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Article

Projected Changes in Dry and Wet Spells over West Africa Using Markov Chain Approach

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Abstract: The study examines projected changes in dry- and wet-spell probabilities in West Africa using a Markov chain approach. Four simulations of regional climate models from the CORDEX-Africa program were used to analyze projected changes in intraseasonal variability. The results show an increase in the probability of having a dry day, a dry day preceding a wet day and a dry day preceding a dry day, and a decrease in the probability of wet days in the Sahel region under anthropogenic forcing scenarios RCP4.5 and RCP8.5. The decrease in wet days is stronger in the far future and under the RCP8.5 scenario (up to -30%). The study also finds that the probability of consecutive dry days (lasting at least 7 days and 10 days) is expected to increase in the Western Sahel, the Central Sahel, and the Sudanian Area under both scenarios, with stronger increases in the RCP8.5 scenario. In contrast, the decrease is expected over the Guinea Coast, with the changes more important under the RCP4.5. These changes in dry- and wet-spell probabilities are important for water management decisions and risk reduction in the energy and agricultural sectors. The study also highlights the need for decision-makers to implement mitigation and adaptation policies to minimize the adverse effects of climate change.

Keywords: West Africa; Markov chain process; climate change; dry spells; wet spells

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC, 2013) has scientifically confirmed that global warming is due to the increase in human-induced greenhouse gas (GHG) emissions on the world's climate. According to Krishnan and Sanjay (2017), climate change constitutes a great challenge to modern society because of its major implications with regard to environmental, agricultural, natural resources, ecosystems, and socio-economic aspects. In the past few decades, seasonal changes in the Western Africa has been influenced by an increase in average annual precipitation, due to both an increase in the number of wet days and an increase in the average intensity and number of extreme events, particularly in the southern parts of Western Africa (Nkrumah et al., 2019). In this region, water resources and agricultural production are highly dependent on climate variability, especially in the semi-arid Sahel. Rainfall is one of the most commonly used meteorological parameters for determining climate variability in the West Africa. According to Ta (2016), its measurement is a major consideration in the tropics as it contributes significantly to hydrological and climate studies. In addition, future trends and changes in weather and climate extremes have been studied in West Africa (Sylla et al., 2015; Sarr and Camara, 2017; Diedhiou et al., 2018; Ogega et al., 2020; Didi et al., 2020; Yapo et al., 2020). These studies mainly used indices including dry and wet spells defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) to study the spatiotemporal evolution of temperature and precipitation extremes (Klein Tank et al., 2009). Wet and dry spells are known to affect food security and water management; however, they have been less studied in the West African region (Froidurot and Diedhiou, 2017; Biao

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and Alamou, 2018; Ayanlade et al., 2018). Sen (2015) showed that disasters induced by alternating dry and wet periods have increased owing to global warming.

While these dry and wet spells are useful for the quantitative description of drought, flood, and flash flood occurrence assessments (Biao and Alamou, 2018), studies on future changes in the probability of occurrence of these high-impact events in West Africa are nascent.

The Markov chain process is a useful tool for determining the beginning and end of the rainy season, as well as dry and wet spells, which largely determines the success of rainfed agriculture and the availability of water resources (Pandharinath, 1991; Rockström et al., 2002; Basse et al., 2021). The study's purpose is to assess future changes of the dry and wet days probabilities over West Africa using Markov chain process under the RCP4.5 and RCP8.5 scenarios of the simulations of regional climate models from the CORDEX-Africa programme (Giorgi et al, 2009; Jones et al. 2011; Hewitson et al., 2012; Nikulin et al., 2012). The remainder of this paper is organized as follows. Section 2 discusses the data and methods used in this study. In Section 3, the results are analyzed and discussed. Section 4 presents the summary and future outlook.

2. Data and Methods

2.1. Data

Daily rainfall data from four (04) regional climate models (RCMs) involved in the Coordinated Regional Climate Downscaling Experiment (CORDEX) (Giorgi et al., 2009; Jones et al., 2011; Hewitson et al., 2012; Nikulin et al., 2012) were analyzed in this study. CORDEX aims to produce numerical simulations to better characterize fundamental regional and local climate features, their variability, and changes using regional climate models (Mbaye et al., 2019). Table 1 summarizes the climate model data with the forcing global climate model (GCM), the institute, the RCM, the historical period (1976-2005) and the two future times: the near future (2021-2050) and the far future (2071-2100). The choice of these RCMs is motivated by their capacity to simulate the general features of the African climate, particularly in Western Africa (Sarr et al., 2018; Coulibaly et al., 2018; Lawin et al., 2019, Kouadio et al., 2020; Koffi et al., 2023). These data have a horizontal resolution of 0.44° x 0.44° and a daily time step for different Representative Concentration Pathway (RCP) scenarios. The scenario RCP4.5 is a trajectory describes a radiative forcing of ~4.5 $W.m^{-2}$ with stabilization after 2100, corresponding to policies close to the mitigation efforts proposed by governments at Paris COP21 (Barredo et al., 2017). RCP8.5 refers to a radiative forcing above 8.5 $W.m^{-2}$ in 2100. The ensemble mean of the four regional climate models (arithmetic mean) was computed and analyzed in this study.

Table 1. Climate model used with these characteristics (i.e, global climate models (GCM), institute, regional climate models (RCM)) and simulation periods.

Driving GCM	Institute	RCM	Historical Period	Projection Period
ICHEC-EC-EARTH	MPI	REMO	1976-2005	2021-2050 ; 2071-2100
	KNMI	RACMO22T	1976-2005	2021-2050 ; 2071-2100
	DMI	HIRHAM5	1976-2005	2021-2050 ; 2071-2100

CNRM-CERFACS	CLMcom	CCLM4-8-17	1976-2005	2021-2050 ; 2071-2100

2.2. Methods

The probabilities of occurrence of the dry and wet days were determined using daily rainfall data processed with the Markov chain. A day is classified as dry (wet) if the daily rainfall is less than 1 mm (above or equal to 1 mm) (Froidurot and Diedhiou, 2017; Diba et al., 2018; Bichet and Diedhiou, 2018a, 2018b; Todzo et al., 2020; Basse et al., 2021; Fall et al., 2021). The Markov chain probability model has been shown to be suitable for describing the long-term frequency behaviour of wet and dry periods. The first-order Markov chain is the most basic and extensively used in academic publications. It is characterized by a Markovian property, where the current state relies solely on the preceding state (Ray et al., 2018; Basse et al., 2021).

The process of occurrence of a binary first-order Markov chain is thus depicted:

$$P_{ij} = Pr(X_t = j \mid X_{t-1} = i, X_{t-2} = i_{t-1}, \ldots, X_1 = i_1) = Pr(X_t = j \mid X_{t-1} = i) \quad (1)$$

Where, $i, j, i_1 \ldots, i_{t-1} \in \{0, 1\}$ and Pr and P_{ij} represent respectively, the probability and the transition probabilities from state i (dry and wet) to state j (dry and wet).

Consider the transition matrix as :

$$\begin{bmatrix} P_{00} & P_{01} \\ P_{10} & P_{11} \end{bmatrix}$$

Where, P_{00}, P_{01}, P_{10} and P_{11} represent respectively, the conditional probabilities to have a dry day preceded by a dry day, a wet day preceded by a dry day, a dry day preceded by a wet day and a wet day preceded by a wet day.

Thus, $P_{00} + P_{01} = 1$ and $P_{10} + P_{11} = 1$

The initial probabilities to have a dry day and a wet day are noted P_0 and P_1, respectively.

These different probabilities used are calculated as follows (Ray et al., 2018; Basse et al., 2021):

Initial probabilities

$$P_0 = \frac{N_0}{N} \quad (2)$$

$$P_1 = \frac{N_1}{N} \quad (3)$$

Transition probabilities

$$P_{00} = \frac{N_{00}}{N_0} \quad (4)$$

$$P_{11} = \frac{N_{11}}{N_1} \quad (5)$$

$$P_{01} = 1 - P_{00} \quad (6)$$

$$P_{10} = 1 - P_{11} \quad (7)$$

Where, N_0, N_1, N_{00} and N_{11} represent respectively, the number of the dry days, the number of the wet days, the number of the dry days preceded by the dry days and the number of the wet days preceded by the wet days.

Then, the probabilities of a dry and wet period lasting n-days are shown in equations 8 and 9, respectively (Biao and Alamou, 2018; Basse et al., 2021).

$$P(D = n) = P_{00}^{n-1}(1 - P_{00}) \quad (8)$$

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$$P(W = n) = P_{11}^{n-1}(1 - P_{11}) \quad (9)$$

The dry- and wet-spell probabilities were analyzed for diverse time intervals (i.e. 7 and 10 day durations) as in Basse et al. (2021) and Fall et al. (2021). These durations have been chosen to take into account various synoptic patterns in the rainy season African Easterly Waves (Diedhiou et al., 1999; Froidurot and Diedhiou, 2017) and they are motivated by the fact that longer dry spells in August over the Sudano-Sahelian regions is one of the factors explaining the yield reductions, as August is the heading phase when the plant needs enough water to develop (Ouédraogo et al., 2013).

