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Projected Changes in the Characteristics of Dry and Wet Episodes over Côte d'Ivoire

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ABSTRACT

This study analyses the persistence and frequency of multi-day dry and wet rainfall episodes over Côte d'Ivoire, which are quantified using CPC observations (1979–2022) and a 14-member Coordinated Regional Climate Downscaling

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Experiment (CORDEX)-Africa ensemble under RCP4.5 and RCP8.5. Rather than focusing solely on total rainfall, we quantify rainfall by duration and frequency of dry spells and wet episodes to capture duration-driven drought and flood risks. Historically, dry episodes last 8–15 days, with maximum annual dry spells of 25–40 days, while wet episodes persist for 3–6 days and occur 48 times per year. Projections show substantial changes in rainfall sequencing. Under RCP4.5, mean dry-episode durations increase by +1 to +2 days by mid-century and +2 to +4 days by late-century; under RCP8.5, increases reach +2 to +3 days and +3 to +6 days, respectively, with maximum dry-spell extensions of +15 to +25 days in northern regions. Wet episodes become 1–4 events per year, less frequent but lengthen by +1 to +4 days, especially along the coast under RCP8.5. These shifts suggest fewer but more persistent rainfall events, which heighten drought-related crop-water stress and multi-day flood accumulation risks. The results provide actionable insights for agriculture, hydrology and climate-risk planning by highlighting rainfall sequencing and persistence metrics not captured by traditional rainfall totals. This nuanced perspective enhances understanding of drought, flood accumulation, and agricultural risk under changing climate conditions.

Keywords: Côte d'Ivoire; Dry Episodes; Wet Episodes; Rainfall Persistence; West African Monsoon; Coordinated Regional Climate Downscaling Experiment (CORDEX)-Africa

1. Introduction

Rainfall variability in West Africa is governed by complex interactions among large-scale atmospheric circulation, regional moisture transport, and land-atmosphere feedback. Numerous studies have documented substantial fluctuations in rainfall totals at interannual and decadal scales [1,2]. These variations are strongly modulated by the West African Monsoon (WAM), whose meridional migration influences the spatial and temporal distribution of wet and dry conditions across the region [3,4]. While much attention has been given to changes in seasonal rainfall amounts, far fewer studies have examined the internal structure of rainfall in terms of the sequencing of multi-day dry and wet events, despite their relevance for understanding hydroclimatic variability.

Large-scale ocean-atmosphere modes exert a strong influence on rainfall organisation in West Africa. The Atlantic Niño and equatorial Atlantic SST anomalies affect convective activity and moisture supply along the Guinea Coast [5,6]. Variability in the zonal Walker circulation and Indo-Pacific warm pool modulates subsidence and convective inhibition over West Africa [7,8]. These modes affect not only accumulated rainfall but also the persistence of dry spells and clustering of wet days [9,10]. Several modelling studies suggest that anthropogenic warming may further modify rainfall intermittency, leading to longer dry sequences and more persistent wet events in monsoon regions [11,12].

In Côte d'Ivoire, previous studies have primarily focused on long-term trends in rainfall totals, changes in monsoon onset and cessation dates, and extreme rainfall behaviour [13–15]. Although these analyses provide valuable insight, they do not fully capture the organisation of rainfall into multi-day episodes. Episode-based metrics such as duration, frequency, and maximum event length offer a complementary perspective by characterising rainfall persistence and intermittency at subseasonal scales [15,16]. However, no comprehensive assessment has yet been conducted to quantify historical dry and wet rainfall episodes across Côte d'Ivoire or to evaluate how these characteristics may evolve under future climate forcing.

Regional climate model ensembles, such as CORDEX-Africa, provide a valuable framework for assessing future changes in rainfall sequencing. Several evaluations have shown that CORDEX simulations capture key aspects of West African rainfall variability, including seasonal cycles and broad spatial patterns [17–20]. Nevertheless, model skill varies across regions and time scales, and the ability of these models to reproduce multi-day rainfall persistence has not been extensively examined for Côte d'Ivoire.

This study addresses these gaps by analysing persistent dry and wet episodes using CPC observations (1979–2022) and a 14-member CORDEX-Africa ensemble. We assess historical episode characteristics, evaluate model performance in reproducing temporal rainfall structures, and quantify projected changes under RCP4.5 and RCP8.5 for mid-century and late-century horizons. By focusing on rainfall sequencing rather than totals, this work contributes new insight into the hydroclimatic response of Côte d'Ivoire to future climate forcing and complements broader assessments of monsoon variability in West Africa.

The remainder of this paper is organised as follows. Section 2 describes the data and methods used to identify and evaluate dry and wet rainfall episodes. Section 3 presents historical diagnostics and projected changes in episode characteristics based on observations and the CORDEX-Africa ensemble. Section 4 discusses the physical interpretation of these findings and associated uncertainties. Section 5 summarises the main conclusions.

2. Data and Methods

2.1. Data

Daily precipitation observations were taken from the Climate Prediction Center (CPC) Unified Gauge-based product[20] for the period 1979 to 2022. This dataset provides a spatially consistent gridded rainfall product and is widely used for hydroclimatic analyses in West Africa.

Future climate projections were obtained from a 14-member CORDEX-Africa regional climate model (RCM) ensemble, each driven by different global climate models (GCMs) under the RCP4.5 and RCP8.5 emission scenarios. All CORDEX simulations were bilinearly regridded to 0.25° × 0.25° to match CPC resolution before analysis. This ensures spatial comparability between observations and model outputs. Projections were evaluated over three periods:

- historical baseline: 1976 to 2005
- mid-century: 2036 to 2065
- late-century: 2071 to 2100

The period 1979–2022 is used exclusively for evaluating the CORDEX simulations against CPC observations, as it provides the longest continuous and internally consistent observational record for Côte d'Ivoire. In contrast, the analysis of historical and future climate states uses 30-year periods in accordance with WMO and IPCC recommendations, which define 30-year climate normals as the standard for assessing long-term climatic conditions. The selected windows (1976–2005, 2036–2065, and 2071–2100) ensure statistical robustness and reduce the influence of interannual variability while enabling consistent comparison between historical and projected climates. Projected changes were computed using the multi-model ensemble mean, which reduces random model noise and is widely used in CORDEX analyses for spatial climate fields[17,19].

