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Research Article

Keywords: Saharan Heat Low, Cameroonian hydroclimate, West African Monsoon, Maximum Covariance Analysis, Lead-lag analysis

Posted Date: September 29th, 2026

DOI: <https://doi.org/10.21203/rs.3.rs-11182752/v1>

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Additional Declarations: No competing interests reported.

On the Link between the Saharan Heat Low and the Cameroonian Hydroclimate

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Abstract

Using ERA5 reanalyses from ECMWF and CHIRPS precipitation data, this study investigates the link between the Saharan Heat Low (SHL) and the Cameroonian hydroclimatic variability during the West African Monsoon (WAM) for the reference period 1991-2020. Maximum Covariance Analysis (MCA) demonstrates that a single, robust physical mode (Mode 1) dominates the coupled system between the Saharan atmospheric indices (Field X) and the Cameroonian hydroclimatic parameters (Field Y), accounting for 67.18 % of the total squared covariance with p-value = 0.0216. Expansion coefficients reveal a strong interannual correlation ($r=+0.70$), confirming tight temporal coherence between SHL intensity and regional hydroclimatic anomalies. A weak SHL phase is associated with positive 925 hPa specific humidity (q_{925}) and outgoing longwave radiation (OLR) anomalies, yet correlates negatively with precipitation across most Cameroon's sub-regions. An exception occurs along the Cameroon

Volcanic Line, where windward orographic forcing drives localized convective rainfall, highlighting a physical decoupling between boundary-layer moisture availability and convective initiation. Time-lagged cross-correlations isolate two preferential response windows at $\tau = +3$ to $+4$ days and $\tau = +8$ days, the latter emerging prominently during July-August (JA). This delay mirrors the 3-10 day synoptic periodicity of the SHL pulsations and their dynamical coupling with African Easterly Waves (AEWs) and the African Easterly Jet (AEJ). Extreme SHL deepening ($EC_x < -1.5\sigma$) triggers prominent regional precipitation surges ($EC_y > +1.5\sigma$) within 3 to 8 days, particularly over the Western Highlands, the Adamawa Plateau and the Coastal Equatorial area. Conversely, SHL relaxation ($EC_x > +1.5\sigma$) induces severe intraseasonal dry spells ($EC_y < -1.5\sigma$). σ represents the standard deviation of the time series.

Keywords: *Saharan Heat Low, Cameroonian hydroclimate, West African Monsoon, Maximum Covariance Analysis, Lead-lag analysis.*

1 Introduction

The West African Monsoon (WAM) is the major rain-bearing system across sub-Saharan Africa, supporting rain-fed agriculture, water resources, and ecosystem stability for millions of people (Laing et al., 1999). A fundamental component of the WAM system is the Saharan Heat Low (SHL), a deep, thermally driven low-pressure system that develops over the hyper-arid Sahara during boreal summer in response to intense solar radiation and strong surface heating (Lavaysse et al., 2009). Acting as a thermodynamic pump, the SHL helps drive the cross-equatorial monsoon flow by maintaining a strong pressure gradient between the relatively cold sea surface temperatures of the Gulf of Guinea and the intensely heated continental surface of the Sahara (Sultan & Janicot, 2003). The resulting thermal contrast enhances the northward low-level advection of moisture-laden maritime air, thereby governing the seasonal migration of the Intertropical Discontinuity (ITD) and modulating the spatial and temporal distribution of convective precipitation across tropical Africa (Flamant et al., 2007; Lavaysse et al., 2009; Lenouo et al., 2010; Shekhar & Boos, 2017).

The SHL may play an important role in the development and intensification of heat waves over the Sahara and the Sahel by modulating the regional thermodynamic and circulation environment (Oueslati et al., 2017). As a region of intense lower-tropospheric heating and low pressure, variations in the intensity and position of the SHL can influence regional circulation, warm-air advection, and the transport of moisture and dry air. Such processes may favour the development and persistence of heat extremes through distinct, and potentially interacting, mechanisms. These include enhanced sensible heating and reduced cloud cover, leading to increased incoming solar radiation and stronger daytime warming, as well as increased atmospheric moisture and associated enhancement of downward longwave radiation, which may contribute to elevated nighttime temperatures.

Because the SHL is also a key component of the WAM system, its variability may further influence the spatial extent, duration, and intensity of heatwaves through interactions among regional circulation, land-atmosphere coupling, moisture transport, and radiative feedback. Despite these potentially important links, the direct and systematic influence of SHL variability on the characteristics of heatwaves over the Sahara and Sahel remains poorly quantified. A dedicated investigation of the relationship between SHL dynamics and heatwave occurrence, intensity, and persistence is therefore needed to improve understanding of regional temperature extremes and their underlying physical mechanisms.

Previous studies of SHL dynamics have demonstrated that the SHL is far from a static thermal system. Instead, it exhibits pronounced intraseasonal variability, driven in part by interactions between mid-latitude Rossby waves and tropical convection (Chauvin et al., 2010; Roehrig et al., 2011). More recently, Ngoungue Langue et al. (2021) assessed the ability of seasonal forecasting systems to reproduce the principal modes of SHL variability using ERA5 reanalysis as a reference. Although the physical links between SHL intensity, its intraseasonal pulsations, and precipitation across the Sahelian belt are increasingly well established (Chauvin et al., 2010), the influence of this major thermal forcing on the transition zone between West and Central Africa remains poorly understood.

Cameroon, often described as “Africa in miniature” because of its remarkable diversity of landscapes and climates, represents a major climatic and hydrological transition zone in Central Africa. The country encompasses strong climatic gradients, ranging from the hyper-humid equatorial coast and southern forest to the semi-arid sudano-sahelian plains of the Far North. Within the framework of the African Monsoon Multidisciplinary Analysis (AMMA) programme, Embolo Embolo et al. (2017) investigated convection and atmospheric static stability across West Africa, including the humid equatorial region south of 10°N. However, the potential role of SHL variability in modulating these thermodynamic processes was not explicitly examined. In addition, Pu and Cook (2010) demonstrated the important influence of the West African Westerly Jet (WAWJ) on the regional hydroclimate. Nevertheless, the extent to which remote thermal forcing associated with the SHL influences convective initiation, moisture transport, and moisture-flux convergence over Cameroon remains insufficiently understood.

To address these knowledge gaps, the present study aims to provide a comprehensive investigation into the physical teleconnections linking the Saharan Heat Low and the Cameroonian hydroclimate. The specific objectives are to :

1. Present Synoptic regimes in West Africa, with particular emphasis on the Sahara and its surrounding regions and examine their relationships with atmospheric conditions over Cameroon during December-February (DJF) and July-September (JAS) representing the contrasting dry and wet seasons, respectively ;
2. Apply Maximum Covariance Analysis (MCA) to identify the dominant coupled spatial patterns between variability in the Saharan Heat Low (SHL) and the Cameroonian hydroclimate, with the aim of characterizing their principal modes of synchronous covariability;
3. Investigate Lead-Lag relationships and signal propagation to determine the characteristic time scale, within a 0 to +10 day window, linking atmospheric perturbation over the Sahara, such as an intensification or thermal surges of the SHL, to subsequent changes in convection and precipitation across the distinct climatic sub-regions of Cameroon;
4. Investigate the underlying dynamical mechanisms governing the coupled SHL-Cameroon hydroclimate system by examining atmospheric circulation, thermodynamic conditions, and moisture transport during contrasting states of SHL activity.

Our central research Hypothesis states that : the spatial pulsations of the SHL exert coupled, non-linear control over regional moisture flux, Outgoing Longwave Radiation (OLR), and precipitation distribution across Cameroon, exhibiting distinct lead-lag relationships on 0–10 day synoptic timescales.

The paper is structured as follows: the materials and the methods are presented in the next section ; the results are presented and discussed in Sections 3 ; finally, a conclusion is given in section 4.

2 Materials and Methods

This section presents the areas of study, the data collected and the methodology used to treat the topic.

2.1 Study areas and data Collection

In the present study we used ERA5 reanalyses, from the European Center for Medium-range Weather Forecast (ECMWF), and Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) data (Table 1).

The data were collected, at daily and monthly time steps within a thirty-year period from 1991 to 2020. The study domains involved are West Africa including Sahara (Fig. 1a) and Cameroon with its climatic sub-zones (Fig. 1b).

Table 1 Description of the data collected

Parameter	Type	Resolution (°)	Time Step	Pressure level (hPa)
Mean Sea Level Pressure (MSLP)	ERA5	0.25× 0.25	Daily and monthly	-
Geopotential (Z)	ERA5	0.25 × 0.25	Daily and monthly	925 ; 700
Zonal wind (u) and meridional wind (v)	ERA5	0.25 × 0.25	Monthly	925 ; 850
Dew point temperature at 2 m (d2m)	ERA5	0.25 × 0.25	Monthly	-
Specific humidity (q)	ERA5	0.25 × 0.25	Monthly	925
Total net Thermal Radiation (ttr) converted to Outgoing Longwave Radiation (OLR)	ERA5	0.25 × 0.25	Monthly	-
Precipitation	CHIRPS	0.05× 0.05	Daily and monthly	-

The primary study area, West Africa, spans latitudes 0°N to 35°N and longitudes 20°W to 20°E (Fig. 1a). Within this region, the blue rectangle delineates the Saharan region situated between 18°N-26°N and 10°W-10°E. This Saharan domain was selected to encompass the core spatial boundaries of the SHL during its peak activity, minimising convective noise from the Sahelian zone. The main topographic features of West Africa are :

- ◆ **The Highlands and Mountains** : The Ahaggar, Aïr and Tibesti massifs located respectively in southern Algeria, northern Niger and northern Chad, the Jos Plateau in Central Nigeria, the Fouta Djallon located in Guinea, Sierra Leone and Liberia, the Cameroon volcanic line and Adamawa Plateau in Cameroon.
- ◆ **The plains and basins** : coastal plains along Atlantic Ocean from Senegal to Nigeria, featuring lagoons, mangrove and river deltas (in particular the Niger Delta), the Sudanian and Sahelian savannas, the Lake Chad Basin shared by Chad, Niger, Nigeria and Cameroon.

