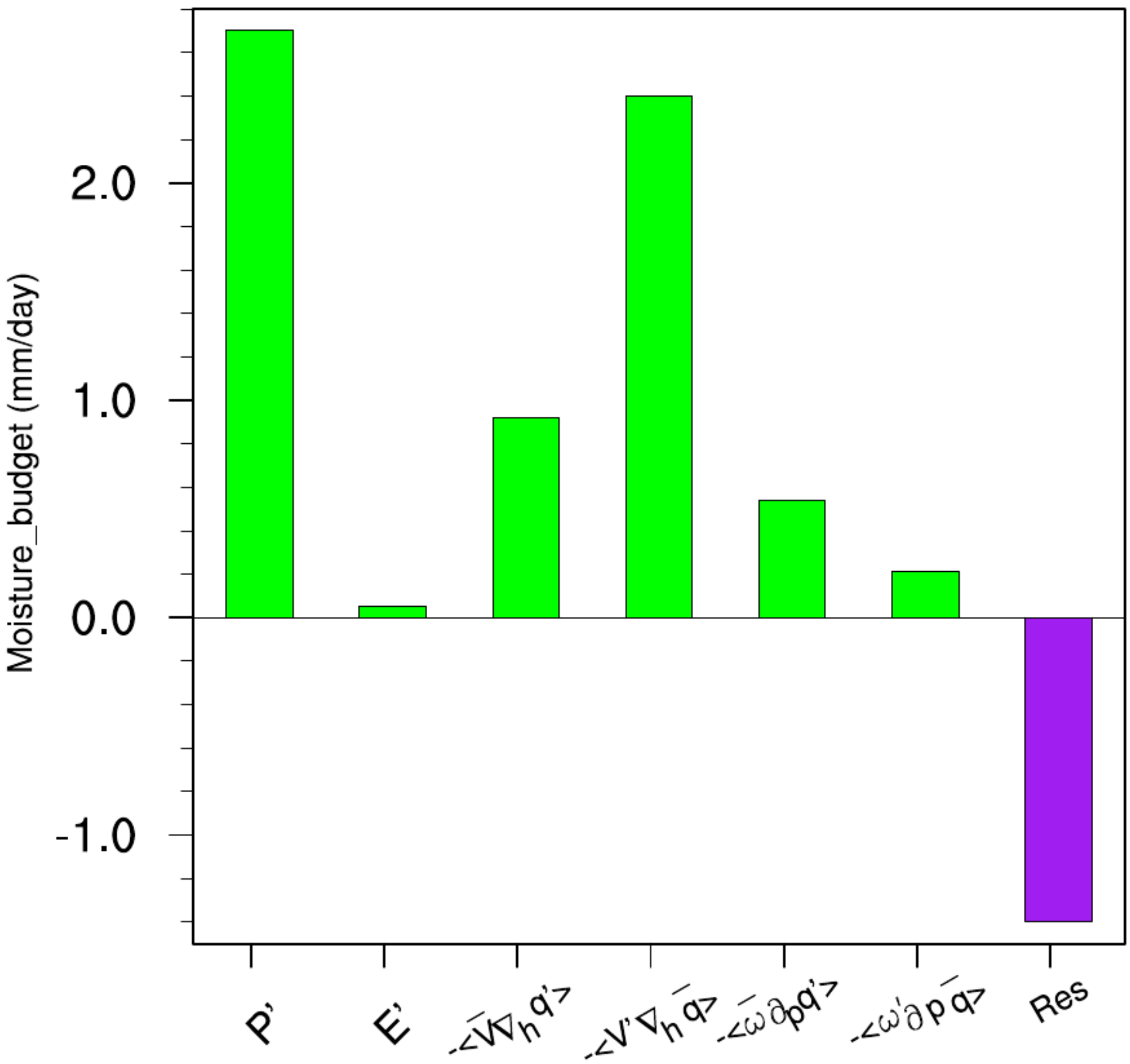
Reviewer#1:

This manuscript examines the drivers of the October 2019 extreme rainfall event over western central Africa. I find the overall approach to be novel and useful, but there are some statements in the abstract and conclusions that are not fully supported by the results shown, so I recommend major corrections.

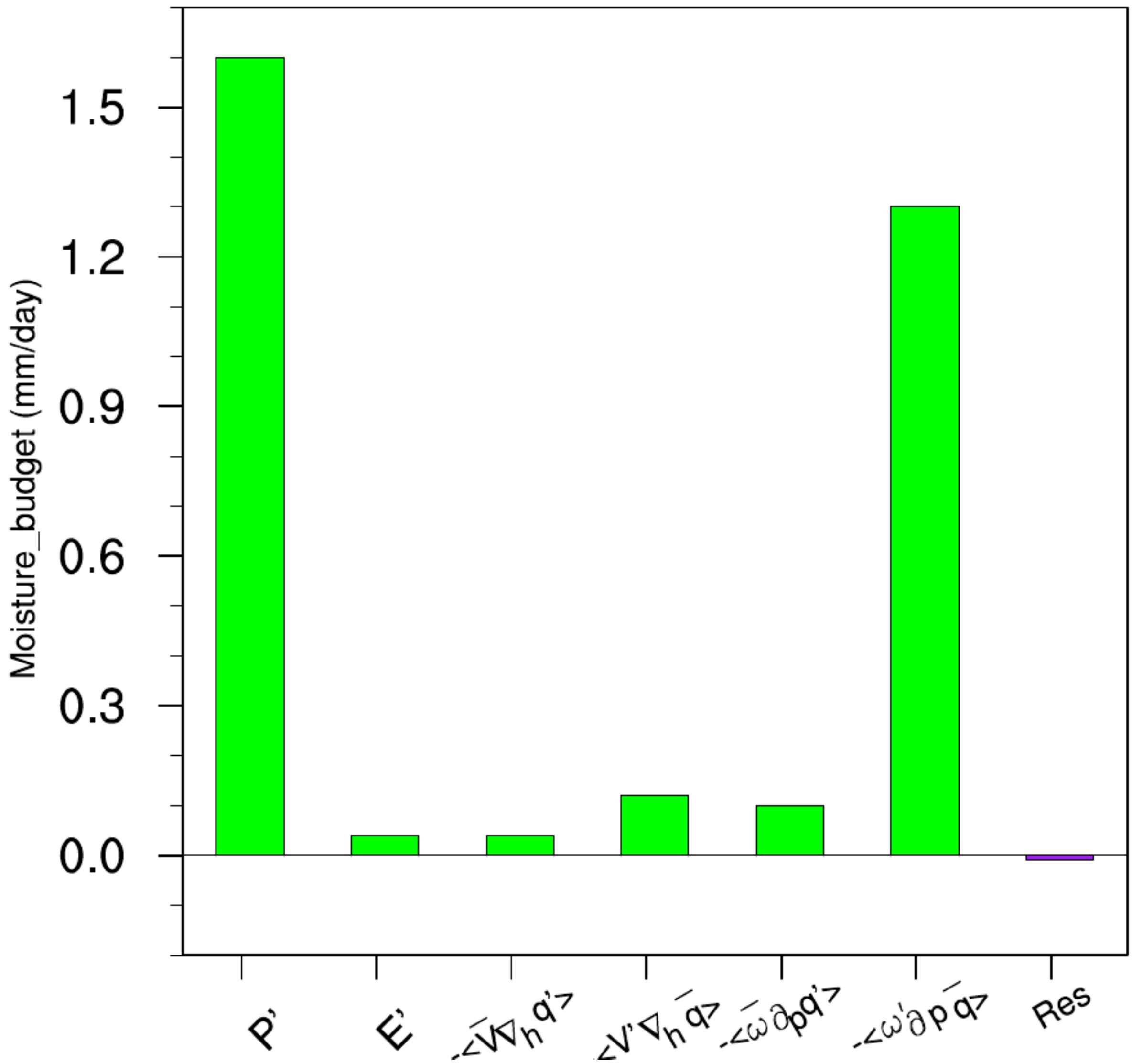
Major points:

1. As there appear to be different processes at work over the central and northern parts of the domain, results should in many cases be shown and discussed (including in the abstract and conclusions) for two sub-regions separately, e.g. Fig 4, 6, 7. Statements in the abstract about the dominance of meridional wind anomalies (L39) appear more relevant to the northern rather than the central part of the domain. I also don't think that 'Western Equatorial Africa' (as stated in the caption of Fig. 4) is an accurate description of the current domain, as it includes regions far from the equator.

Answer: **We express our gratitude to the reviewer for bringing this to our attention. The results will be discussed separately in the two sub-regions (6S-5N and 6N-14N), and we will replace 'Western Equatorial Africa' with 'West Central Africa'. The new text will read as follows: "**The strong variations 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 variations in latent heat in the thermodynamic effect**" and the legends to figures 5 and 6 will be updated to**



“Fig. 5. Monthly mean anomalies in moisture budget for October 2019, averaged over the Northern part of West Central Africa (6°N-14°N, 6°-20°E). **” and**



"Fig. 6. Monthly mean anomalies in moisture budget for October 2019, averaged over the Southern part of West Central Africa (6°S-5°N, 6°-20°E). **" , respectively.**

2. L30: There is a large residual term in the moisture budget, so this should be mentioned as a caveat when discussing the partition into dynamic and thermodynamic terms.

<u>Answer:</u> Thanks for this suggestion. We will discuss the importance of the residual term in examining the split between dynamic and thermodynamic terms as follows "Analysis of the moisture budget reveals that the precipitation anomalies in October were mainly controlled by dynamic effects. Horizontal moisture advection induced by horizontal wind anomalies controls extreme precipitation north of West Central Africa, while vertical moisture advection induced by vertical velocity anomalies controls extreme precipitation south of West Central Africa. Changes in the thermodynamic effect, although not the key factor responsible for the events of October 2019, contribute up to 35% of the total effect on the northern part and 15% on the southern part of the domain. The residual term on the northern part (6°N-14°N, 6°-20°E) is important and provides a caveat when estimating dynamic and thermodynamic processes**”**

3. L36 and L366: The MSE budget is diagnostic, so no statements about causality can be made without other supporting evidence. The vertical and horizontal dynamic terms balance one another but there is not enough evidence presented here to say that the vertical term is ‘dominated’ by the horizontal term, as to me that implies causality.

<u>Answer:</u> Thanks to the reviewer for the remark. Based on equation 9 of the present manuscript, the vertical term in the MSE balance is a result of the horizontal advections and the energy balance. This diagnosis allows us to establish links with the increase in the vertical movement of the MSE. In the present study, it allowed us to establish that in the north of the domain, the vertical movement was correlated with horizontal advections induced by changes in the meridional wind, while in the south, the energy balance was correlated with an increase in the vertical movement of the MSE. We will rephrase the text to avoid confusion between correlation and causation. The new text will read as follows:
“Diagnosis of the MSE balance averaged over the northern part of west Central Africa shows that the anomalous vertical motion is dominated by the dynamic effect, i.e. the wet enthalpy advection induced by the horizontal wind anomalies. This is confirmed by the high correlation ($r = 0.6$) between the two terms compared to the other terms. Whereas to the west of the Congo Basin, the increase in the net energy balance dominated the changes in vertical motion ($r = 0.51$). The horizontal advection of the MSE induced by the variation of the wet enthalpy and the vertical advection of the MSE induced by the variation 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 variations 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 variations in latent heat in the thermodynamic effect”.

