Reviewer 1

The authors sincerely addressed most of my comments. Below are additional comments for the authors' consideration. Most of them are about the divergent results between correlation analysis and SHAP-driven clustering combined with RF.

We would like to thank the Reviewer for the thorough review of our manuscript. We have revised the manuscript by carefully considering all the comments. During this process, we also introduced several additional changes, which we believe have further improved the quality and presentation of the work. We hope that the current version will be found suitable for publication. Below, we provide a detailed and point-by-point responses to the specific review comments.

Major comments:

1. It is unclear which indices play a major role in the Sahel drought. In the abstract, line 13 highlights GMT and IPWP. Yet, lines 19-20 emphasize AMO and NTA. Does it mean that the correlation analysis and RF model results are inconsistent? In addition, line 15 states that AMO has a distinct influence. It is unclear what "distinct" means. I suggest the authors specify what "positive correlation" means in physical terms. For example, it could mean when AMO is at warm phase, drought severity increases, or something like that.

   We thank the Reviewer for this insightful observation. We acknowledge that the abstract may have appeared inconsistent by highlighting GMT and IPWP in one part and AMO and NTA in another. We have revised the abstract and discussion to explicitly state that these approaches are not inconsistent but rather provide different perspectives: GMT and IPWP act as overarching amplifiers of drought intensity, while AMO and NTA govern the spatial differentiation of drought patterns:

   Correlation analysis revealed strong negative relationships between SPEI-12 and GMT (up to -0.76) and IPWP (-0.71), underscoring their role in drought intensification. Conversely, AMO (0.40) showed a positive correlation, meaning that during its warm phase rainfall tends to increase, alleviating drought severity, while its cold phase intensifies drought. This reflects a spatially heterogeneous influence distinct from the consistently negative effects of GMT and IPWP. Using the SHAP-driven clustering, AMO and NTA emerged as key discriminators of regional drought regimes. Thus, correlation analysis and RF/SHAP highlight complementary perspectives: parameters such as GMT and IPWP drive overall drought intensification, while parameters such as AMO and NTA govern the regional differentiation of drought patterns.

2. Similar as above, line 401 indicates that AMO is the most influential feature across all three clusters, yet Fig. 5 shows AMO has weak correlation with SPEI-12 across much of the domain (most |r| ≤0.25). Conversely, indices such as

GMT and IPWP show stronger correlations (>0.25) but are not picked by RF. Please discuss why these diagnostics differ. This will better link various components of the paper.

We appreciate the Reviewer's careful comparison of the correlation maps (Fig. 5) with the SHAP-based feature importance results. The apparent discrepancy arises because the two approaches capture different aspects of the climate–drought relationship:

- Correlation analysis measures the strength of direct, linear associations between each climatic index and drought severity (SPEI-12). From this perspective, indices such as GMT and IPWP show stronger average correlations because they act as broad-scale amplifiers of drought through warming-induced evapotranspiration and moisture deficits.
- SHAP-driven Random Forest analysis, in contrast, does not rely on linearity. Instead, it evaluates how much each index contributes to distinguishing between clusters of drought regimes. Even if an index like AMO shows weak average correlation values across the entire Sahel, its spatially heterogeneous effects (positive in some areas, negative in others) and its interaction with other indices allow it to play a disproportionately large role in separating the clusters. This is why AMO emerges as a top SHAP contributor despite its modest mean correlation. Conversely, GMT and IPWP, though strongly correlated overall, do not necessarily improve the model's discrimination among clusters because their influence is more spatially uniform.