Cameroon, the second study area encompassed within West Africa, spans latitudes 1.5°N to 13.5°N and longitudes 8°E to 16.5°E (Fig. 1b). The area is divided into five climatic sub-zones (red rectangles on Fig. 1b) : the Sudano-Sahelian (Hereafter SS), the Sudano-Guinean (Hereafter SG), the Western and Adamawa Highlands (Hereafter WA), the Coastal Equatorial (Hereafter CE) and the Southern Forest (Hereafter SF).

The mean annual rainfall across Cameroon's climatic sub-zones derived from CHIRPS data for the reference period 1991-2020 are : SS (686 mm), SG (1112), WA (1797 mm), SF (1700 mm) and CE (2863 mm) (Fig. 2b).

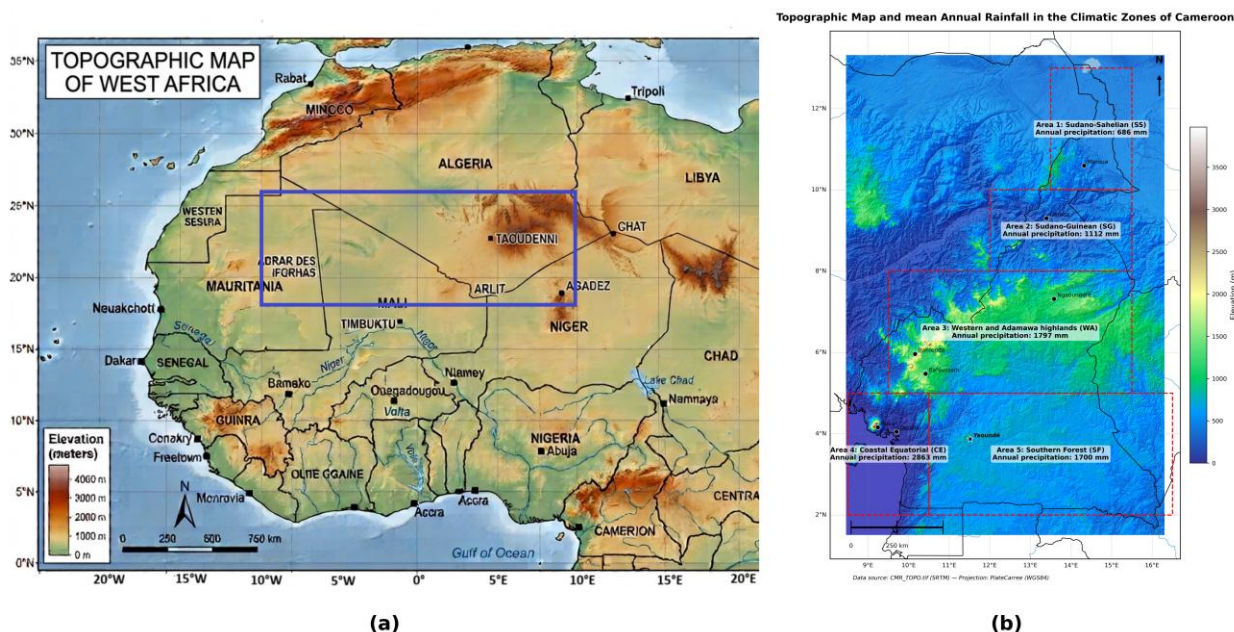


Figure 1: Topographic maps of (a) West Africa and (b) Cameroon. The blue rectangle in (a) delineates the Sahara region while the red rectangles in (b) delineate Cameroon's climatic sub-zones

2.2 Theoretical recall and Methodology

2.2.1 Characterizing SHL thermodynamic indices and Cameroonian hydroclimatic parameters

To characterise the SHL, we used Low Level Atmospheric Thickness (LLAT) and Mean Sea Level Pressure (MSLP).

MSLP serves as direct indicator of thermal lows dynamics while remaining uncorrupted by terrain-induced elevation distortions.

LLAT is typically defined as the geopotential height difference between 700 hPa and 925 hPa pressure levels. LLAT is direct evidence of hypsometric Equation, which states that the thickness of an atmospheric layer between two pressure surfaces is directly proportional to the layer-mean virtual temperature.

$$LLAT = Z_{700} - Z_{925} = \frac{R_d \bar{T}_v}{g} \ln \left(\frac{925}{700} \right) \quad (1)$$

Following Lavaysse et al. (2009), the core of the SHL is defined using the 90th percentile of LLAT as a detection threshold, retaining only values that exceed this limit.

In the present study, the Cameroonian hydroclimate is characterised by Wind, Precipitation, 925 hPa Specific Humidity (q925), Outgoing Longwave Radiation (OLR) and Dew Point Temperature (d2m). The 15°C dew point isotherm was used to delineate the surface trace of the ITD (Beucher et al., 2013 ; Parker et al., 2018), while OLR values below 200 W/m² were applied to isolate regions of deep convection. Cameroon was divided into five sub-climatic zones, SS, SG, WA, CE and SF, as previously mentioned in subsection 2.1.

To investigate the link between the SHL and the Cameroonian hydroclimate, we used normalized parameter indices, defined at point i as follows :

$$Z_i = \frac{X_i - \bar{X}}{\sigma} \quad (2)$$

Where X_i is the individual observation value, $\bar{X}$ the sample mean over the reference period, and σ the sample standard deviation.

Z (Z-score) is a dimensionless, zero-mean parameter with unit variance.

2.2.2 Maximum Covariance Analysis (MCA) Method

MCA is a multivariate statistical technique primarily used in climate, oceanography and atmospheric sciences. It is used to isolate paired spatial patterns that maximize cross-covariance between two distinct datasets across time.

To execute MCA, we considered two fields X and Y : Field X, describing the SHL in the Sahara via MSLP and LLAT, and Field Y representing the Cameroonian hydroclimate through precipitation, q925 and OLR.

The first step consisted in forming cross-covariance matrix C_{XY} between Field X and Field Y across N time steps, computed as :

$$C_{XY} = \frac{1}{N-1} XY^T \quad (3)$$

Then, we performed Singular Value Decomposition (SVD) :

$$C_{XY} = U \Sigma V^T \quad (4)$$

Where $\mathbf{U} = (\mathbf{u}_1, \mathbf{u}_2, \dots, \mathbf{u}_k)$ represents the left singular vectors (spatial patterns of X) and $\mathbf{V} = (\mathbf{v}_1, \mathbf{v}_2, \dots, \mathbf{v}_k)$ denotes the right singular vectors (spatial patterns of Y).

$\Sigma = \text{diag}(\sigma_1, \sigma_2, \dots, \sigma_k)$ refers to a square diagonal matrix of singular values sorted in descending order.

Finally, we extracted :

◆ Expansion coefficients (for time series ECx and ECy) to show temporal covariability :

$$a_k = u_k^T \text{ and } b_k = v_k^T ;$$

◆ Heterogeneous correlation maps to depict spatial patterns and coupled variability

$$r_{x,k}(i) = \text{Corr}(X(i,:), b_k) = \frac{\frac{1}{N-1} \sum_{t=1}^N X(i,t) b_k(t)}{s_{x,i} s_{b,k}} \quad (5)$$

$$r_{y,k}(j) = \text{Corr}(Y(j,:), a_k) = \frac{\frac{1}{N-1} \sum_{t=1}^N Y(j,t) a_k(t)}{s_{y,j} s_{a,k}} \quad (6)$$

$X(i,:)$ is the time series at the spatial grid point i of Field X , $Y(j,:)$ is the time series at the spatial grid point j of Field Y

$s_{x,i}$ and $s_{y,j}$ are respectively the sample standard deviation of X at grid i , and the sample standard deviation of Y at grid j

$s_{a,k}$ and $s_{b,k}$ are the sample standard deviations of time series a_k and b_k respectively ;

◆ Squared Covariance Fraction (SCF%) to measure the fraction of total covariance explained by each mode :

$$SCF_k = \frac{\sigma_k^2}{\sum_{i=1}^k \sigma_i^2} \quad (7)$$

Statistical significance of the correlations was evaluated using **10000 Monte Carlo permutations**.

2.2.3 Lead-Lag Analysis

To evaluate the temporal dynamics and the delayed response of the Cameroonian hydroclimate related to the SHL's variations, a lead-lag cross-correlation was performed.

Data processing and computation of standardized indices

Daily data of ECx (explicative variable) over the Saharan domain and of ECy (response variable) across Cameroon and its climatic sub-zones were treated according to the following steps :

1. Detrending : long term trend was suppressed from each daily time series ;
2. 21-day smoothing : a 21-day centered window was applied to filter high frequency noise and isolate the intraseasonal variability;
3. Standardization : the filtered series were standardized following equation (2).

Lead-lag cross correlation

To determine if a ECx anomaly at day t over Sahara leads and modulates the Cameroonian hydroclimate (variable ECy) at day $t + \tau$, the Pearson correlation coefficient $r(\tau)$ was computed for lag times from $\tau = 0$ to $\tau = +10$ days :

$$r(\tau) = \frac{\sum_{t=1}^{N-\tau} (EC_X(t) - \overline{EC_X})(EC_Y(t+\tau) - \overline{EC_Y})}{\sqrt{\sum_{t=1}^{N-\tau} (EC_X(t) - \overline{EC_X})^2 \sum_{t=1}^{N-\tau} (EC_Y(t+\tau) - \overline{EC_Y})^2}} \quad (8)$$

◆ Lag convention : $\tau > 0$ indicates that ECx leads ECy ;

◆ Sign of coefficient r

- $r(\tau) > 0$ indicates that an initial negative state across the predictor field X at $t = 0$ transitions into a positive anomaly field at $t+\tau$, coinciding with the peak positive response across the target field Y .

- $r(\tau) < 0$ reveals that a negative anomaly across the predictor field X at time t is associated with a positive response across the target field Y at time $t+\tau$.

Temporal sensitivity test

To evaluate the signal stability and maturity during boreal summer, cross-correlation was executed over two distinct temporal windows:

- ◆ the complete season (JJAS): June to September (122 days per year);

- ◆ and the core window (JA): July and August (62 days per year) identified as the peak SHL's phase.

Statistical significance testing via 10000 Monte Carlo permutations

Due to temporal autocorrelation induced by the 21-day smoothing, classic parametric hypothesis test underestimates standard errors. Therefore, statistical significance was evaluated via a non-parametric Monte Carlo permutation test (10000 iterations).