4. L41-43: I didn’t see any convincing evidence presented in this study linking the moisture or MSE budget results to Atlantic SSTs or the Saharan heat low. This is the hypothesis of Nicholson et al., 2021, but the authors need to show much more explicitly whether or not their results support this hypothesis.

<u>Answer</u>: We **understand the reviewer's concern. The work of Nicholson et al . (2022) established that in addition to warm Atlantic SSTs, there was an anomalous meridional mean sea level pressure (MSLP) gradient in the Central African Sahel between a lower MSLP over the eastern Sahara and higher pressure between 10 and 15°N. In addition, they**

highlighted that the trans-equatorial meridional wind fluctuated with the activity of the African easterly waves over the Gulf of Guinea. The MSE advection decomposition shows that the anomalous meridional direction dominated in the moisture and MSE advection north of west-central Africa. The new text will read as follows: "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. One of the reasons would be due to the fact 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)".

5. L163-164 and L186-187: It can't just be assumed that the d/dt terms in the moisture and MSE budget are small when applying these budgets to an individual month. This needs to be demonstrated, or at the very least it should be stated that the d/dt term could contribute to the residual in each budget.

<u>Answer</u>: We thank the reviewer's remark, we will take this into account in the revised manuscript by specifying that the d/dt terms could contribute to the residuals in each budget. 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, as specified by Seager et al. (2010), represents the top of the atmosphere. 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**"**

6. The MSE budget in Fig. 9 doesn't look to me like it adds up correctly. Is the residual the wrong sign?

<u>Answer</u>: Thanks to the reviewer for the concern. We would like to point out that there is no sign error in Figure 9.

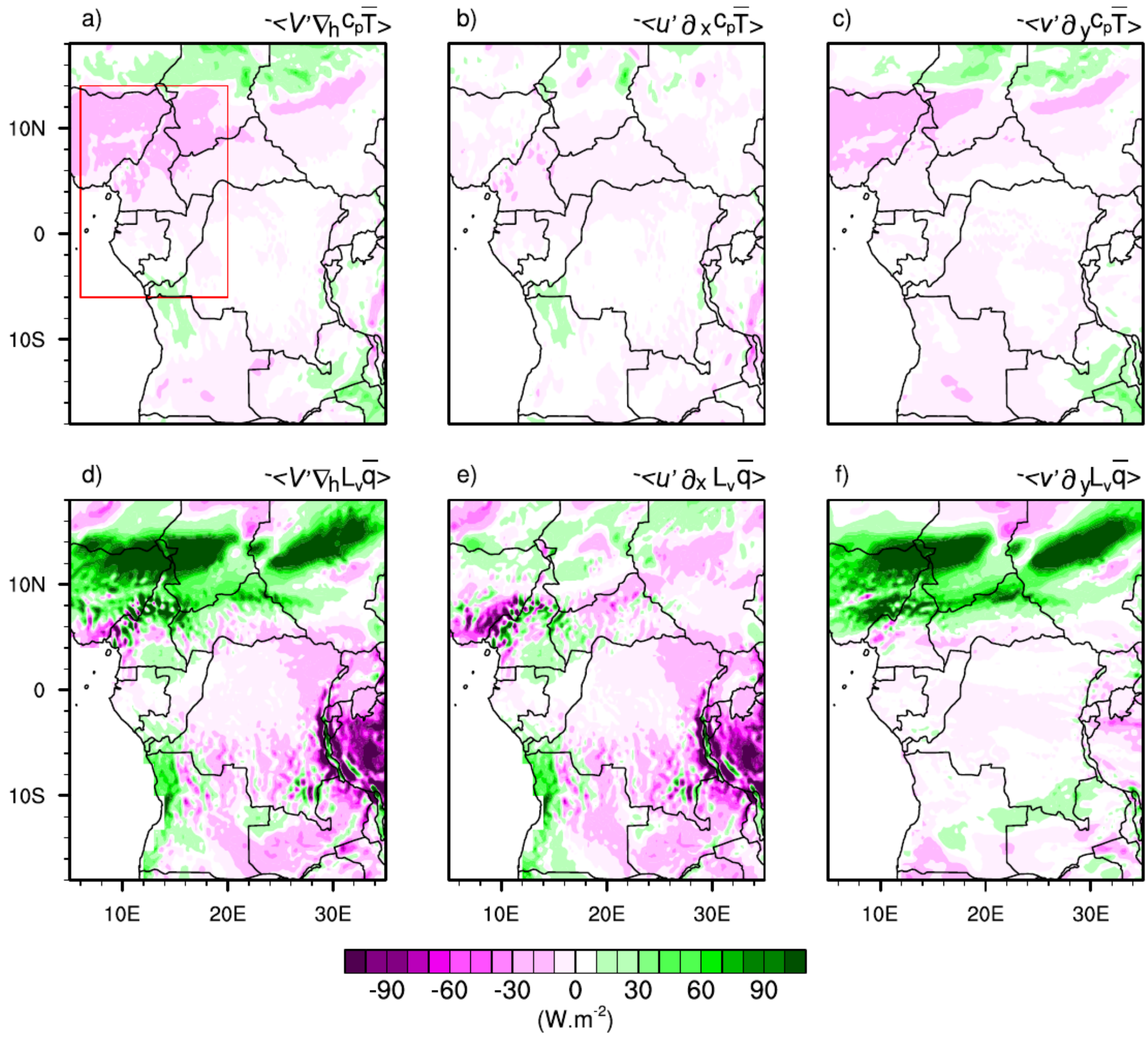


Fig. 9. Horizontal advection of (a–c) climatological dry enthalpy and (d–f) latent energy by anomalous wind, designated as a dynamic effect during October 2019 over West Central Africa. (a,d) Total advection, (b, e) zonal component, and (c, f) meridional component.

Minor points:

1. L104: The reference to the greenhouse effect here is confusing. Although an increase in WV would be associated with an enhanced greenhouse effect, I don't think there is evidence that this process significantly contributes to increasing low-level convergence.

Answer: We thank the reviewer's remark, we have reworded this in the revised manuscript. The new text will read as follows: "The increase in diabatic heating on the coast can contribute to the acceleration of near-surface winds (Pokam et al. 2014)."

2. L105: The convergence feedback mechanism described here is no longer generally accepted. Instead, the large-scale flow and, precipitation and diabatic heating are more generally thought to evolve together under the constraint of convective quasi-equilibrium. However, I do accept that when horizontal moisture gradients exist, as they do between land and ocean, the concept of a feedback might be more appropriate, as increased horizontal flow could increase boundary layer MSE over land, and therefore result in increased precipitation. In any case, this point probably needs a bit more clarification.

Answer: We thank the reviewer's remark, Further clarifications will be provided as follows: "The increase in diabatic heating on the coast can contribute to the acceleration of near-surface winds (Pokam et al. 2014). An increase in this quantity implies an increase in latent warming, associated with a strong ocean-continent horizontal moisture gradient, which can lead to a strengthening of the boundary layer MSE, with a positive feedback process leading to extreme precipitation"

3. L105-107: Has it really been demonstrated that the reduction in heating has driven the reduction in rainfall, or have both things decreased together?

Answer: Kenfack et al (2024) demonstrated that both processes have decreased at the same time. The new text will read as follows: "Further, it has been demonstrated that a simultaneous reduction in the heating source and rainfall has been observed in reanalyses over recent decades in the Congo Basin (Kenfack et al. 2024)"

4. L141: When diagnosed from reanalysis, this is more generally referred to as the 'apparent diabatic heating'.

<u>Answer</u>: We thank the reviewer's remark, we have reworded this in the revised manuscript. The new text will read as follows: "Apparent diabatic heating as proposed by Yanai and Tomita (1998) and Pokam et al. (2014)"

5. Equations: Please improve the image quality of all equations.

<u>Answer</u>: The comment will be taken into account.

6. L169: This should say 'non-linear and transient processes', as some of the neglected non-linear terms are related to the mean flow.

<u>Answer</u>: We thank the reviewer's remark, we will reword this in the revised manuscript. The new text will read as follows: "The residual term "Res" contains the non-linear and transient processes associated with the joint variations in water vapor content and circulation"

7. 6: This should be Lq, not cvq.

<u>Answer</u>: Unfortunately, the cation in figure 6 does not include the suggestion made by the reviewer

8. 6: You need to specify that variations in geopotential height along pressure levels are neglected in this MSE budget formulation

<u>Answer</u>: We thank the reviewer's remark, we have reworded this in the revised manuscript. The new text will read as follows: "In addition, it should be noted that variations in geopotential height along pressure levels are neglected in this formulation of the MSE budget."

9. L188: I think 'remaining terms' would be more precise than 'remainder' here.

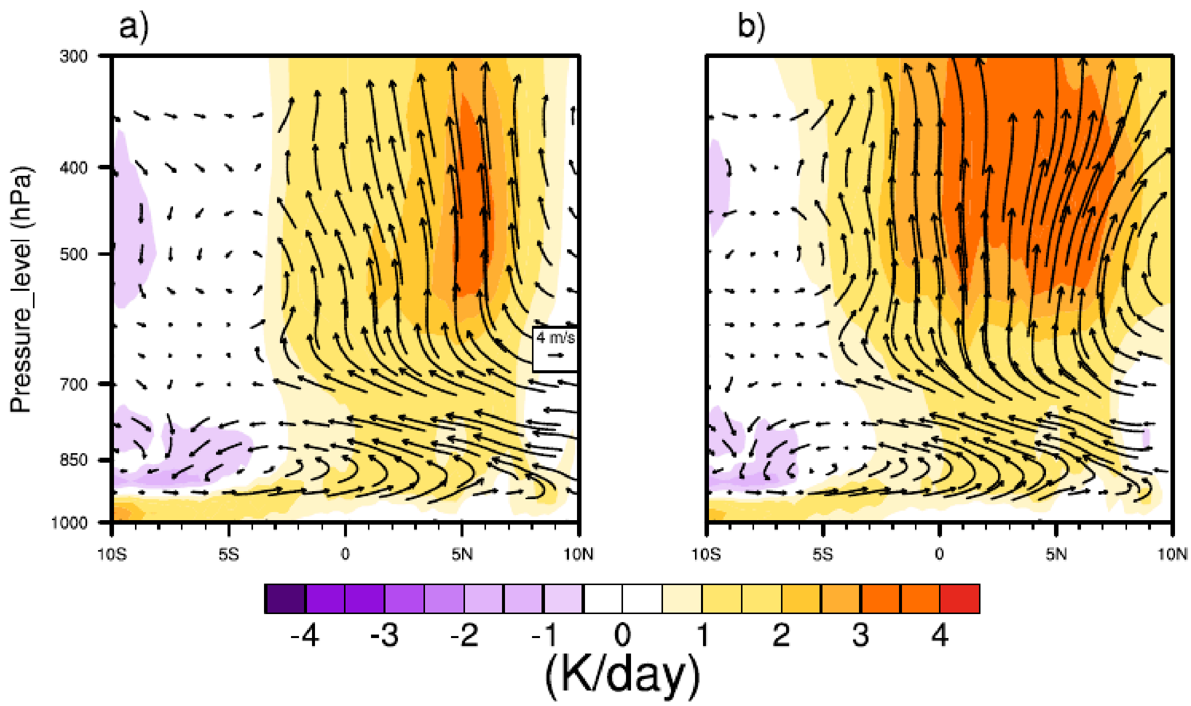
<u>Answer</u>: Done as suggested. The new text will read as follows: "The remaining terms in equation 6 can be decomposed into horizontal and vertical advection components"

10. L201: The diabatic heating over the continent is associated with moist instability, but I don't think 'favouring it' is the correct way to phrase this.