The RCM-GCM combinations used in the study are listed in **Table 1**.

Table 1. Lists the RCM-GCM pairs and their availability through the ESGF and associated modelling group.

RCM	Driving GCM	Scenario(s)	Data Source/Status
SMHI-RCA4	CanESM2	RCP4.5, RCP8.5	ESGF
SMHI-RCA4	CNRM-CM5	RCP4.5, RCP8.5	ESGF
SMHI-RCA4	EC-EARTH-r12	RCP4.5, RCP8.5	ESGF
SMHI-RCA4	IPSL-CM5A-MR	RCP4.5, RCP8.5	ESGF
SMHI-RCA4	MPI-ESM-LR	RCP4.5, RCP8.5	ESGF
CLMcom-CCLM4-8-17	EC-EARTH-r12	RCP4.5, RCP8.5	ESGF
CLMcom-CCLM4-8-17	HadGEM2-ES	RCP4.5, RCP8.5	ESGF
DMI-HIRHAM5	EC-EARTH-r3	RCP4.5, RCP8.5	ESGF
KNMI-RACMO22E	EC-EARTH-r1	RCP4.5, RCP8.5	ESGF
CCCma-CanRCM4	CanESM2	RCP4.5, RCP8.5	CCCma FTP
MPI-CSC-REMO2009	MPI-ESM-LR	RCP4.5, RCP8.5	RCM Group
MPI-CSC-REMO2009	CNRM-CM5	RCP4.5, RCP8.5	RCM Group
CNRM-ALADIN52	CNRM-CM5	RCP4.5, RCP8.5	RCM Group (not all variables available)
BCCR-WRF331	NorESM1-M	RCP4.5, RCP8.5	RCM Group

Bias Adjustment

No bias correction was applied. Dry and wet episodes were defined using percentile thresholds computed independently for each model, meaning that episode identification is relative to each model's own climatology. This approach avoids the influence of systematic biases in absolute rainfall magnitude and is widely used in studies of rainfall persistence and subseasonal variability[15,16]. Sensitivity tests (not shown) using alternative thresholds (5th–15th and 85th–95th percentiles) produced similar spatial patterns, confirming methodological robustness.

2.2. Methods

Definition of Dry and Wet Episodes

Persistent dry and wet episodes were identified at each grid cell using percentile-based thresholds and minimum run-length criteria:

- A dry episode occurs when daily rainfall is ≤10th percentile of the local rainfall distribution for at least 10 consecutive days.
- A wet episode occurs when daily rainfall is ≥90th percentile for at least 3 consecutive days.

Percentiles were computed from the baseline period 1976–2005, ensuring threshold definitions reflect local climatological conditions. The choice of a ≥10-day minimum duration for dry episodes follows the conceptual framework of Huth et al.[21] (2000), who emphasise that persistent dry spells should represent multi-day sequences long enough to meaningfully interrupt seasonal rainfall regimes. In West Africa, subseasonal dry phases during the monsoon frequently extend beyond one week and may reach or exceed 10 days, as documented in regional analyses of rainfall persistence and monsoon breaks[1,4,16] (Nicholson, 2013; Fitzpatrick et al., 2020; Panthou et al., 2018). Using a 10-day threshold, therefore, ensures that detected dry episodes correspond to meteorologically and agronomically significant events, rather than short-lived fluctuations. This duration is consistent with established practice in tropical rainfall persistence studies and supports a robust characterisation of rainfall sequencing in the region.

For each calendar year, four episode-based indicators were computed (**Table 2**):

1. **Mean duration** (days): Average number of consecutive days per episode.
2. **Maximum duration** (days): Longest uninterrupted episode within the year.
3. **Mean frequency** (events per year): Number of dry or wet episodes occurring within the year.
4. **Maximum frequency** (events per year): Highest annual count observed across the ensemble.

Table 2. Description of episode-based indicators used in this study.

Indicator	Unit	Definition/Calculation	Represents	Sectoral Relevance	References
Mean Duration	days per episode	Average number of consecutive days within each dry or wet episode during a year.	Typical persistence of rainfall deficits or excesses.	Crop-water demand, irrigation scheduling, agricultural field operations.	Nicholson[1], Tamoffo[22]
Maximum Duration	days	Longest uninterrupted dry or wet episode occurring within a year.	Worst-case multi-day stress or accumulation event.	Drought preparedness, reservoir operation, multi-day flood accumulation risk.	Alexander[18], Trisos[23]
Mean Frequency	episodes per year	Average number of dry or wet episodes occurring per year.	How often transitions between dry and wet states occur.	Planting calendar optimisation, soil-moisture management, water-allocation planning.	Olusegun[9], Joly[24], Yapo[25]
Maximum Frequency	episodes per year	The highest number of episodes recorded within a single year.	Fragmentation or clustering of rainfall into multiple short sequences.	Early warning systems, slope stability, urban drainage performance.	Diedhiou[2], Seneviratne[26]

These metrics capture the temporal organisation of rainfall, which strongly influences drought stress, agricultural water demand, soil-moisture dynamics, and multi-day runoff generation. The chosen percentile and run-length thresholds follow established practices for characterising rainfall persistence in West Africa[1,15,16].

2.3. Model Evaluation

Model skill was assessed using the Taylor diagram[27], which summarises:

- Spatial correlation
- Ratio of modelled to observed spatial standard deviation
- Centred root-mean-square difference (RMSD)

The correlation coefficient is computed as:

$$r = \frac{\sum_{i=1}^{n}(x_i - x)(y_i - y)}{\sqrt{\sum_{i=1}^{n}(x_i - x)^2}\ \sqrt{\sum_{i=1}^{n}(y_i - y)^2}}$$

The centred RMSD is:

$$\text{RMSD} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[(x_i - x) - (y_i - y)\right]^2}$$

where x_i and y_i represent modelled and observed rainfall, and $\bar{x}$ and $\bar{y}$ their spatial means.