3 Results and discussions

3.1 Overview of main low level climatological features across the Sahara and Cameroon

Figure 2 presents low level mean synoptic regimes across West Africa and Cameroon during boreal winter (December-February season: DJF) and summer (July-September season: JAS) for the reference period 1991-2020.

During the DJF season, a high-pressure system exceeding 1015 hPa, establishes over the Sahara, facilitating the southward penetration of cold, dry Harmattan winds and thereby displacing the ITD equatorward to approximately 6°N (Fig. 2a). Meanwhile, in Cameroon, this dry air reaches the WA sub-region of Cameroon, which acts as natural barrier where it weakens (Fig. 2b). The 15°C 2m-dewpoint isotherm, located around 5°N in Cameroon, represents the ITD's surface trace separating the moist monsoon air from the dry Harmattan winds (Parker et al., 2018).

During the JAS season (Fig. 2c), the SHL establishes over the Sahara (with its core reaching an average LLAT value approximately 2440 gpm), driving the northward migration of the ITD and steering moist monsoon winds into the Sahelian belt (Lavaysse et al., 2009). Zooming into the regional domain over Cameroon demonstrates that the entire country is traversed by the southwesterly monsoon winds, and the superimposed dew point temperatures remain consistently above the 15°C threshold, placing the ITD well beyond Cameroon's northern boundary (Fig. 2d).

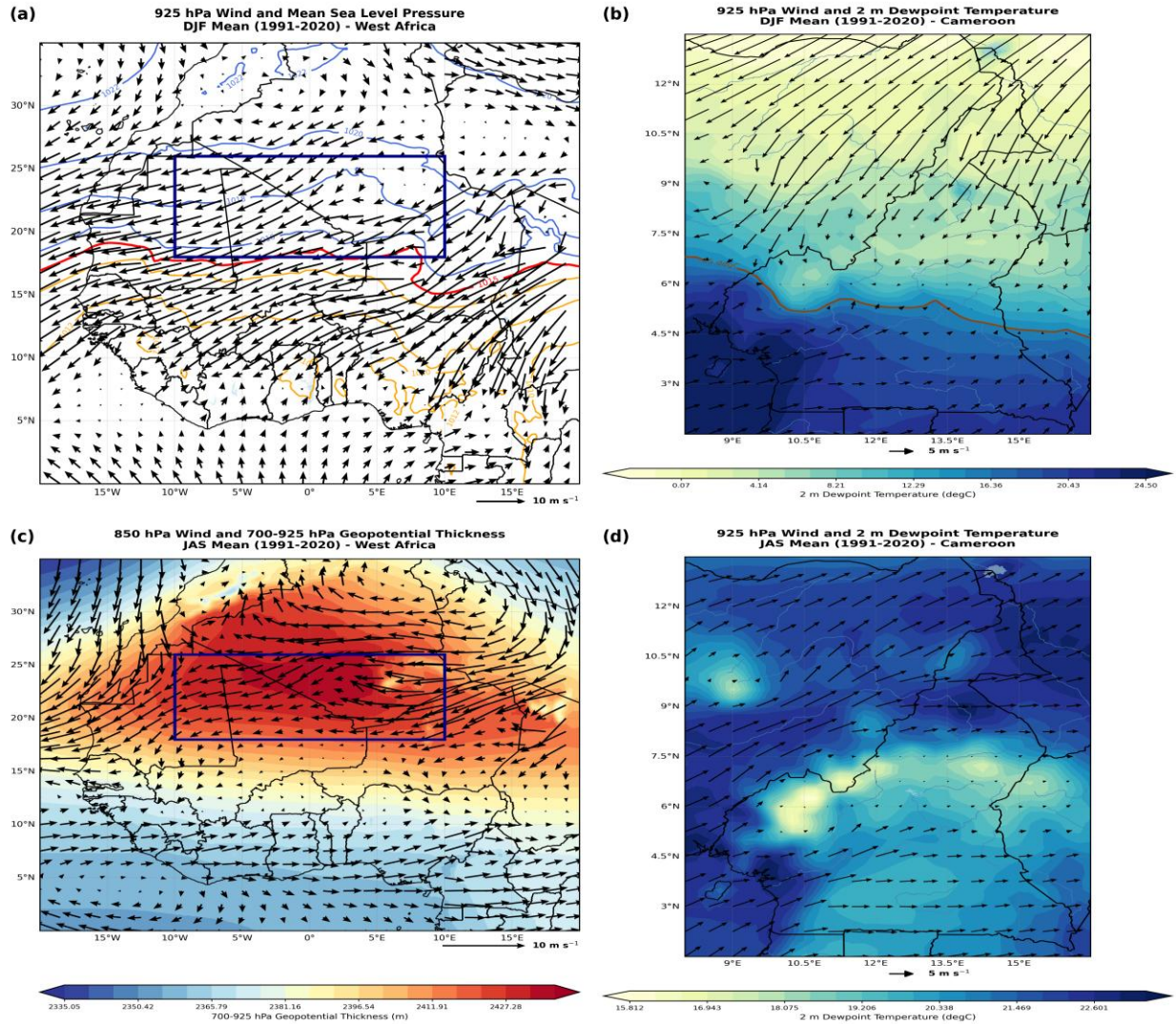
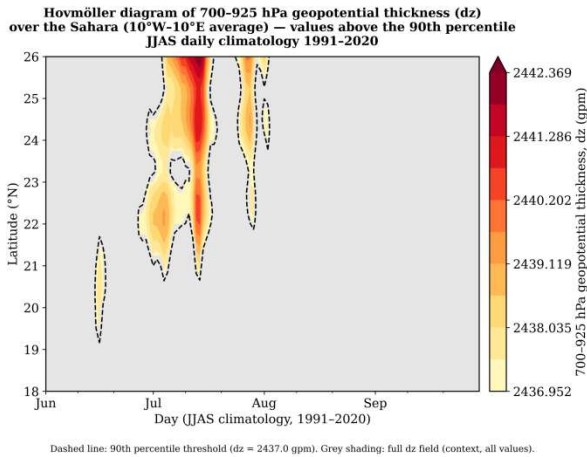
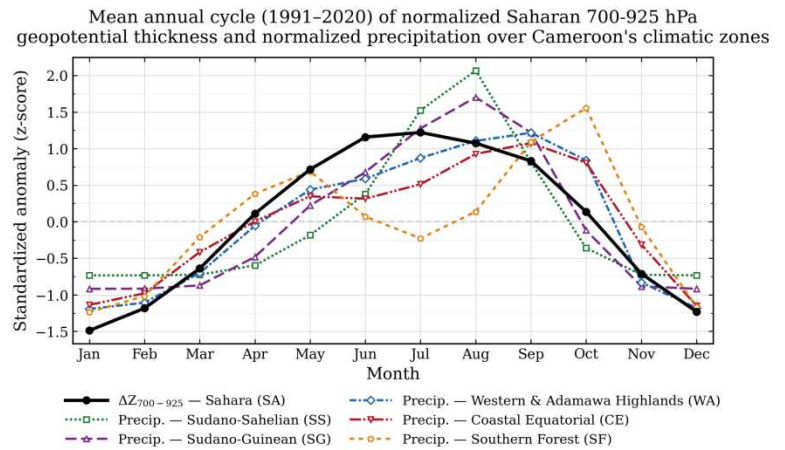


Figure 2 : West Africa and Cameroon mean low level synoptic features during DJF and JAS seasons for the reference period 1991-2020. In (a) and (c), the blue rectangle delineates the Sahara region. Wind is represented by vectors. In (a) sea level pressure level is shown in contours, with the red line indicating the 1015 hPa isobar separating high pressures (blue isobars) from low pressures (orange isobars). The low level atmospheric thickness (LLAT) in (c) and dew point temperature in (b) and (d) are shown in shaded contours. The red line in (b) represents the 15°C dew point isotherm.

Figure 3a depicts the mean latitudinal evolution of the SHL's core during the June-September (JJAS) season for the reference period 1991-2020. To track the core, only values of LLAT exceeding the 90th percentile threshold (2437 gpm) were considered (Lavaysse et al., 2009). We observe that the SHL's core is primarily concentrated in July-August (JA) at latitudes above 20°N, with its peak occurring in mid July.



(a)



(b)

Figure 3 : (a) Hovmöller diagram of 700-925 hPa geopotential thickness (LLAT) over the Sahara during the JJAS season (values above the 90th percentile are averaged within the window 10°W-10°E) and (b) Mean annual cycle of normalized LLAT and normalized precipitation over Cameroon's climatic zones, for the reference period 1991-2020 .

Figure 3b contrasts the mean annual cycle of normalized LLAT over the Sahara against the normalized precipitation regimes across Cameroon's distinct climatic sub-regions, for the baseline 1991-2020. Saharan LLAT exhibits a distinct unimodal seasonal cycle, characterized by positive anomalies from April through October and negative values during the boreal winter (November to March). Across Cameroon, precipitation regimes are predominantly unimodal, with the exception of the SF area, which displays a classic bimodal distribution. The unimodal LLAT profile reflects the seasonal cycle of solar forcing, where surface diabatic heating over the hyper-arid Sahara drives low-tropospheric thermal expansion from April to October (Lavaysse et al., 2009; Chauvin et al., 2010).

During the peak phase of the SHL from June to August, LLAT reaches its annual maximum ($+1.25\sigma$) in July, corresponding directly to the zenith of the SHL. The resulting deepening of the SHL maximizes the meridional pressure gradient between the Sahara and the Gulf of Guinea, pulling the ITD and the main WAM convective belt to their northernmost positions (Thorncroft et al., 2011). Concurrently, the SF sub-region experiences its mid-summer rainfall minimum (-0.25σ), reflecting the short dry season. Conversely, peak precipitation across the remaining sub-regions exhibits a clear northward phase lag relative to the Saharan thermal peak : rainfall reaches its annual maximum one month later (August) in the SS and SG sub-regions, and two months later in the CE and WA sub-regions. The covariability observed between Saharan LLAT and Cameroon precipitation regimes underscores the large-scale thermodynamic control exerted by the SHL. Indeed, as the SHL begins its early retreat in August, the main convective core moves southwards across 8°N-12°N. The combination of sustained monsoonal moisture advection (q_{925}) and active African Easterly Waves (AEWs) drives peak precipitation over the SS and SG transition zone (Janicot et al., 2008). The delayed peak in September over WA and CE coincides with the southward retreat of the ITD back toward the equatorial band. As the monsoonal flow decelerates, moisture converges heavily along the Gulf of Guinea coastline and the high reliefs of Cameroon Line (Mount Cameroon and the Adamawa Plateau). Orographic enhancement, combined with high low-level static instability along the coast, triggers intense meso-scale convective systems (MCSs), yielding maximum seasonal rainfall over these Western and Coastal highlands (Sighomnou, 2004).