<u>Answer</u>: Thanks to the reviewer for the concern. The new text will read as follows: "The contrast in warming between the ocean and the continent can lead to significant diabatic warming over the continent, reinforcing atmospheric instability (Pokam et al. 2014)"

11. L221-223: I can't see evidence for this in Fig. 1. An anomaly plot might make things clearer.

<u>Answer</u>: The suggestion taken into account. The anomaly plot will be added in Fig. 1c



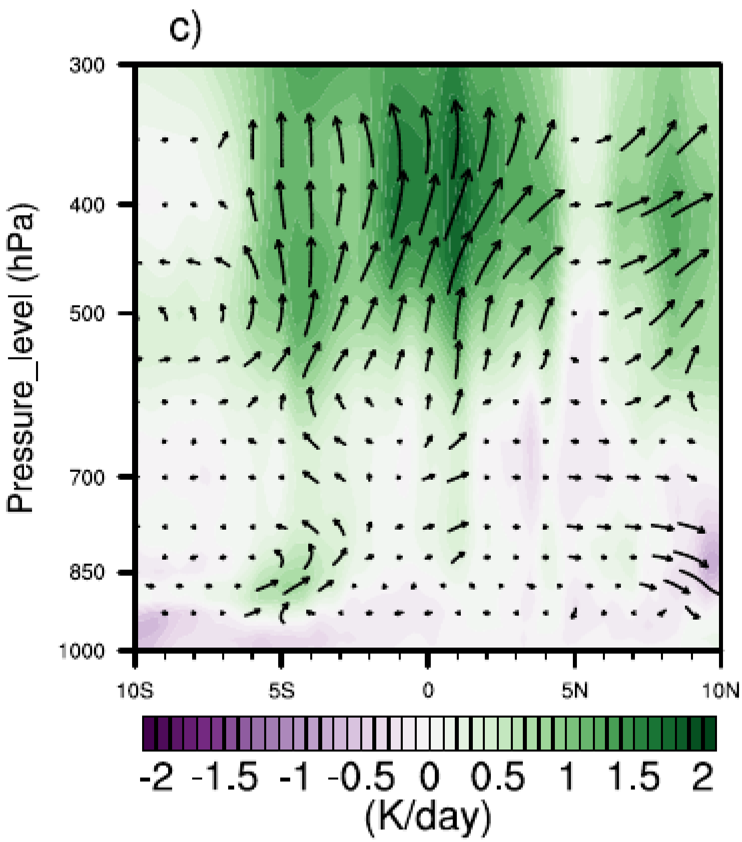


Fig 1. Diabatic heating and divergent meridional circulation (vectors; ms^{-1}) during the SON season for a) the 1988-2017 climatology, b) the 2019 mean and c) the anomaly, all averaged between the 6° and 20°E. As the vertical velocity is much weaker than the meridional wind, its values have been enhanced by a factor 600 for the clarity of the graph.

12. L231-232: I don't think the boundaries of West Central Africa have been defined yet in the manuscript.

<u>Answer</u>: The area of West Central Africa considered in this study is delimited by the box in Figure 6 (6°S-14°N, 6°-20°E). This is also indicated on the captions of all the regional averages and also in the text.

13. L243: Need to provide evidence or a reference for this statement.

<u>Answer</u>: Nicholson et al . (2022) indicated that Record-breaking tropical Atlantic SSTs were probably a major factor for the three western-most regions, particularly the strong coastal anomalies. The warming in the equatorial Atlantic, abetted by an anomalously strong thermal low over the Sahara, may have played a role in delaying the retreat of the West African monsoon, leading to positive rainfall anomalies over the Sahel and Guinea Coast. We will add this reference to support the statement. We have added the reference of Nicholson et al. (2022).

14. L256-258: I think this shows that moisture extended further north over West Africa in October 2019, not that there was more moisture in Equatorial West Africa as stated.

<u>Answer</u>: Thanks to the reviewer for the remark. The new text will read as follows: **"**Analysis of the anomalies confirms that the humidity extended further north in West Central Africa in October 2019, compared with the climatology."

15. L258-259: Although the moisture source is the Atlantic, it is not necessarily a consequence of warmer SSTs. The northward extension of the meridional winds is the key process here, so perhaps that is more associated with anomalies in the Saharan heat-low?

<u>Answer</u>: The key process was the northward extension of the meridional winds. This shift favored the northward extension of humidity. In addition, the anomalies of the Saharan heat low, as highlighted by Nicholson et al . (2022), were significant, which favored precipitation.

16. L262-263: That result is more relevant to long-term responses to global warming. For regional monthly anomalies, changes in winds will be equally or more important drivers of changes in humidity over land.

<u>Answer</u>: We thank the reviewer's remark, we have reworded this and the new text will read as follows: "Indeed, the increase in humidity associated with a substantial heating source contributes to an increase in precipitation. In addition, In the case of the monthly anomalies, the changes in the winds are thought to be a response to the increased moisture advection from the oceans as a result of global warming."

17. L267: Which heating sources?

<u>Answer</u>: This is the atmospheric heating source. we have reworded this and the new text will read as follows: "In the Congo Basin, atmospheric heating source combined with the vertical advection of moisture induced by anomalous vertical motion are responsible for most of the interannual variability of precipitation (Kenfack et al., 2024)"

18. 4 caption: The reference here should be to Fig. 5, not Fig. 2.

<u>Answer</u>: We thank the reviewer's remark, we have reworded this and the new text will read as follows: "Fig. 4. Monthly mean anomalies in moisture budget for October 2019, averaged over the Northern part of West Central Africa (6°N-14°N, 6°-20°E)."

19. L285-286: I'm not sure how this result about dependence on surface heating is directly relevant to the moisture budget results shown here.

<u>Answer</u>: We understand the reviewer's concern. Preliminary studies by Cook et al. (2019) (https://doi.org/10.1007/s00382-019-05033-3) showed that the precipitation anomalies are not directly related to local surface warming and do not involve changes in moisture transport from the Atlantic or Indian Oceans. We also showed that changes in evaporation were small during the 2019 extreme event, indicating that the observed precipitation anomalies do not depend on surface heating processes.

20. 5: Need to show the pattern of the residual term as well, because it is large. The pattern might also give some clues as to what is causing the large residual.

<u>Answer</u>: suggestion taken into account. The residual term will be added and discussed in the text.

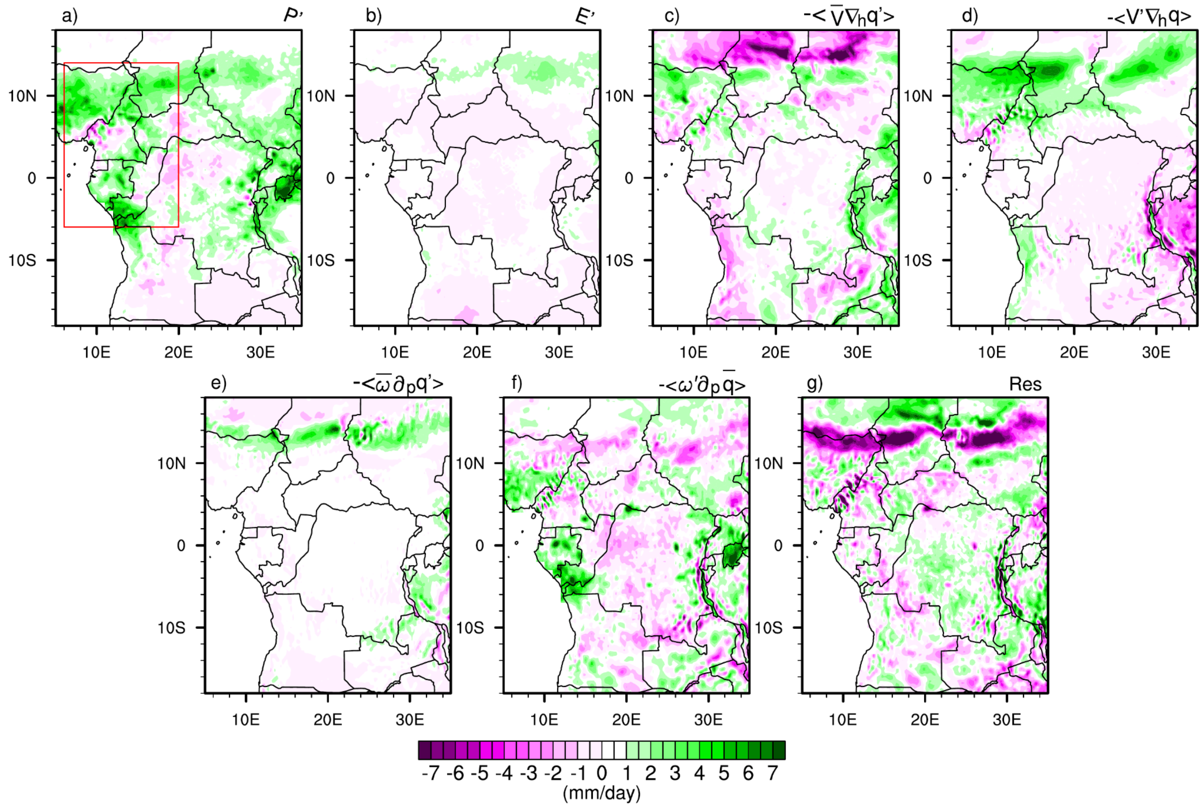


Fig. 6. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa. (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture by 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.

21. L313: Although the increase in diabatic heating is related to the precipitation change, I don't think it can be said to be driving it.

<u>Answer:</u> We agree with the reviewer. We have reworded this and the new text will read as follows: "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)."

22. L314-315: From the maps shown here, the increased moisture looks to be mainly associated with winds penetrating further northwards into West Africa, rather than any general increase in moisture associated with increased Atlantic SSTs.

<u>Answer:</u> We understand the reviewer's concern. 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 west to south-west. this will be reported in the text.

23. L318: Why is this the 'second' dynamic parameter?

<u>Answer:</u> This is the second dynamic parameter, because the regional average shows that the horizontal advection of moisture induced by the anomalous horizontal movement is the first dynamic parameter to have contributed to the increase in precipitation. The new text will read as follows: "The previous results clearly showed that the vertical advection of moisture induced by the vertical velocity anomaly was identified as the second dynamic parameter (after the horizontal advection of moisture induced by the anomalous horizontal movement) contributing to the increase in precipitation in October 2019."

24. L320: Grammar doesn't quite work here.

<u>Answer:</u> We thank the reviewer's remark, We have reworded this and the new text will read as follows: "Diagnosis of the MSE budget, which takes account of the thermal state of the atmosphere and the effect of atmospheric circulation, is used to analyze the atmospheric perturbation related to the moisture transport."

25. 6: Please change the colours used here for the benefit of readers with red-green colour-blindness.

<u>Answer</u>: We thank the reviewer's remark, figure colors have been modified.

