**Reviewer 1**

General Assessment:

Although the topic is very interesting and relevant, the analysis appears somewhat simplistic. The connection between the presented results and the conclusions is not always clearly demonstrated, and some interpretations seem speculative. In particular, additional and clearer analyses would be needed to substantiate the proposed climatological shift around 2003 and its relevance to the 2024 event.

**Response:**

We would like to thank the reviewer for their positive evaluation of the relevance and interest of our study, as well as for this critical oversight. We acknowledge that the connection between the long-term climatological shift (around 2003) and the specific synoptic drivers of the August 2024 extreme event needed a more rigorous, quantitative demonstration to avoid any speculative interpretation.

To address this and deepen the analysis, we have thoroughly revised the manuscript and implemented the following major improvements:

1. Rather than an abrupt structural regime shift in the trend itself, the year 2003 marks a key climatological transition threshold where the long-term linear Sen's slope intersects the historical baseline mean.
2. **Connecting Climatology to the 2024 Event:** We have clarified the narrative to demonstrate better how this post-2003 altered background state (characterized by a mean northward displacement of the ITF and increased baseline moisture) increased the probability and intensity of the synoptic-scale dynamic-thermodynamic coupling observed in August 2024.
3. **Refining Interpretations:** We have carefully rephrased sections where interpretations could be perceived as speculative, ensuring every claim regarding the intensification of the West African Monsoon over the Chadian Sahara is strictly anchored in our budget analyses (Moist Static Energy and low-level convergence...).

A point-by-point response to your specific comments, along with the corresponding modifications in the text, is provided below.

**Abstract:** The link between the proposed 2003 tipping point (climatological evolution) and the specific 2024 event is not clearly established.

**Response:** We acknowledge that using the term "tipping point" created confusion. We have rephrased the Abstract to accurately reflect that 2003 represents the threshold year where the long-term humidification trend crossed the historical climatological mean, shifting the baseline state. The updated text in the Abstract now reads: “*While the exceptional rainfall of August 2024 was triggered by acute synoptic-scale dynamic-thermodynamic coupling, its extreme magnitude was favored by a robust multi-decadal humidification trend. This trend crossed the historical climatological mean around 2003, transitioning the region into a consistently moister background state that has altered the baseline susceptibility of the Chadian Sahara to extreme monsoonal rainfall events.*”

**Section 3.1 and Figure 2:** The authors mention a sharp break in trends visible in both datasets of Figure 2, but there is no clear visual evidence supporting this claim. Instead, the series appear closer to a linear trend over the whole period with a few atypical positive or negative anomalies. This weakens the argument for a structural shift emphasized in the abstract and throughout the text. In addition, the hydrological consequences discussed at the end of the paragraph are not supported by sufficient evidence. Hydrological regimes depend on many factors beyond rainfall during a single month, including antecedent conditions, evaporation, and water use. This part therefore seems overly speculative.

**Response:**

We thank the reviewer for this insightful comment. We realize that our use of the term "structural shift" or "sharp break" was misleading from a purely statistical standpoint, as it implied an abrupt change in the trend slope itself. We completely agree with the reviewer that both the TAMSAT and CHIRPS datasets are best characterized by a robust, continuous, and statistically significant monotonic linear trend over the entire 1983-2024 period, as evidenced by the high confidence levels of the Sen's slope estimates ($p = 1.35 \times 10^{-5}$ for TAMSAT and $p = 1.06 \times 10^{-4}$ for CHIRPS). However, our definition of the "**2003 tipping point**" was intended to reflect a climatological threshold rather than an abrupt statistical regime shift. Specifically, 2003 marks the exact intersection where the long-term upward trend permanently crosses the historical 41-year climatological mean (12.7 mm for TAMSAT, 9.6 mm for CHIRPS). To make this explicit, we have revised the text to clarify this physical mechanism:

1. ***Before 2003:*** *The regional climate was dominated by dry conditions, with the vast majority of years falling well below the long-term mean.*
2. ***After 2003:*** *Due to the robust humidification trend, a clear regime climatological transition occurs. Post-2003, nearly all annual values shift above the historical mean, establishing a moister "new normal" background state.*
3. ***The 2024 Event:*** *This record-breaking event (reaching an unprecedented ~70 mm/month in TAMSAT) represents an extreme manifestation that sits at the tail end of this multi-decadal humidification trend. We have revised Section 3.1 and updated the Abstract to replace terms like "structural shift" or "tipping point" with more accurate terminology, such as "**climatological transition threshold**" or "**forced multi-decadal trend crossing the baseline mean**".*