3.2 Statistical assessment of the link between the SHL and the Cameroonian hydroclimate

3.2.1 Maximum Covariance Analysis (MCA)

To evaluate the connection between the SHL and the Cameroonian hydroclimate, MCA was applied to two distinct fields: Field X (MSLP and LLAT characterizing the SHL over Sahara) and Field Y (precipitation, q925 and OLR capturing the Cameroonian hydroclimate). The analysis was executed, for the reference period 1991-2020, during the JAS season, which captures the SHL.

Figure 4a highlights Mode 1 as the primary driver, accounting for 67.18% of the total squared covariance between Fields X and Y; this relationship is statistically significant ($P = 0.0216 < 0.05$). The remaining modes (2 and 3) do not pass the significance test ($P = 0.0651$ and $P = 0.1096$). Thus, the covariability between the SHL and the Cameroonian climate during the JAS season is dominated by a single robust physical mode of variability. MCA summary is given in Table 2.

During the JAS season over the 1991-2020 baseline period, the expansion coefficients of Mode 1 reveal a strong positive inter-annual correlation ($r=+0.70$) between both fields (Fig. 4b). Therefore, a pronounced temporal coherence exists between the SHL's intensity and the hydroclimatic response over Cameroon. Severe anomalies (such as the marked negative anomaly recorded in 1999-2000) are synchronous, showing that modulations at the SHL scale resonate directly across Cameroon's hydroclimate patterns.

The results of MCA Mode 1 confirm that both seasonal and intraseasonal hydroclimatic variability in Cameroon is directly modulated by the SHL. This finding is in close agreement with foundational studies of the WAM system (Sultan & Janicot, 2003; Lavaysse et al., 2009). The intensification of the SHL establishes a sharp thermal and pressure gradient between the low-latitude ocean (Gulf of Guinea) and Saharan interior, serving as the primary synoptic driver pulling the monsoonal flow inland.

Table 2 Sahara/Cameroon MCA Modes-Summary table (JAS season 1991-2020)

Mode	Sing. Value	SCF (%)	Cum. SCF (%)	r	MC p-value	Signif.
1	2.96e+03	67.18	67.18	0.695	0.0216	Yes*
2	1.66e+03	21.92	89.10	0.800	0.0651	No
3	966	7.39	96.49	0.626	0.1096	No

* Significant at $p < 0.05$ (10000 Monte Carlo permutations)

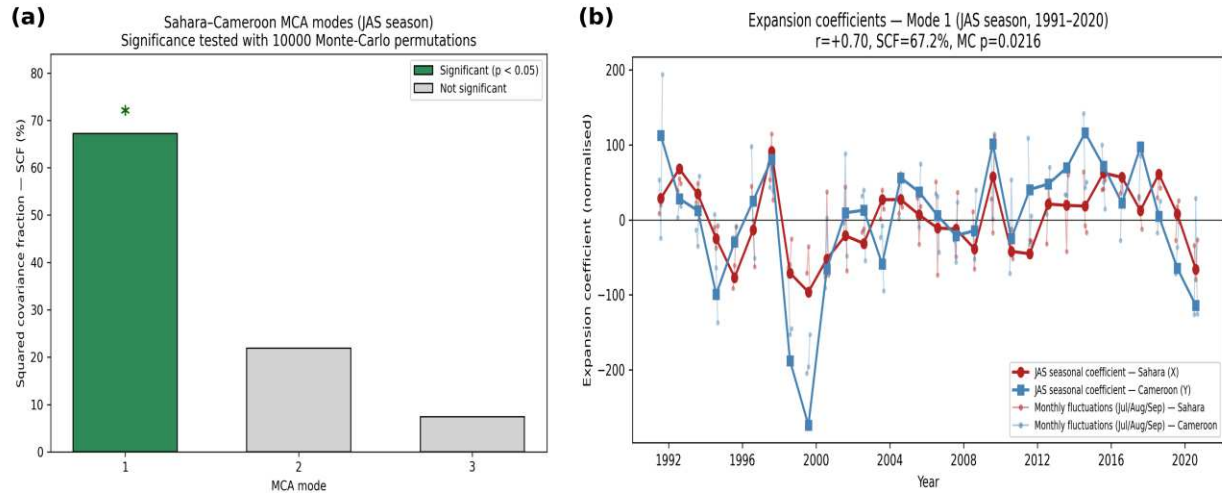


Figure 4 : (a) Sahara (SHL, Field X) versus Cameroon (hydroclimate, Field Y) MCA modes during the JAS season of the baseline 1991-2020. The histograms refer to the squared covariance fraction of each mode. (b) Inter-annual evolution of expansion coefficients of Mode 1 during JAS season for the reference period 1991-2020. The red and blue curves represent the evolution of expansion coefficients for Saharan Heat Low indices (Field X) and for Cameroon hydroclimate (Field Y) respectively.

Figure 5 displays the heterogeneous spatial correlation patterns (during the JAS season of the reference period 1991-2020), which reflect the spatial distribution of anomalies during the positive phase of MCA Mode 1. Because spatial correlation maps are presented relative to positive phase of MCA Mode 1, positive (negative) correlation coefficients directly correspond to positive (negative) physical anomalies relative to the 1991-2020 climatology. A negative phase of MCA Mode 1 induces converse results leading to a contrasting analysis.

Figure 5a indicates that MSLP is positively correlated over the Sahara (+0.5 to +0.7) while Figure 5b evinces that the spatial structure of LLAT exhibits a clear north-south dipole characterized by negative anomalies north of 21°N and positive anomalies southwards. An increase in MSLP over the Sahara indicates lower-tropospheric cooling, marking temporary filling or relaxation of the SHL. According to hypsometric equation, this reduces the thermal meridional gradient between the Sahara and the gulf of Guinea, which in turn weakens the monsoonal moisture advection towards the Sahelian belt (Lavaysse et al., 2009; Chauvin et al., 2010). Precipitation exhibits contrasting patterns across Cameroon; negative correlations are observed across most of Cameroon except for some neutral-to-positive correlations in the WA sub-area and in the transitional zone between the SS and the SG regions (Fig. 5c). q925 spatial distribution displays positive correlations (up to +0.5) prevailing over the majority of Cameroon, except for the SS, eastern SF and southern CE areas, which display near-zero correlations (Fig. 5d). Widespread positive correlations (up to +0.7) are depicted in the OLR pattern, despite near-zero values recorded across the western Highlands and a section of the Adamawa Plateau (Fig. 5e).

The positive phase of MCA Mode 1, corresponds to positive MSLP anomalies over the Sahara, indicating an attenuation/relaxation of the SHL. This weakening of the thermal low reduces the pressure gradient between the Gulf of Guinea and the continent. Consequently, monsoonal moisture advection is altered:

while low level specific humidity (q_{925}) remains high south of 10°N over Cameroon, the weaker pressure draw fails to maintain deep convection (as indicated by high OLR values).

The relaxation of the SHL also alters the broad-scale convergence architecture of the region. A weakened SHL allows a southwards retreat of the ITD (Diedhiou et al., 1999). the main-producing convective belt, typically composed of MCSs, is either shifted away or structurally suppressed over Central Africa, leading to negative precipitation anomalies across most Cameroon's climatic sub-regions with the exception of the Cameroon Volcanic Line, where localized orographic forcing maintains convective activities.

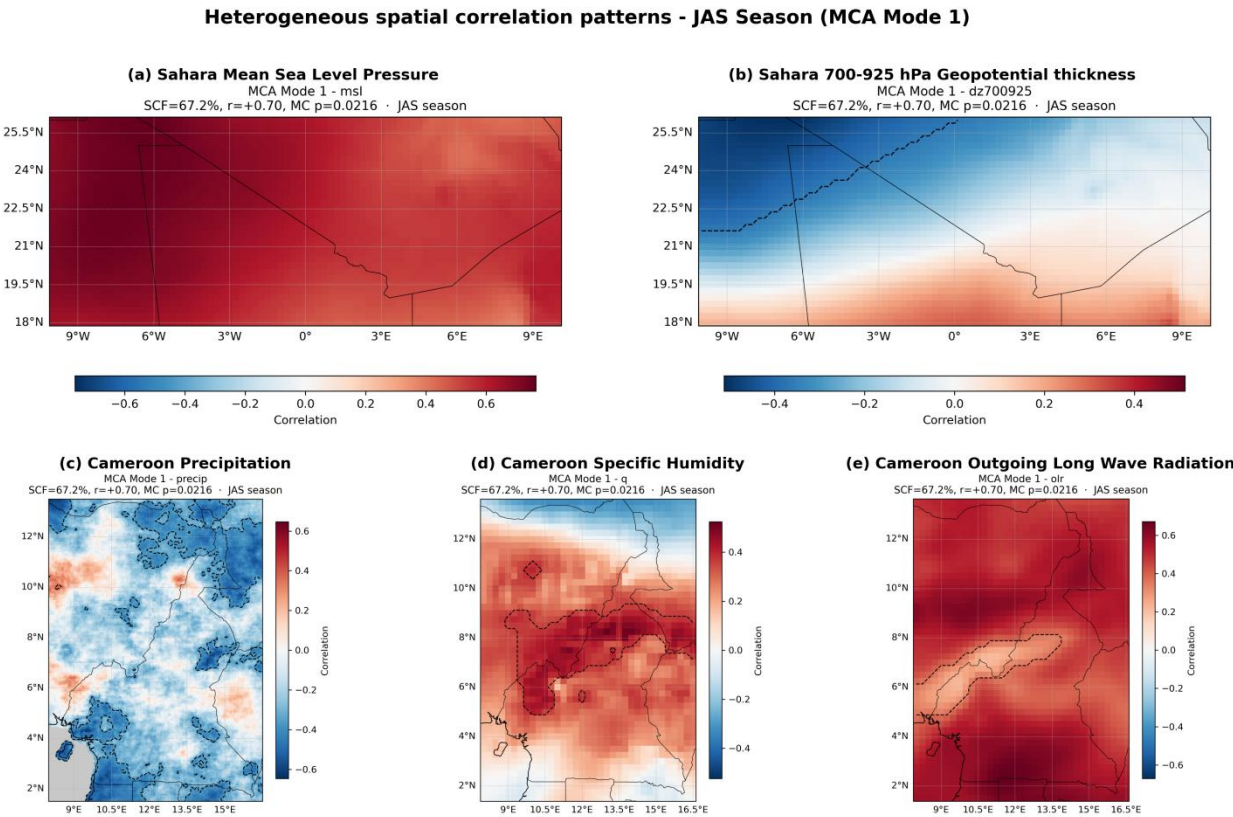
A crucial insight from this analysis is the physical decoupling between low-level moisture availability and actual convective initiation (elevated OLR values, signaling suppressed convection, contrasted with high q_{925} values, which provide the thermodynamic fuel for deep convection). Indeed, although low-level specific humidity remains high across the majority of Cameroon, this moisture is stagnant. Without a strong inland pressure gradient to drive the horizontal convergence and mechanical uplift along the topography, boundary-layer moisture remains unorganized. This absence of dynamic convergence and vertical lifting hinders air parcels from reaching their Level of Free Convection (LFC). The resulting absence of deep, cold cloud tops (cumulonimbus tops) exposes warmer lower-tropospheric and surface layers to space, generating the observed positive OLR anomalies and triggering widespread dry spells (Thorncroft et al., 2011).