We have clarified this distinction in the revised Discussion (Section 4.1), emphasizing that correlation highlights direct associations, whereas SHAP/RF reveals the indices most relevant for identifying distinct hydroclimatic regimes. These diagnostics should therefore be viewed as complementary rather than contradictory:

Beyond linear associations, the correlation structure between global climate drivers and regional drought variability reveals an intricately woven network of teleconnections that challenge traditional dichotomies of cause and effect. The AMO emerges as a bifurcated influence, exerting positive correlations in western and central-eastern Sahel but negative correlations in central-western regions such as Burkina Faso. This spatially divergent response suggests that the AMO does not exert uniform control over Sahelian drought but rather interacts with localized boundary conditions in ways that defy simplistic interpretations. It is important to note that the apparent differences between the correlation maps (Fig. 5) and the SHAP-based feature importance results do not represent inconsistencies but rather reflect the different nature of these diagnostics. Correlation analysis highlights the strength of direct, linear associations between climatic indices and drought intensity, which explains why GMT and IPWP show strong correlations across much of the Sahel. In contrast, SHAP-driven Random Forest analysis evaluates the contribution of each index to the classification of distinct drought regimes. Although AMO shows relatively weak average correlations, its spatial heterogeneity and nonlinear interactions with other indices allow it to emerge as a key *discriminator among clusters. Conversely, the more spatially uniform influence of GMT and IPWP, while important for overall drought intensification, contributes less to distinguishing regional drought regimes. Thus, correlation and SHAP/RF provide complementary insights: the former identifies direct associations with drought severity, while the latter uncovers the indices most relevant for separating hydroclimatic regimes. Similarly, GMT and IPWP exhibit strong negative correlations with SPEI-12 (-0.76 and -0.71), reinforcing their role as primary drought intensifiers, while Sahel P maintains a positive correlation (0.22), acting as a partial counterbalance to the prevailing drying trend. The weaker and inconsistent influence of AO and NAO underscores the selective and spatially constrained nature of extratropical climatic influences on the Sahel.*

3. It is unclear based on what criteria that the authors determine the "most correlated climatic indices" (Fig. 5). If the authors used the mean correlation, AMO, CAR, and TNA actually have low absolute means (0.06, −0.07, −0.07), while indices that are not shown, such as Niño-4, TNI, and Niño-3.4 have larger absolute means (−0.20, 0.15, −0.12). If instead the authors used extremes (e.g., minimum/maximum values), please justify why a single extreme value is an appropriate criterion. Also note that mixing positive and negative correlations can lead to a small mean value even when |r| is large. I recommend reporting the mean of the absolute correlations to better reflect the correlation strength.