Regarding the hydrological comments, we agree that drawing conclusions about hydrological regimes based solely on a single month's rainfall without accounting for antecedent soil moisture, potential evapotranspiration, and water use is speculative. Since a comprehensive hydrological budget is beyond the scope of this atmospheric study, we have removed the speculative statements regarding hydrological regime shifts at the end of the paragraph. We now strictly restrict our discussion to the documented socio-economic and flooding impacts as reported by local agencies.

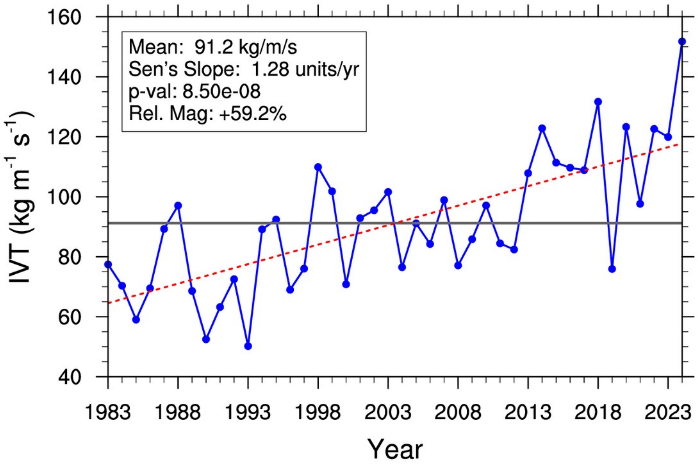
**Section 3.2:** To compare the temporal evolution of precipitation with atmospheric drivers, it would be useful to include a figure showing the temporal evolution of an integrated indicator of wind convergence or humidity. This would help assess whether similar variability and trends are present as those shown in Figure 2.

**Response:** We highly appreciate this constructive recommendation, which strengthens the core dynamic-thermodynamic linkage of our manuscript. To address this comment and bridge the gap between long-term precipitation and atmospheric forcing, we have analyzed the multi-decadal (1983-2024) time series of Integrated Vapor Transport (IVT) during August from the ERA5 reanalysis over our specific Northern Chad domain. We have integrated these results into the revised manuscript as a new figure.

As anticipated by the reviewer, this atmospheric driver exhibits a remarkable and statistically significant co-variability with the TAMSAT and CHIRPS precipitation series. The IVT trend is highly robust, with a Sen's slope of 1.28 units/yr and a p-value of 8.50e-08, representing a relative magnitude increase of +59.2% over the 42-year period. The IVT time series mirrors the exact same behavior as the rainfall data:

1. Late 20th-Century Drought Cycles: The series is dominated by persistent negative anomalies during the 1983s and 1990s, reflecting a suppressed moisture supply to the region.
2. The 2003 Regime Shift: Similar to the precipitation data, the IVT crosses its historical climatological mean (91.2 kg/m/s) around the 2003 threshold year, transitioning the regional atmosphere into a consistently heightened moisture-loading state.
3. The 2024 Historical Record: The IVT reaches an unprecedented peak in August 2024 (exceeding 150 kg/m/s), marking the highest value in the entire 1983-2024 record.

This strong co-alignment confirms that the exceptional event of August 2024 did not occur in isolation but was robustly modulated by a long-term, physically consistent intensification of the atmospheric moisture transport background state over the Chadian Sahara. Section 3.2.1 has been expanded with a new dedicated paragraph to explicitly discuss these long-term trends and contextualize the synoptic drivers of the 2024 extreme event.




Minor comments

113: Does MSE decrease CIN or increase CAPE? Please clarify.

**Response:** We thank the reviewer for this insightful precision. We agree that in a theoretically, an increase in Moist Static Energy (MSE) operates through both components of atmospheric instability by simultaneously boosting the CAPE and reducing the CIN.

We have now updated the text to reflect this dual thermodynamic mechanism.