The persistence of localized positive rainfall anomalies along the windward slopes of the Cameroon Volcanic Line during periods of weakened synoptic monsoon draw illustrates the paramount role of orographic enhancement over central Africa (Sighomnou, 2004). Pristine marine boundary-layer air masses, exported from the South Atlantic Anticyclone, preserve sufficient low-level moist static energy during their cross-equatorial trajectory (Peyrillé & Lafore, 2007). When encountering steep topographic barriers, such as Mount Cameroon and the Western Highlands, the forced mechanical ascent supplies the localized updraft velocity required to overcome any mid-level convective inhibition (CIN) and reach the LFC. Furthermore, complex-terrain interactions, including lee-side warming and windward moisture trapping associated with Foehn-type circulations, accentuate thermal contrast, destabilizing the column an maintaining localized deep convection even under unfavorable large-scale synoptic conditions.

The contribution of each variable in the MCA Mode 1 is given in table 3 below.

This table indicates that MSLP and precipitation are the primary variables governing the coupled variability between Field X and Field Y, accounting respectively for 86.8% and 84%. Therefore, MSLP will be retained in subsequent analyses, as the main parameter characterizing the SHL, while precipitation will serve as the primary metric for the Cameroonian hydroclimate. However, results derived from LLAT will also be presented for comparison purpose.

376
377



378 **Figure 5 : Heterogeneous spatial correlation patterns between Field X (Sahara) and Field Y (Cameroon) for Mode**
379 **1during JAS season of the reference period 1991-2020. Field X :(a) Mean Sea Level Pressure (MSLP), (b) Level**
380 **Atmospheric Thickness (LLAT), (c) Precipitation, (d) 925 hPa Specific humidity (q925) and (e) Outgoing Longwave**
381 **Radiation (OLR)**

382

383 **Table 3 Mode 1-Contribution of each variable within its group (JAS season 1991-2020)**

Group	Variable	Contribution (%)
X (Sahara-SHL)	Mean Sea Level Pressure (MSLP)	86.8
	Low Level Atmospheric thickness (LLAT)	13.2
	Precipitation	84.0
Y (Cameroun hydroclimate)	Outgoing Longwave Radiation (OLR)	12.5
	925 hPa Specific humidity (q925)	3.5

384

385 **3.2.2 Lead-Lag temporal dynamics and signal propagation**

386 This subsection aims to determine the time lag (within a 0 to +10 day window) between an initial
387 atmospheric trigger, such as a MSLP (ECx) surge or dip, in the Sahara and the resulting precipitation

(ECy) anomalies across Cameroon's climatic sub-zones. The statistical significance of the correlations are evaluated using 10000 Monte Carlo permutations.

3.2.2.1 Lead-Lag analysis between Mean Sea Level Pressure over Sahara and Precipitation across Cameroon

Treating Cameroon as a single domain, a sensitivity lead-lag analysis reveals a consistent primary response across both the JJAS (full SHL period) season and the JA (core SHL period) window (Fig. 6a). During the JJAS period, at zero-lag ($\tau = 0$), there exists a significant negative correlation ($r \approx -0.20$, $p < 0.05$) between precipitation and MSLP, which denotes that a deep SHL leads immediately to increased precipitation over Cameroon. Furthermore, the figure exhibits a statistically significant positive correlation peaking at a 4-day lag ($r \approx 0.31$, $p < 0.05$). Restricting the temporal window to the core JA season enhances the coupling, with significant peaks emerging at lag of 3-4 days ($r \approx 0.38$, $p < 0.05$) and a secondary peak at 8 days ($r \approx 0.39$, $p < 0.05$). This indicates that while the primary atmospheric response occurs 3-4 days post-SHL surge, a secondary modulation, at a 8-day lag, is especially active during peak monsoon.

Subdividing Cameroon into climatic sub-zones yields the following observations.

At zero lag ($\tau = 0$ days), precipitation across virtually all sub-regions is negatively correlated to Saharan MSLP index, whereas the SF area uniquely demonstrate a positive correlation. Indeed, the strong updrafts and dynamic mass convergence occurring over the northern landmass during deep SHL phases (negative MSLP anomalies) induce compensating large-scale subsidence on its northern periphery. The SF sub-region falls directly beneath this anomalous mid-tropospheric descending branch. This subsidence caps the boundary layer, stabilizes the column, and suppresses convective cloud development despite high low-level specific humidity. This physical structure directly mirrors the mechanism responsible for the equatorial short dry season observed during mid-summer across the Guinean-Congolese forest domain (Bigot et al., 1997).

For the SS sub-region, the JJAS season exhibits significant positive correlation ($r \approx 0.24$, $p < 0.05$) between precipitation and Saharan MSLP peaking at a 4-day lag (Fig. 6b). However, during the peak JA, this lag extends to 8 days with a stronger correlation ($r \approx 0.29$, $p < 0.05$).

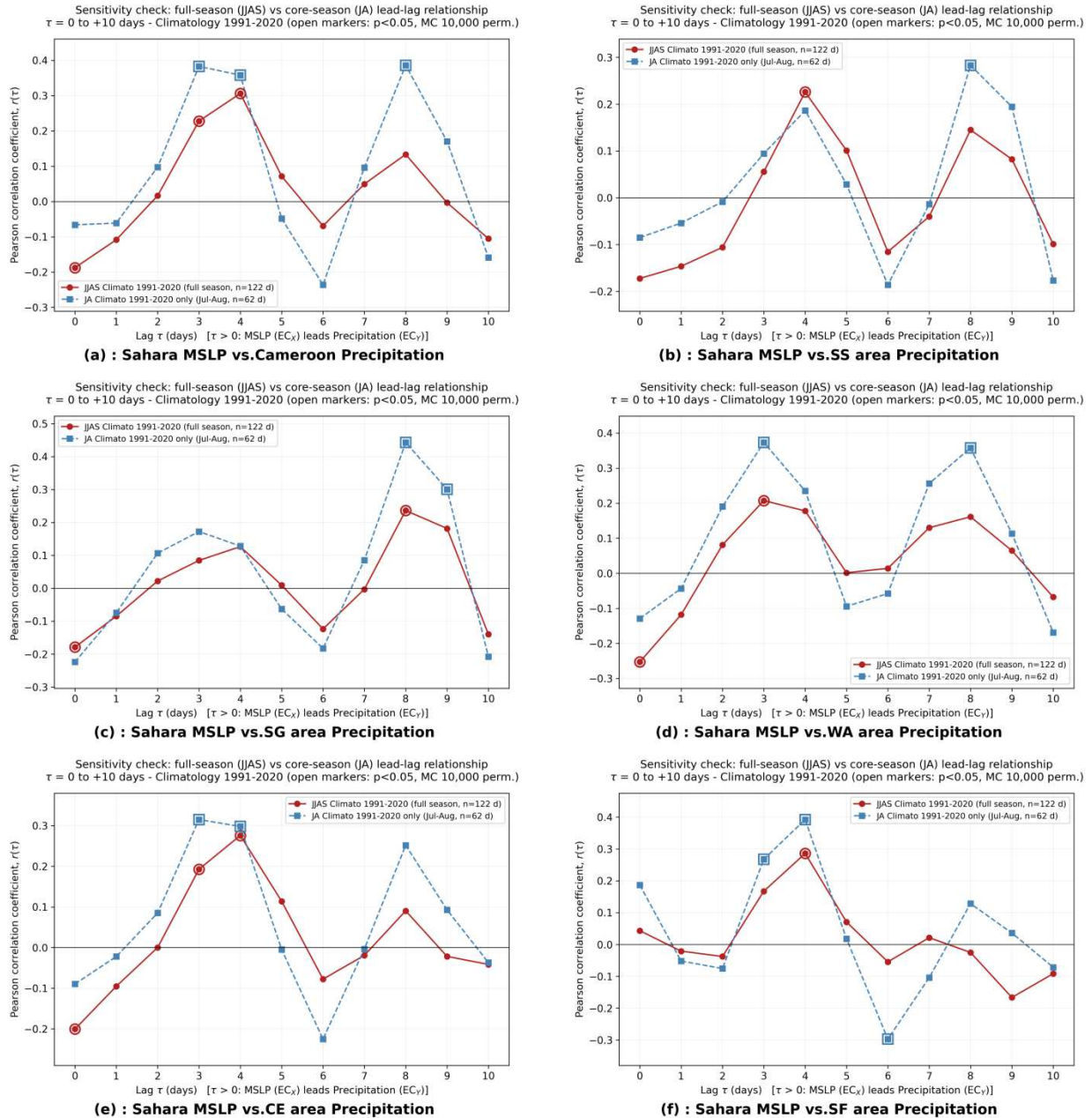
The lead-lag plot related to the SG sub-region, during the JJAS season, evinces statistically positive correlation ($r \approx 0.23$, $p < 0.05$), between precipitation and Saharan MSLP, peaking at an 8-day lag (Fig. 6c). This 8-day delay persists during the core JA season, accompanied by a markedly stronger correlation ($r \approx 0.44$, $p < 0.05$).

