Reviewer#2:

The authors seek to explain the anomalously strong 2019 West Central African October rains through a moisture and MSE budget analysis. They find that anomalous meridional transport and anomalous moisture / wet enthalpy export (possibly driven by the combination of a strong Saharan Heat Low and high Atlantic SSTs?) contributed to extreme rainfall in the region.

Overall, this is an important question to study and the authors do a decent job explaining the complex factors making the 2019 rainy season so strong. I have some remaining questions, primarily around the underlying reasons for the anomalies discussed here, in addition to some extra suggested analysis. Contingent on those changes, I recommend publication after Major Revisions.

Major questions

 # SSTs and the Saharan Heat Low

The authors occasionally bring up the role of anomalously high SSTs in the Atlantic Ocean, but that argument could be developed further, especially since it may be linked to the anomalous onshore moisture transport mentioned in the study. Perhaps a figure showing anomalous SSTs (maybe as part of the summary figure I suggest below) could help as well.

The same goes for the Saharan Heat Low, which is mentioned a few times as a driver of the anomalous meridional circulation, but not shown or explained further. It seems like the authors are arguing that these two factors may be the underlying drivers of the anomalies shown in the paper (if I understood correctly!) and it would be great to be more explicit about this, explain the argument better, and show them in a diagnostic figure as well.

<u>Answer:</u> We understand the reviewer's concern. First of all, previous work has shown the influence of Atlantic Sea Surface Temperatures (SSTs) and the Sahara Thermal Low on extreme precipitation in October 2019. For instance, in Figures 1 below on SST anomalies, the reviewer can see that there have been positive SST anomalies along the Atlantic coast. This increase led to moisture transport from the ocean to the continent. In addition, Figure 2 below shows that there was an anomalous meridional mean sea level pressure (MSLP) gradient over the Central African Sahel with low pressure over the eastern Sahara and high pressure between 10 and 15°N. This has been developed in the document, for example in the analysis of the moisture balance. the new text will read as follows:

"However, changes in the thermodynamic effect, although not the key factor responsible for the October 2019 events, contributed up to 35% of the total effect (the sum of dynamic and thermodynamic contributions) on the northern part and 15% on the southern part of the domain. This could be since the increase in diabatic heating contributes to the change in the thermal state of the atmosphere, i.e. the increase in thermodynamic effects (changes in humidity). In fact, Nicholson et al. (2022) reported that the increase in SST in the tropical Atlantic strengthened the advection of moist air from the Atlantic towards the region, with an increase in the moisture flux from the west to southwest". **Also in the analysis of the moist static energy budget, the new text will read as follows:** "Given the influence of the wind anomaly components on the displacement of dry enthalpy and latent heat, a further decomposition of the $-\langle V'\cdot\nabla_h c_p\bar{T}\rangle$ and $-\langle V'\cdot\nabla_h l_V\bar{q}\rangle$ terms along the zonal (Figs. 11b,e) and meridional (Figs. 11c,f) directions appear necessary. Figure 11a shows that the advection of dry enthalpy induced by the horizontal wind anomaly decreased over the area-averaged, with the highest values between 6°N and 14°N. The advection of dry enthalpy by the meridional wind anomaly (Fig. 11c) is particularly responsible for the decrease in the $-\langle V'\cdot\nabla_h c_p\bar{T}\rangle$ term compared with the advection of dry enthalpy induced by the zonal wind anomaly (Fig. 11b), which is weak. For the transport of latent heat (Fig. 11d), the influence of the advection of $-\langle V'\cdot\nabla_h l_V\bar{q}\rangle$ term under the effect of the anomalous meridional circulation is the main term responsible for the supply of moist air to the northern part of the area, while the low contribution to the south is associated with a low input of moist air from the zonal wind anomaly (Fig. 11f). Analysis of the advection of dry enthalpy and latent heat by anomalous winds shows that the meridional wind anomaly had a significant impact compared with the zonal wind anomaly. In addition, the advection of the dynamic term associated with latent heat contributed significantly to the supply of MSE to West Central Africa compared to the advection of the dynamic term associated with dry enthalpy. A possible reason could be that, in addition to the warm Atlantic SSTs, there was also an anomalous meridional mean sea level pressure (MSLP) gradient in the Central African Sahel between a lower MSLP over the eastern Sahara and a higher pressure between 10 and 15°N. In addition, the trans-equatorial meridional wind fluctuated with the activity of the African easterly waves over the Gulf of Guinea (Nicholson et al. 2022)" .

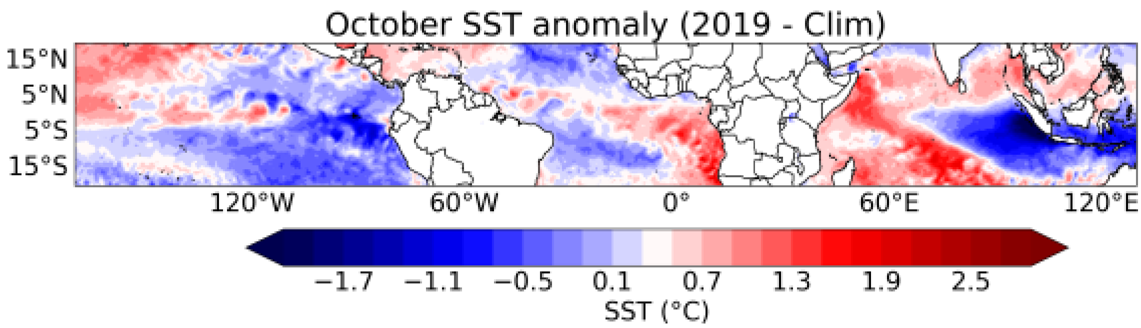

Fig. 1. SST anomalies during October 2019 vs long-term mean (1987-2017).