2.4. Trend and Change-Point Diagnostics

To examine long-term variability and structural shifts in observed rainfall, three complementary diagnostics were applied:

- **Liebmann Windowed-Trend Method**

Because rainfall trends in West Africa are strongly time-scale dependent, the Liebmann windowed-trend diagram [28] was used to assess how the rainfall trend evolves across different window lengths.

The method divides the time series into overlapping sliding windows, computes a linear trend within each window, and displays the sign and magnitude of the trend as a colour field. This enables visual identification of intervals of drying or wetting, as well as the sensitivity of trend estimates to the chosen time scale. (e.g., 5–30 years). For each window, a trend of the form:

$$P(t) = \alpha + \beta t$$

is computed, where β represents the trend slope (mm yr^{-1}).

Results are displayed as a two-dimensional diagram in which:

- the x-axis shows the central year of the window,
- the y-axis shows window length,
- colour shading indicates the magnitude and direction of β,
- contours identify statistically significant trends.

This diagnostic is particularly suited to West Africa, where multi-decadal shifts (e.g., the 1980s–1990s drought) dominate long-term rainfall behaviour.

- **Mann-Kendall Test**

The Mann-Kendall test [29–31] assesses monotonic long-term trends using the statistic:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i)$$

with

$$\operatorname{sgn}(x) = \begin{cases} 1, & x > 0 \\ 0, & x = 0 \\ -1, & x < 0 \end{cases}$$

The Kendall tau coefficient is:

$$\tau = \frac{S}{0.5\, n(n-1)}$$

- **Pettitt Change-Point Test**

Abrupt shifts in median rainfall were identified using the Pettitt test [32]. The statistic is:

$$U_t = \sum_{i=1}^{t} \sum_{j=t+1}^{n} \operatorname{sgn}(x_j - x_i)$$

The estimated change-point t^* corresponds to the maximum absolute value of U_t. The approximate significance is:

$$p \approx 2 \exp\left(\frac{-6U_t^2}{n^3 + n^2}\right)$$

These diagnostics jointly identify long-term tendencies, multi-decadal variability and abrupt regime shifts in the observed rainfall record.

3. Results

3.1. Evaluation of Model Performance

The CORDEX-Africa ensemble shows a modest but coherent ability to reproduce the observed rainfall climatology of Côte d'Ivoire. The Taylor diagram (**Figure 1**) indicates that spatial correlations between individual model simulations and CPC observations remain generally low, with most models clustered between approximately 0.00 and 0.35, and only one model reaching close to 0.50. The multi-model ensemble (MME) performs substantially better, with a correlation of around 0.65 to 0.70, confirming the added value of multi-model averaging in reducing structural uncertainty.

Model dispersion and centred root-mean-square difference (RMSD) also highlight structural spread across simulations. Most individual models underestimate the observed spatial standard deviation, as shown by their position inside the unit-standard-deviation circle. Correspondingly, RMSD values are higher for individual simulations, whereas the MME lies closest to the reference point, indicating reduced overall error relative to CPC. Taken together, the three Taylor-diagram metrics show that although individual CORDEX models vary widely, their ensemble mean provides a considerably more reliable representation of the spatial rainfall structure.

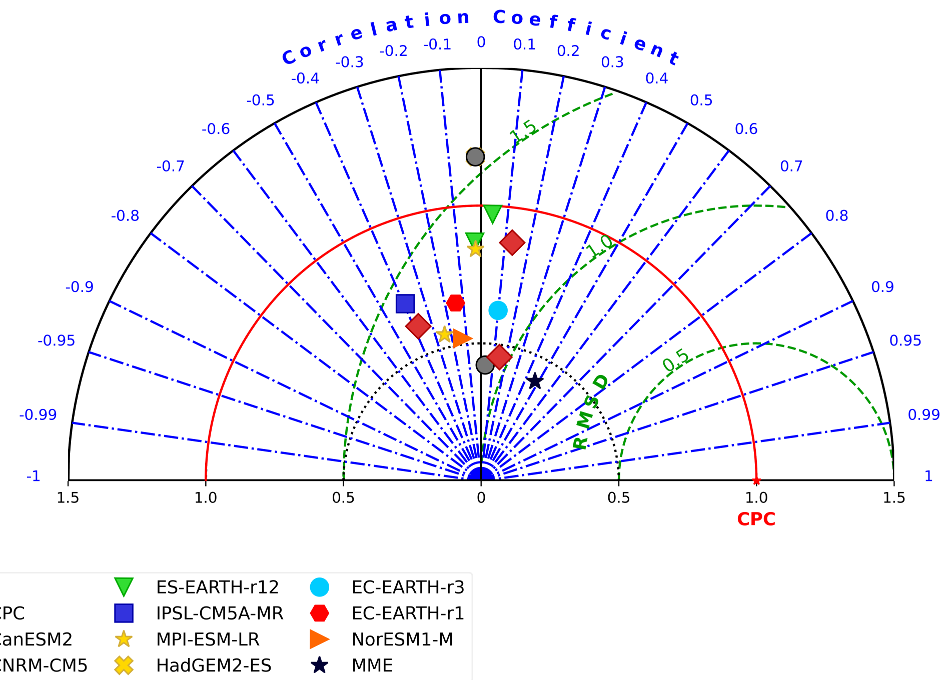

Figure 1. Taylor diagram comparing fourteen CORDEX-Africa climate models with CPC observations in terms of spatial correlation, standard deviation, and centred root-mean-square difference (RMSD).

Note: The reference point (red star) represents observations.