In this study, the results are presented as the relative deviation (RD) between the two periods:

$$RD = 100 \times \left(\frac{PP - HIST}{HIST}\right) \quad (10)$$

where PP represents the average summer projection period under the RCP scenarios, and HIST represents the reference period (1976-2005).

Figure 1 shows the historical average summer rainfall (July-September) ensemble mean of models in West Africa that covers 20°W-20°E longitude and 0-20°N latitude. The sub-regions (Western Sahel, Central Sahel, Sudanian Zone and Guinea Coast) are also represented as in Froidurot and Diedhiou (2017) and Basse et al. (2021). The historical seasonal rainfall ensemble mean presents a zonal distribution with higher values in the mountainous areas (Fouta Djallon Mountains, Plateau of Jos, and Mountains of Cameroon). The ensemble mean represents the summer rainfall realistically. This distribution corresponds to the findings of Sarr et al. (2018) and Diba et al. (2016) who showed that regional climate models reproduce West African summer rainfall quite well.

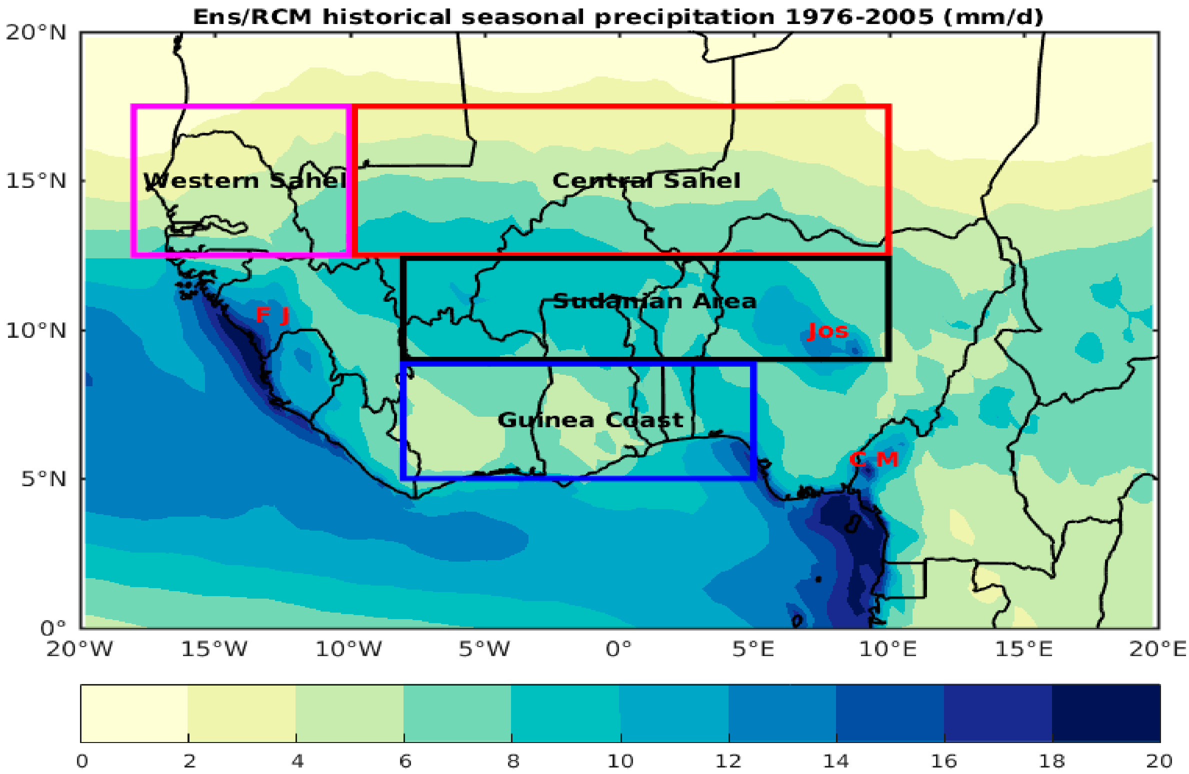

Figure 1. Ensemble mean of summer precipitation (July-September) of CORDEX models for the historical period (1976-2005) in West Africa. The four rectangles illustrate the Western Sahel (magenta), Central Sahel (red), Sudanian Area (black), and Guinea Coast (blue). The mountainous areas are also represented: Fouta Djallon Mountains (FJ), Plateau of Jos (Jos), and Mountains of Cameroon (CM).

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3. Results and Discussion

3.1. Spatial Variability of Summer Rainfall

The modelled summer period rainfall (July-September) changes during the near and far futures under the RCP4.5 and RCP8.5 scenarios are presented in Figure 2. In general, most Sahelian regions will experience a decrease in average rainfall of about -25% in the near future under both scenarios (Figure 2a-b) compared to the average value of the historical period. However, the Guinean regions are expected to experience an increase of approximately 30% under both scenarios. Changes in rainfall in the far future (Figure 2c-d) show a generally larger decrease (increase) than in the near future in the Sahelian regions (more than 30% in the Guinean regions). These results for the Guinean areas are similar to those of Yapo et al. (2020) in Côte d'Ivoire. These studies showed an increase in the rainfall intensity (SDII) under climate change. Moreover, the decrease in mean rainfall in the Sahel is in agreement with the results of Sarr and Camara (2017) and Diba et al. (2021).

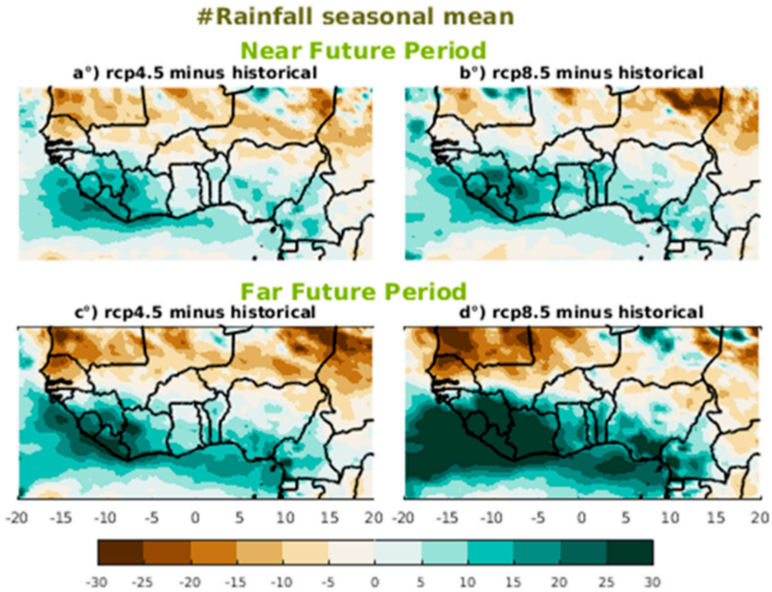

Figure 2. Rainfall changes (%) during the near (a, b) and far (c, d) future, following the RCP4.5 and RCP8.5 scenarios relative to the historical period.

3.2. Spatial Variability of Summer Probabilities

The probability changes of a dry day (P_0) and a wet day (P_1) in the near future and far future are presented in Figure 3. In the near future, the model ensemble average shows an increase in the P_0 probabilities over the Sahelian regions and a decrease over the Guinean regions under both scenarios (Figure 3c, d) compared with the historical period (1976-2005). This change is more pronounced under the RCP8.5 scenario (up to 15%) in the Sahel and under the RCP4.5 scenario (up to -25%) in the Guinean coast. For the P_1 probabilities (Figure 3e, f), a decrease was noted over the Sahelian regions, especially over the north for both scenarios. This decrease is more prominent in the RCP8.5 scenario (up to -25%), particularly in northern Senegal, Mauritania, and northern Mali. The changes in the P_0 probabilities in the far future (Figure 3g, h) generally exhibit a larger increase (decrease) than in the near future in the Sahelian regions (Guinea regions) by more than 30% (up to -25%) under RCP8.5. As in the case of the P_0 probabilities, the P_1 probabilities (Figure 3i, j) show a stronger decrease (increase) in the Sahelian regions (Guinea Coast) than in the near future. The increase in the P_0 probabilities over the Sahelian regions is due to a decrease in mean rainfall while the decrease in the P_1 probabilities over the Guinean coasts is due to an increase in mean rainfall.