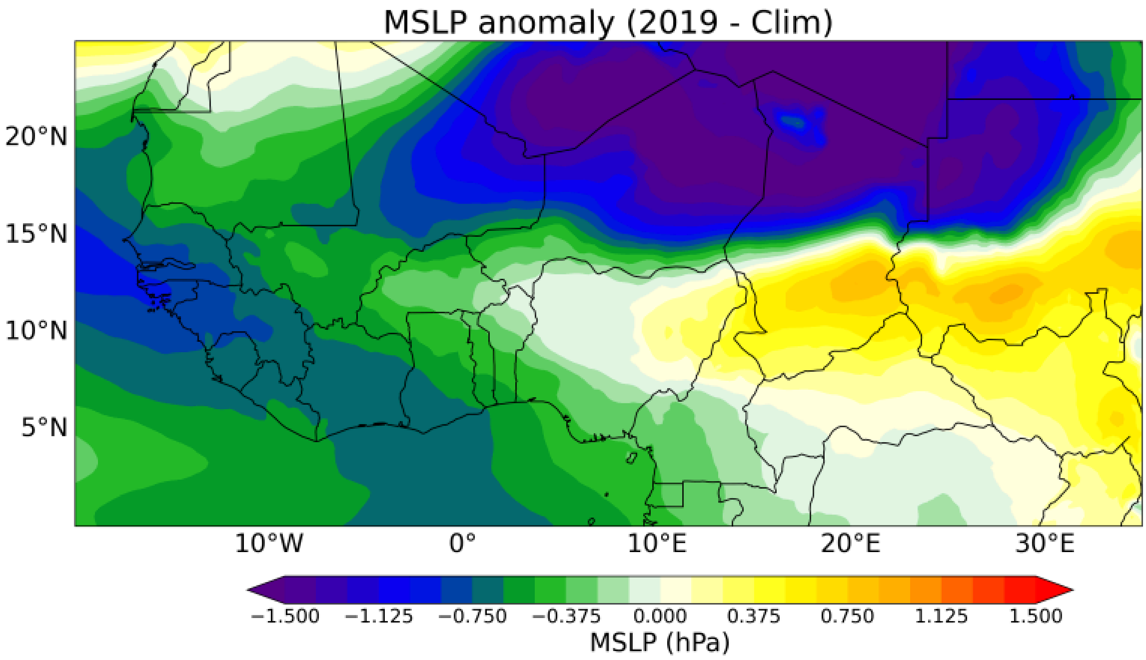

Fig. 2. Mean sea-level pressure anomalies (MLSP) during October 2019 vs long-term mean (1987-2017).

 # Role of large-scale circulation

The paper could benefit from placing the anomalous circulation / thermodynamics in the context of larger-scale circulation effects happening. 2019 was an El Niño year, are these results typical of El Niño states? (or other major oscillations that affect west central Africa).

<u>Answer:</u> Thanks to the reviewer's suggestion. First of all, research by Lutz et al. (2013) established the link between Atlantic SST anomalies and the Niño. Furthermore, Vallès-Casanova et al (2020) showed that 2019 was particularly impacted by an intense Atlantic Niño with SST anomalies along the east coast of the equatorial Atlantic. This therefore establishes the link between dynamical/thermodynamical processes and the large-scale circulation. There was also an active MJO over Africa (Wainwright et al., 2020), but Nicholson et al. (2022) showed that the normalized amplitude of the local MJO was less than one during the wet phase in October. The new text will read as follows: "The results of this study show that moisture advection induced by horizontal wind anomalies and vertical moisture advection induced by vertical velocity anomaly were crucial mechanisms in the anomalous October 2019 exceptional rainfall increase over West Central Africa. In addition, changes in the MSE budget, mainly through the meridional circulation (dynamic effect), and latent heat (thermodynamic effect) also played an important role in the northern part of the area, while the increase in the energy balance contributed considerably to the change in the MSE balance in the southern part of the area. However, there was little contribution from dry enthalpy. These results are consistent with those of Nicholson et al (2022) who showed that the increase in equatorial Atlantic SSTs associated with the late retreat of the West African monsoon played an important role in precipitation anomalies in the Sahel. Changes in SSTs along the east coast of the equatorial Atlantic display a similar pattern to the Atlantic Niño as described by Lutz et al. (2013). Furthermore, Vallès-Casanova et al. (2020) also highlighted the fact that 2019 was characterized by a particularly intense Atlantic Niño, which lasted until October, placing the dynamic and thermodynamic processes in the context of the large-scale circulation. The importance of the dynamic contribution during extreme precipitation events has been reported in other regions, notably over southern China (Wen et al. 2022; Sheng et al. 2023). This calls for comprehensive evaluations of both dynamic and thermodynamic contributions, and their possible feedback, to assess the potential impact of climate change on extreme precipitation events in this region".

 # Robustness checks with another reanalysis product

Given the data sparsity over much of equatorial Africa, reanalysis products tend to struggle with aspects of the regional circulation. More generally, they often struggle to close moisture budgets (which may be part of the reason the residual is so high in the budget calculations?). It would be good to see a robustness check of the primary results with another reanalysis product (Hua et al. 2019 suggest MERRA-2, for example).

<u>Answer:</u> We thank the reviewer for pointing this out. It is true that the scarcity of measurement data presents a real problem in the analysis of the moisture budget in equatorial Africa. We used the MERRA-2 reanalysis products to check the robustness of the primary results. For this purpose, we included the interannual precipitation anomalies from MERRA-2 (see Figure 1 below). We note that, despite a few differences, the ERA5 and MERRA2 reanalysis products show similar evolutions and are in agreement on the October 2019 precipitation peak. We have also represented the October 2019 moisture budget with MERRA-2 (see Figure 2 below). The same dominant effects can be observed in both reanalysis products, despite some differences in terms of intensity. The two moisture budgets show that the products of the two reanalyses are in agreement and close similarly the moisture budget during the exceptional event of October 2019 in West Central Africa. However, in the context of our study, we opted for ERA5 and the primary results obtained

by MERRA2 will be added in supplementary material. Secondly, recent work by Cook and Vizy (2021) (https://doi.org/10.1007/s00382-021-06066-3) has shown that the ERA5 reanalysis products are suitable for analyzing the hydrodynamics of regional and seasonal rainfall variations in the Congo Basin. In addition, Kenfack et al. (2024) (DOI: 10.1002/joc.8410) analyzed the moisture budget and its implication for rainfall decline during the rainy season in the Congo Basin inferred from ERA-5 reanalysis.