Temporal variability is also reproduced at decadal scales. The Liebmann windowed-trend diagrams (**Figure 2**) show that both the CPC observations and the ensemble capture key phases of multi-decadal variability between 1979 and 2005: a wet period in the early 1980s, the pronounced dry interval from the early 1990s to the early 2000s, and a partial recovery thereafter. Sensitivity to trend-window length (**Supplementary Materials Figure S1**) confirms a robust shift in rainfall regime during the late 1980s.

Trend diagnostics reinforce these features. The Mann-Kendall test (**Figure 3**) detects a weak and statistically non-significant long-term downward trend ($\tau = -0.118$, $p = 0.26$). The Pettitt test (**Figure 3**), however, identifies a significant change-point in 1989, marking the onset of the sustained dry period that extends through the 1990s and early 2000s. These historical behaviours are consistently reproduced by the ensemble mean, supporting the reliability of the dataset for analysing rainfall episode characteristics.

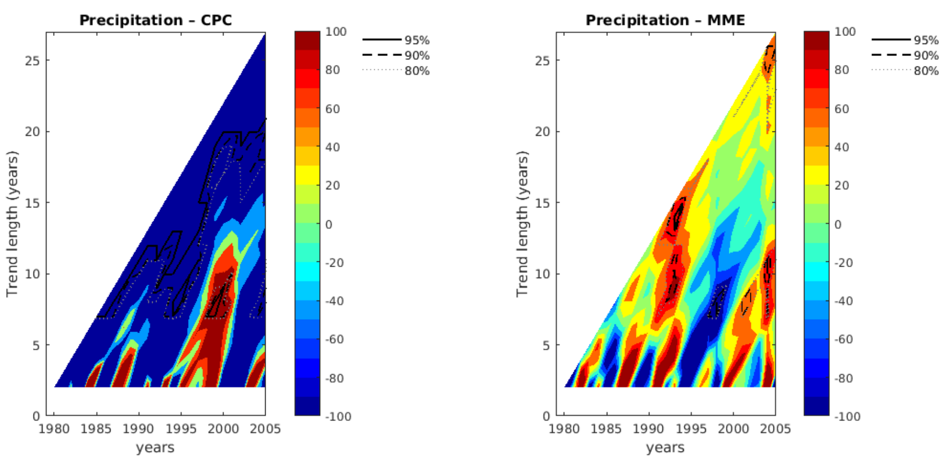

Figure 2. Liebmann diagrams of annual rainfall trends for observations (CPC) and the multi-model ensemble over 1979–2005. Colours show trend slopes (mm yr^{-1}); contours mark significance (95%, 90%, 80%).

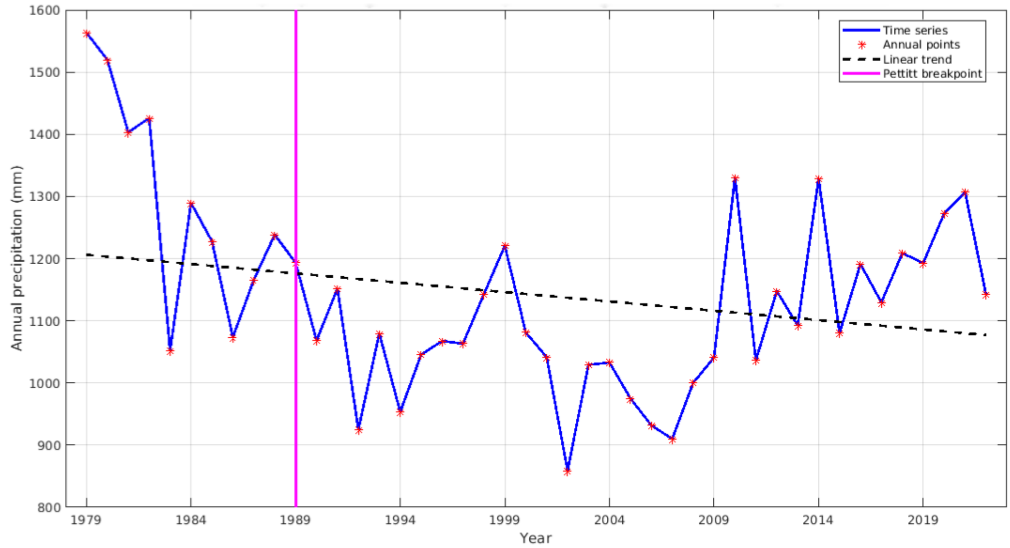

Figure 3. Annual CPC precipitation over Côte d'Ivoire (1979–2022), showing the Mann-Kendall trend analysis and Pettitt change-point test.

Note: The blue line represents annual rainfall, red asterisks show individual yearly totals, and the dashed black line indicates a weak, non-significant downward trend ($\tau = -0.118$, $p = 0.2616$). The magenta vertical line marks the significant 1989 change-point ($p = 0.0391$).

3.2. Historical Rainfall Variability (1979–2022)

Observed rainfall over Côte d'Ivoire exhibits marked interannual and decadal variability from 1979 to 2022. Standardised annual rainfall anomalies (**Figure 4**) show alternating wet and dry years, including strongly positive anomalies in the late 1970s and early 1980s (up to +2.5 to +3 standard deviations), followed by an extended dry period from the early 1990s into the early 2000s. Rainfall begins to recover gradually after 2010, with several wetter-than-average years during the 2010s and early 2020s.