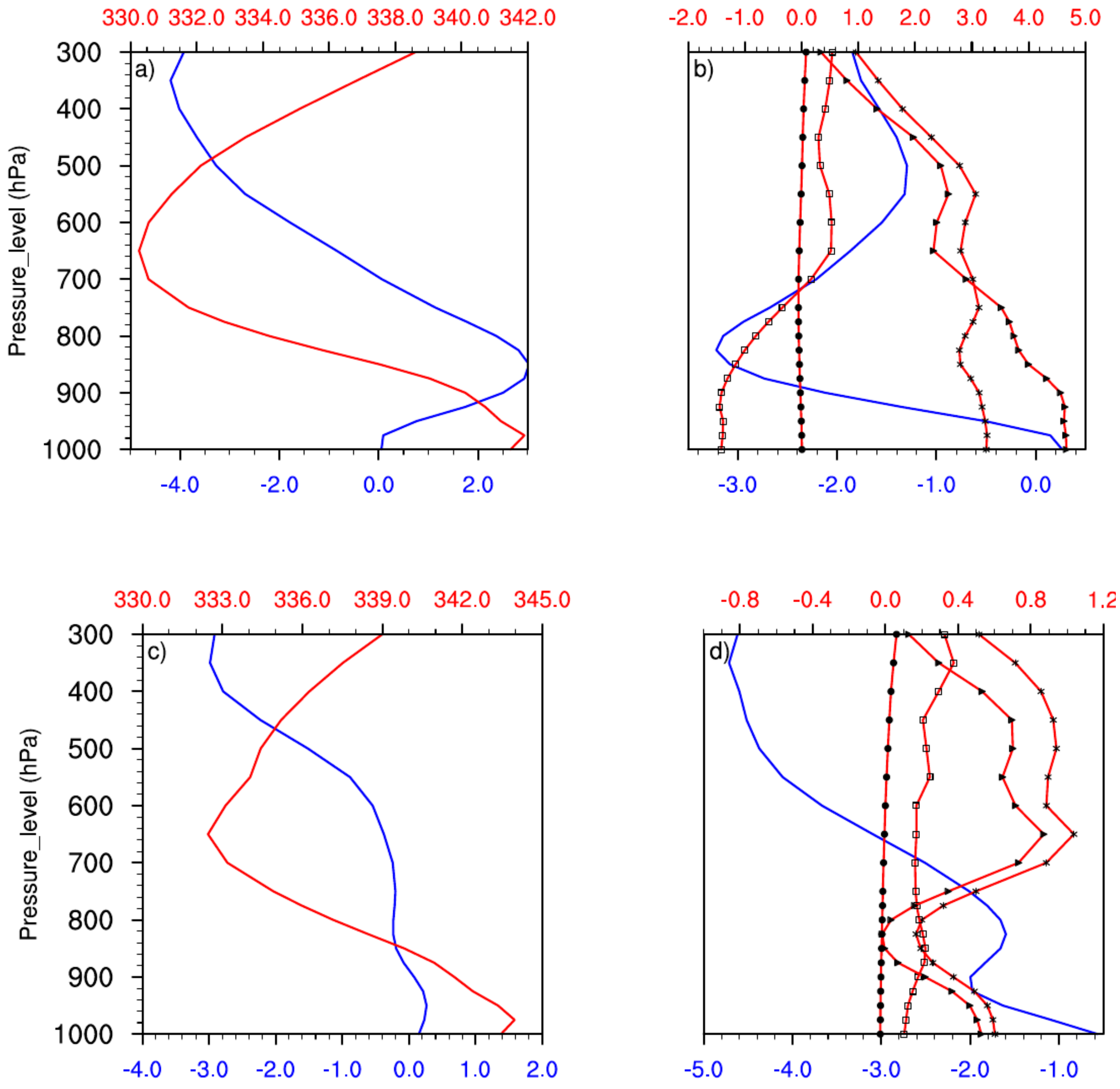


Fig. 7. Vertical profile of a) vertical velocity anomaly ω' (blue line: $10^{-2} Pa.s^{-1}$) and MSE climatology $\bar{m}$ (red line: $10^{3} J.Kg^{-1}$), and b) vertical velocity climatology ϖ (blue line: $10^{-2} Pa.s^{-1}$), MSE anomaly m' (line with stars: $10^{3} J.Kg^{-1}$), enthalpy anomaly $c_p T'$ (line with squares: $10^{3} J.Kg^{-1}$), latent energy anomaly $l_v q'$ (line with triangles: $10^{3} J.Kg^{-1}$) and geopotential anomaly Ψ' (line with dark circle: $10^{3} J.Kg^{-1}$) averaged

over the Northern part of West Central Africa (6°N-14°N, 6°-20°E) and c), d) the same parameters averaged over the Southern part of West Central Africa (6°S-5°N, 6°-20°E) during October 2019.

26. L339: Minimum, not maximum

<u>Answer</u>: Comment taken into account. Sentence rephrased and the new text will read as follows: "The structure of the MSE climatology is similar to that observed to the north, with a minimum around 650 hPa."

27. L340-341: Not necessarily. This depends on the vertical structure of the omega anomalies. This relationship needs to be checked.

<u>Answer</u>: We have reworded this and the new text will read as follows: "As a result, positive (negative) values of $\langle \omega' \partial_p \bar{m} \rangle$ depends on the vertical structure of the omega anomalies."

28. L346: I don't think it is correct in this context to say that Lq' approached m'. The vertical gradients of the two terms are very different, and it is the vertical gradients that are crucial here.

<u>Answer</u>: Comment taken into account. the new text will read as follows: "However, this includes three terms, namely, gz' which is weak in the entire tropospheric column, the enthalpy anomaly c_pT', which tends to increase, and l_vq',tends to behave similarly to m' between 650 hPa and 300 hPa. To the south of the domain (Fig. 7c), the vertical velocity anomaly shows negative values from 900 hPa up to the upper troposphere, accelerating the anomalous vertical movement."

29. L357-364: This flux term should be investigated further by separating it into surface vs SW and LW radiative fluxes and potentially clear-sky vs cloudy radiative fluxes. From Fig. 8e the flux term seems to be co-located with the rainfall anomaly, so one interpretation is that this is a radiative response to increase in deep convective clouds.

<u>Answer</u>: We thank the reviewer's remark, However, with reference to the reviewer's question 30, we checked the MSE balance script, and obtained a slight increase in net energy. The updated energy balance (Fig. 10e) shows a very small change over the northern part of the domain where the precipitation anomalies are observed. This would imply that, given this small change in energy relative to the climatology, we do not believe that the precipitation anomalies in this area are a consequence of a radiative response.

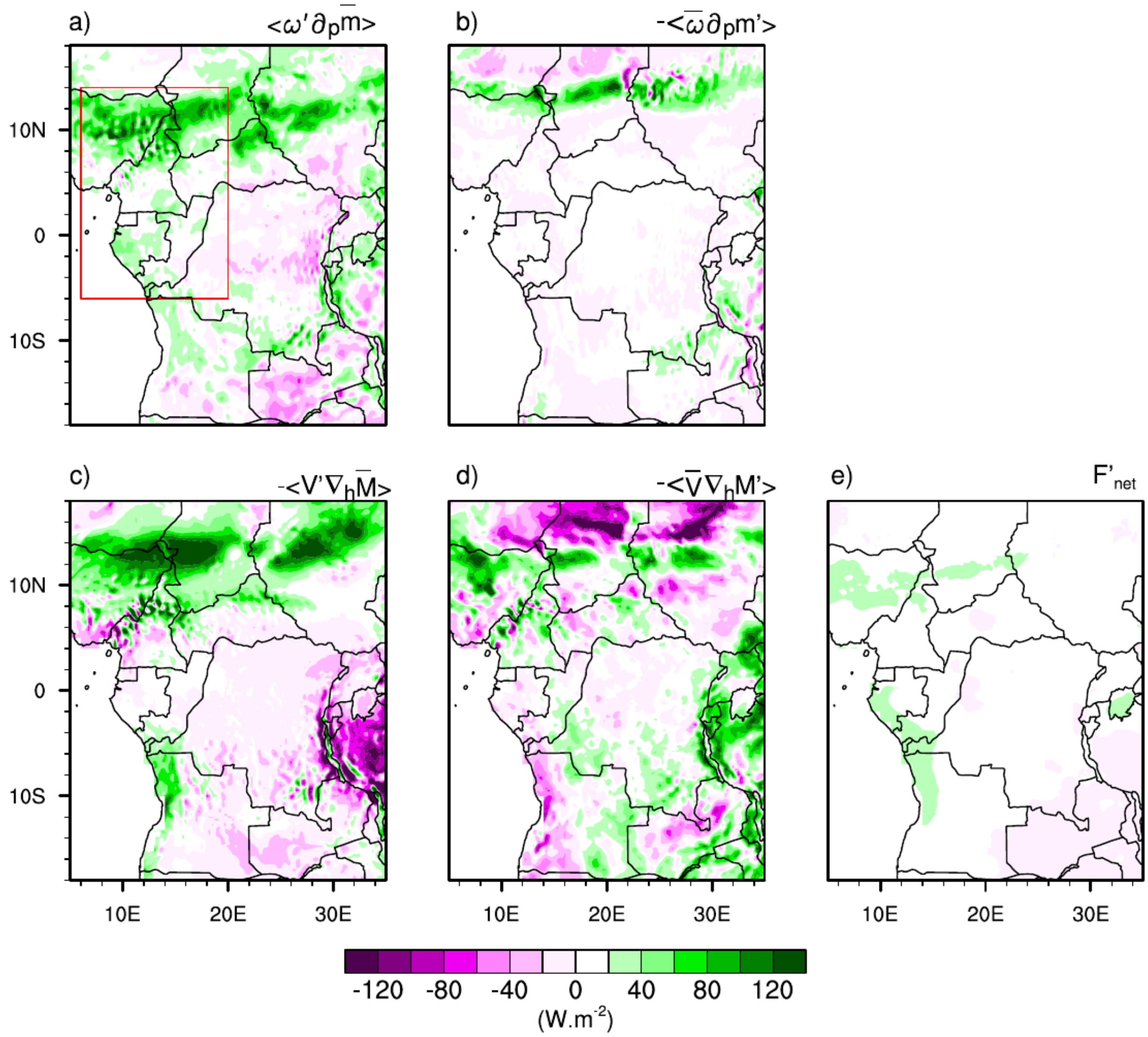


Fig. 10. Spatial distributions of each term of the Moist Static Energy (MSE) balance equation during October 2019 over West Equatorial Africa. (a) vertical advection of climatological MSE by anomalous vertical velocity, (b) vertical advection of anomalous MSE by climatological vertical velocity, (c) 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.

30. L360-364: I would have thought that the MSE budget implies that a reduction in energy into the column would be associated with a reduction in ascent and precipitation, not an increase.