Across the WA sub-zone, the JJAS precipitation correlate significantly with Saharan MSLP ($r \approx 0.20$, $p < 0.05$), reaching a maximum positive response at a 3-day lag (Fig. 6d). The core JA season strengthens the coupling, revealing a primary significant peak ($r \approx 0.38$, $p < 0.05$) at a 3-day lag alongside a secondary maximum ($r \approx 0.36$, $p < 0.05$) at 8 days, hence a 5-day periodicity of the signal propagation.

In the CE sub-area, the lead-lag relationship between precipitation and Saharan MSLP yields significant correlations ($r \approx 0.28$ and 0.20 , $p < 0.05$) at respectively 3 and 4-day lag during the JJAS season (Fig. 6d).

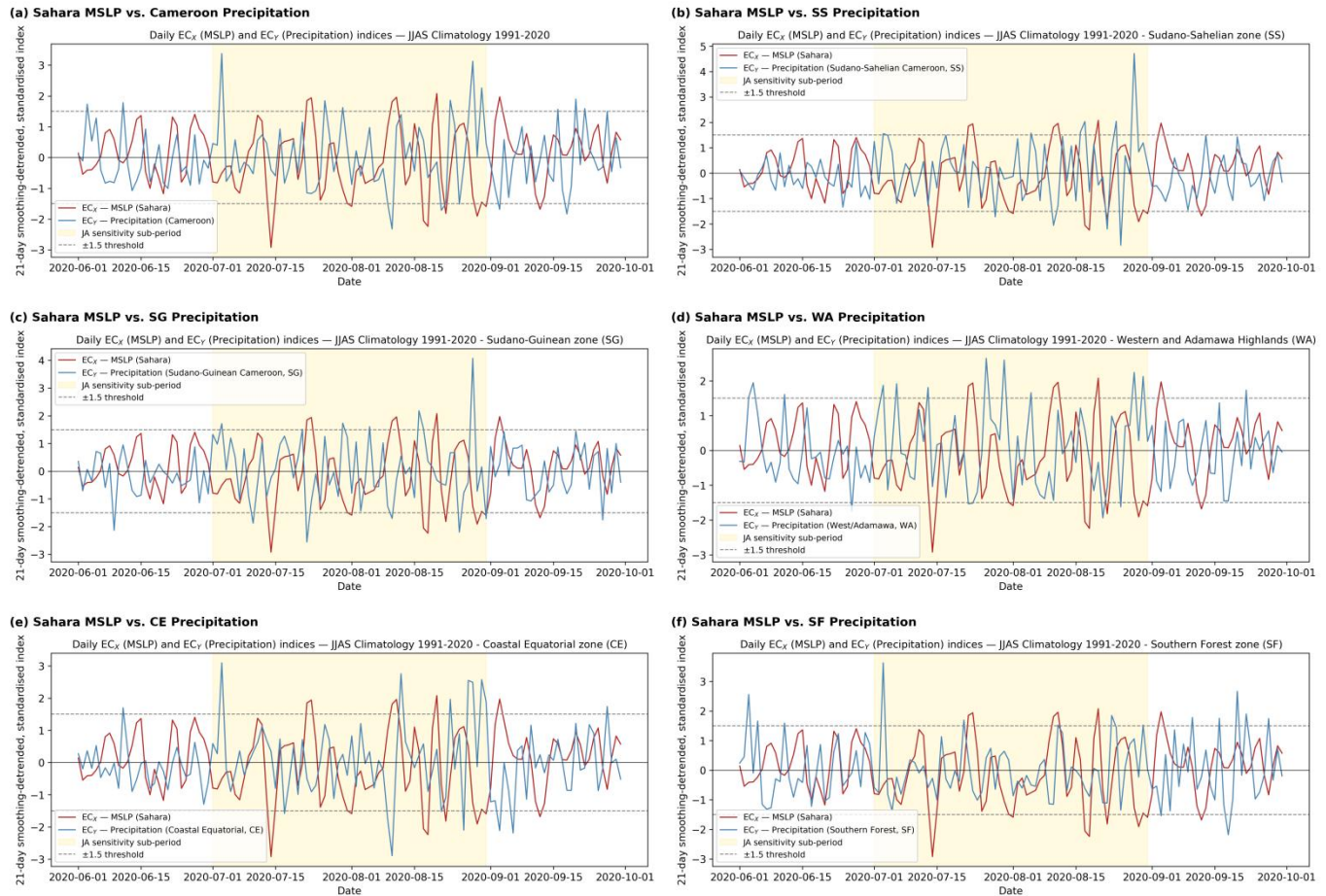
425 While this 3-4 day lag time persists during the peak JA season, the statistical association strengthens ($r \approx$
 426 0.30 , $p < 0.05$).

427 Figure 6e indicates a significant positive correlation between ECx and ECy ($r \approx 0.29$, $p < 0.05$) at a 4-day
 428 lag during the JJAS season over the SF climatic sub-region. The JA period evinces a statically significant
 429 maximum correlation ($r \approx 0.4$, $p < 0.05$) recorded at a 4-day lag and followed by a significant negative
 430 minimum ($r \approx -0.3$, $p < 0.05$) 2 days later ($\tau = 6$ days).



431 **Figure 6 : Lead-lag relationship between MSLP over the Sahara and Precipitation in Cameroon's climatic zones within**
 432 **the window 0 to +10 days, for the JJAS season (red curve), with sensitivity check during JA (blue curve).**

433



434

435 **Figure 7 : Daily time series of the standardized Mean Sea Level Pressure index over the Sahara (EC_x, red curve) versus**
 436 **the regional precipitation standardized index across Cameroon (EC_y, blue curve) during the JJAS season. The gray**
 437 **dashed horizontal lines clearly mark the ± 1.5 standard deviation thresholds, and the yellow shading highlights the**
 438 **core JA sensitivity window. Note: On the x-axis, 2020 refers to the 1991-2020 climatological baseline.**

439 Figure 7 represents the time-series plot of EC_x (MSLP, red) versus EC_y (Precipitation, blue) across
 440 Cameroon and its five sub-regions (SS, SG, WA, CE and SF) within the full JJAS season for the 1991-2020
 441 climatological daily cycle. MSLP exhibits an inverse phase coupling with Cameroonian rainfall during the
 442 JJAS season. Extreme negative MSLP excursions (EC_x < -1.5σ) signifying severe thermal deepening of the
 443 SHL, leads to prominent regional precipitation surges (EC_y > $+1.5\sigma$) by 3-8 days. This lagged response is
 444 most coherent during the core JA window, particularly over the WA area (Fig. 7d) and the CE zone (Fig.
 445 7e). Conversely, positive anomalies (EC_x > $+1.5\sigma$) reflect SHL relaxation phases that reduce the land-sea
 446 pressure gradient, resulting in pronounced intraseasonal dry spells (EC_y < -1.5σ)

447 This lead-lag sensitivity analysis between Saharan MSLP and Cameroon's precipitation indices (Fig. 6
 448 and Fig. 7) highlights preferential response windows at lags of $\tau = +3$ to $+4$ days and $\tau = +8$ days. This
 449 physical delay corresponds precisely to the synoptic-scale periodicity of SHL pulsations (3-10 day band)
 450 and their coupling with the propagation of African Easterly Waves (AEWs) and the African Easterly Jet
 451 (AEJ). As demonstrated by Janicot et al. (2008), thermal anomalies over the Sahara require 3 to 5 days to

reorganize regional circulation, adjust the geostrophic gradient, and ultimately modulate rainfall genesis across transitional zones such as Cameroon.