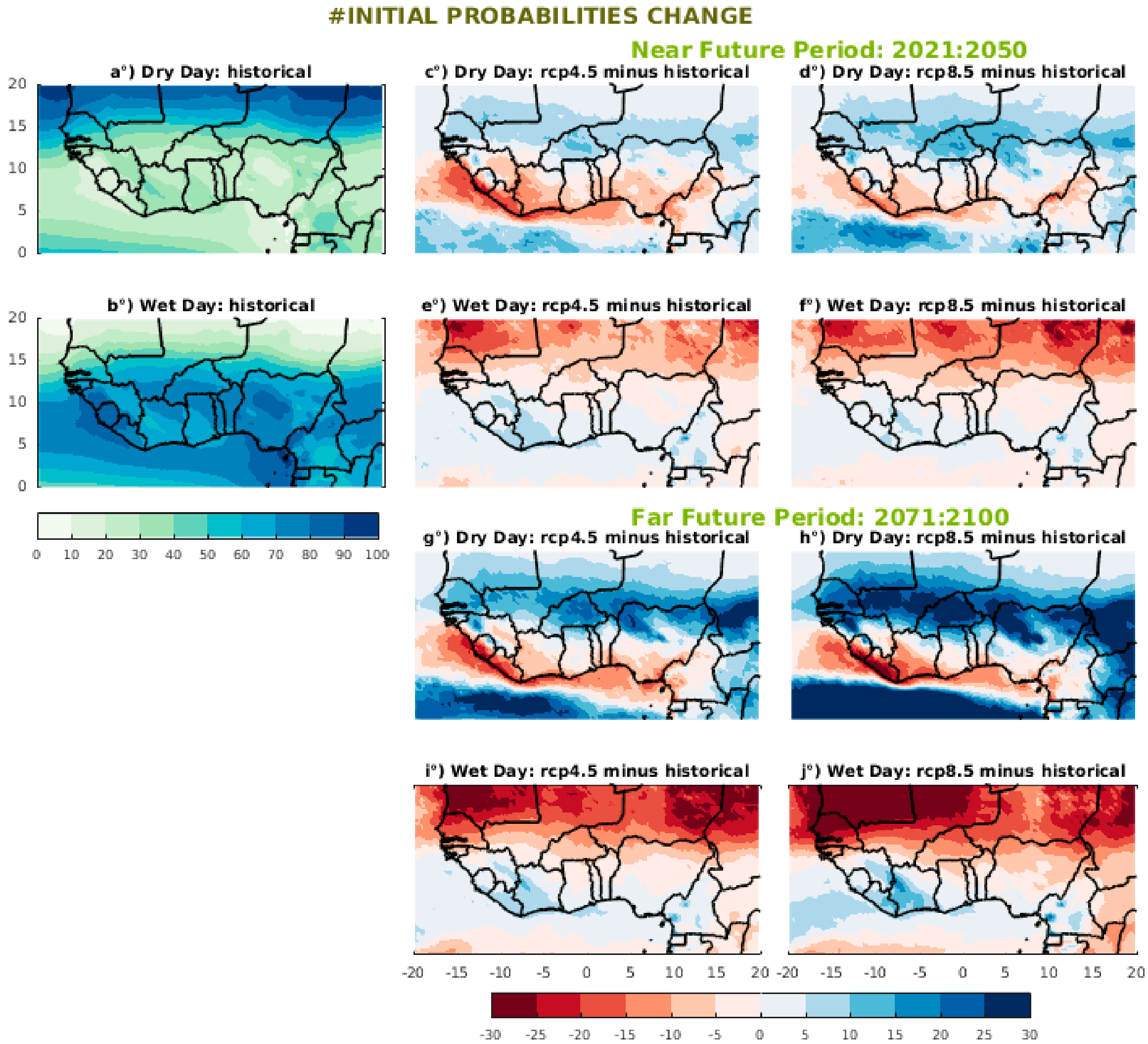

Figure 3. Probability changes (%) of dry and wet days for the historical period (**a, b**), RCP4.5 (**c, e, g, i**) and RCP8.5 (**d, f, h, j**) scenarios with respect to the historical period during the near future (top) and far future (bottom).

The differences in the transition probabilities (P_{00}, P_{01}) between the historical and future periods are shown in Figure 4. In the near future, the model ensemble mean predicted an increase in the P_{00} probabilities in the northern parts of West Africa, particularly in the Sahelian regions, and a decrease in the south (i.e., Guinea Coast) under both scenarios (Figure 4c, d) compared to the reference period. The increase in the Sahelian regions is more important in RCP8.5, especially over the Central Sahel (up to 15%) and the decrease over the Guinea Coast is more remarkable under RCP4.5 (up to -30%). Considering the P_{01} probabilities, shown in Figure 4e-f, the model ensemble mean shows a decrease in the northern parts of West Africa under both scenarios compared to the historical period, more pronounced in the large part of the Sahel under the RCP8.5 scenario (up to -25%). However, an increase is diagnosed in the southern part of West Africa, especially over the Guinea Coast, under both scenarios, with larger changes under the RCP4.5 scenario (up to 25%). This picture is similar in the far future (Figure 4g-j), where the rainy season is associated with an increase in the P_{00} probabilities (Figure 4g-h) in the most parts of the Sahel (about 25%) and a decrease in the Guinea Coast (about -30%) under the RCP8.5 scenario. In contrast to the P_{00} probabilities, the P_{01} probabilities are characterized by an increase in the Sahel and a decrease over the Guinea Coast (Figure 4i-j). However, the changes were more pronounced under the RCP8.5 scenario (up to -30% in the majority of the Sahel and up to 25% in the Guinea Coast).

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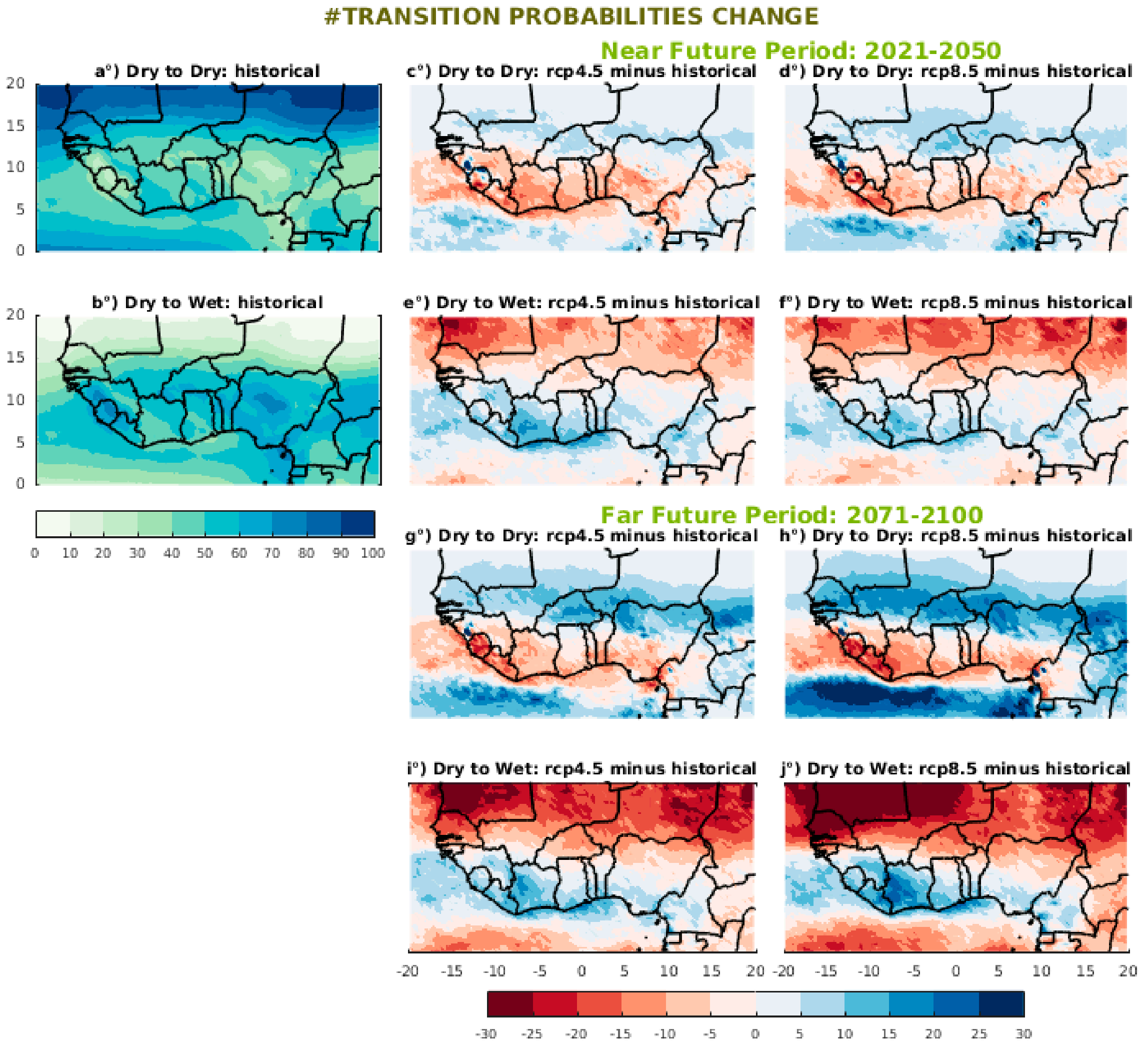

Figure 4. Same as Figure 3, but for the dry-to-dry day probabilities and dry-to-wet day probabilities.