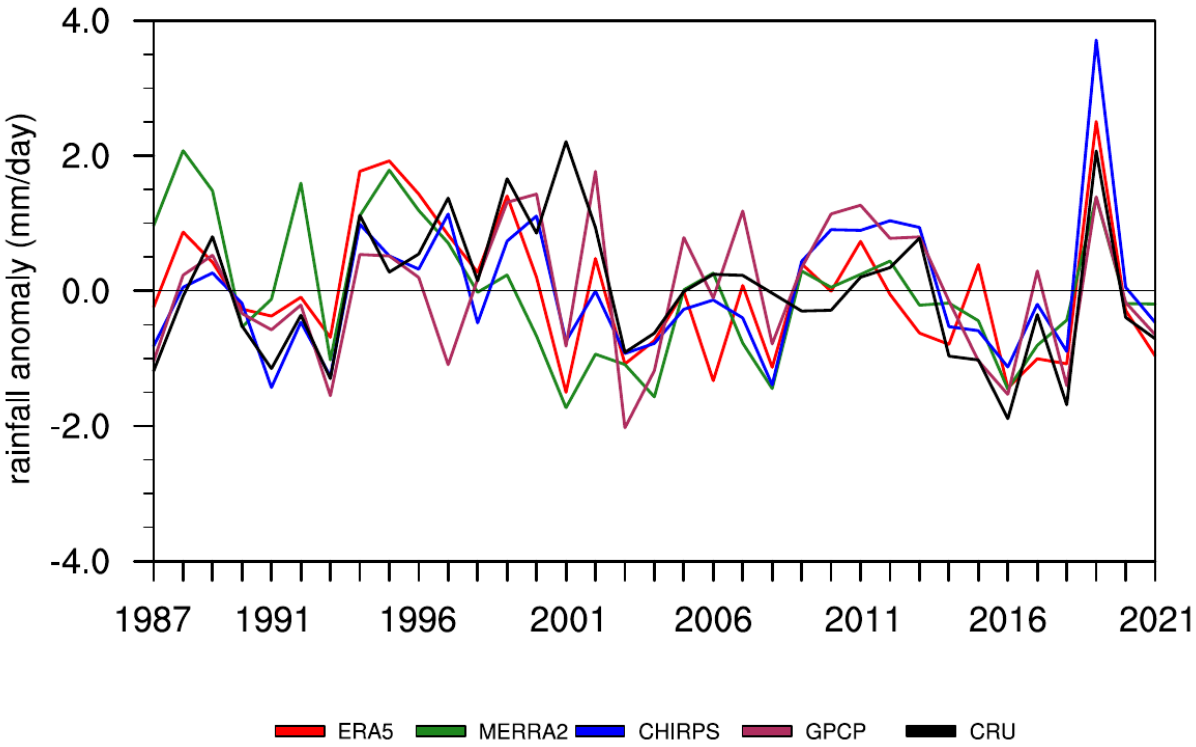

Fig 1. Temporal evolution of October rainfall anomaly over West Central Africa (6°N-14°N, 6°-20°E), from reanalysis data ERA5 (red), MERRA2 (forestgreen), and from observational data CHIRPS (blue), GPCP (maroon) and CRU (black), covering the period 1987–2021.