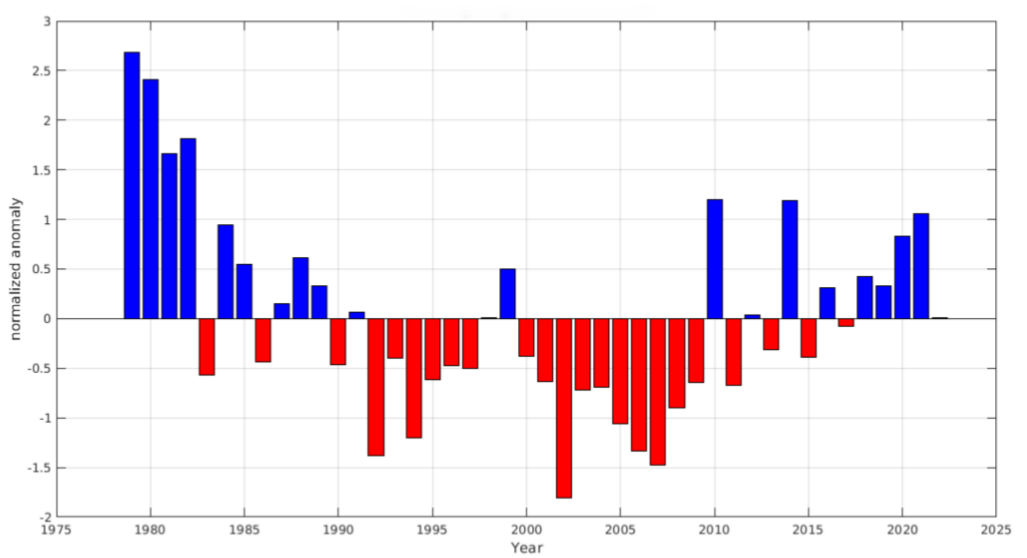

Figure 4. Standardised anomalies of annual rainfall for 1979–2022.

Note: Blue bars indicate wetter-than-average years; red bars indicate drier years.

The long-term annual series (**Figure 3**) demonstrates large year-to-year fluctuations superimposed on a weak, non-significant downward trend ($\tau = -0.118$, $p = 0.26$). Although no monotonic decline is detected, the prolonged dry interval of the 1990s to early 2000s, followed by a gradual improvement after 2010, is clearly evident.

Decadal rainfall distributions (**Figure 5**) reinforce these transitions. The 1980s show reduced median rainfall relative to the late 1970s, followed by an even drier decade in the 1990s. Rainfall remains generally below the long-term median during the 2000s, while the 2010s show partial recovery. These decadal-scale shifts align with well-documented variations in West African Monsoon intensity and Atlantic sea-surface temperature anomalies, including warm-phase Atlantic Niño events that weakened monsoon inflow during the 1980s–1990s drought period [8,33–35].

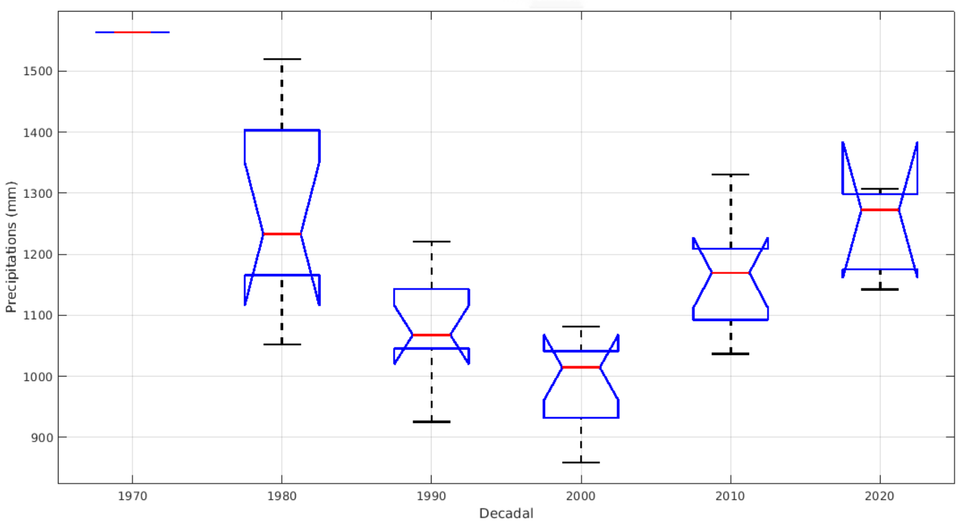

Figure 5. Decadal boxplots of annual rainfall for 1979–2022, highlighting reduced rainfall in the 1990s–2000s and recovery in the 2010s.

The merged Mann-Kendall and Pettitt analysis (**Figure 3**) identifies a statistically significant change-point in 1989 ($p = 0.039$), marking the onset of the multi-decadal dry phase of the 1990s and early 2000s. This structural break is consistent with previously reported regional rainfall regime shifts across West Africa and reflects a transition toward reduced monsoon penetration. These historical features provide essential context for interpreting dry and wet episode characteristics, which respond more strongly to decadal monsoon variability than to long-term linear trends.

3.3. Historical Characteristics of Dry and Wet Episodes (1976–2005)

Dry and wet rainfall episodes exhibit a strong meridional gradient across Côte d'Ivoire, reflecting the structure of the West African Monsoon. During the historical baseline (1976 to 2005):

- dry episodes typically last 8 to 15 days, with maximum annual durations of 25 to 40 days, particularly over northern Côte d'Ivoire where monsoon breaks are more frequent (**Figure 6a,d**)
- wet episodes last 3 to 6 days and occur 4 to 8 times per year, with the highest frequencies along the southern coastal belt (**Figure 7a,d**).

These contrasts are consistent with earlier analyses of rainfall persistence and subseasonal variability across West Africa. **Supplementary Materials Figure S4** provides further detail on spatial patterns in maximum dry-spell duration.

These observed characteristics form the baseline for evaluating projected changes.

- **Projected Changes in Episode Characteristics**

Projected changes are assessed relative to the historical baseline (1976 to 2005) for mid-century (2036 to 2065) and late-century (2071 to 2100) under RCP4.5 and RCP8.5. The following figures summarise projected changes in mean duration, maximum duration and mean frequency of dry and wet episodes.

- **Dry Episodes**

Mean duration (**Figure 6**) increases across most regions:

- RCP4.5: approximately +1 to +2 days by mid-century and +2 to +4 days by late-century
- RCP8.5: +3 to +6 days by late-century

The strongest increases occur in the northern interior, consistent with projections of reduced monsoon penetration and enhanced land-atmosphere drying.