The probabilities P_{11} and P_{10} are shown in Figure 5. West Africa is characterized by high (low) P_{11} (P_{10}) probabilities, particularly over the ITCZ and mountainous regions (Figure 5a, b). These model-averaged findings are consistent with the results observed by Basse et al. (2021) over the same areas. The changes in the P_{11} probabilities in the near future (Figure 5c-d) are characterized by a decrease in the northern parts of West Africa under both scenarios. The decrease is more pronounced under the RCP8.5 scenario (up to -20%). In contrast, a weak increase is projected under both scenarios in the southern part of West Africa (southern Conakry Guinea, Liberia, Sierra Leone and Côte d'Ivoire). Regarding the P_{10} probabilities (Figure 5e, f), the model ensemble mean predict an increase over the north and a decrease over the south of West Africa under both scenarios. The increase over the north is more pronounced following the RCP8.5 scenario (Figure 5f) and the decrease over the south following the RCP4.5 scenario (Figure 5e).

The changes in P_{11} probabilities during the far future are reported in Figure 5g and h for the two scenarios. In general, considering both scenarios, we observe a decrease in the P_{11} probabilities of up to -15% under the RCP4.5 scenario and at more than -25% under the RCP8.5 scenario in the northern parts of West Africa region, except for the southern areas (Sierra Leone, Liberia, southern Conakry Guinea, southern Côte d'Ivoire and southern Nigeria) where an increase of about 5% under the RCP4.5 and up to 10% under the RCP8.5 scenarios is observed. The changes in the P_{11} probabilities are larger in the far future than in the near future.

Regarding the P_{10} probabilities (Figure 5i, j), an inverse scenario is observed with respect to the P_{11} probability. An increase of up to 20% under the RCP4.5 scenario and more than 30% under

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the RCP8.5 scenario is expected over the northern part of West Africa. However, some parts in the south of West Africa will experience a decrease in the P_{10} probabilities under both scenarios and is more pronounced under the RCP8.5 scenario (up to -30%).

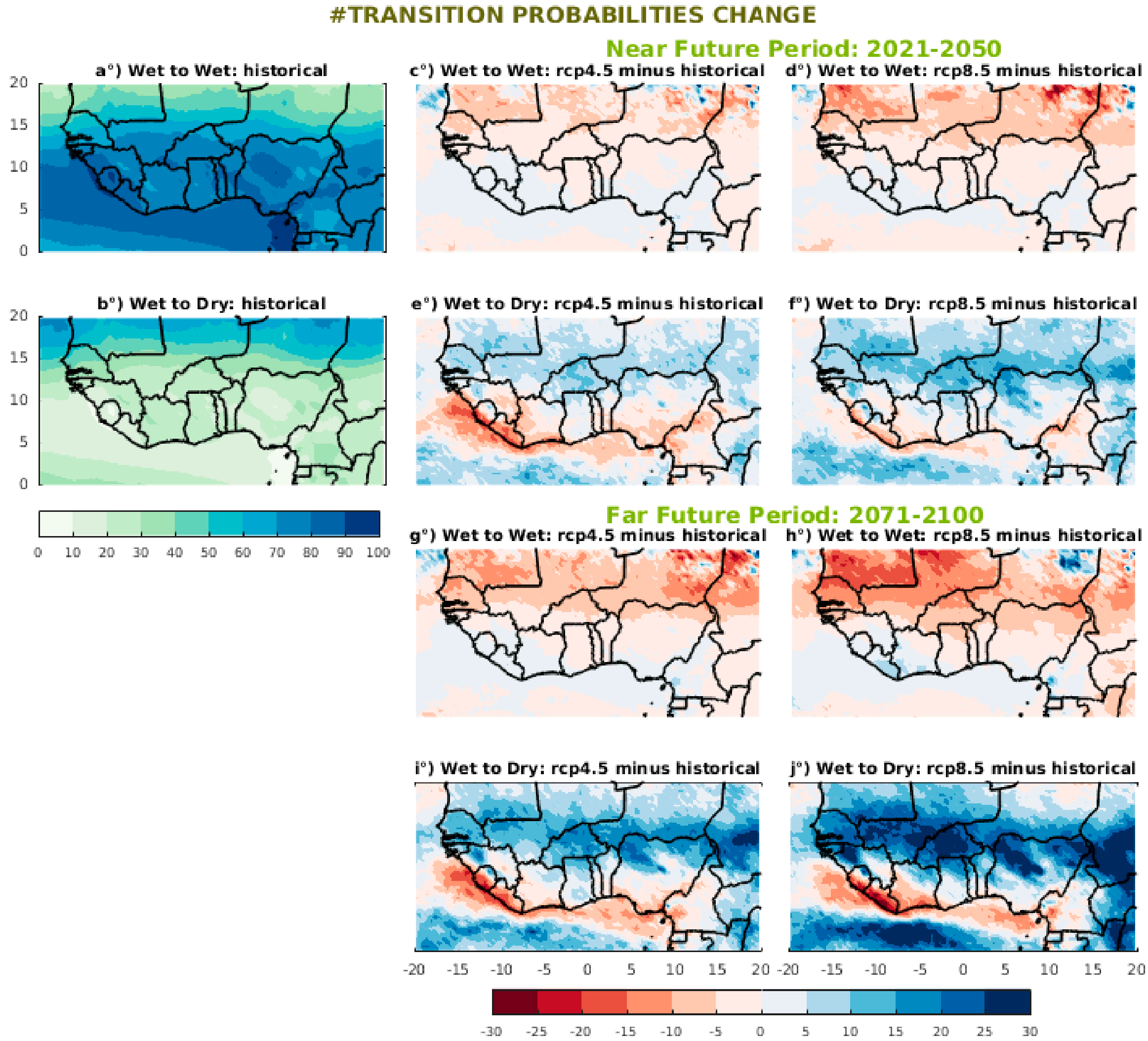

Figure 5. Same as Figure 3, but for the probabilities of wet-to-wet days and wet-to-dry days.

The average changes in consecutive dry days of different durations from historical simulations (1970-2005) as well as changes in future periods are evaluated and the results are illustrated in Figure 6. As shown in Figure 6a, the West African region exhibits low probabilities of 7-day dry spells located in the Inter-Tropical Convergence Zone (ITCZ), particularly in the mountainous areas such as the high plateau of Fouta Djallon, the plateau of Jos and the mountains of Cameroon. The overall model mean probabilities of 10-day dry spells (Figure 6b) is similar to that of 7-day dry spells but with lower probabilities over most of West Africa. The changes in the probabilities of 7-day and 10-day dry spells in the near future under the RCP4.5 and RCP8.5 scenarios are shown in Figure 6c-d and Figure 6e-f, respectively. Under global warming, the models average shows an increase in the 7 and 10-day dry spell probabilities over the Sahelian regions under both scenarios, but the magnitude of the changes and their spatial extension are greater under RCP8.5 (up to 100% for 7-day and more than 100% for 10-day dry spell probabilities). However, a decrease of up to -50% in the 7-day dry spell probability occurrence and up to -75% in the 10-day dry-spell probabilities occurs over the Guinea Coast for both global warming scenarios. The same is true in the far future (Figure 6g-j), where the rainy season is associated with a more important increase compared to the near future in the dry-spell probabilities in the Sahel and a decrease over the Guinea Coast. However, our results confirm those of Sarr and Camara (2017), who predicted the increase the occurrence in the maximum duration

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of dry spells over the Sahel. Furthermore, our results are also consistent with those of Yapo et al. (2020) over Côte d'Ivoire (Guinea Coast region) during the summer monsoon season (JAS).