The text (Line 113) has been revised as follows: *"Thermodynamically, an increase in MSE reflects a warmer and moister boundary layer, which directly enhances the convective available potential energy (CAPE) while simultaneously reducing convective inhibition (CIN)."*

120: Not sure about the reference Panthou et al. (2020); it is also missing from the reference list.

**Response:** Thank you for pointing this out. The reference Panthou et al. (2020) was indeed a remnant from an earlier draft and was missing from the bibliography. It has now been completely removed from the text (Line 120) to ensure full consistency with the reference list.

l126: I do not agree with the term "low rainfall variability." The previous sentences could be improved. There is confusion between extreme hazard values and impacts. This part should be clarified.

**Response:** We completely agree with the reviewer's assessment. The term *"low rainfall variability"* was inaccurate, as hyper-arid regions are actually characterized by high interannual variability but **low mean annual rainfall**. We also acknowledge the confusion between the physical hazard values and their socio-economic impacts.
To address this, we have thoroughly revised the sentences to clearly decouple the climatological background (hyper-aridity) from the societal impacts (vulnerability due to lack of infrastructure designed for torrential events).
The text has been corrected as follows: *"This crisis highlighted the acute vulnerability of local socio-ecosystems, which are historically adapted to a hyper-arid regime with low mean annual rainfall. In such environments, even a minor absolute increase in precipitation represents a severe hydrometeorological hazard, triggering disproportionate societal disruptions due to the lack of infrastructure designed for torrential rain."*

l129: Clarify the meaning of "true" in the text.
**Response:** We agree with the reviewer. The word "true" was an unnecessary qualitative descriptor and has been completely removed from the sentence to maintain a strict scientific and objective tone.
The text now reads: "*...while the specific atmospheric mechanisms driving rainfall in the Saharan desert remain insufficiently documented.*"

l149: "Extreme thermal amplitude and negligible annual rainfall" should be defined more scientifically.
**Response:** We acknowledge the reviewer's feedback regarding the qualitative nature of these terms. To enhance scientific precision, we have replaced "extreme thermal amplitudes" with a more accurate description of the diurnal and seasonal temperature variations. Furthermore, we have replaced "negligible annual precipitation" with the standard quantitative threshold for hyper-arid Saharan regimes (mean annual precipitation below 50 mm).
The text has been revised as follows: "*The regional climate is hyper-arid, characterized by high diurnal and seasonal thermal ranges and a mean annual precipitation below 50 mm.*"

Figure 1: Improve the caption by explaining the different panels. The right panel is not clearly described.
**Response:** Thank you very much for this important observation, which will allow us to better situate the reader within the geographical area of this study. The first map presents the general climatic conditions of northern Chad, and the second map shows some of the towns and villages in the area to demonstrate that, despite the desert landscape, there is a very real human presence. Therefore, we have added the following comment at the bottom of this figure: "*Figure 1 shows northern Chad in Africa. Caption A shows that this predominantly desert area is bordered to the south by the 100 mm isohyet. Caption B presents the four administrative provinces whose socioeconomic losses from the August 2024 floods were analyzed. It is noticeable that despite the desert environment, numerous settlements are located there, generally in oases.*"

Subsection 2.3: The detailed computation of climatological anomalies and convergence is quite obvious and may not be necessary.

**Response:** We take the reviewer's point. The mathematical descriptions and detailed steps for computing standard climatological anomalies and wind convergence have been removed in Subsection 2.3 to avoid stating the obvious. We have condensed this section to focus strictly on the specific baseline periods used (1983 - 2024) and the spatial domain of integration, ensuring the methodology remains concise yet reproducible.

l274: Is this region displayed in Figure 1, panel b?

**Response:** We thank the reviewer for this remark. Indeed, this area is visible in Figure 1. To complete the referencing at this level of writing, we have each sentence on line 274 as follows: "*The interannual variation in August rainfall in northern Chad (16°-24°N, 13°-25°E - figure 1) characterizes a hydro-climatic regime defined by extreme scarcity and high interannual variability, where monthly totals historically hover around a low climatological baseline of 9 to 13 mm.*"

l275: What is meant by "structural volatility"?

**Response:** We acknowledge that the term "structural volatility" is less standard in climatology. By this expression, we intended to describe the permanent, intrinsic feature of hyper-arid regimes where rainfall is not only scarce but subject to extreme, non-linear fluctuations from one year to the next.