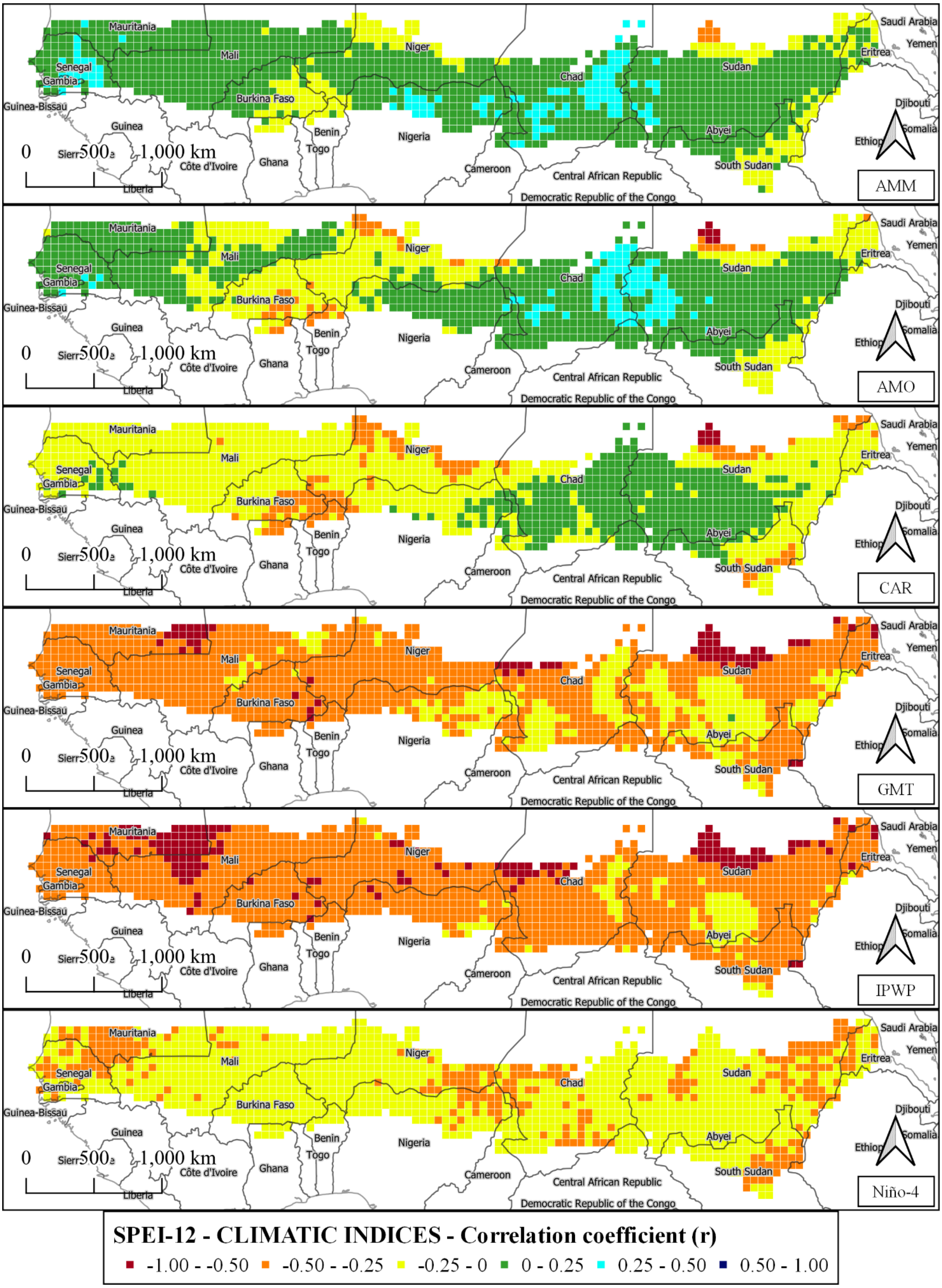
   We thank the Reviewer for this helpful comment. In fact, Figure 5 reports a selection of the most correlated climatic indices rather than an exhaustive list. Based on the mean of the absolute correlations, the eight indices with the strongest overall relationships to SPEI-12 are IPWP, TSA, GMT, PDO, Sahel P, Niño-4 (now added to Figure 5), NTA, and WHWP.

   However, we also chose to include additional indices such as AMO, AMM, CAR, and TNA because, although their mean correlations were relatively low, they exhibited distinctive spatial patterns in certain parts of the Sahel, including strong localized positive or negative peaks. These indices therefore provide important insights into regional heterogeneity that would not be captured by absolute mean values alone.

   To avoid confusion, we have revised the text to clarify this selection criterion. Specifically, the sentence *"while Figure 5 provides the maps of the correlations between SPEI-12 gridded data and the most correlated climatic indices"* has been updated to:

   Figure 5 provides the maps of correlations between SPEI-12 gridded data and a subset of 12 climatic indices, selected either for their high mean absolute correlations (IPWP, TSA, GMT, PDO, Sahel P, Niño-4, NTA and WHWP) with SPEI-12 or for their distinctive spatial patterns across the Sahel (e.g., AMO, AMM, CAR, TNA).

   The updated Figure 5 is shown below:


AMM
AMO
CAR
GMT
IPWP
Niño-4
Mauritania
Mali
Niger
Senegal
Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Togo
Ghana
Côte d'Ivoire
Liberia
Nigeria
Cameroon
Chad
Central African Republic
Democratic Republic of the Congo
Sudan
South Sudan
Abyei
Eritrea
Djibouti
Somalia
Saudi Arabia
Yemen
0
500
1,000 km
SPEI-12 - CLIMATIC INDICES - Correlation coefficient (r)
-1.00 - -0.50
-0.50 - -0.25
-0.25 - 0
0 - 0.25
0.25 - 0.50
0.50 - 1.00