Answer: Indeed, the reviewer is right. The MSE and energy budgets have been checked. A small increase in net energy is observed over the northern and southern zones of the domain. This justifies the increase in vertical advection of the MSE induced by changes in vertical velocity to the south of the domain. The new text will read as follows: "The difference between the net energy balance for 2019 and the climatology (Fig. 10e) shows low positive values in the north and south of the region respectively. Such an increase (mainly to the south of the area) is associated with a strengthening in the vertical structure of the MSE anomaly through ascending currents and, consequently, an increase in precipitation"

31. L378: This relationship between the thermodynamic and dynamic terms seems to vary a lot depending on the sub-region.

Answer: Indeed. Analyses are carried out in each sub-zone separately as suggested by the reviewer. The new text will read as follows: "There is a high concentration of positive values in both dynamic terms, up to 120 $W \cdot m^{-2}$ in the north of West Central Africa. In addition, the two thermodynamic terms $-\langle \omega \partial_p m' \rangle$ (Fig. 10b) and $-\langle \bar{V} \cdot \nabla M' \rangle$ (Fig. 10d), although weak, also contributed to reinforcing the vertical advection of MSE induced by the vertical motion anomaly. It should be remembered that the term $-\langle \omega \partial_p m' \rangle$ remains very weak over the region as a whole, with the exception of the northern part where a slight layer of positive values can be observed. Terms $-\langle V' \cdot \nabla \bar{M} \rangle$, $-\langle \bar{V} \cdot \nabla M' \rangle$ and $-\langle \omega \partial_p m' \rangle$ in the MSE have a similar spatial distribution to terms $\langle -V' \cdot \nabla \bar{q} \rangle$, $\langle -\bar{V} \cdot \nabla q' \rangle$ and $\langle -\bar{\omega} \partial_p q' \rangle$ in the moisture, which is in agreement with the findings of Kenfack et al. (2024). The difference between the net energy balance for 2019 and the climatology (Fig. 10e) shows low positive values in the north and south of the region respectively. Such an increase (mainly to the south of the area) is associated with a strengthening in the vertical structure of the MSE anomaly through ascending currents and, consequently, an increase in precipitation"

32. L386: By itself it would result in this, but the combination of other budget terms are larger.

<u>Answer</u>: Indeed, the reviewer is right. The revisions to the result show that the other terms of the budget were more important over the Sahel compared to the contribution of net energy. The new text will read as follows: "The difference between the net energy balance for 2019 and the climatology (Fig. 10e) shows low positive values in the north and south of the region respectively. Such an increase (mainly to the south of the area) is associated with a strengthening in the vertical structure of the MSE anomaly through ascending currents and, consequently, an increase in precipitation. Although the dynamic contribution is the most important, the thermodynamic contribution cannot be neglected. This would mean that interaction between atmospheric dynamic and thermodynamic variables would induce significant indirect effects on October 2019 precipitation anomalies over West Central Africa."

33. L388: I think 'interaction' would be a better word than 'feedbacks' here.

<u>Answer</u>: suggestion taken into account. The new text will read as follows: This would mean that interaction between atmospheric dynamic and thermodynamic variables would induce significant indirect effects on October 2019 precipitation anomalies over West Central Africa.

34. L392: This is clearer for the northern part of the domain than the central part.

<u>Answer</u>: The reviewer is right. The new text will read as follows: "The aforementioned results clearly show that enthalpy advection induced by the horizontal wind anomaly is crucial in understanding the processes at the origin of October 2019 extreme precipitation over northern part of West Central Africa."

35. L407-408: I think 'area-averaged' would be better than 'entire' here, as this result doesn't hold everywhere in the domain.

<u>Answer</u>: suggestion taken into account. The new text will read as follows: "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."

36. L418: This should say 'MSE' instead of 'moist air'.

<u>Answer</u>: suggestion taken into account. The new text will read as follows: "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."

37. L437-438: Again, I don't think there is any evidence here to link this directly with enhanced Atlantic SSTs. It is the wind anomalies that are crucial.

<u>Answer</u>: Please refer to the answer to question 13. The new text will read as follows: "Variations in latent heat are strong in the meridional direction, while the zonal direction shows a reduction in abnormal latent heat. This could be due to the strong meridional wind associated with the increase in SST in the tropical Atlantic, which results in strong advection of water vapor into West Central Africa, leading to precipitation."

38. L453-456: This is overstating how much we can learn from this analysis. In order to link the October 2019 rains to global warming a formal detection and attribution study would be needed.

Answer: We understand the reviewer's concern. At this stage we would like to talk about speculation. The new text will read as follows: "We proceeded by decomposing the water balance and MSE equation, separating the associated dynamic and thermodynamic effects. Changes in atmospheric circulation are behind dynamic processes, while changes in water vapor are behind thermodynamic processes. This approach provides a better understanding of the mechanisms behind rainfall anomalies. The thermodynamic effect, in particular, can be used to speculate on the influence of global warming on heavy rainfall in October 2019, notably on the increase in the temperature of the troposphere and its water vapor content."

39. L457-458: Are there also easterly anomalies over equatorial West Africa? This whole analysis would benefit from separating the central and northern parts of the domain, as different processes appear to be at work. It may be that there is a common driver, but that is not currently demonstrated here.

Answer: Easterly anomalies exist (current figures 11b,e and figures 12b,e) but are not significant enough to cause extreme precipitation in October 2019. In addition, the domain has been subdivided into the northern part where the heaviest precipitation is recorded (6°N-14°N, 6°-20°E) and the central part of the domain (6°S-5°N, 6°-20°E) where extreme precipitation is less important. The new text will read as follows: "The main feature of October 2019 on the northern part of the area was a strong southerly circulation compared with the typical climatology for 1988-2017. In addition, a more pronounced rate of humidity associated with significant diabatic heating over West Central Africa up to 15°N were recorded."

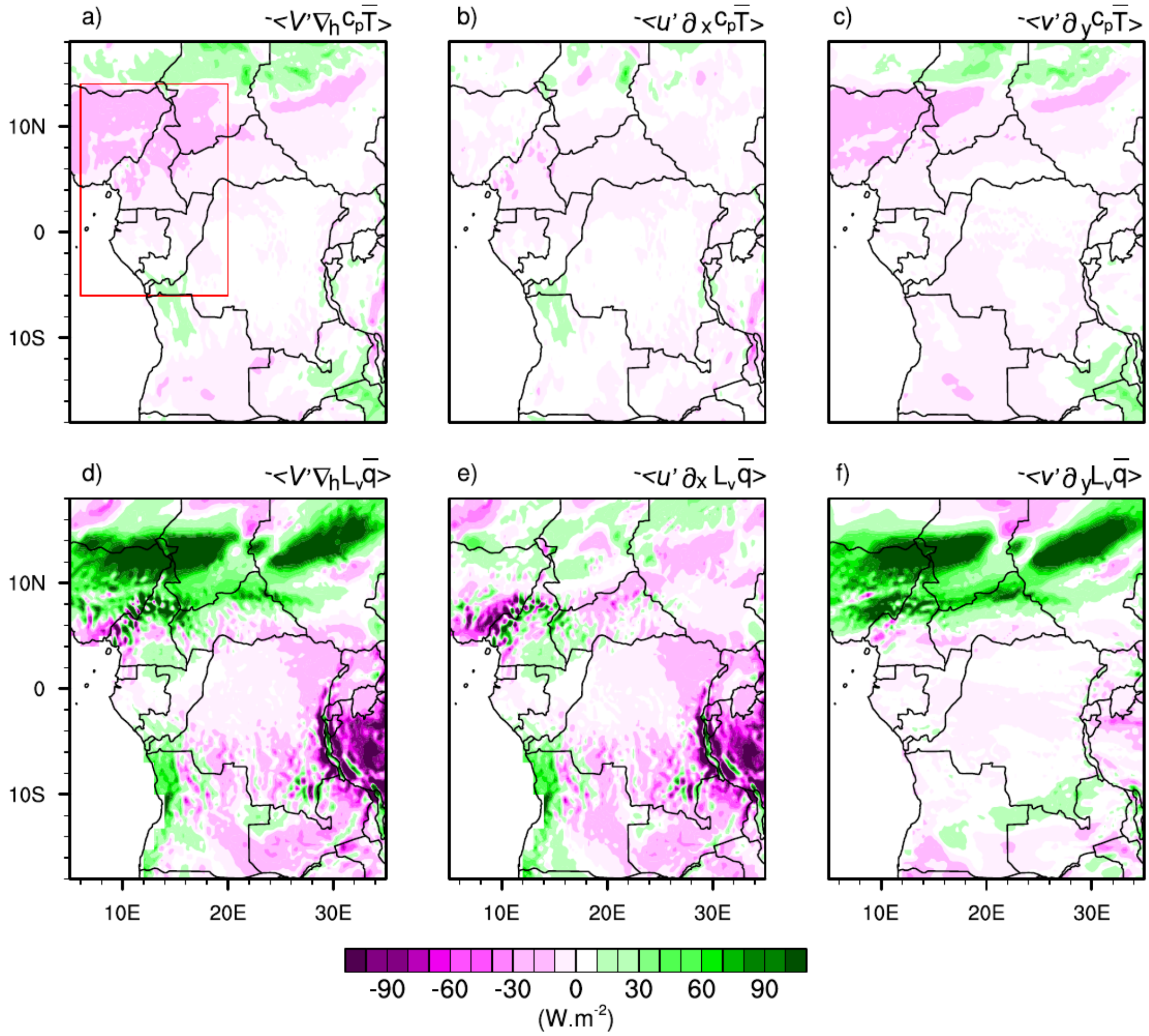


Fig. 11. Horizontal advection of (a–c) climatological dry enthalpy and (d–f) latent energy by anomalous wind, designated as a dynamic effect during October 2019 over West Central Africa. (a, d) Total advection, (b, e) zonal component, and (c, f) meridional component.

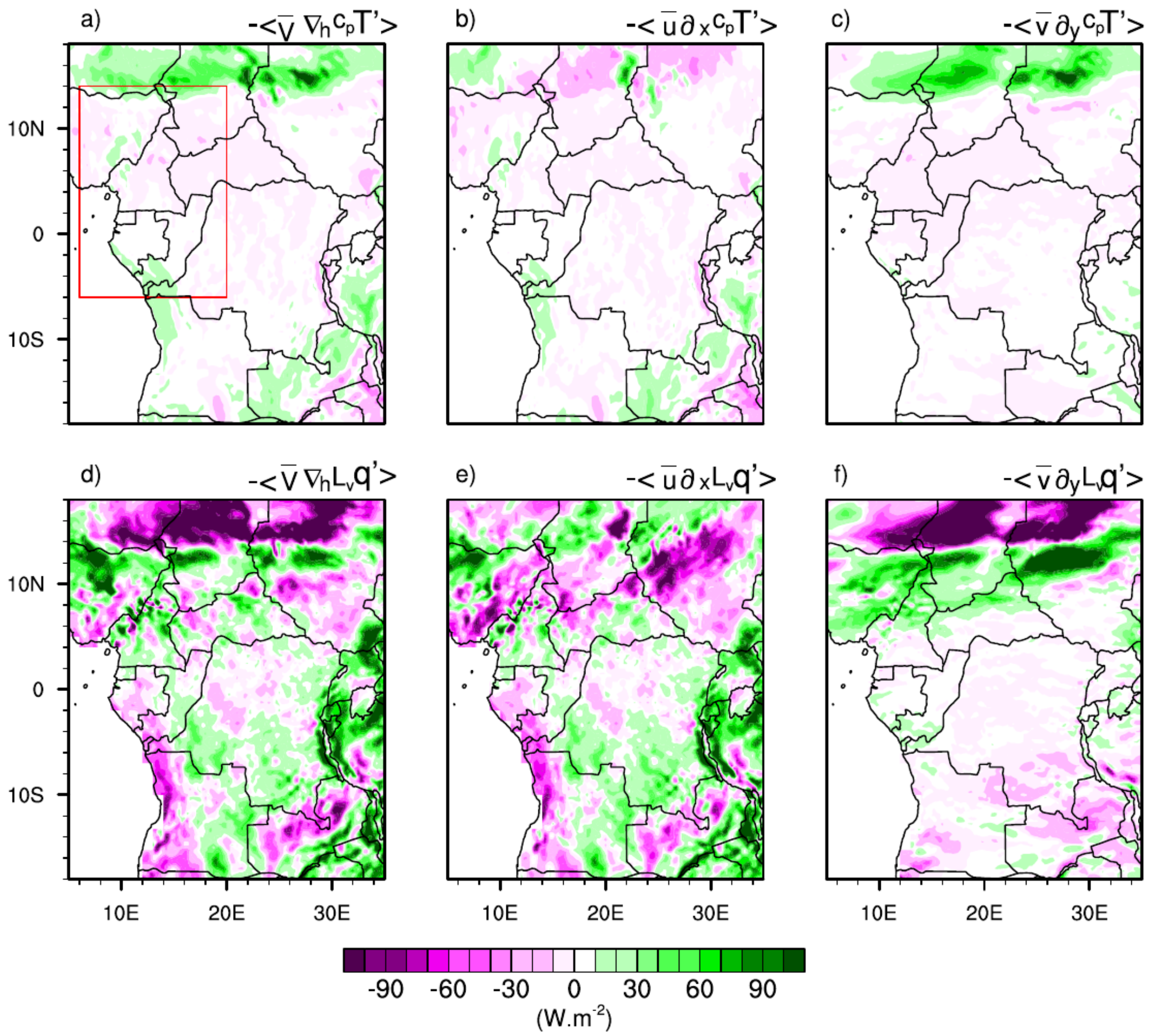


Fig. 12. As in Fig. 11, but for the thermodynamic effect (horizontal advection of anomalous dry enthalpy and latent energy by climatological wind) during October 2019 over West Central Africa.