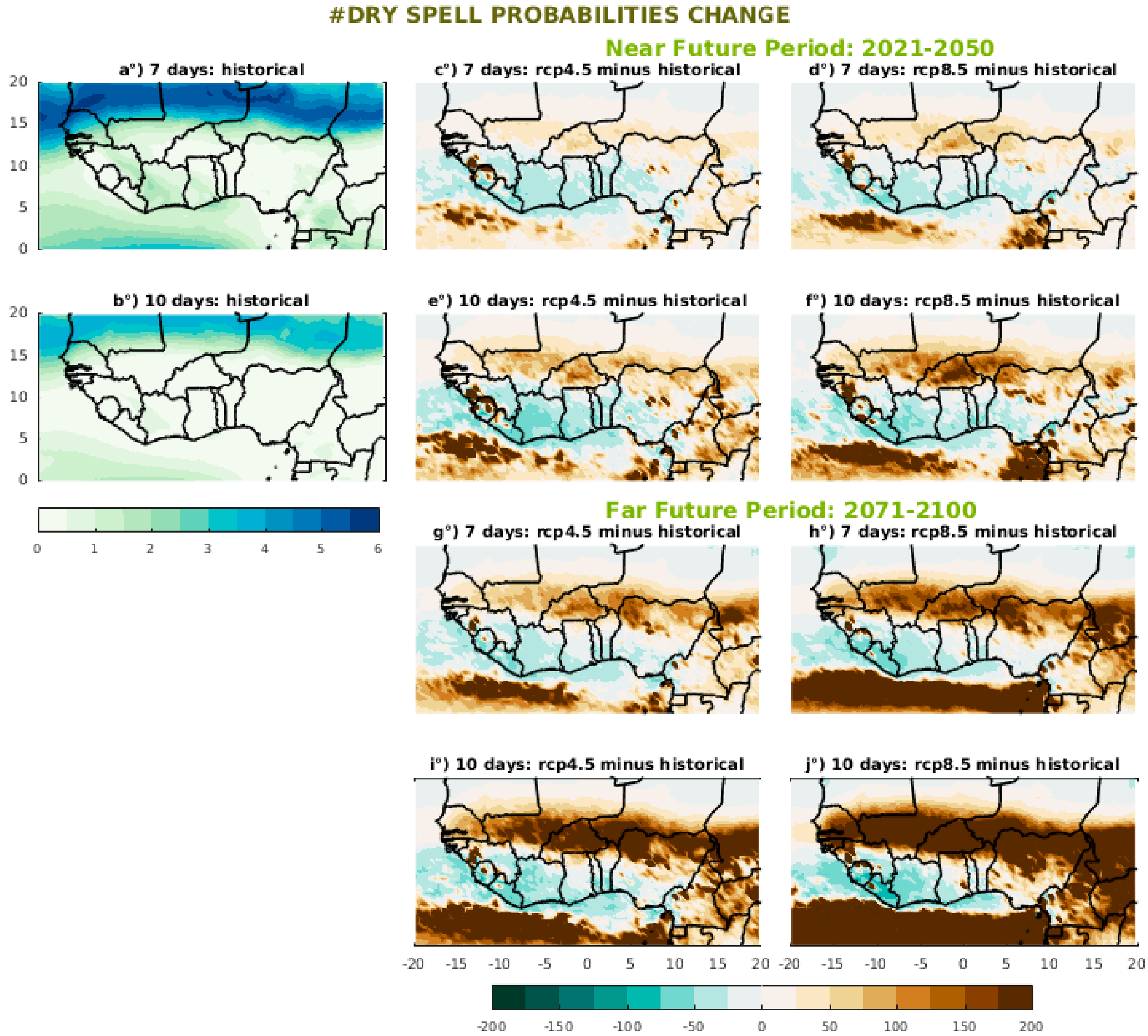

Figure 6. Same as Figure 3, but for the 7 and 10-day probabilities of dry spells.

Similar to the consecutive dry days, the ensemble mean of the consecutive wet day probabilities with varying lengths over the historical period are shown in Figures 7a and b. As shown in Figure 7a, the model ensemble mean shows higher probabilities of the seven consecutive wet days, located in the ITCZ and low probabilities in the northern Sahel. The probabilities of consecutive wet days decrease with increasing duration (Figure 7b) and are noted in mountainous areas. These regions with higher probabilities of consecutive wet days are also characterized by a higher rainfall mean and higher intensity during the West African monsoon season (Basse et al., 2021).

Changes in the 7-day wet-spell probabilities during the near future are shown in Figures 7c and d, following scenarios RCP4.5 and RCP8.5. A decrease in the 7-day wet-spell probabilities is projected over the Sahelian regions under both scenarios. However, the decrease is more pronounced in the RCP8.5 scenario (up to -40%). These changes are also observed in the 10-day wet-spell probabilities (Figure 7e, f) with a larger decrease (up to -60%) comparing to the 7-day dry-spell probabilities. In addition, a lower increase is expected in some areas of the Guinea Coast (Guinea Conakry, Liberia, Côte d'Ivoire). Thus, the far-future changes in the 7-day wet-spell (Figure 7g, h) and the 10-day wet-spell (Figure 7i, j) probabilities show a generally larger decrease under RCP8.5 (up to -80% for the 7-day wet spell and more than -90% for the 10-day wet-spell probabilities) in the Sahel sub-regions than in the near future. However, a weaker increase in the consecutive wet days probabilities appears

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across the Guinea Coast, particularly south of the regions such as Côte d'Ivoire, Guinea Conakry, and Liberia and is more pronounced following the RCP8.5.

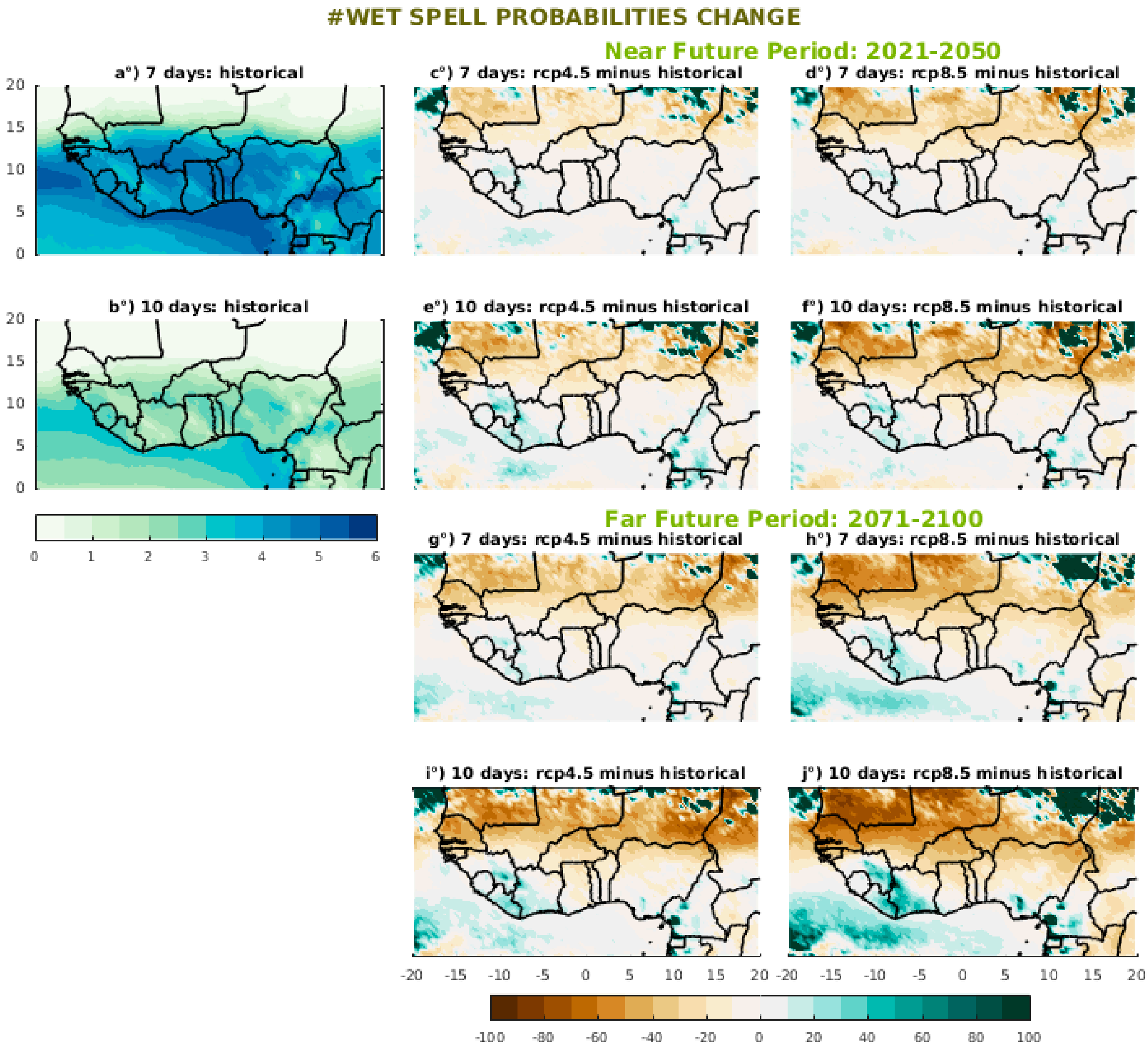

Figure 7. Same as Figure 3, but for the probabilities of wet spell of 7 and 10 days.