To align with standard meteorological terminology, we have replaced "structural volatility" with "high interannual variability" in the revised text.

The text has been updated as follows: "*The interannual variation in August rainfall in northern Chad (16°–24°N, 13°–25°E) characterizes a hydro-climatic regime defined by extreme scarcity and high interannual variability…*"

Figure 3: The anomaly seems to depict a cyclonic wind circulation pattern, but this is not associated with a southward shift of the ITCZ on the western side of the circulation. Could the authors comment on this?

**Response:** We thank the reviewer for this comment regarding the dynamic structures in Figure 3. The anomaly field (Figure 3c) indeed reveals a well-defined cyclonic wind anomaly pattern centered over the Chad-Niger border.

In a classical, isolated synoptic system, the western flank of a cyclonic circulation typically induces a northerly wind anomaly that can push the Intertropical Front (ITF) southward. However, during August 2024, this did not occur for two key physical reasons:

1. Large-scale monsoonal forcing: the cyclonic anomaly is embedded within a highly energized, deeper, and wider-than-usual West African Monsoon (WAM) flow. As seen in Figure 3b, the south-westerly monsoonal winds were exceptionally strong and maintained a strong, continuous penetration northward across the entire longitudinal band (10°E - 30°E). This large-scale dynamic thrust completely counteracted and overwhelmed any local northerly advection on the western side of the cyclonic anomaly.
2. Deep Saharan heat low (SHL) displacement: the anomalous cyclonic feature is structurally linked to the northward migration and intensification of the SHL. This thermal setup continuously pulled the low-level convergence moisture boundary further north. Therefore, instead of tilting southward, the ITF reached an unprecedented northward position, even on the western side of the cyclonic structure, stabilizing near 20°N - 21°N. (Figure 3b).

To clarify this for the general reader, we have added a brief explanatory sentence in the revised manuscript (Section 3.2, lines ) highlighting that the large-scale monsoonal push overrode the local northerly anomalies of the cyclonic pattern, keeping the ITF consistently shifted northward.

Figure 5: The authors do not comment on the very strong descending wind anomaly below 700 hPa during summer 2024. How do they explain this feature?

Response: The reviewer is entirely correct, and this feature is indeed an artifact of the anomaly calculation combined with the meteorological sign convention for vertical velocity (ω in Pa/s), where negative values denote ascent).

Geographically, the region between 15°N and 18°N experienced upward motion in both the climatology ($\omega_{clim} < 0$) and during August 2024 ($\omega_{2024} < 0$), as confirmed by the actual wind vectors in Figures 5a and 5b.

However, because the core of the deepest convective ascent migrated unusually far north (beyond 20°N) in August 2024, the upward vertical velocity within the 15°N - 18°N band was weaker in absolute terms than its historical climatological counterpart ($|\omega_{2024}| < |\omega_{clim}|$). Mathematically, subtracting a strongly negative climatological value from a less negative 2024 value yields a positive anomaly ($\omega_{2024} - \omega_{Clim} > 0$).

In meteorological plotting, this positive anomaly is visually translated into downward-pointing vectors. It represents a relative deficit in upward moisture cell intensity compared to the baseline, rather than an actual synoptic-scale subsidence. We have clarified this statistical nuance in the revised text to avoid any confusion.

l484: Same comment as previously regarding CIN.

**Response:** We thank the reviewer for this important clarification regarding the dual thermodynamic role of MSE. An increase in low-level MSE inherently affects both parameters: it enhances the buoyancy of the lifted parcel, thereby expanding the convective available potential energy (CAPE) aloft, while concurrently reducing the negative area at the base of the profile, thus lowering the convective inhibition (CIN).

To reflect this accurately, we have revised the text to state that the increased MSE simultaneously maximizes CAPE and reduces the CIN barrier.

The text has been updated as follows: "*The spatial overlap of MSE maxima, convergence zones, and ascent cores suggests a dynamic-thermodynamic locking mechanism, wherein increased low-level MSE simultaneously maximizes convective available potential energy (CAPE) and reduces the convective inhibition (CIN) barrier…*"

l514: The title of subsection 3.2.5 sounds unclear; please rephrase.

**Response:** Done. The title of subsection 3.2.5 has been rephrased to be more precise and direct: *"3.2.5. Magnitude and Relative Contribution of the August 2024 Rainfall Anomalies"*.