Maximum dry-spell duration also increases substantially:

- RCP4.5: +5 to +8 days
- RCP8.5: +15 to +25 days by late-century

This implies that extreme dry spells may exceed 40 to 60 days in northern Côte d'Ivoire.

Changes in frequency are more limited (**Figure 8**). Under RCP4.5, frequency remains similar to historical values, whereas RCP8.5 shows modest increases of +1 to +2 events per year in northern areas. This indicates that future dryness intensification is driven primarily by duration, not event count.

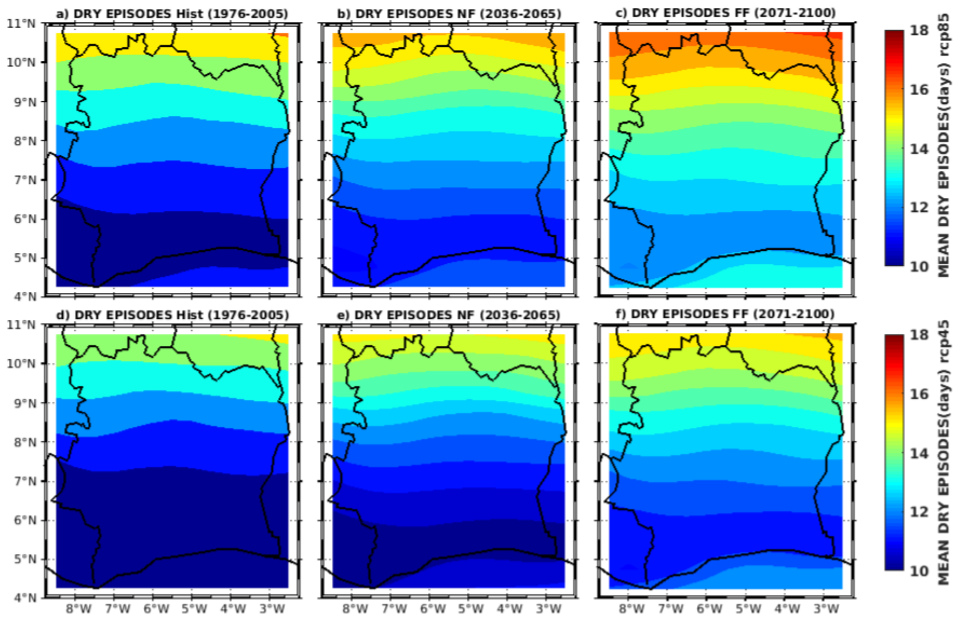

Figure 6. Mean duration (days) of dry episodes for the historical period (1976–2005) and future projections under (**a–c**) RCP8.5 and (**d–f**) RCP4.5.

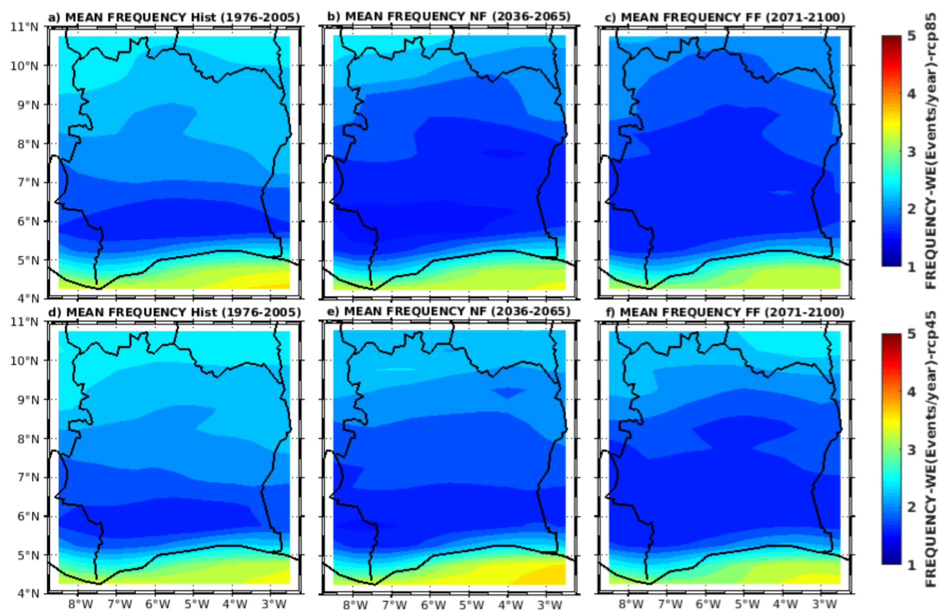

Figure 7. Mean annual wet-episode frequency (events per year) for the historical period (1976–2005) and future projections under (**a–c**) RCP8.5 and (**d–f**) RCP4.5.