3.3. Mean Changes of Dry and Wet Spells

The quantitative values during the rainy season (JAS) over the four regions of West Africa (Western Sahel, Central Sahel, Sudanian Area and Guinea Coast) are reported in table 2 for rainfall indices, 7- and 10-day dry-spell, and 7- and 10-day wet-spell probabilities. As shown in table 2, the models ensemble mean shows (on average) the rainfall decrease in the Sahelian regions (Western and Central Sahel) with maxima of -13.22% in the Western Sahel following the RCP8.5 scenario and -7.46% in the Central Sahel following the RCP4.5 scenario, during the far future. However, the rainfall increase is projected in the Sudanian Area and over the Guinea Coast with maxima of 10.94% and 26.07% over the Guinea Coast during the near and far future, respectively and under the RCP8.5 scenario. Regarding the dry-spell probabilities, an increase (on average) is projected in the Western Sahel, Central Sahel and Sudanian Area for all considered categories (i.e., 7 and 10-day durations). The maxima of the probabilities are observed in the Central Sahel (up to 82.35%, on average) when we consider the 7-day dry-spell probabilities and in the Western Sahel (up to 223.04%, on average) in the case of the 10-day dry-spell probabilities during the far future and following the RCP8.5 scenario. In contrast, the dry-spell probabilities decrease is predicted over the Guinea Coast during the two future periods. However, the decrease is more important during the far future and under the RCP4.5 scenario with the probabilities of -27.42% for the 7 days dry spells and of -34.10% for the 10 days dry

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spells. In addition, a decrease in the probability of wet spells is predicted in the Western Sahel, the Central Sahel and the Sudanian Area. This decrease of the 7 (10) days wet-spell probabilities reaches -35.51% (-47.22%) in the Central Sahel, -43.75% (-57.68%) in the Western Sahel and -13.77% (-24.53%) in the Sudanian Area during the far future following the RCP8.5 scenario. Over the Guinea Coast, small changes are expected during the two periods and under both scenarios.

Table 2. Mean changes (in %) relative to the historical time (1976-2005) in the sub-regions of West Africa.

Periods	2021-2050		2071-2100	
Scenarios	**RCP4.5**	**RCP8.5**	**RCP4.5**	**RCP8.5**
		Rainfall		
Western Sahel	-5.71	-1.44	-10.04	-13.22
Central Sahel	-6.04	-3.00	-7.46	-6.55
Sudanian Area	1.71	5.67	3.13	8.28
Guinea Coast	7.51	10.94	12.58	26.07
		7-day dry-spell probabilities		
Western Sahel	11.63	15.55	25.90	47.17
Central Sahel	24.40	34.52	56.65	82.35
Sudanian Area	2.66	15.52	49.77	81.23
Guinea Coast	-33.33	-27.18	-27.42	-25.61
		10-day dry-spell probabilities		
Western Sahel	27.24	34.73	60.61	126.53
Central Sahel	51.18	76.91	133.91	223.04
Sudanian Area	19.75	43.71	120.10	215.20
Guinea Coast	-40.93	-35.03	-34.10	-20.60
		7-day wet-spell probabilities		
Western Sahel	-14.64	-23.23	-29.33	-43.75
Central Sahel	-14.54	-24.01	-28.36	-35.51
Sudanian Area	-3.41	-5.92	-8.22	-13.77
Guinea Coast	0.37	-0.25	-0.15	1.43
		10-day wet-spell probabilities		
Western Sahel	-17.90	-31.50	-40.49	-57.68

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Central Sahel	-20.54	-34.68	-41.31	-47.22
Sudanian Area	-6.07	-11.01	-15.33	-24.53
Guinea Coast	3.16	0.71	1.94	6.38

3.4. Interannual Variability of Probabilities

Temporal changes are analyzed during the rainy season (July-September) for different probabilities from the historical (1976-2005) (olive line) to the future horizon (2006-2100) following the RCP4.5 (blue line) and RCP8.5 (red line) scenarios. The future change of the anomalies, compared to the historical period is done for the four areas in West Africa (Figure 1).

The results of future projections of seasonal rainfall for the different West African subregions by 2100 are illustrated (Appendix A, Figure A1) and show an accentuation of rainfall variability. A slight downward trend is projected in the Western Sahel and the Central Sahel (Figure A1a and b, respectively) under both scenarios. In the Sudanian Area (Appendix A, Figure A1c) and over the Guinea Coast (Appendix A, Figure A1d), an increasing trend is projected under both scenarios. The RCP8.5 scenario is more alarming, with an increase of 4.5 mm in the Sudanian Area and approximately 7 mm over the Guinea Coast by 2100. This divergence between the scenarios over the Guinea Coast is not specific to our study because Yapo et al. (2020) showed this difference in the simple daily intensity index (SDII) in Côte d'Ivoire.

Future projections of the P_0 probability anomalies in the four West African areas (Appendix A, Figure A2) all show increasing trends following the RCP4.5 and RCP8.5 warming scenarios over all regions except the Guinea Coast (Appendix A, Figure A2d), where a slight decreasing trend is projected under both scenarios. The upward trend would initially follow a slight slope until 2050, when the increase in the P_0 probability will be higher and under RCP8.5. However, we observe inverse trends in the P_1 probability anomalies (not shown) compared to the P_0 probability anomalies over all selected sub-regions under both scenarios. Similarly, the P_{00} probability anomalies (Appendix A, Figure A3) as well as the P_{10} probabilities anomalies (Appendix A, Figure A4) would increase over all regions, except the Guinea Coast where a decreasing trend is noted and is more prominent following the RCP8.5 scenario. The increase trend will be more accentuated under RCP8.5, especially in the Western Sahel by 2100. On the other hand, future projections of the P_{11} and the P_{01} probabilities anomalies (not shown) would predict opposite trends over each area compared to the P_{00} and P_{10} probabilities anomalies. These results show that the dry days would be more frequent over the Sahelian regions which are characterized by a decrease in rainfall during the future horizons.

The future projections of the 7-day and 10-day dry-spell probability anomalies are shown in Figures 8 and 9, respectively. As presented in Figure 8a and b, increasing trends of the 7-day dry-spell probability anomalies are projected over the Sahelian regions in the future under both scenarios. The divergence between the scenarios is more visible in the Western Sahel than in the Central Sahel by 2100. In the Sudanian Area (Figure 8c), increasing trends are projected in the future for both scenarios. This increase is more accentuated under RCP8.5. Over the Guinea Coast (Figure 8d), a downward trend in the 7-day dry-spell probabilities anomalies is expected during the future horizon following both scenarios. However, the two scenarios show little divergence by 2100. Similar trends to those of the 7-day dry spells are observed in the case of the 10-day dry-spell probabilities anomalies (Figure 9) but with lower amplitude than the 7-day dry-spells.

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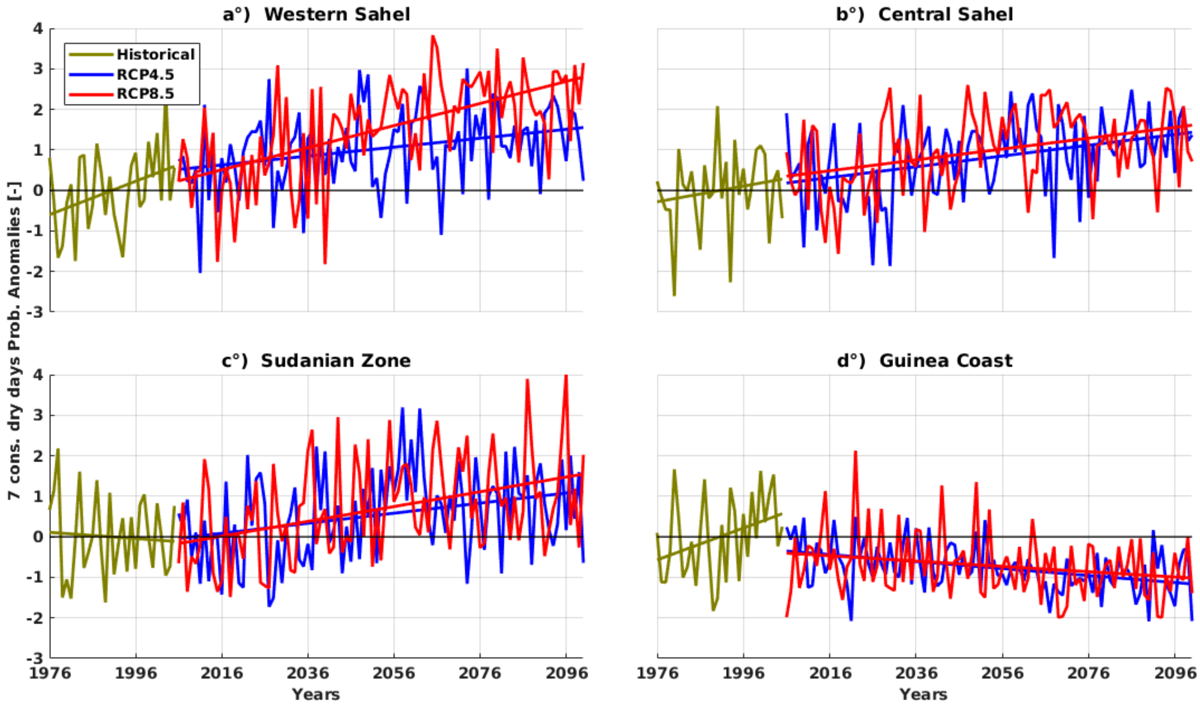

Figure 8. Temporal evolution of probability of 7 days dry spells: **a°)** Western Sahel, **b°)** Central Sahel, **c°)** Sudanian zone and **d°)** Guinea Coast during the WAM (JAS) season under RCP4.5 and RCP8.5.