40. L463 and L464: The word 'controls' implies causality, which has not been demonstrated here.

<u>Answer</u>: The reviewer is right. Indeed, we want to talk about the dominant processes . We have reworded this and the new text will read as follows: "The diagnosis of the water balance reveals that the exceptional rainfall in October 2019 is mainly dominated by dynamic effects. However, moisture advection induced by horizontal wind anomalies is the dominant process of precipitation anomalies over the northern part of the zone, while vertical moisture advection induced by vertical velocity anomalies is the dominant process of precipitation extremes in the south, mainly over Gabon and southern Congo Brazzaville."

41. L475: This is true in the northern part of the domain, but not the equatorial part I don't think

<u>Answer</u>: The two sub-regions have been discussed separately. the new text will read as follows: "The MSE vertical advection anomaly is dominated over the northern part of the area by the dynamic term (i.e. the advection of the wet enthalpy induced by the horizontal wind anomalies) compared to the thermodynamic terms (i.e. the horizontal advection of the MSE induced by the variation of the wet enthalpy and the vertical advection of the MSE induced by the variation of the MSE). In the southern part, the increase in the net energy balance compared with the climatology is the dominant process that has contributed most to the change in the structure of the vertical anomaly of the MSE. An extended analysis shows that these variations in the MSE over the north of West Central Africa were governed by its meridional component, in particular the variations in the meridional wind in the dynamic effect and the meridional variations in latent heat in the thermodynamic effect. It should be pointed out that in both cases, the contribution of dry enthalpy helped to reduce the dynamic term and was small in the thermodynamic term."

"

42. L485-487: It's not clear to me whether the results shown here really are consistent with those of Nicholson et al. (2021). More analysis is needed to demonstrate that.

<u>Answer</u>: Nicholson et al (2022) indicated that record SSTs in the tropical Atlantic are likely to have been an important factor for the three westernmost regions, particularly the strong coastal anomalies. The warming of the equatorial Atlantic, favoured by an unusually strong thermal low over the Sahara, may have contributed to delaying the retreat of the West African monsoon, resulting in positive rainfall anomalies over the Sahel and the Guinean coast. In addition, further analysis of the dynamic and thermodynamic processes showed that the precipitation anomalies were induced by

dynamic effects in the moisture and MSE budgets associated with the meridional circulation over the Sahel where the pronounced precipitation anomalies were observed, thus establishing a link between the two studies. 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 on 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 over 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. 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."

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.

Answer: **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)" .

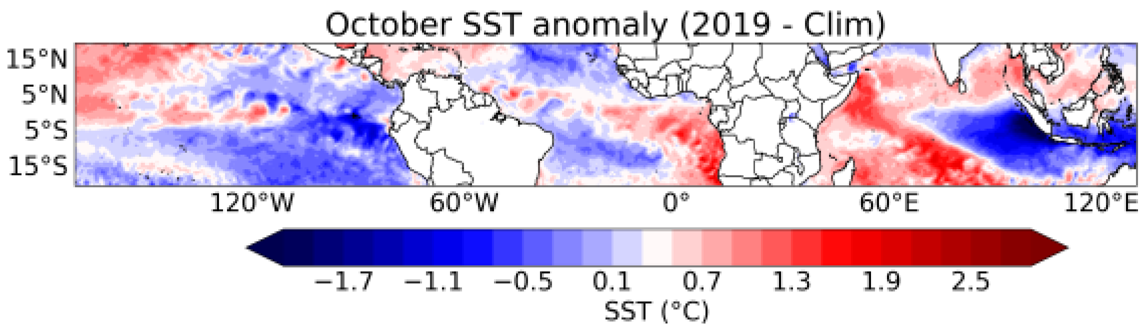


Fig. 1. SST anomalies during October 2019 vs long-term mean (1987-2017).

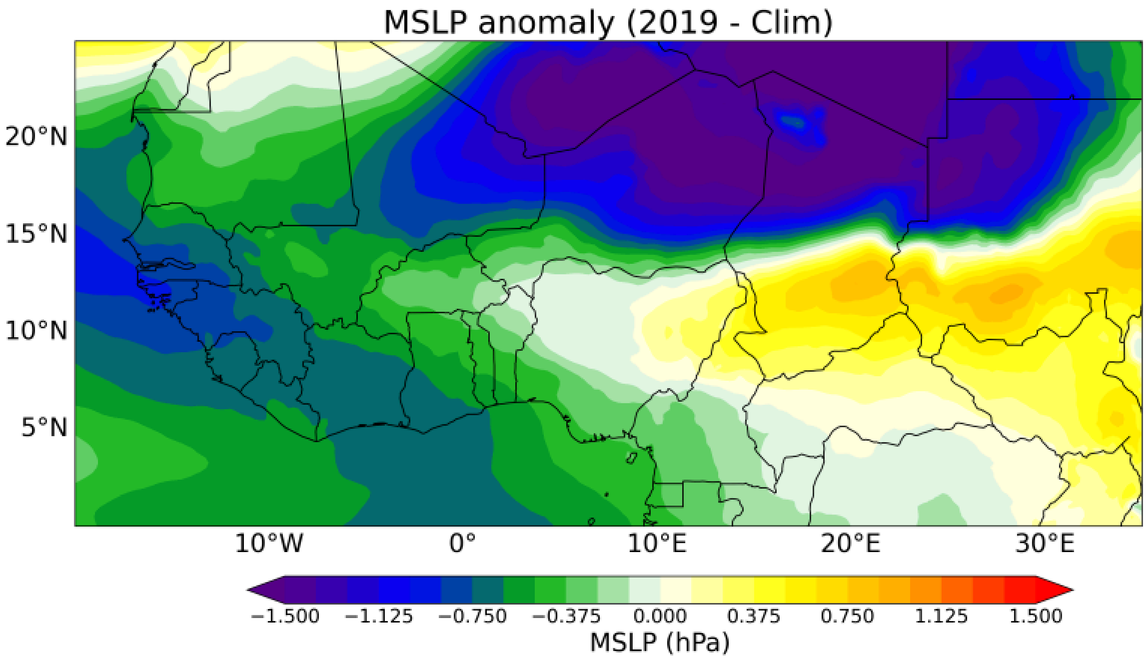


Fig. 2. Mean sea-level pressure anomalies (MLSP) during October 2019 vs long-term mean (1987-2017).

 # 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.

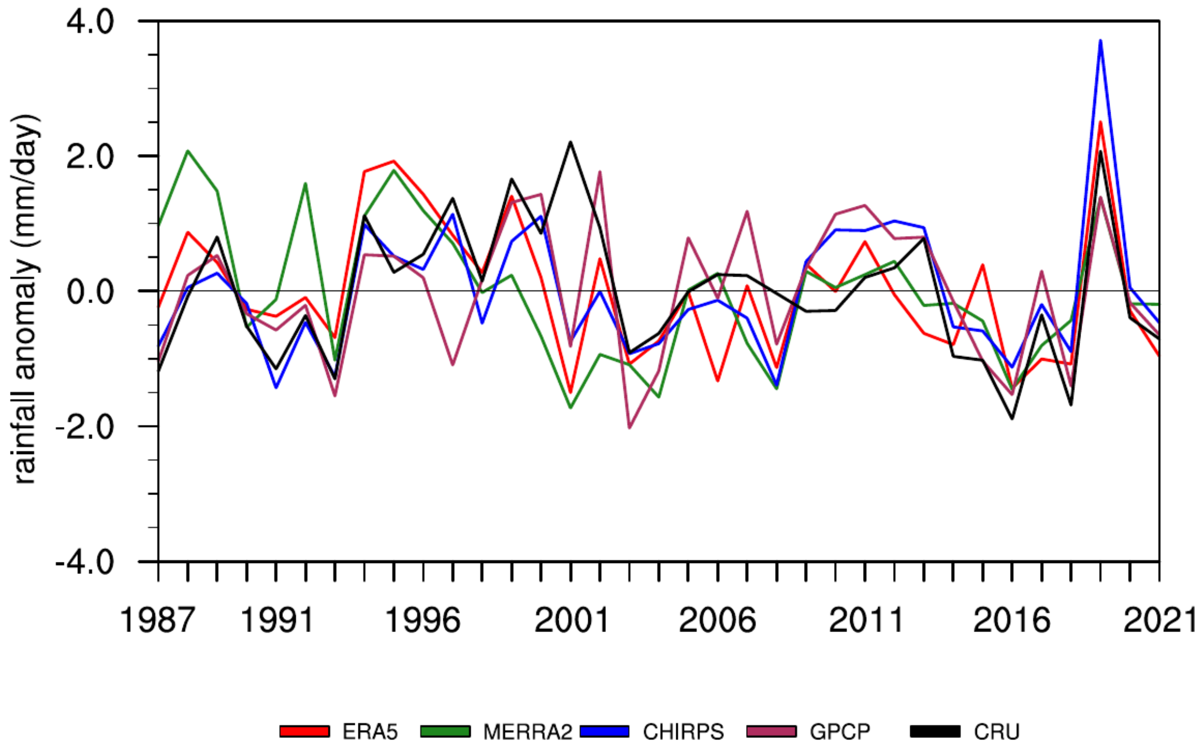


Fig 1. Temporal evolution of October rainfall anomaly over West Central Africa (6°N-14°N, 6°-20°E), from reanalysis data ERA5 (red), MERRA2 (forestgreen), and from observational data CHIRPS (blue), GPCP (maroon) and CRU (black), covering the period 1987–2021.

