this study). The effect of wind–evaporation–SST (WES) feedback on the meridional see–saw of SST in the tropical Atlantic Ocean is negligible during summer (Supplementary figures 5(a) and (b)). In Supplementary figure 5(b) we find that the cooling of SST in 0AMZ (black curve) leads to reduced evaporation in the southern tropical Atlantic Ocean, suggesting the role of oceanic processes on tropical Atlantic ocean on longer timescales. Therefore, we propose that the Amazon runoff–induced strengthening of AMOC (largely driven by oceanic advective processes) and the resultant AMV plays a major role in the cooling of the southern tropical Atlantic Ocean.

The JAS rainfall in 0AMZ shows a mean increase (shades of red) in the region enclosed by the box in figure 4(a) (maximum increase of 0.63 mm day$^{-1}$ over the ocean). In contrast, the mean rainfall in 2AMZ reduces over the North Atlantic Ocean (-0.47 mm day$^{-1}$) and the Sahel region with peak reduction of -0.95 mm day$^{-1}$ over the ocean (figure 4(b)). To the south of southern Sahel, the rainfall response reverses with suppressed rainfall in 0AMZ and enhanced rainfall in 2AMZ (figures 4(a) and (b)). As seen in figure 2(b), the northern zonal band of high decadal variance has a contrasting response to the changes in the southern band. This is due to the AMV–induced excursion of Atlantic ITCZ between the northern and the southern band on a multi–decadal timescale. The surface wind difference also shows convergence towards the high rainfall band (vectors in figures 4(a) and (b)). Consistent with the earlier studies, our simulations show that anomalous warming (cooling) over the tropical North Atlantic Ocean lowers (increases) the surface pressure leading to a weakening (strengthening) of low–level trade winds and northward (southward) displacement of summer ITCZ [43, 44]. When the AMV is positive, the ITCZ prefers to migrate to the northern band (towards underlying warmer water) bringing heavy rainfall whereas the rainfall over the southern band diminishes. However, except over the western coastal regions, the runoff–induced changes in simulated land rainfall (figures 4(a) and (b)) is not significant (significant regions are demarcated by black dots).

Timeseries of decadally smoothed difference in AMV (black curve) and mean JAS rainfall (bar chart) over the region delineated in figure 2 are shown for 0AMZ (figure 4(c)) and 2AMZ (figure 4(d)) for the last hundred years. Evidently, the 100–200 years of JAS rainfall in 0AMZ enhances in the northern band associated with a basin–wide warming in the north Atlantic (positive AMV). Though there are few years with negative rainfall years averaged over the box (8 years with a reduction of more than -0.25 mm day$^{-1}$), the low–frequency positive rainfall episodes are stronger in both magnitude and duration (34 years with > 0.25 mm day$^{-1}$ rainfall; figure 4(c)). Similarly, episodes of low rainfall dominated over the box enclosed in the 2AMZ case with only 7 positive events and 93 negative events (figure 4(e)) in conjunction with negative AMV. In summary, the runoff–induced strengthening (weakening) of AMV reinforces the rainfall in the northern (southern) zonal band of high decadal variance and diminishes (strengthens) to the south (north) when Amazon runoff is intercepted (doubled). The response in rainfall for the individual months of June, July, and August in 0AMZ and 2AMZ also show similar meridional shifts in the ITCZ position (Supplementary figures 6(a)–(f)). However, the response to doubling of Amazon is not exactly opposite to that of Amazon
shut down since the interactions in the climate system are highly non-linear. But, we find that the large-scale features associated with AMV and Atlantic ITCZ show opposite signals with and without Amazon runoff, adding robustness to the conclusions drawn in this study.

4. Summary and conclusions

We have shown that the multidecadal variability of rainfall over the North Atlantic Ocean and West Africa is influenced by the freshwater input from the Amazon. The strength of multidecadal variability in SST (AMV) controls the low–frequency climate in both the tropics and extratropics including the large-scale atmospheric circulation and rainfall pattern. The atmosphere responds to the fluctuations in AMV by an apparent north–south shift in the mean position of the ITCZ. A comprehensive understanding of the factors affecting AMV is essential for the long-term prediction of ITCZ in the Atlantic sector since its latitudinal position is modulated by the AMV–driven SST anomalies [16, 45]. Our results reveal that freshwater input into the tropical ocean is one of the factors that affect the AMV. The resultant change in rainfall signifies the vital role of Amazon discharge in modulating the mean position and intensity of the Atlantic ITCZ on multidecadal timescales.

Two sensitivity experiments were conducted using the CESM model to study the climatic role of Amazon runoff by intercepting and doubling the Amazon discharge into the equatorial Atlantic Ocean. When the Amazon runoff is suppressed, the upper ocean responds by an increase in SSS and a strengthening of the oceanic meridional circulation, carrying warmer South Atlantic water to the north. The AMOC and AMV strengthen in the absence of Amazon runoff. As a result, the North Atlantic switches into a warmer–than–normal phase, favoring a positive AMV in the absence of runoff. The region of highest rainfall response lies exactly over the region where the multidecadal variability is sensitive to the phase of AMV. Thus the Amazon runoff affects the multidecadal Atlantic ITCZ through its influence on basin–wide temperature. In an alternate experiment, when the runoff from Amazon is doubled, the SST and rainfall response is opposite to the shutdown experiment. The 100–200 year difference in simulated rainfall in each of the summer months (July, August, and September) signifies the sensitivity of Atlantic ITCZ to the runoff–induced variability in the underlying SST pattern (Supplementary figure 6). This suggests that a long-term significant variation in Amazon runoff would affect the regional hydrological cycle over the West African nations as seen in Supplementary figure 7.

The factors affecting the long-term variability of climate are of utmost importance for the regional hydrology of the North Atlantic Ocean and the adjacent landmasses including West Africa whose economy thrives on agriculture and related industries [46]. The West African region between 10° N and 20° N (comprising the Sahel) is one of the most vulnerable regions since its economy and agriculture largely relies on the rainfed water during summer months [47]. Therefore, prolonged changes in rainfall over the West African nations can significantly impact freshwater availability and agriculture. As seen in Supplementary figure 7(b), the inland river flow is significantly affected by the changes in rainfall over the catchment area. Though the conclusions reached are based on idealized freshwater modification experiments and the forcing is exaggerated compared to the natural variability, we attempt to explain the role of Amazon runoff on the multidecadal variability of SST and the overlying ITCZ. The experiments should be considered like numerous other freshwater hostings studies wherein an unrealistically huge freshwater is added or removed from the ocean, to assess the response of AMOC and its climatic implications. Furthermore, carrying out century–long simulations by increasing and decreasing Amazon runoff (based on observed variability) is computationally expensive. The results presented here signifies the importance of incorporating river runoff in model simulations for a better representation of salinity, temperature, and rainfall. The results show that Amazon runoff has a vital role in the dynamics, thermodynamics, and freshwater cycle of the tropical Atlantic Ocean and West Africa.

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Data availability statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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