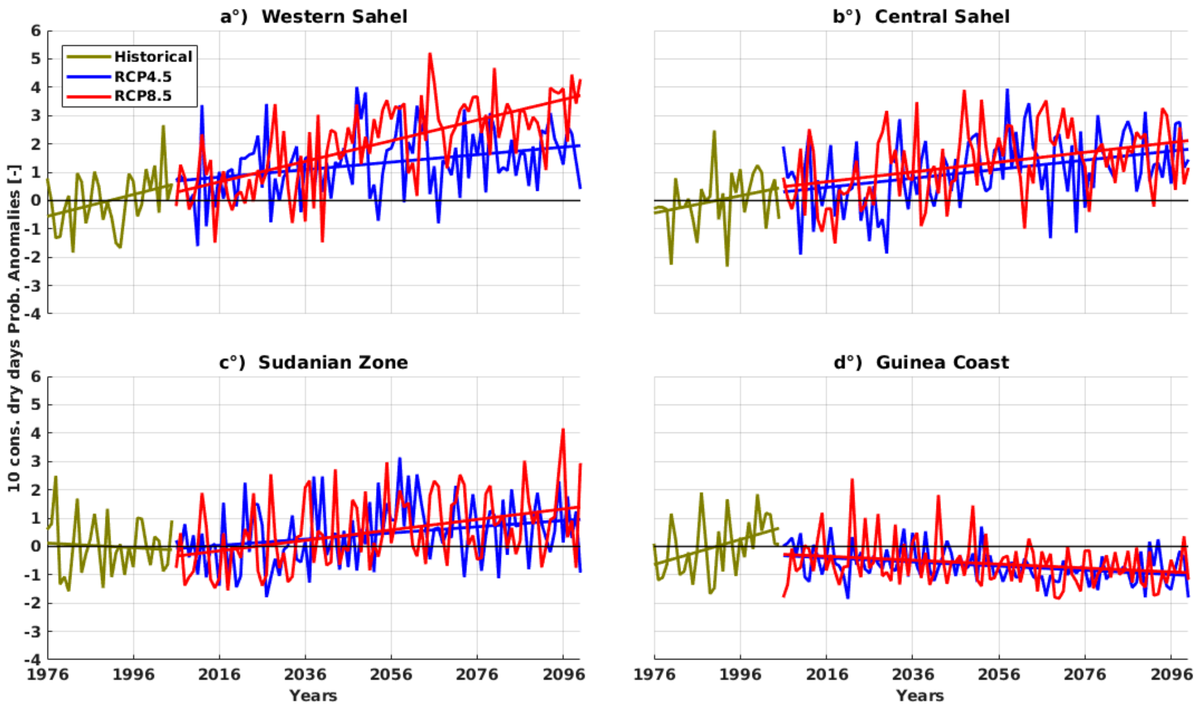

Figure 9. Same as Figure 8, but for the probability of having 10 consecutive dry days.

3.5. Dry- and Wet-Spell Probabilities Uncertainties in the West Africa Sub-Domains

For a more quantitative assessment, the mean seasonal changes for dry (Figures 10 and 11) and wet (Figures 12 and 13) spells are presented in the form of box-whisker plots for the two future periods (near and far future), according to the RCP4.5 and RCP8.5 scenarios for each selected sub-domain (Figure 1).

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Regarding the dry-spell probabilities, the main characteristic is the expected increase across the Sahel areas (i.e. Western and Central Sahel) and the decrease in the Guinea Coast for both the near future (Figure 10) and the far future (Figure 11) and under RCP4.5 and RCP8.5 during the summer period. The extent of change is more marked in the far future than in the near future and under RCP8.5. Over the Sahel areas, the median, the 25th and the 75th percentiles exhibit positive values, underscoring the robustness of the increase in the dry-spell probabilities. Similarly, over the Guinea Coast, the median, the 25th and the 75th percentiles are negative, suggesting that the decrease in the dry-spell probabilities is also a consistent result. In the Sudanian Area, the changes during the summer season are considerably uncertain in the near future (Figure 10), because the interquartile interval covers negative and positive signs for both scenarios. On the horizon to 2100 (Figure 11), an increase in the probability of dry spells is projected under both scenarios, except for the 10-day dry-spell probabilities under RCP8.5, because the interquartile interval includes negative and positive signs.

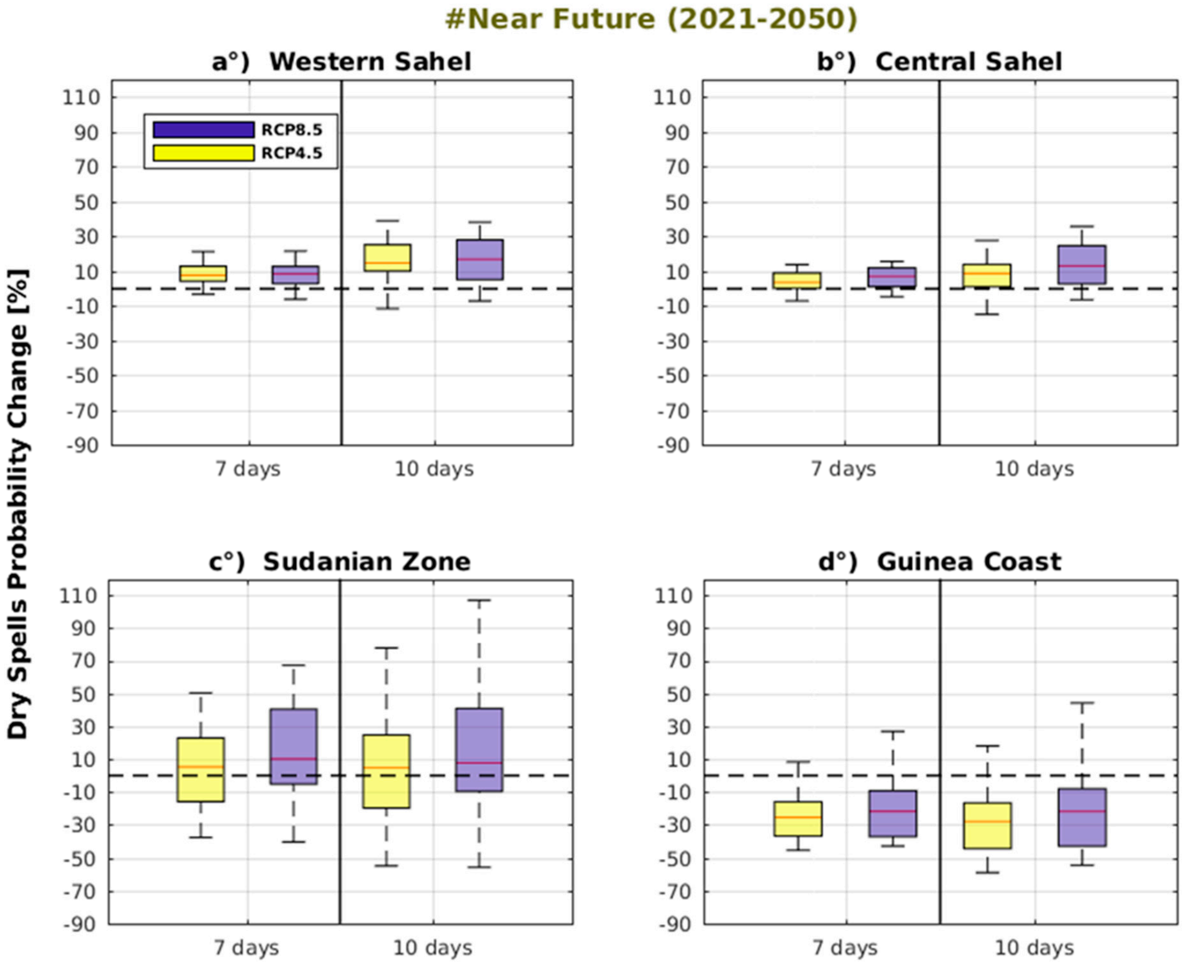

Figure 10. Boxplots of dry-spell probabilities change during the near future: **a°)** Western Sahel, **b°)** Central Sahel, **c°)** Sudanian Area and **d°)** Guinea Coast.