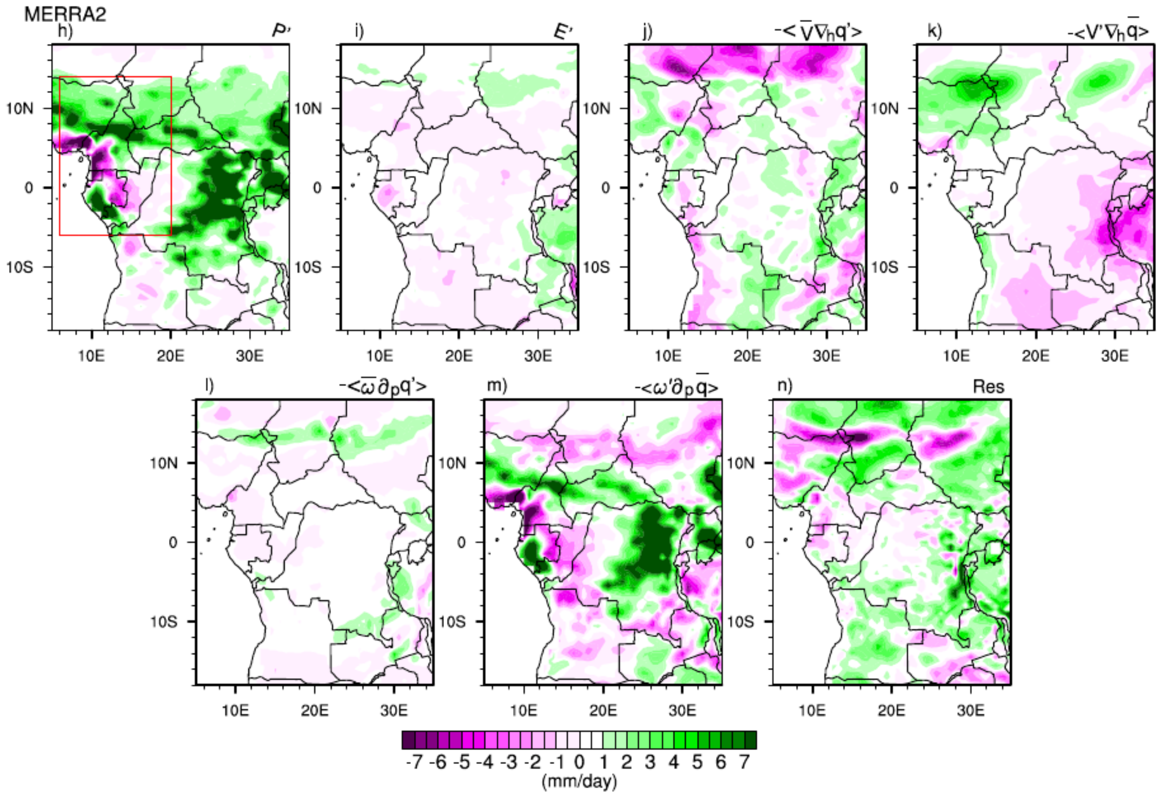

Fig. 2. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa. (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture by anomalous wind, (e) vertical advection of anomalous moisture by climatological vertical velocity, (f) vertical advection of climatological moisture by anomalous vertical velocity and (g) the residual term.

 # The large residual

I would appreciate a more in-depth discussion of the residual, which is the largest single term on the right side of the P-E balance equation. Could it be partially caused by poor moisture budget closure in reanalysis products? Given how large it is – the authors suspect possible influence of the MJO – would rainfall have been substantially lower (or higher, since it seems to counteract precipitation in the balance) if the MJO were in a different phase?

<u>Answer:</u> We thank the reviewer for pointing this out. First of all, the moisture budget averages were analyzed separately for the northern (6°N-14°N, 6°-20°E) and southern (6°S-5°N, 6°-20°E) parts of the domain. In addition, the spatial representation of the residual term has been added (see figure 7 below). The results show that the residual term

is high in the northern part of the domain, precisely between 12°N and 14°N, while it is small throughout the rest of the domain. Nicholson et al. (2022) mentioned the fact that the local normalised amplitude of the MJO was less than one in October 2019. However, other reasons have been mentioned that could explain the size of the residual term between 12 and 14. The text has been reworked and the new text will read as follows: "Indeed, the northward shift and strengthening of the northern component of the East African Jet (AEJ-N) in October are verified (Nicholson et al. 2022). This is illustrated by the anomalous 700 hPa zonal wind in October 2019. In addition, the anomalous variance of the band-pass filtered 700 hPa meridional wind over 2-6 days is also visible, indicating African easterly wave activity (Reed et al., 1977). Other studies also point out that rainfall fluctuations in equatorial Africa are associated with Kelvin waves (Jackson et al., 2019)**".**

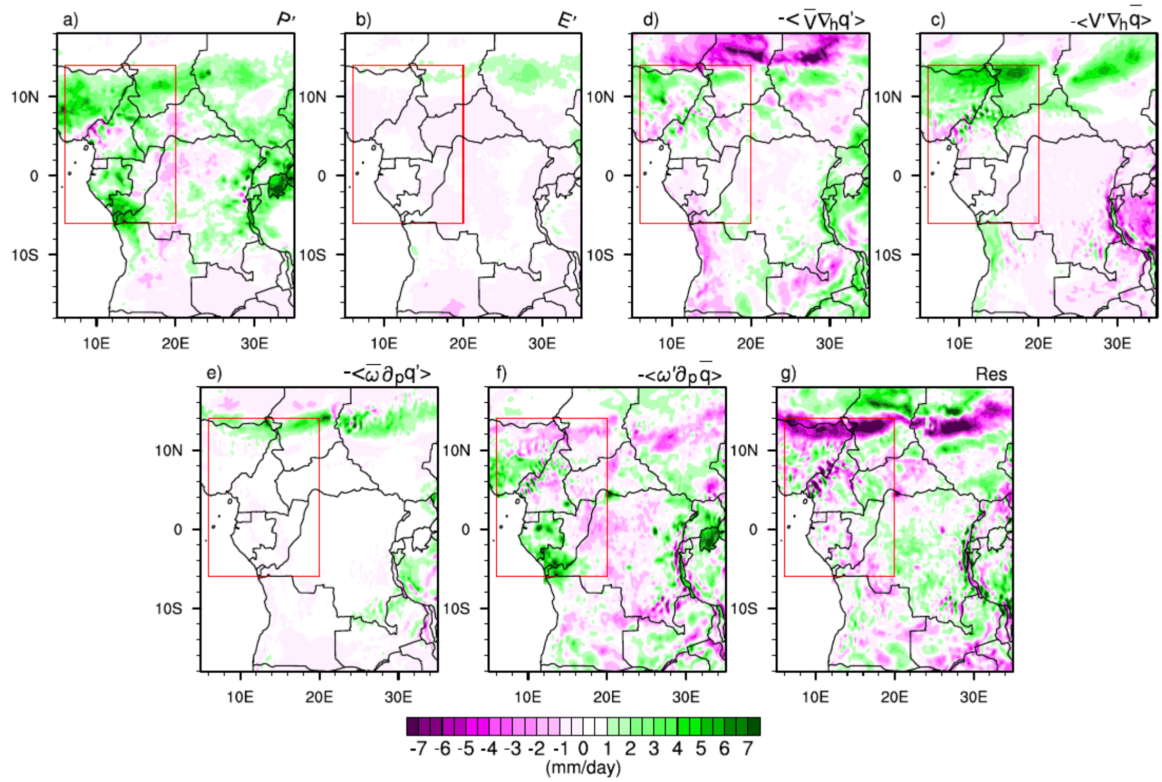

Fig. 7. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa. (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture by anomalous wind, (e) vertical advection of anomalous moisture by climatological vertical velocity, (f) vertical advection of climatological moisture by anomalous vertical velocity and (g) the residual term.