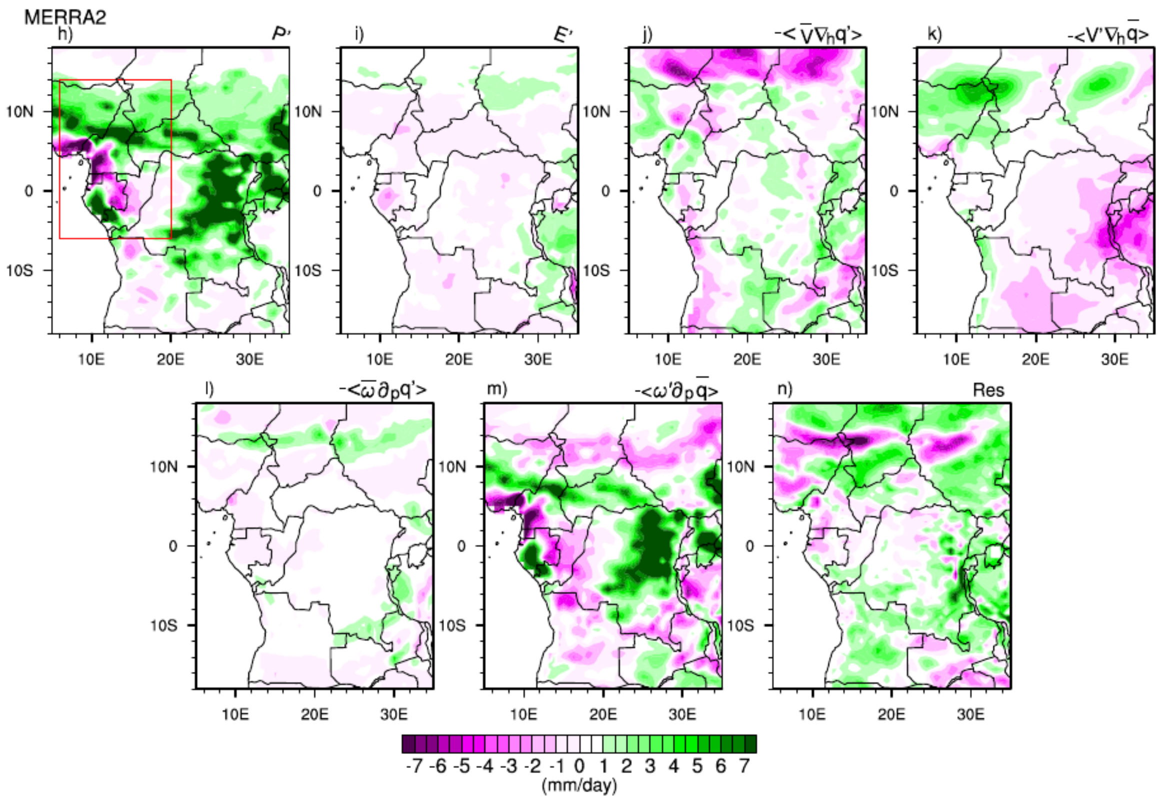


Fig. 2. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa. (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture by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

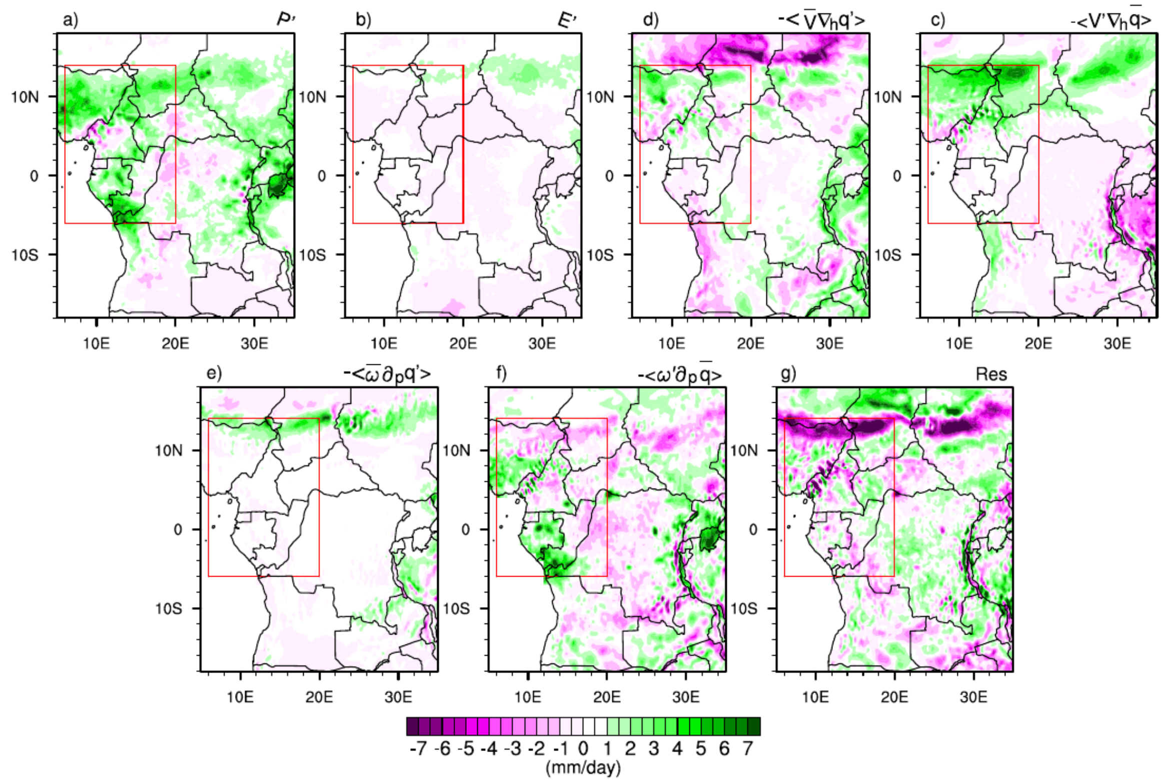


Fig. 7. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa. (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture by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

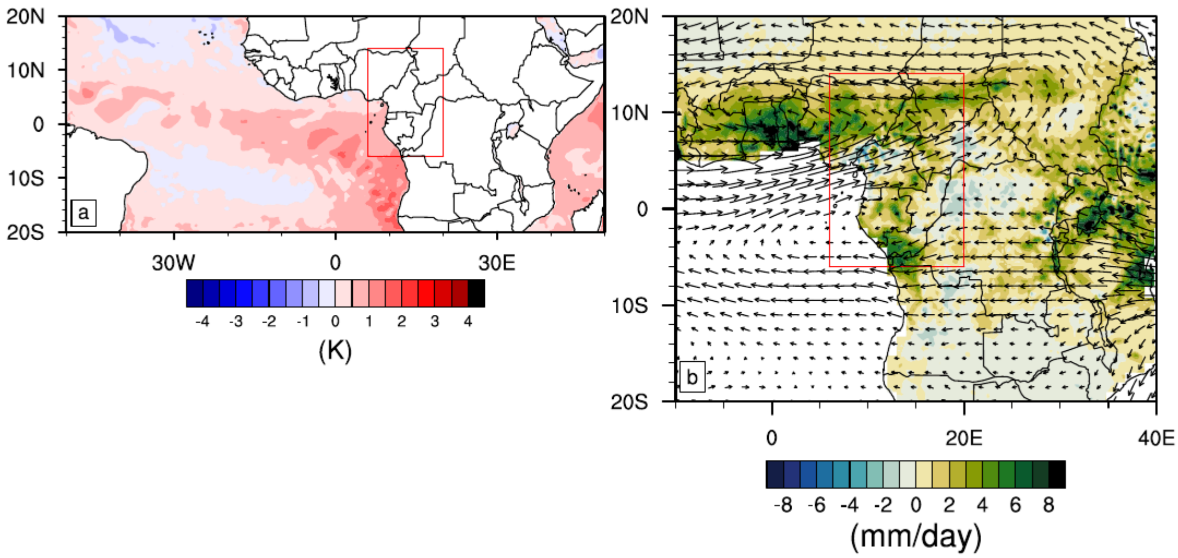


Fig 1. SST a) and rainfall b) anomalies during October 2019. The vectors represent anomalies of vertically integrated atmospheric moisture flux. The red box indicates the Central West Africa area.

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

Answer: 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?)

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

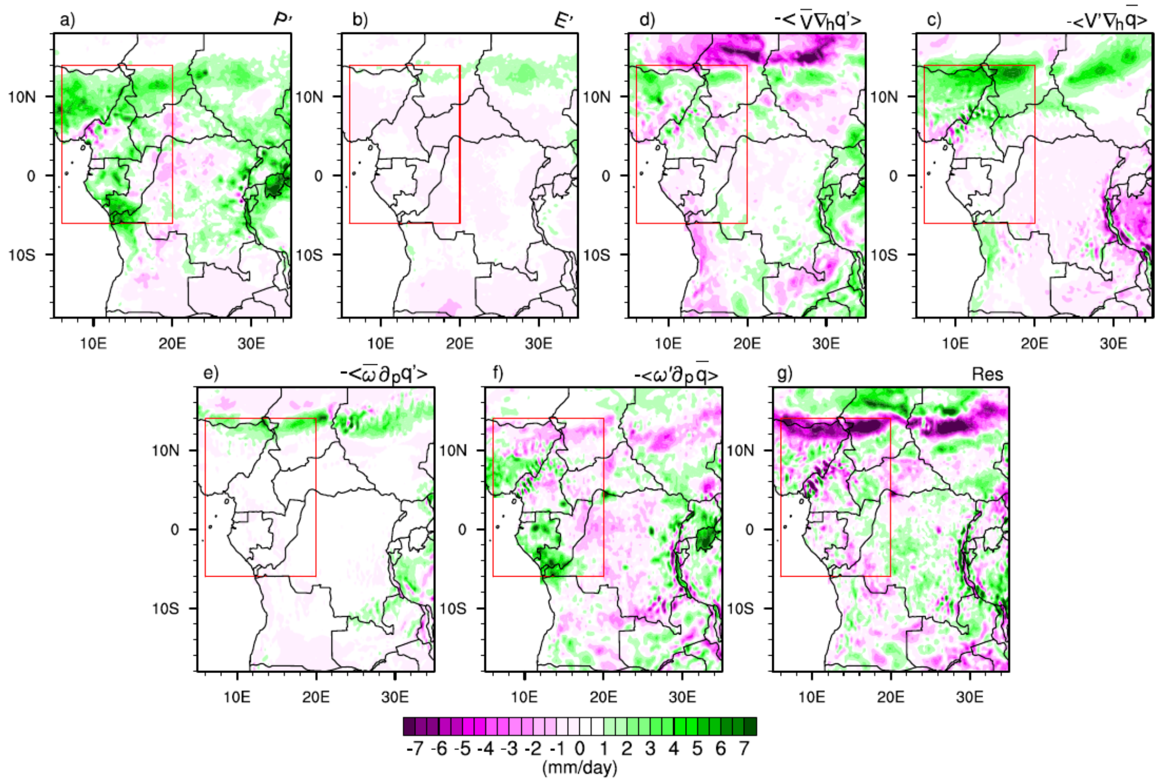


Fig. 7. Spatial distributions of each term of the water budget equation during October 2019 over West Equatorial Africa (Red box). (a) Precipitation anomalies, (b) evaporation anomaly, (c) horizontal advection of anomalous moisture by climatological wind, (d) horizontal advection of climatological moisture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