3.2.2.2 Lead-Lag analysis between Low Level Atmospheric Thickness over Sahara and Precipitation across Cameroon

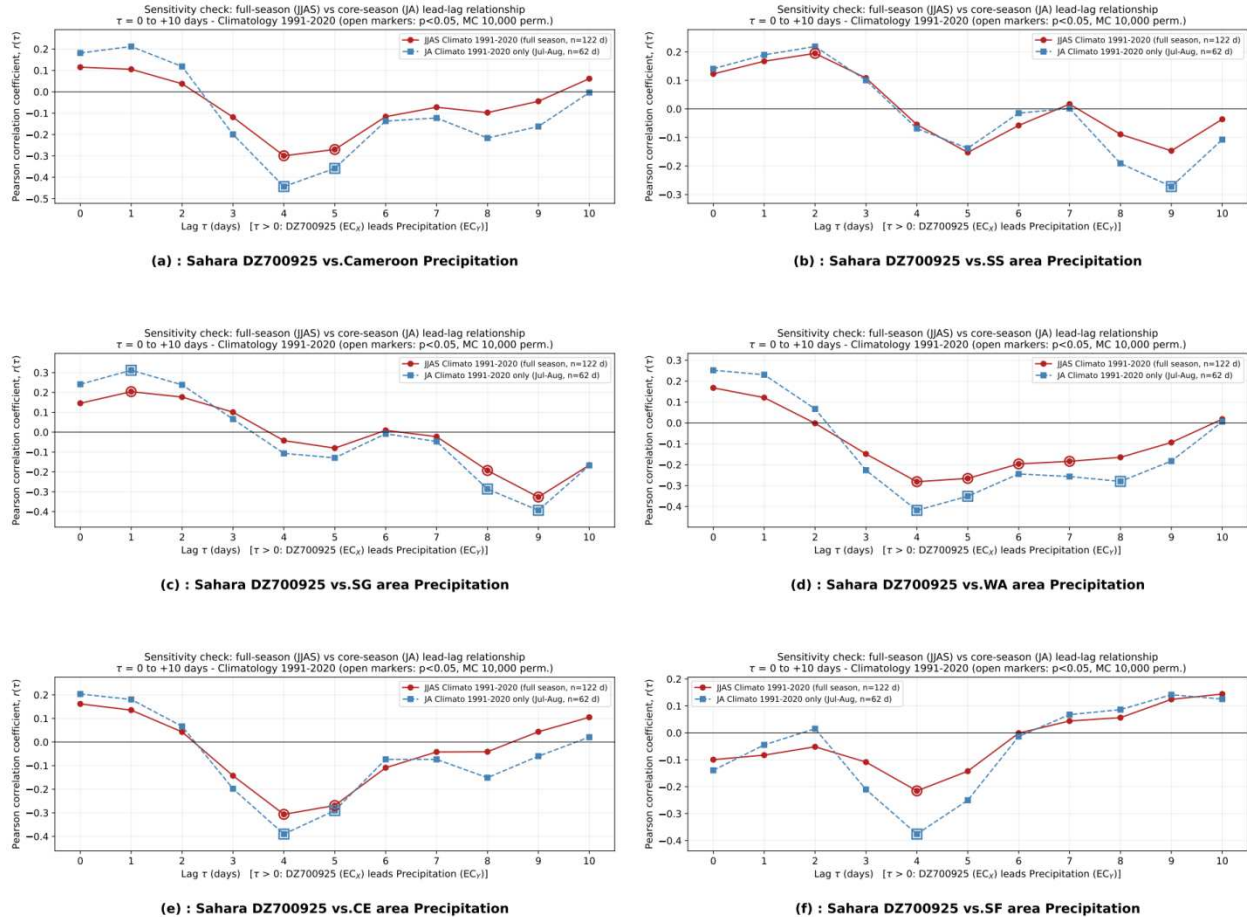


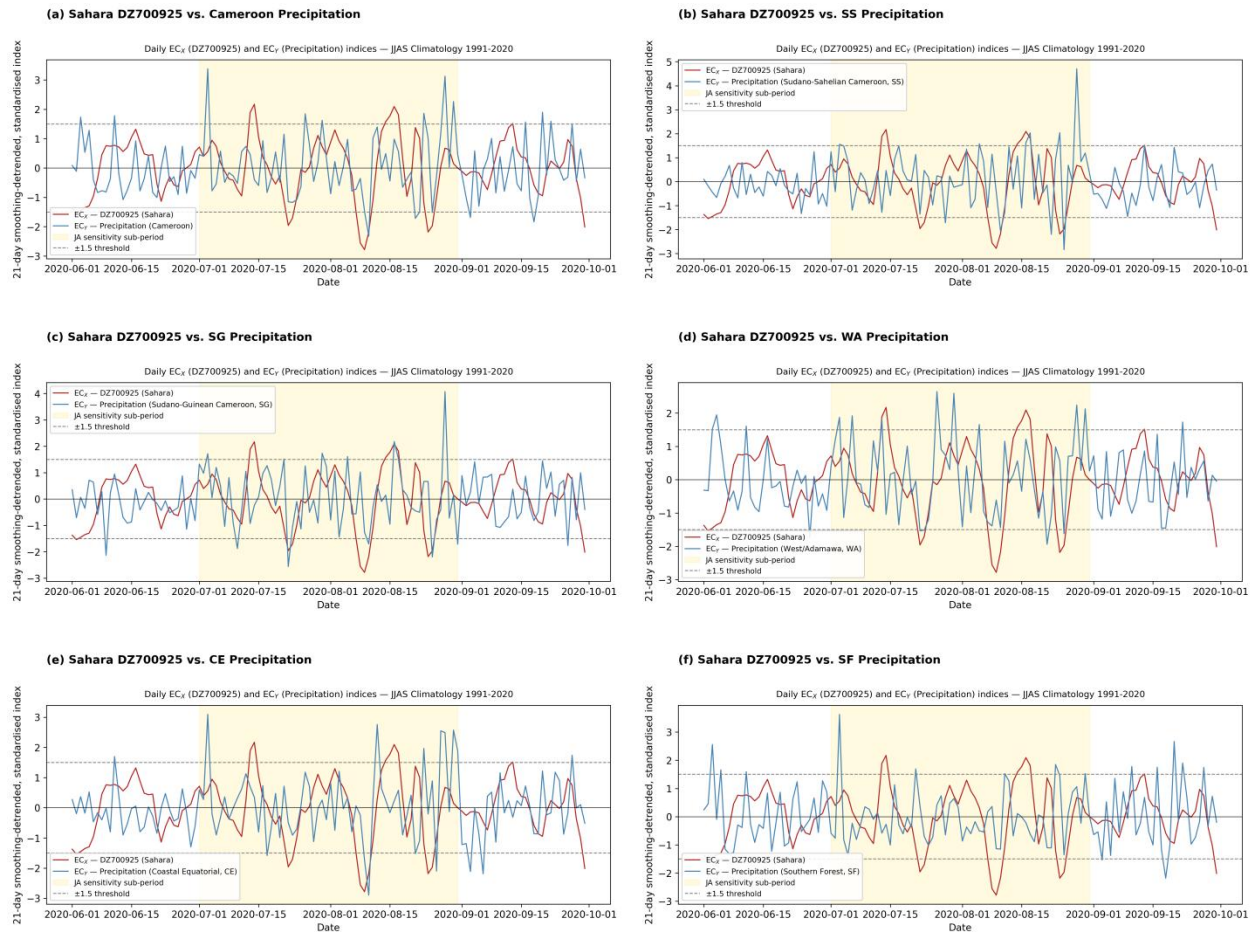
Figure 8 : Lead-lag relationship between LLAT over the Sahara and Precipitation in Cameroon's climatic zones within the window 0 to +10 days, for the JJAS season (red curve), with sensitivity check during JA (blue curve).

Figure 8 displays Lead-lag analysis between LLAT over the Sahara and precipitation across Cameroon and its climatic sub-regions during the full JJAS and the core JA seasons for the 1991-2020 baseline period.

At zero-lag ($\tau = 0$), Cameroon as a whole—along with nearly all its climatic sub-regions—exhibits positive correlations (though non-significant) during both the JJAS and the JA seasons, except for the SF area, which shows negative correlations. Therefore, high LLAT values over Sahara induce immediate augmentation of precipitation across the majority of Cameroon.

Both seasons display synchronous lag times, although the correlations are stronger during the core JA season. Cameroon as a whole, shows statistically significant negative correlation ($r \approx -0.3$ during JJAS and -0.43 for JA, $p < 0.05$), peaking at a 4-day lag, followed by another negative correlation ($r \approx -0.3$, $p < 0.05$) one day later at $\tau = 5$ days (Fig. 8a). The SS region exhibits a single significant positive correlation ($r \approx 0.2$, $p < 0.05$) at $\tau = 2$ days during the JJAS season, while a single significant negative correlation ($r \approx -0.29$, $p < 0.05$) is observed during the JA season at a 9-day lag time (Fig. 8b). The SG area displays

470 significant positive correlations across both seasons at a 1-day lag ($r \approx +0.2$ for JJAS and $+0.3$ for JA, $p <$
 471 0.05), which alternate with significant negative correlations at longer lags, reaching $r \approx -0.2$ (JJAS) and $-$
 472 0.3 (JA) at $\tau = 8$ days, and peaking to $r \approx -0.3$ (JJAS) and -0.4 (JA) at $\tau = 9$ days (Fig. 7c). Across the WA
 473 zone (Fig. 8d), significant negative correlations occur at a 4, 5, 6, 7-day lag times during the JJAS season
 474 ($r \approx -0.2$ to -0.3 , $p < 0.05$), and at a 4, 5, 8-day lag times for the JA season ($r \approx -0.3$ to -0.4 , $p < 0.05$).
 475 Significant negative correlations are observed across The CE area (Fig. 8e) peaking at a 4-day lag ($r \approx -0.3$
 476 for JJAS and -0.4 for JA, $p < 0.05$), and weakening 1 day later at $\tau = 5$ ($r \approx -0.3$ for both seasons, $p <$
 477 0.05). The SF region exhibits a single significant negative correlation at a 4-day lag (Fig. 8f) for both JJAS
 478 ($r \approx -0.2$, $p < 0.05$) and JA ($r \approx -0.4$, $p < 0.05$).



479 **Figure 9 : Daily time series of the standardized Low Level Atmospheric Thickness index over the Sahara (ECx, red**
 480 **curve) versus the regional precipitation standardized index across Cameroon (ECy, blue curve) during the JJAS season.**
 481 **Note: On the x-axis, 2020 refers to the 1991-2020 climatological baseline.**

482 Figure 9 plots the standardized LLAT expansion coefficients (ECx, red curve) over the Sahara versus the
 483 regional precipitation standardized index (ECy, blue curve) across Cameroon and its five sub-regions.
 484 Comparing this figure with the previous analogous one (MSLP, Fig. 7) highlights the mechanism
 485 operating on low atmospheric levels: LLAT and MSLP act in exact thermodynamic phase opposition over
 486 the Sahara. Thresholds of $\pm 1.5 \sigma$ effectively isolate extreme thermal and hydrological events. Excursions
 487 of LLAT above $+1.5\sigma$ mark intense thermal expansion events (deep SHL), which systematically lead major
 488 precipitation pulses ($ECy > +1.5\sigma$) across Cameroon by a few days, most notably over the WA (Fig. 9d)

and the CE (Fig. 9e) regions. Conversely, sharp contractions in LLAT ($EC_x < -1.5\sigma$) reflect the SHL relaxation phases that drive widespread dry spells ($EC_y < -1.5\sigma$). This phase lead-lag relationship is particularly coherent with the core JA window, demonstrating the direct control of intraseasonal SHL pulsations on Cameroon rainfall regimes.

4 Conclusion

This study establishes the thermodynamic link between the Saharan Heat Low (SHL) and Cameroonian hydroclimate variability during the West African Monsoon (WAM). By executing Maximum Covariance Analysis (MCA) on the 1991-2020 climatology alongside daily lead-lag diagnostics across the full monsoon season (June-September, JJAS) and the core window (July-August, JA), we isolated the coupled spatial structure and delayed response dynamics governing regional precipitation.

The main findings are summarized as follows :

1. Leading synoptic co-variability (MCA Mode 1)

A single, robust physical mode dominates the coupled system. MCA Mode 1 accounts for 67.18 % of the total squared covariance with $p = 0.0216$, whereas higher-order modes (Mode 2 and 3) are statistically insignificant ($P = 0.0651$ and $P = 0.1096$ respectively). The expansion coefficient of Mode 1 demonstrate a strong interannual correlation ($r=+0.70$), confirming tight temporal coherence between SHL intensity and regional hydroclimatic anomalies, consistent with the continental-scale thermal engine framework described by Lavaysse et al. (2009).