Figures

It would be very helpful to the reader if the authors could add a new Figure 1 that shows an overview of the study region, with the box over which values are averaged clearly marked. Perhaps the map could show (in addition to lat/lon, borders, and the study area) SST anomalies over ocean, rainfall anomalies over land, and moisture transport (or circulation) as arrows. This would neatly tie together some of the primary arguments of the study and make it easier to geographically place the results (I at least always find it hard to just go off latitude / longitude without a corresponding map).

<u>Answer:</u> Appreciation to the reviewer for the suggestion. We conducted further analyses and a new figure 1 (see below) is added to the manuscript. It shows the SST anomalies (Fig. 1a) and the precipitation anomalies (Fig. 1b). The vectors represent anomalies of vertically integrated atmospheric moisture flux. The red box indicates the Central West Africa area. The new text will read as follows: "The increase in SSTs in the eastern Atlantic (Fig. 1a) is identified as one of the causes of the positive precipitation anomalies over western central Africa in October 2019. The warming contrast between the ocean and the continent favoured the strengthening of the moisture advection associated with the precipitation anomalies over West Central Africa (Fig. 1b). This is in agreement with Nicholson et al. (2022)".

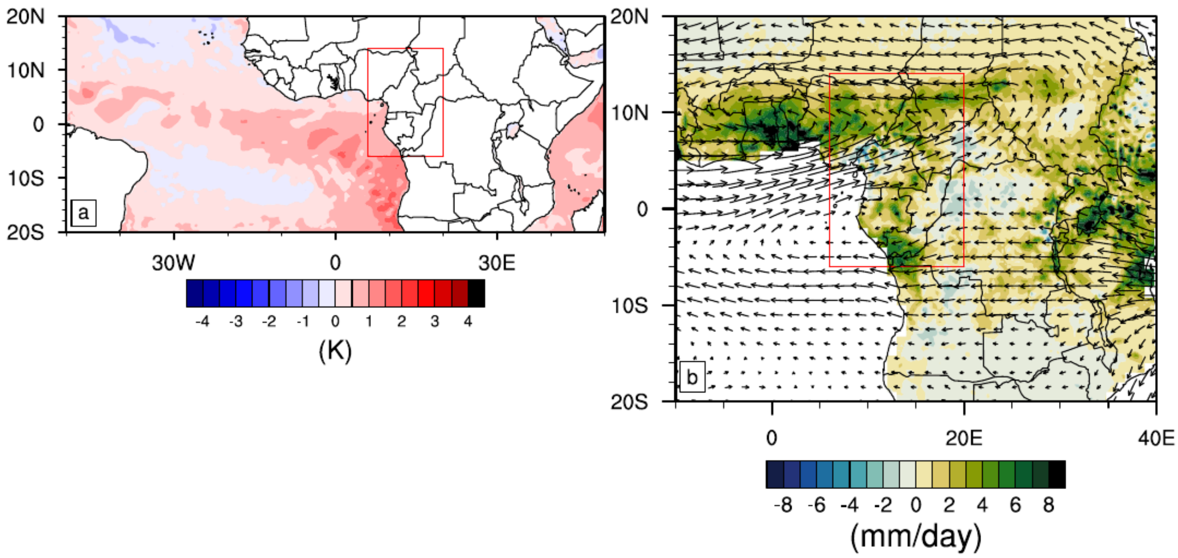

Fig 1. SST a) and rainfall b) anomalies during October 2019. The vectors represent anomalies of vertically integrated atmospheric moisture flux. The red box indicates the Central West Africa area.

In Figures 1 and 3, would it be possible to title the subplots? ("1988-2017 avg." and "2019 avg." for Figure 1 for example).

<u>Answer:</u> Done as suggested. The new title will read as follows: "Fig 2. Diabatic heating and divergent meridional circulation (vectors; ms^{-1}) during the SON season for a) 1988-2017 avg, b) 2019 avg and c) the anomaly, all averaged between the 6° and 20°E. As the vertical velocity is much weaker than the meridional wind, its values have been enhanced by a factor of 600 for the clarity of the graph." and "**Fig. 4**. Specific humidity and meridional wind (contours: m/s) in October for a) 1988-2017 avg, b) 2019 avg and c) the anomaly, averaged between 6°-20°E."

In Figure 5 and 8-10, could you specify that the box in panel a is the box over which values are averaged in the analysis? (and could you please replicate the box in every panel?)

<u>Answer:</u> Done as suggested. The new Figures 7 and 11-13 are as follows:

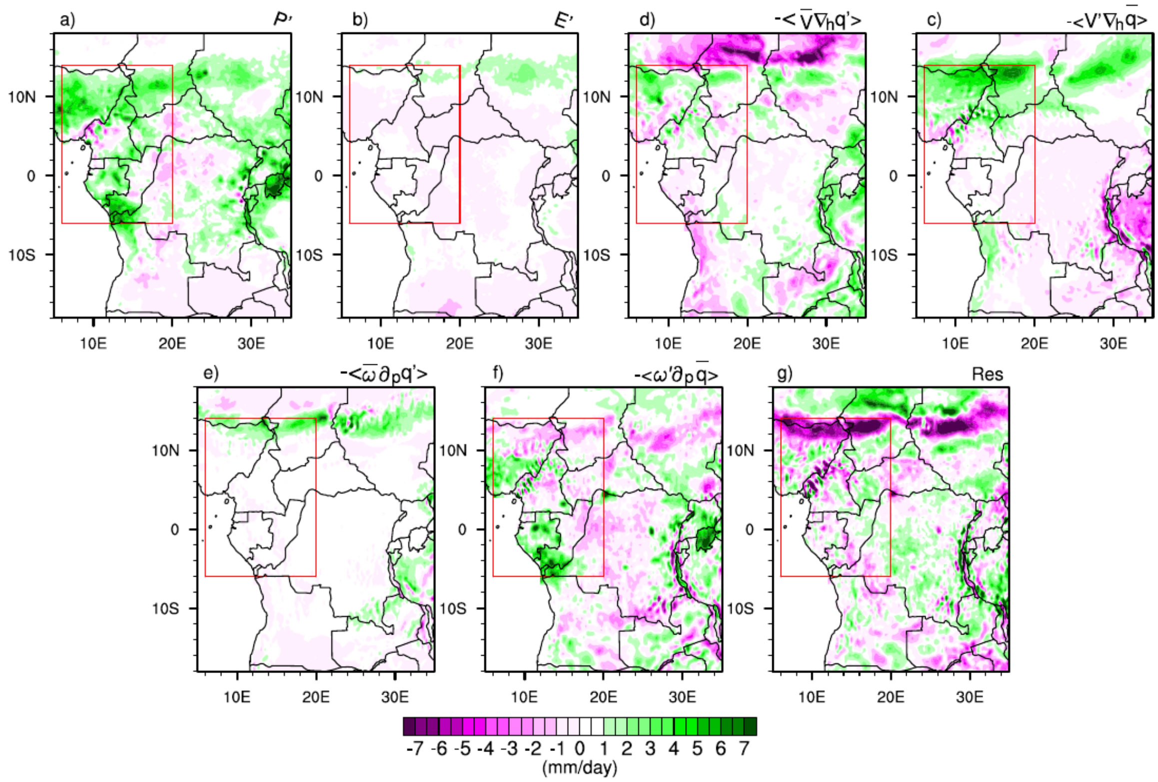

Fig. 7. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa (Red box). (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture by anomalous wind, (e) vertical advection of anomalous moisture by

climatological vertical velocity, (f) vertical advection of climatological moisture by anomalous vertical velocity and (g) the residual term.

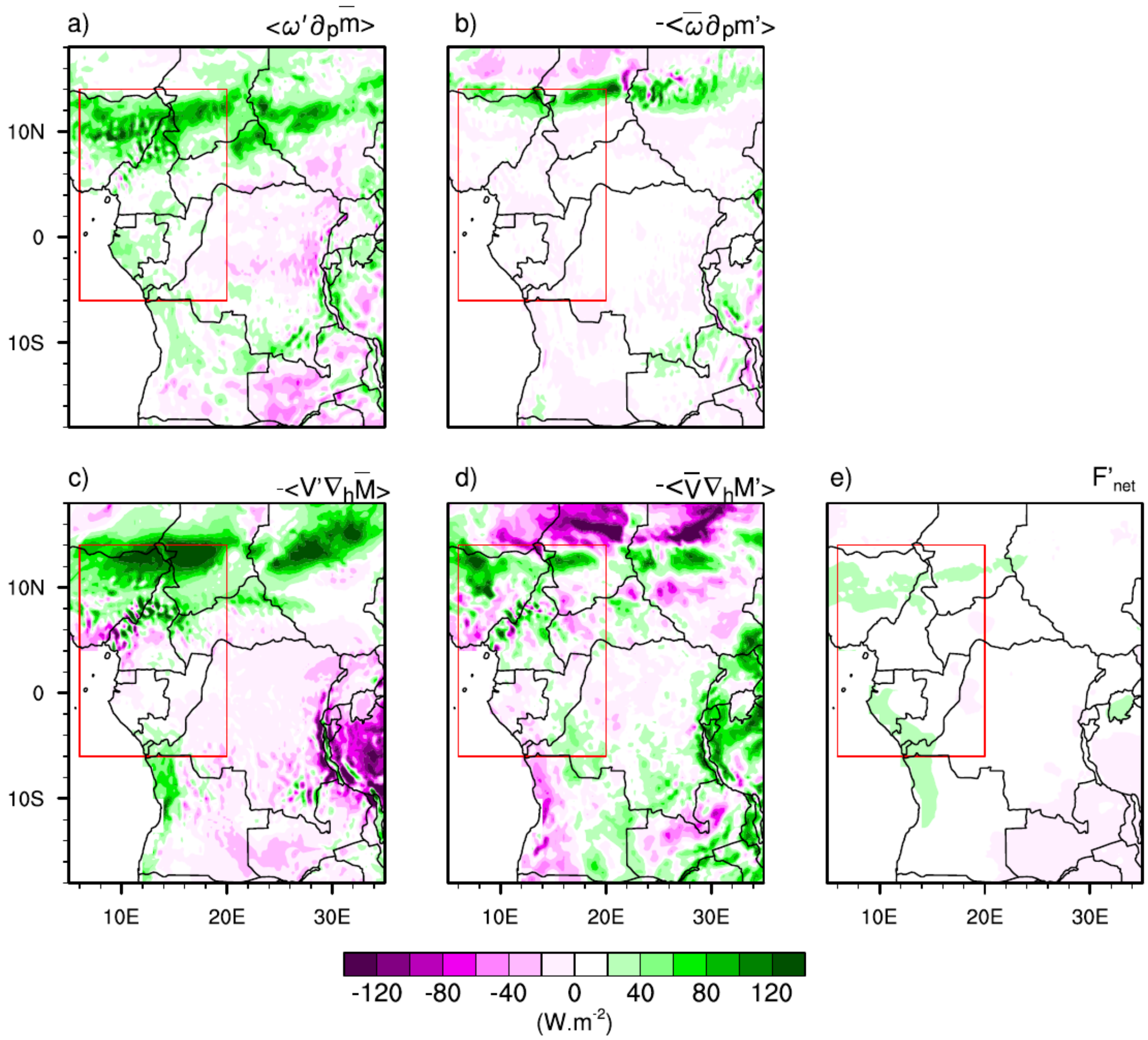

Fig. 11. Spatial distributions of each term of the Moist Static Energy (MSE) balance equation during October 2019 over West Equatorial Africa (Red box). (a) vertical advection of climatological MSE by anomalous vertical velocity, (b) vertical advection of anomalous MSE by climatological vertical velocity, (c) horizontal advection of anomalous moist enthalpy by climatological wind, (e) horizontal advection of climatological moist enthalpy by anomalous wind, and (f) net energy flux (at the surface and top of the atmosphere) in the atmospheric column.