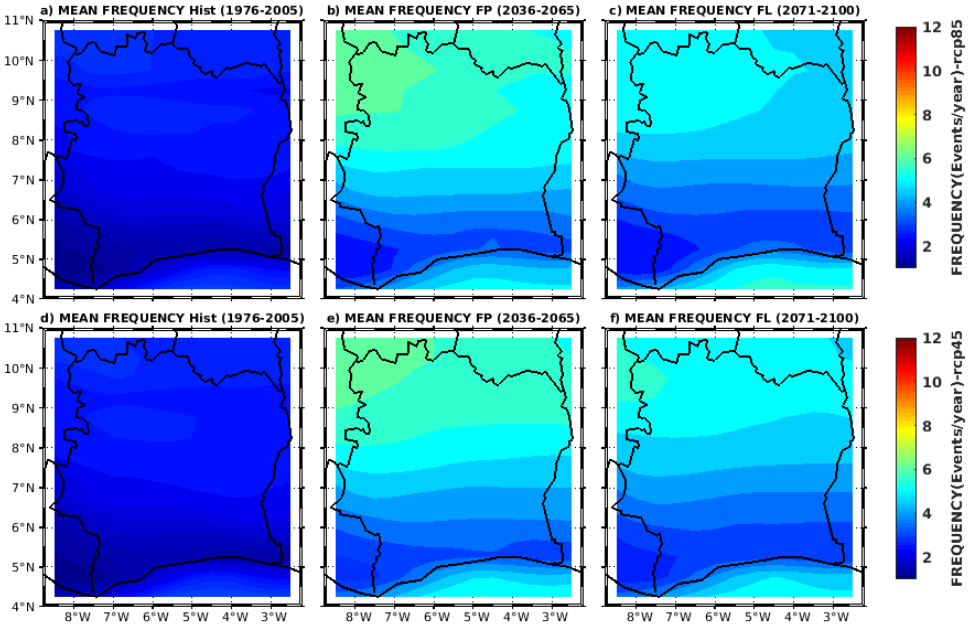

Figure 8. Mean annual dry-episode frequency (events per year) over Côte d'Ivoire for the historical period (1976–2005) and future projections under (**a–c**) RCP8.5 and (**d–f**) RCP4.5. Panels (**a,d**) show the historical baseline, panels (**b,e**) mid-century (2036–2065), and panels (**c,f**) late-century (2071–2100).

- **Wet Episodes**

Wet-episode duration (**Figure 9**) increases across most regions:

- RCP4.5: +1 day at mid-century and +1 to +2 days by late-century
- RCP8.5: +2 to +4 days in the late century

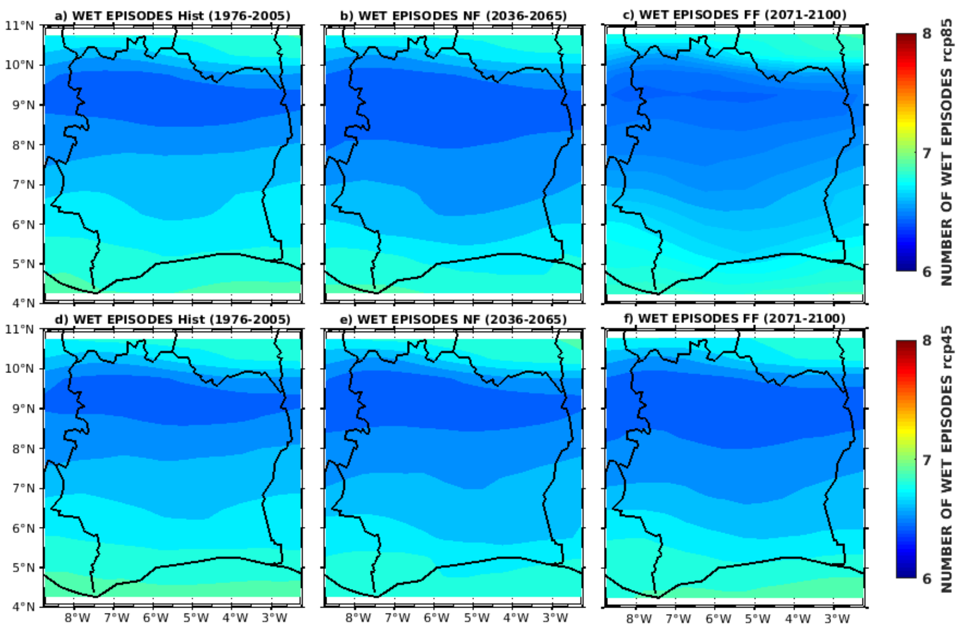

Figure 9. Mean duration (days) of wet episodes for the historical period (1976–2005) and future projections under (**a–c**) RCP8.5 and (**d–f**) RCP4.5. Panels (**a,d**) show the historical baseline, (**b,e**) mid-century conditions (2036–2065), and (**c,f**) late-century conditions (2071–2100).

The longest increases appear along the southern coastal belt. Maximum wet-episode durations increase by +3 to +10 days (**Supplementary Materials Figure S2**), implying stronger multi-day accumulation. Wet-episode frequency decreases across the country (**Figure 6**):

- RCP4.5: approximately −1 event per year
- RCP8.5: −2 to −4 events per year by late-century

This shift toward fewer but more persistent wet events suggests an increasingly intermittent but more intense rainfall regime.

3.4. Summary of Projected Changes

A coherent set of changes emerges from the projected evolution of dry and wet rainfall episodes across Côte d'Ivoire (**Figures 6–9**).

1. Dry episodes become progressively longer, with the most pronounced extensions occurring in northern Côte d'Ivoire under both emissions scenarios. This reflects a tendency toward more persistent monsoon breaks, consistent with regional projections of increased land-atmosphere drying and reduced low-level moisture transport under warming.
2. Wet episodes become fewer but longer, especially along the southern coastal belt, where organised convection is climatologically strongest. The combination of reduced frequency and increased duration suggests a shift toward more intermittent but more persistent rainfall events, a pattern also highlighted in recent regional CORDEX assessments.
3. The reorganisation of rainfall timing exceeds changes in total rainfall amounts. Alterations in event sequencing, including longer dry spells, fewer but more persistent wet episodes, and changes in clustering, are likely to influence agricultural planning, water-resource management, and multi-day flood accumulation more directly than changes in seasonal or annual totals.

Overall, these results underscore the importance of analysing rainfall persistence and sequencing. Episode-based metrics offer insights into future hydroclimatic risks that are not captured by conventional assessments of rainfall means or extremes.

4. Discussion

The results demonstrate a coherent reorganisation of rainfall sequencing across Côte d'Ivoire, with important implications for monsoon behaviour, hydrological processes and climate-risk management. The projected lengthening of dry spells and the shift toward fewer but longer wet episodes are consistent with well-documented thermodynamic and dynamic responses to warming in tropical regions. Increased atmospheric moisture capacity, enhanced moisture convergence and altered convective inhibition under higher temperatures have been shown to modify the persistence and organisation of rainfall events across West Africa [11,26,36]. These mechanisms provide a physically grounded explanation for the episode-based signals identified in this study.