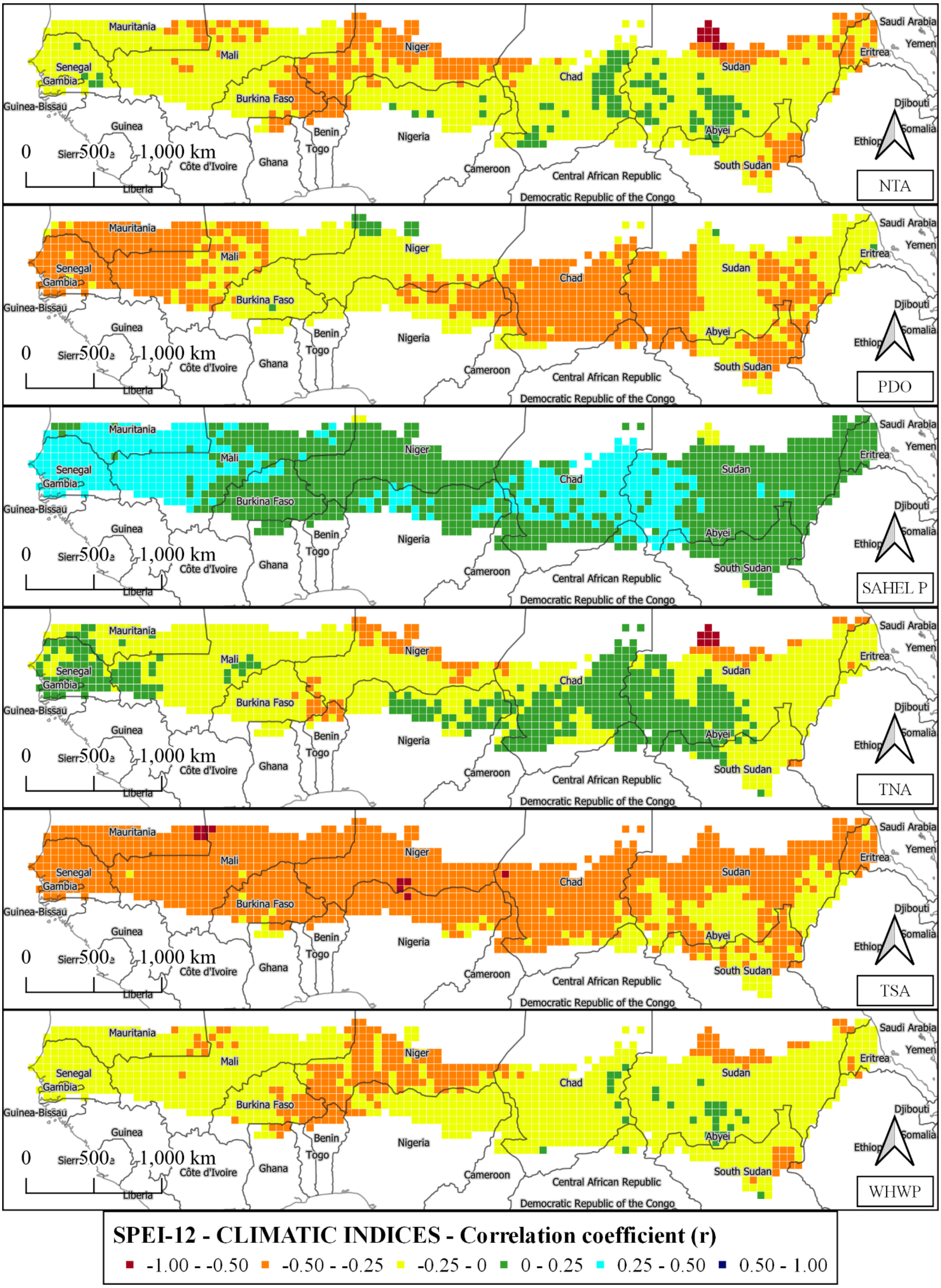


Figure 5. Maps of the correlations between SPEI-12 gridded data and a subset of 12 climatic indices (continue).

The updated Table S3 is shown below and included in the supplementary material.

Table S3. Mean, maximum, minimum values, standard deviation of the correlations, and mean of the absolute correlations, calculated between SPEI-12 gridded data and climatic indices. The color bar ranges from red (negative correlations) to blue (positive correlations) and from green (lower standard deviation) to yellow (higher standard deviation).