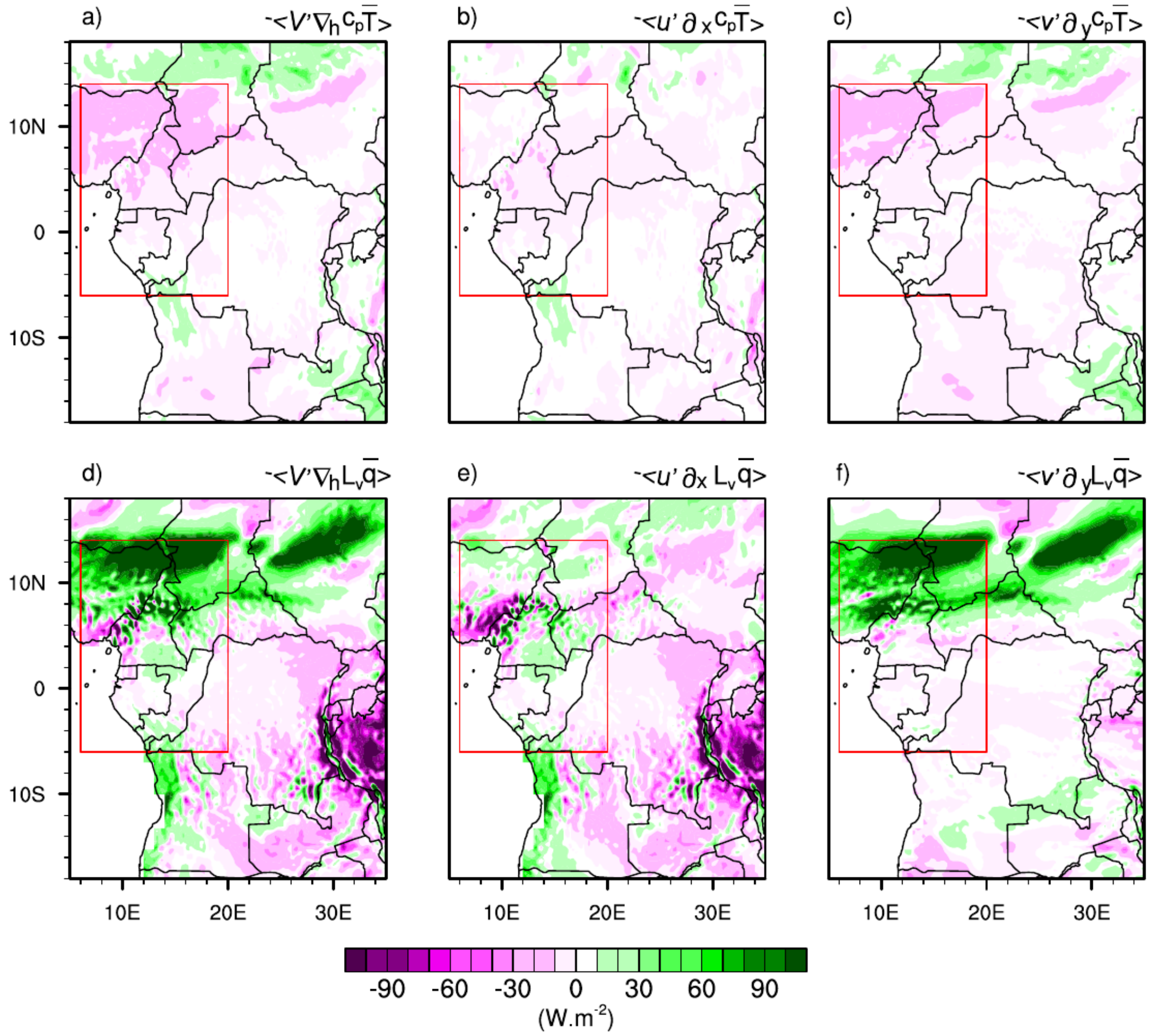

Fig. 12. Horizontal advection of (a–c) climatological dry enthalpy and (d–f) latent energy by anomalous wind, designated as a dynamic effect during October 2019 over West Central Africa (Red box). (a, d) Total advection, (b, e) zonal component, and (c, f) meridional component.