A key feature of the projections is the intensification of the north-south hydroclimatic gradient. The strongest enhancements in dry-episode duration occur in northern Côte d'Ivoire, an area already highly sensitive to fluctuations in monsoon penetration. Similar extensions of multi-day dry spells have been observed in the Sahel and northern West Africa [16,22], where reductions in low-level moisture transport and weakening of the monsoon inflow have contributed to increased aridity. The close agreement between models in this region strengthens the interpretation that monsoon-related processes, including variability in Atlantic Niño events and land-atmosphere feedbacks, are driving the projected patterns [8,37].

Changes in wet episodes also align with the established understanding of mesoscale convective organisation in the region. Warmer conditions can enhance convective available potential energy (CAPE) and promote longer-lasting mesoscale convective systems, especially along the southern coast, where organised convection is climatologically dominant [36]. The simultaneous reduction in frequency and increase in duration observed in this study indicates a shift toward more intermittent but more persistent rainfall events. Comparable patterns were identified in recent CORDEX analyses showing increased rainfall intermittency, longer wet events and modified subseasonal rainfall structure under strong forcing scenarios [18,19,25]. These findings enhance confidence that the projected changes are physically robust and consistent with ensemble-level behaviour across West Africa.

Beyond the dynamical interpretation, these results are hydrologically significant. Multi-day rainfall accumulation, rather than single-day intensity, often governs flood generation, soil saturation and groundwater recharge in West Africa. Previous studies have highlighted similar decoupling between rainfall totals and persistence, showing that subseasonal rainfall structure plays a decisive role in agricultural productivity and drought vulnerability [1,15,16]. The projected reorganisation of rainfall timing therefore has direct consequences for planting calendars, irrigation scheduling and catchment-scale runoff generation, even in the absence of strong long-term trends in annual rainfall.

Uncertainties nonetheless remain. The CORDEX models differ in their representation of rainfall intermittency, consistent with known limitations related to parameterised convection [38,39]. Internal climate variability, including ENSO, the Atlantic Niño, the Atlantic Multidecadal Variability (AMV) and other SST-driven modes, will continue to modulate rainfall episodes independently of long-term climate forcing [8,40]. The absence of bias adjustment introduces additional uncertainty; although the percentile-based thresholds reduce sensitivity to mean-field biases, certain aspects of rainfall sequencing may still be affected. Sensitivity analysis of percentile thresholds and minimum run-length requirements would also offer additional clarity and is recommended for future work.

Despite these limitations, the high model agreement on the sign of change, the consistency with physical theory and the strong alignment with existing literature all reinforce the robustness of the projected evolution of rainfall sequencing in Côte d'Ivoire. The results collectively demonstrate that rainfall timing and persistence are likely to undergo more substantial changes than rainfall totals under future warming. These insights are crucial for climate services, agricultural planning, water-resource management and urban flood-risk reduction.

5. Conclusions

This study investigated historical and projected changes in the persistence and sequencing of multi-day dry and wet rainfall episodes over Côte d'Ivoire using CPC observations (1979 to 2022) and a 14-member CORDEX-Africa ensemble under RCP4.5 and RCP8.5 scenarios. The results show that, even in the absence of strong long-term trends in seasonal or annual rainfall totals, the internal organisation of rainfall is projected to undergo substantial modification. Three coherent and scientifically robust findings emerge.

First, dry spells are projected to lengthen across all regions, with the most pronounced increases in northern Côte d'Ivoire. Both mean and maximum dry-episode durations intensify under all scenarios, with late-century extensions of more than two weeks under RCP8.5. These patterns are consistent with reduced monsoon penetration and weakened moisture transport mechanisms identified in previous regional analyses, suggesting increasing exposure to prolonged water-stress conditions.

Second, wet episodes are projected to become fewer in number but more persistent. Although event frequency declines, their duration increases, especially along the southern coastal belt, where deep convection is climatologically dominant. This behaviour is consistent with thermodynamic expectations under warming, which favour enhanced atmospheric moisture capacity and shifts in convective organisation. As a result, rainfall may increasingly occur in concentrated multi-day episodes, with implications for soil saturation, flood generation, erosion and reservoir management.

Third, the magnitude of projected changes in rainfall sequencing exceeds that of changes in rainfall totals. Metrics such as persistence, duration and clustering provide information on hydroclimatic stress that accumulated rainfall alone cannot capture. These episode-based indicators therefore offer a more sensitive lens through which to assess the impacts of climate change on agricultural drought, water-resource variability and multi-day flood hazard in Côte d'Ivoire.

While uncertainties remain, particularly related to model spread, parameterised convection and internal climate variability, the strong level of ensemble agreement and the consistency with known monsoon processes lend credibility to the projected patterns. Future work should explore the sensitivity of episode detection to threshold and run-length choices, incorporate convection-permitting simulations and examine the influence of large-scale ocean-atmosphere drivers such as the Atlantic Niño and ENSO.

Overall, the findings underscore the value of analysing rainfall sequencing in addition to totals. By quantifying how multi-day dry and wet events may evolve under future climate forcing, this study provides actionable information for climate-smart agriculture, hydrological planning and climate-risk management in Côte d'Ivoire and contributes to a broader understanding of subseasonal rainfall dynamics across West Africa.

Supplementary Materials

The supporting information can be downloaded at https://journals.bilpubgroup.com/files/JASR-12989-Supplementary-Materials.docx.

Author Contributions

S.T., É.Y.A., A.D. (Arona Diedhiou) and A.D. (Adama Diawara): conceptualisation, methodology; S.T. and É.Y.A.: software, data curation, visualisation; S.T., A.D. (Arona Diedhiou), E.Y.A. and A.D. (Adama Diawara): formal analysis and writing original draft. S.T., É.Y.A., A.D., I.D., A.L.M.Y., T.C.F.-N., B.K., F.Y. and A.D.: analysis, validation, review and editing. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

All data used or generated in this study are available for free upon request to the authors.

CHIRPS data are available at https://www.chc.ucsb.edu/data/chirps.

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Conflicts of Interest

The authors declare no conflict of interest.

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