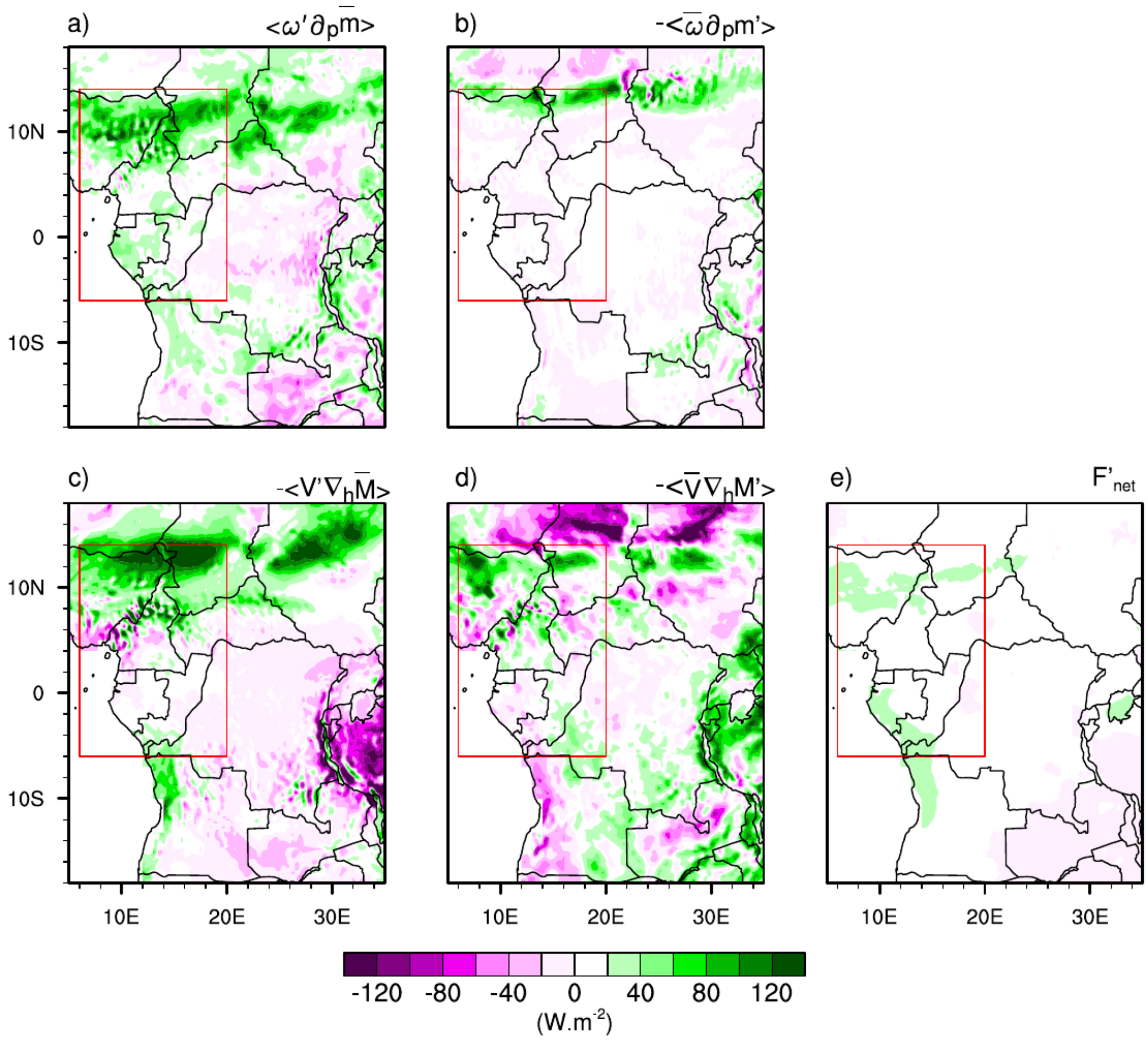


Fig. 11. Spatial distributions of each term of the Moist Static Energy (MSE) balance equation during October 2019 over West Equatorial Africa (Red box). (a) vertical advection of climatological MSE by anomalous vertical velocity, (b) vertical advection of anomalous MSE by climatological vertical velocity, (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.

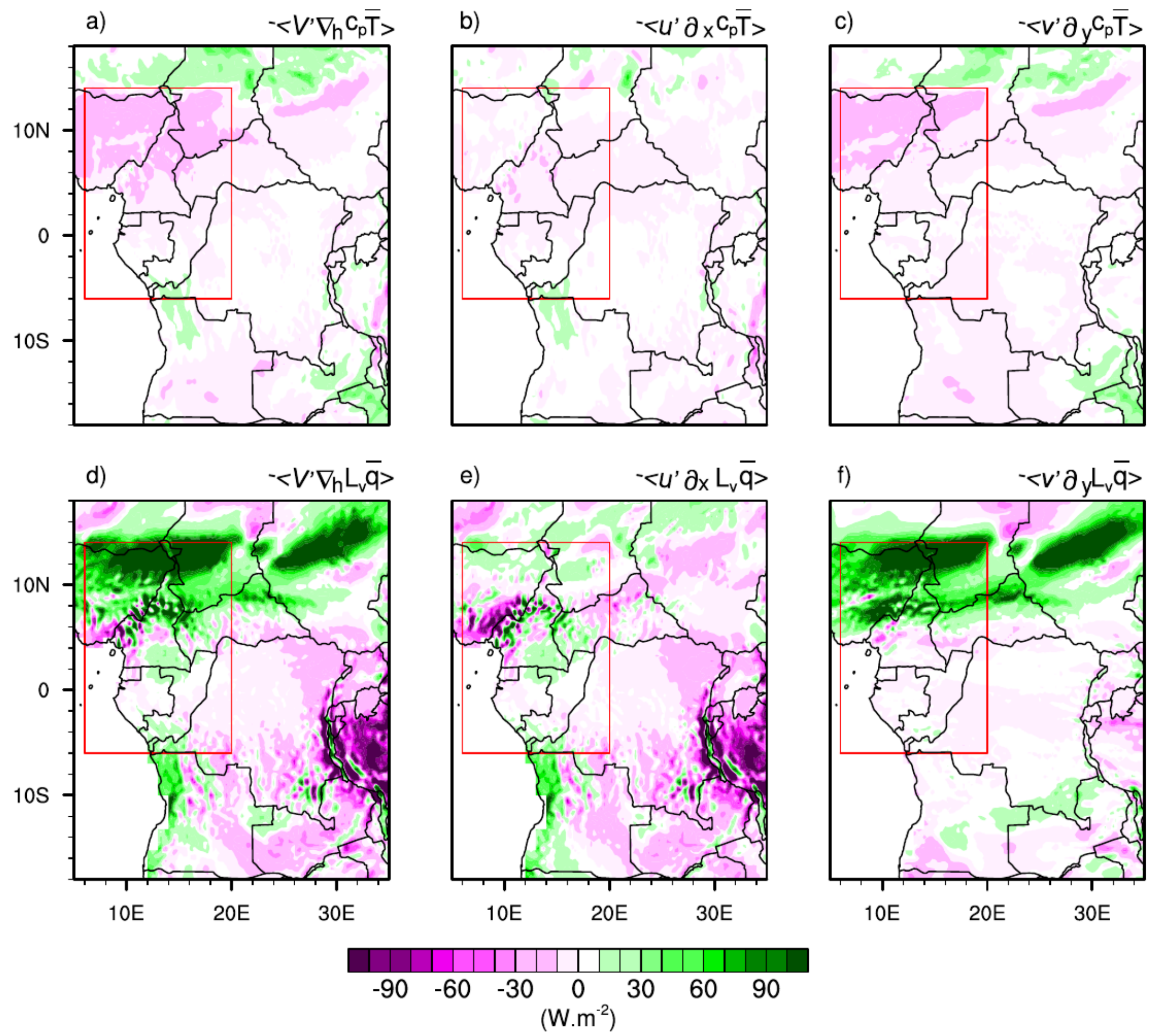


Fig. 12. Horizontal advection of (a–c) climatological dry enthalpy and (d–f) latent energy by anomalous wind, designated as a dynamic effect during October 2019 over West Central Africa (Red box). (a, d) Total advection, (b, e) zonal component, and (c, f) meridional component.

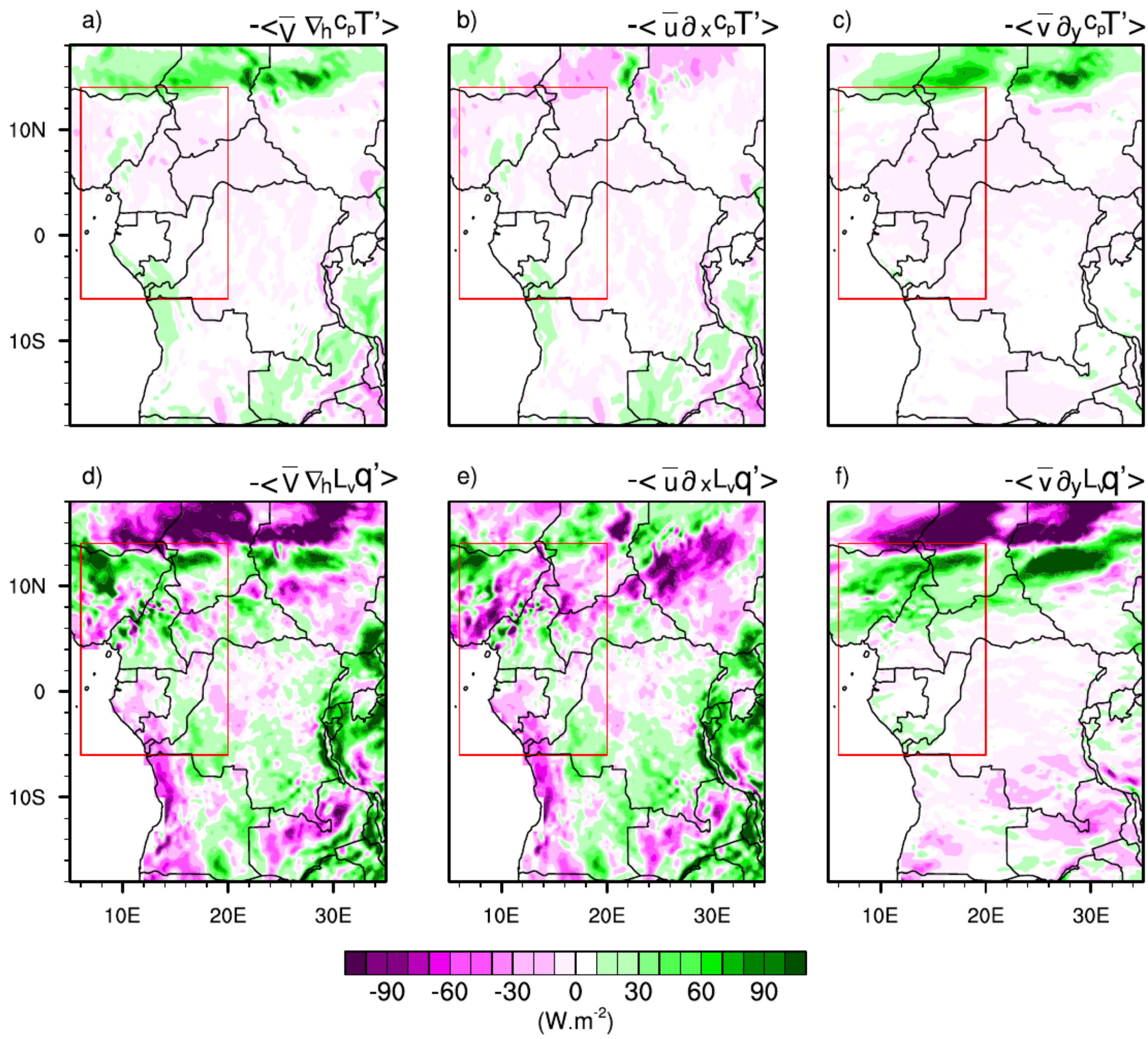


Fig. 13. As in Fig. 12, but for the thermodynamic effect (horizontal advection of anomalous dry enthalpy and latent energy by climatological wind) during October 2019 over West Central Africa (Red box).

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.