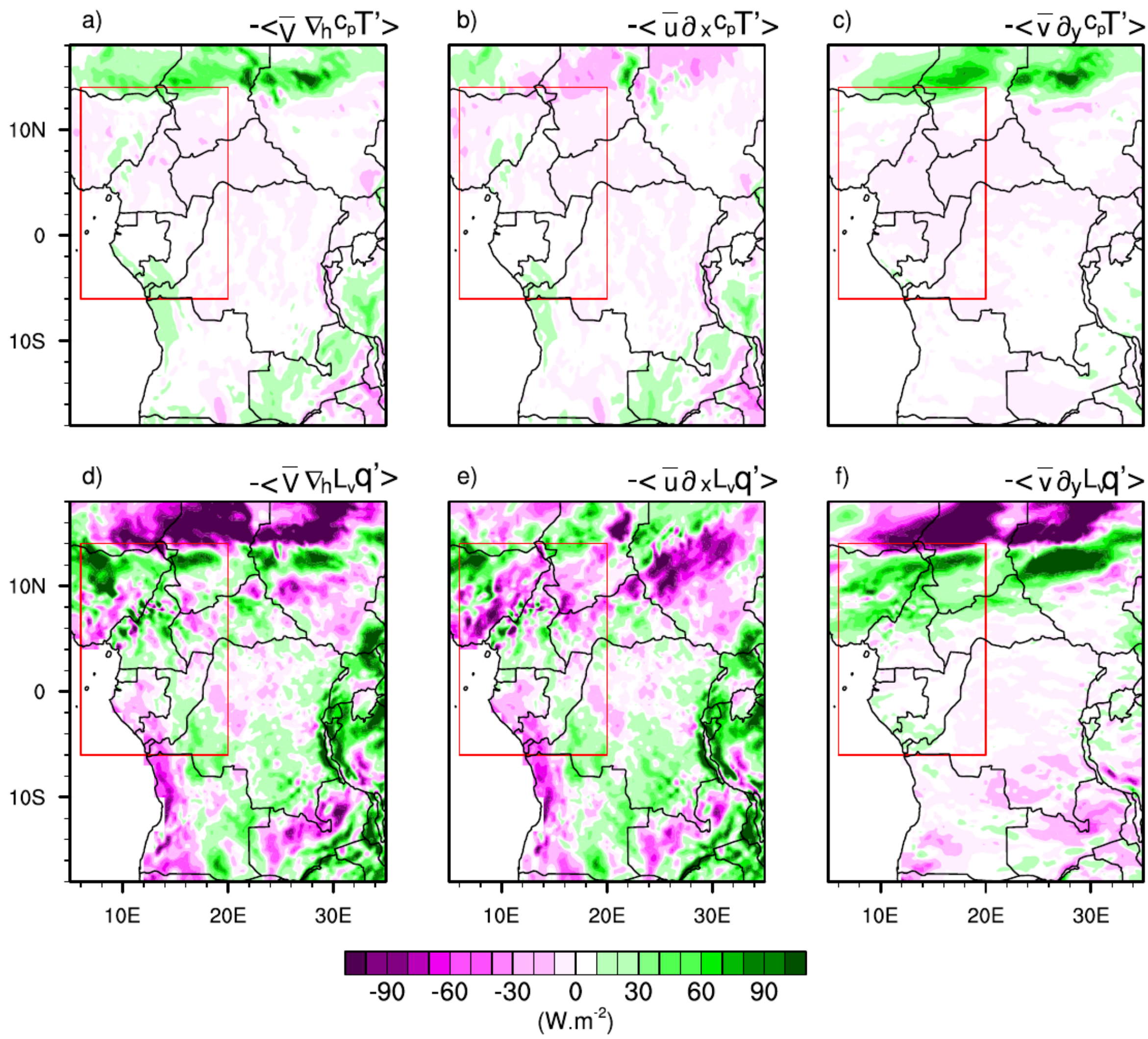

Fig. 13. As in Fig. 12, but for the thermodynamic effect (horizontal advection of anomalous dry enthalpy and latent energy by climatological wind) during October 2019 over West Central Africa (Red box).

Minor questions / points

Abstract: using « anomalies » instead of "variation" in the abstract when referring to the anomaly terms may be easier to understand.

__Answer:__ **We thank the reviewer's remark, we have reworded this in the revised manuscript. The new text will read as follows: "**The horizontal advection of the MSE induced by the anomalies of the wet enthalpy and the vertical advection of the MSE induced by the anomalies of the MSE seem less important (r= 0.29 and -0.19 to the north and -0.17 and 0.03 to the south respectively). The strong anomalies in the MSE balance in the north are linked to its meridional component, in particular the meridional wind anomalies in the dynamic effect and the meridional anomalies in latent heat in the thermodynamic effect."

L72: period missing

Answer: We thank the reviewer's remark. The period has been added and the new text will read as follows: "In particular, given that climate models predict an increasing trend in extreme rainfall in the region (Fotso-Nguemo et al. 2018, 2019; Sonkoué et al. 2018; Tamoffo et al. 2019, 2023) and that extreme precipitation in the region is associated with vegetation dynamics (Zhou et al. 2014; Mariotti et al. 2014; Marra et al. 2022; Garcin et al. 2018), it is crucial to understand the thermodynamic and dynamic mechanisms underlying these exceptional events of October 2019."

L75-76: I would guess the positive SSTs and the increased moisture flux are probably related, right?

Answer: Yes. We have reworded and the new text will read as follows: "Nicholson et al. (2022) showed that the heavy rainfall on the Guinean coast was reinforced by positive sea surface temperature anomalies along the Atlantic coast. This process leads to a significant advection of the moisture flux from the Atlantic, combined with the convergence of the moisture, which contributed to the increase in rainfall in the region (Pokam et al. 2011, Kuete et al. 2019)."

L78-L84: Do you think the anomalously strong East African rains were related to the west central African rains? If so, how? (since the two regions seem often dynamically distinct... but I guess they could be indirectly related through the large-scale circulation?)

Answer: Indeed, we think that the anomalously heavy rainfall in East Africa is linked to the heavy rainfall in West Central Africa, specifically in the Congo Basin. The vertically integrated moisture flux from the east dominates over the flux from the west (see new figure 1 above). However, the two extreme events have different drivers on the Sahel. For instance, Wainwright et al (2020) pointed out that the increase in rainfall over East Africa was a consequence of the positive phase of the Indian Ocean dipole. For west central Africa, the heavy rainfall of October 2019 are a consequence of the Atlantic Niño associated with the late retreat of the West African monsoon.

L150: I think you can drop the 86400 and just specify you're showing output in K/day.

<u>Answer:</u> Done as suggested.

L163: I assume you meant top of the troposphere? I don't think Seager et al. 2010 actually makes a statement on this. They actually integrate to the top available level of the model at the time, which is presumably higher than 300hPa.

<u>Answer:</u> Thanks to the reviewer for the remark. We have reworded and the new text will read as follows: "Angle brackets "⟨⟩" signify the mass integral from the surface (ps = 1000 hPa) to a pressure pt = 300 hPa, which represents the top of the considered atmospheric layer."

L164: How true is this? (i.e., how small are changes in q at the monthly level?)

<u>Answer:</u> We appreciate the reviewer's concern. Previous work (Kenfack et al., 2024) has highlighted the fact that variations in specific humidity are small on a monthly scale. In the present study, we associate changes in q with the residual term. The new text will read as follows: "The first term on the left of equation 4 can be neglected given its small variation over time on a monthly scale and could contribute to the residuals."

L178 / Eq 6: should be cpT + Lvq. In which case you can use m for this as well.

<u>Answer:</u> Done as suggested.