2. Orographic enhancement and thermodynamic decoupling

The heterogeneous cross-correlation patterns (MCA Mode 1), revealed that positive anomalies of MSLP over the Sahara (occurring during weak SHL phase) are linked to positive anomalies of q_{925} and OLR, whereas they are negatively correlated to precipitation across most Cameroon's sub-regions, except for the Cameroon Volcanic Line where strong windward orographic forcing overrides large-scale convective suppression to generate localized precipitations (Sighomnou, 2004). Moreover, these patterns show a clear thermodynamic decoupling : elevated OLR values, indicative of suppressed convection, contrast sharply with high q_{925} , which typically provide the thermodynamic fuel for deep convection initiation.

3. Lead-lag dynamics and signal propagation

Time-lagged cross-correlations isolate two preferential response windows at $\tau = +3$ to $+4$ days and $\tau = +8$ days, with the 8-day lag emerging prominently during the core JA window. This physical delay mirrors the 3-10 day synoptic periodicity of the SHL pulsations and their dynamical coupling with propagating African Easterly Waves (AEWs) and the African Easterly Jet (AEJ) (Janicot et al. 2008; Thorncroft et al. 2011).

At zero lag, Precipitation across the Southern Forest (SF) sub-region exhibits a unique phase inversion (positive correlation with MSLP, negative with LLAT), contrasting with the rest of Cameroon where the SHL filling immediately suppresses rainfall. Thus, when the SHL is deepening (negative MSLP anomalies), precipitation are decreasing across the SF area. This localized suppression during peak SHL phase

reflects mid-tropospheric compensating subsidence over this climatic sub-region characteristic of equatorial short dry season dynamics (Bigot et al. 1997).

Considering MSLP index, extreme SHL deepening ($EC_x < -1.5\sigma$) triggers prominent regional precipitation surges ($EC_y > +1.5\sigma$) within 3 to 8 days, particularly over the Western Highlands, the Adamawa Plateau and the Coastal Equatorial area. Conversely, SHL relaxation ($EC_x > +1.5\sigma$) weakens the land-sea pressure gradient, inducing severe intraseasonal dry spells ($EC_y < -1.5\sigma$).

4. Contribution to Sub-seasonal to Seasonal (S2S) weather forecasting

The existence of a Saharan robust precursor signal at a 3-to-8 day lead time offers a major opportunity for Sub-seasonal to Seasonal (S2S) numerical weather prediction over Cameroon. Anomalies in MSLP and LLAT over the Sahara serve as powerful physical predictors for anticipating intraseasonal dry spells and extreme precipitation events across Cameroon's distinct climatic sub-regions (SS, SG, WA, CE and SF).

Future Directions

These analyses demonstrate that the SHL acts as a primary regional atmospheric driver regulating the sub-seasonal monsoon pulses over Cameroon. Extending this diagnostic framework across the entire Central Africa domain will further refine regional predictability windows for operational Sub-seasonal to Seasonal (S2S) forecasting systems.

Acknowledgements

The authors thank the European Center for Medium-range Weather Forecast (ECMWF) for the ERA5 reanalysis data and the Climate Hazards Center (UCSB) for the CHIRPS precipitation dataset. We acknowledge the Max Planck Institute for Meteorology for the Climate Data Operators (CDO) software used in data processing. Generative AI tools (Claude by Anthropic and Gemini by Google) were utilized for Python code refinement, dataset formatting, and language editing. All code, data analyses, and text were independently verified, tested, and approved by the authors, who accept full responsibility for the manuscript's contents.

Declarations

Funding: There is no funding supporting this research.

Competing Interests: The authors have no relevant financial or non-financial interests to disclose.

Data Availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. The ERA5 data were downloaded via <https://cds.climate.copernicus.eu/>, CHIRPS precipitation data were downloaded at monthly time scale via <https://www.google.com/search?q=https://data.chc.ucsb.edu/products/CHIRPS/v3.0/global/monthly/> and daily CHIRPS data over Cameroon were retrieved using the ClimateSERV portal (NASA/USAID SERVIR; <https://climateserv.servirglobal.net/>).

Code Availability: Custom code used for analysis is available from the corresponding author upon request.

Author Contributions: This manuscript was prepared through the combined contributions of all authors, including contributions to the study design, data, content development, results, interpretation and related scholarly work. Author GBEE selected the research topic, provided and analysed the data, and drafted and formatted the

manuscript. Authors SK, RST, BCEO, CGNL, GMG reviewed the research proposal, analysed some of the data and formatted the final document. Author DAV and AL reviewed the final document. All authors read and approved the final manuscript.

References

- Beucher, F., Lafore J-P., Karbou, F., Roca, R. : High-resolution prediction of a major convective period over West Africa. Q. J. R. Meteorol. Soc. 139. (2013). DOI:10.1002/qj.2225
- Bigot, S., Camberlin, P., Moron, V., Richard, Y. : Structures spatiales de la variabilité des précipitations en Afrique : une transition climatique à la fin des années 60?. *C. R. Acad. Sci. Paris, t.324, Série II a, P. 181-188* (1997).
- Chauvin, F., Roehrig, R., Lafore, J. P. Intraseasonal variability of the Saharan heat low and its link with midlatitudes. *Journal of Climate*, 23(10), 2544–2561 (2010). DOI : 10.1175/2010JCLI3093.1
- Diedhiou, A., Janicot, S., Viltard, A., De Felice, P., & Laurent, H.: Easterly waves regimes and associated convection over West Africa and tropical Atlantic: Results from NCEP/NCAR and ECMWF reanalyses. *Clim Dyn*, 15: 795-822 (1999).
- Embolo Embolo, G. B, Lenouo, A., Nzeukou, A. T., Vondou, D. A., Mkankam Kamga, F. (2017). On convection and static stability during the AMMA SOP3 campaign. *Theoretical and Applied Climatology*, 127(1–2), 197–211 (2017). DOI : 10.1007/s00704-015-1627-3
- Flamant, C., Chaboureaud J.-P., Parker, D. J., Taylor, C. M., Cammas, J.-P., Bock, O., Timouk, F., Pelon, J. : Airborne observations of the impact of a convective system on the planetary boundary layer thermodynamics and aerosol distribution in the inter-tropical discontinuity region of the West African Monsoon. Q. J. R. Meteorol. Soc. 133: 1175–1189 (2007). DOI: 10.1002/qj
- Janicot, S., C. D. Thorncroft, A. Ali, N. Asencio, G. Berry, O. Bock, B. Bourles, G. Caniaux, F. Chauvin, A. Deme, L. Kergoat, J.-P. Lafore, C. Lavaysse, T. Lebel, B. Marticorena, F. Mounier, P. Nedelec, J.-L. Redelsperger, F. Ravegnani, C. E. Reeves, R. Roca, P. de Rosnay, H. Schlager, B. Sultan, M. Tomasini, A. Ulanovsky, ACMAD forecasters team. : Large-scale overview of the summer monsoon over West Africa during the AMMA field experiment in 2006. *Ann. Geophys*, 26, 2569-2595 (2008).
- Laing A. G., Fritsch J. M, Negri A. J. : Contribution of mesoscale convective complexes to rainfall in Sahelian Africa : estimates from geostationary infrared and passive microwave data. *Journal of Applied Meteorology*. Vol 38. P. 957-964 (1999).
- Lavaysse, C., Flamant, C., Janicot, S., Parker, D. J., Lafore, J. P., Sultan, B., Pelon, J. : Seasonal evolution of the West African heat low: a climatological perspective. *Climate Dynamics*, 33(2–3), 313–330 (2009). DOI : 10.1007/s00382-009-0553-4
- Lenouo, A., Monkam, D., Mkankam K. F. : Variability of static stability over West Africa during the northern summer 1979-2005. *Atmos. Res.*, 98, 353–362 (2010).
- Ngoungue Langue, C. G., Lavaysse, C., Vrac, M., Peyrillé, P., & Flamant, C. : Seasonal Forecasts of the Saharan Heat Low characteristics: A multi-model assessment. *Weather and Climate Dynamics*, 2(3), 893–912 (2021). DOI : 10.5194/wcd-2-893-2021
- Oueslati, B., Pohl, B., Moron, V., Rome, S., Janicot, S. : Characterization of Heat Waves in the Sahel and Associated Physical Mechanisms. *Journal of Climate*. Vol. 30. 3095-3115 (2017). DOI: [10.1175/JCLI-D-16-0432.1](https://doi.org/10.1175/JCLI-D-16-0432.1)
- Parker, D., J., Diop-Kane, M., Lafore, J-P.: *Météorologie de l’Afrique de l’Ouest tropicale. Le manuel du Prévisionniste*. EDP sciences. p.756 – 699-742 (2018).
- Peyrillé, P., Lafore, J. P. : An idealized two-dimensional framework to study the West African monsoon. Part II: Large-scale Advection and the Diurnal Cycle . *Journal of the Atmospheric Sciences*. Vol. 64, 2783–2803 (2007). DOI: 10.1175/JAS4052.1

604 Pu, B., Cook, K. H. : Dynamics of the West African Westerly Jet. *Journal of Climate*, 23(23), 6263–6276 (2010). DOI :
605 10.1175/2010JCLI3648.1

606 Roehrig, R., Chauvin, F., Lafore, J. P. : 10-25 Day Intraseasonal Variability of Convection over the Sahel: A role of the
607 Saharan Heat low and midlatitudes. *Journal of Climate*. Vol 24. 5863-5878 (2011). DOI: [10.1175/2011JCLI3960.1](https://doi.org/10.1175/2011JCLI3960.1)

608 Shekhar, R., Boos, W. R. : Weakening and shifting of the Saharan shallow meridional circulation during wet years of the
609 West African monsoon. *Journal of Climate*, 30(18), 7399–7422 (2017). DOI : 10.1175/JCLI-D-16-0696.1

610 Sighomnou, D. Analyse et redéfinition des régimes climatiques et hydrologiques du Cameroun : Perspectives d'évolution
611 des ressources en eau. Thèse de Doctorat d'État, Université de Yaoundé I, Yaoundé, 291 p (2004).

612 Sultan B, Janicot S. :The West African Monsoon dynamics. Part II : the preonset, and onset of the summer monsoon. *J*
613 *Clim* 16 : 3407-3426 (2003).

614 Thorncroft, C. D., Nguyen, H., Zhang, C., Peyrillé, P. : Annual cycle of the West African monsoon: Regional circulations and
615 associated Water Vapor transport. *Q. J. R. Meteorol. Soc.* 137 : 129-147 (2011). DOI : 10.1002/qj.728