Correlation coefficient (r)	Mean	Max	Min	Dev.st	Mean of |r|
AMM	0.12	0.39	-0.34	0.11	0.13
AMO	0.06	0.40	-0.59	0.16	0.14
Arctic Osc.	-0.02	0.15	-0.15	0.04	0.04
BEST	-0.11	0.09	-0.26	0.06	0.11
CAR	-0.07	0.25	-0.61	0.14	0.12
EPO	0.00	0.11	-0.11	0.04	0.03
GBI	0.00	0.05	-0.08	0.02	0.01
GMT	-0.33	0.01	-0.76	0.11	0.33
IPWP	-0.39	-0.08	-0.71	0.10	0.39
NAO	-0.03	0.08	-0.12	0.04	0.04
NAO (Jones)	0.03	0.13	-0.06	0.03	0.03
Nino1+2	-0.07	0.02	-0.14	0.03	0.07
Nino-3	-0.11	0.04	-0.21	0.04	0.11
Nino3+4	-0.12	0.07	-0.28	0.05	0.12
Nino4	-0.20	0.00	-0.37	0.06	0.20
NOI	0.08	0.20	-0.11	0.05	0.08
North Pasific	0.05	0.10	-0.03	0.02	0.05
NTA	-0.15	0.18	-0.61	0.11	0.16
ONI	-0.06	0.15	-0.26	0.06	0.07
PDO	-0.23	0.10	-0.42	0.09	0.24
PMM	-0.01	0.16	-0.21	0.05	0.04
PNA	-0.07	0.03	-0.19	0.03	0.07
QBO	-0.02	0.14	-0.19	0.06	0.05
Sahel P	0.22	0.35	-0.06	0.06	0.22
SOI	0.10	0.24	-0.08	0.06	0.11
Solar Flux	0.05	0.26	-0.22	0.07	0.07
TNA	-0.07	0.23	-0.55	0.12	0.11
TNI	0.15	0.30	-0.04	0.05	0.15
TSA	-0.33	-0.05	-0.54	0.08	0.33
WHWP	-0.16	0.07	-0.49	0.09	0.16
WPI	0.00	0.10	-0.08	0.03	0.02

4. There is inconsistency across sections. Line 381 states that "In Cluster C1, the AMO, CAR and TNA emerged as the most influential variables", and line 386 states "indices like PDO, GMT, IPWP, and TSA show very limited SHAP influence". Yet line 541 describes Cluster C1 as "more strongly influenced by global warming indicators such as GMT and IPWP."

   We thank the Reviewer for highlighting this inconsistency. In the Results (lines 381–386), SHAP analysis identified AMO, CAR, and TNA as the most influential variables in Cluster C1, while GMT and IPWP showed only limited SHAP influence. However, in the Discussion (line 541), Cluster C1 was mistakenly described as being strongly influenced by GMT and IPWP. We have revised the Discussion accordingly: it now emphasizes AMO, CAR, and TNA as the primary drivers in C1, while noting that GMT and IPWP exert a broader, Sahel-wide effect but not specifically on this cluster. This correction ensures consistency between the Results and Discussion:

   Cluster C1, more strongly influenced by indices such as AMO, CAR, and TNA according to SHAP analysis, may require policies focused on long-term resilience, such as promoting sustainable groundwater extraction, enhancing soil moisture retention through agroecological practices, and integrating climate-smart irrigation systems. Although global warming indicators such as GMT and IPWP play an overarching role in drought intensification across the Sahel, their direct influence on Cluster C1 is comparatively limited.

Minor comments:

1. Lines 260–270: IPWP is reported with a mean correlation of −0.79, but the strongest negative correlation is reported as −0.71. Please double-check these values.

   Thanks for the comment. Correlations have been checked, and the values have been corrected:

   The GMT (IQR = 0.14, mean = -0.33) and IPWP (IQR = 0.13, mean = -0.39) indices exhibited strong negative correlations, reaching values of -0.76 and -0.71, respectively.

2. Line 188: A closing bracket is missing.

   Thanks for the comment. The closing bracket has been added:

   (values with RF models)