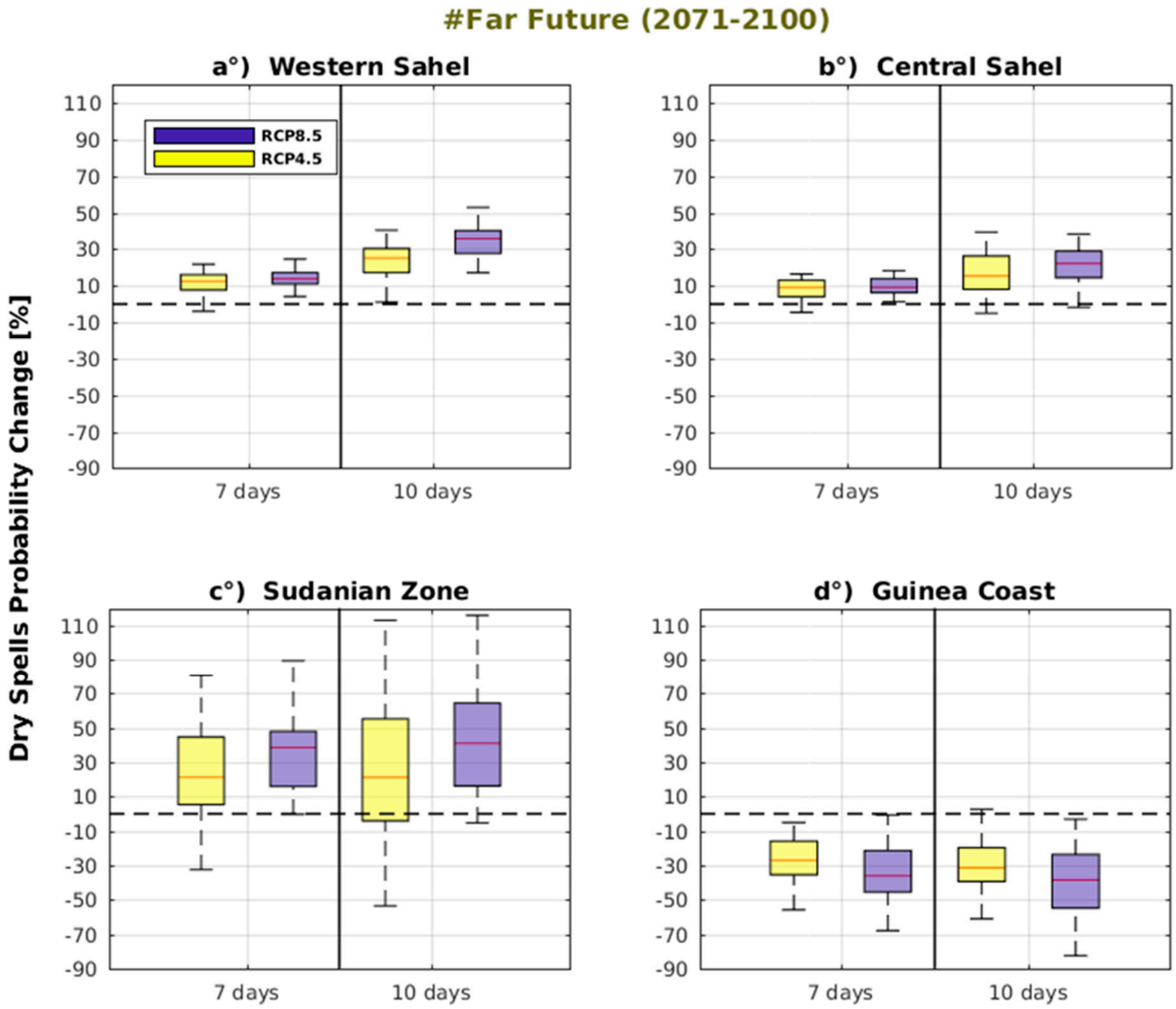

Figure 11. Same than in Figure 10, but for the far future.

For the wet-spell probabilities, the most remarkable feature is the negative evolution expected in the Western Sahel on the horizon to 2050 (Figure 12) and on the horizon to 2100 (Figure 13) and following the two scenarios during the summer season. The changes are more significant in the far future and under RCP8.5. In addition, the median, interquartile ranges, 25th and 75th percentiles, and maximum and minimum are less than 0, which means that the predicted decrease in the wet-spell probabilities is substantially important. In the Central Sahel, the wet-spell probabilities are projected to decrease in both periods and under both scenarios, except for the 7-day wet-spell probabilities in the near future and under both scenarios (Figure 12b), where the changes are rather uncertain because the interquartile interval covers negative and positive signs. The changes in the wet-spell probabilities are also quite uncertain in the Sudanian Area, except for the 7-day wet-spell probabilities by 2100 and following scenario RCP8.5 (Figure 13c). Over the Guinea Coast, the most notable feature is the decrease in wet-spell probabilities by 2050, following the two scenarios (Figure 12d).

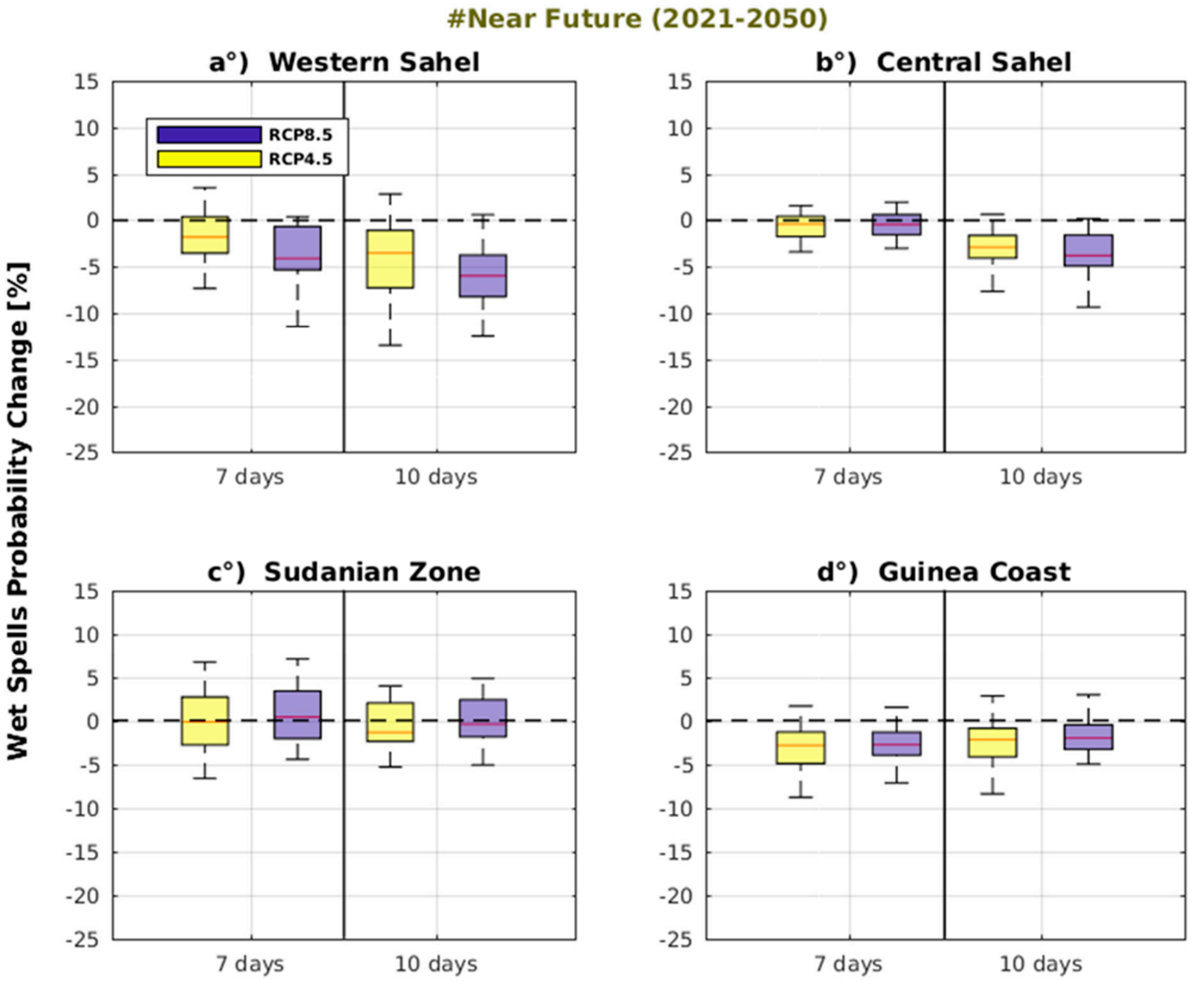

Figure 12. Boxplots of wet-spell probabilities change during the near future: **a°)** Western Sahel, **b°)** Central Sahel, **c°)** Sudanian Area and **d°)** Guinea Coast.

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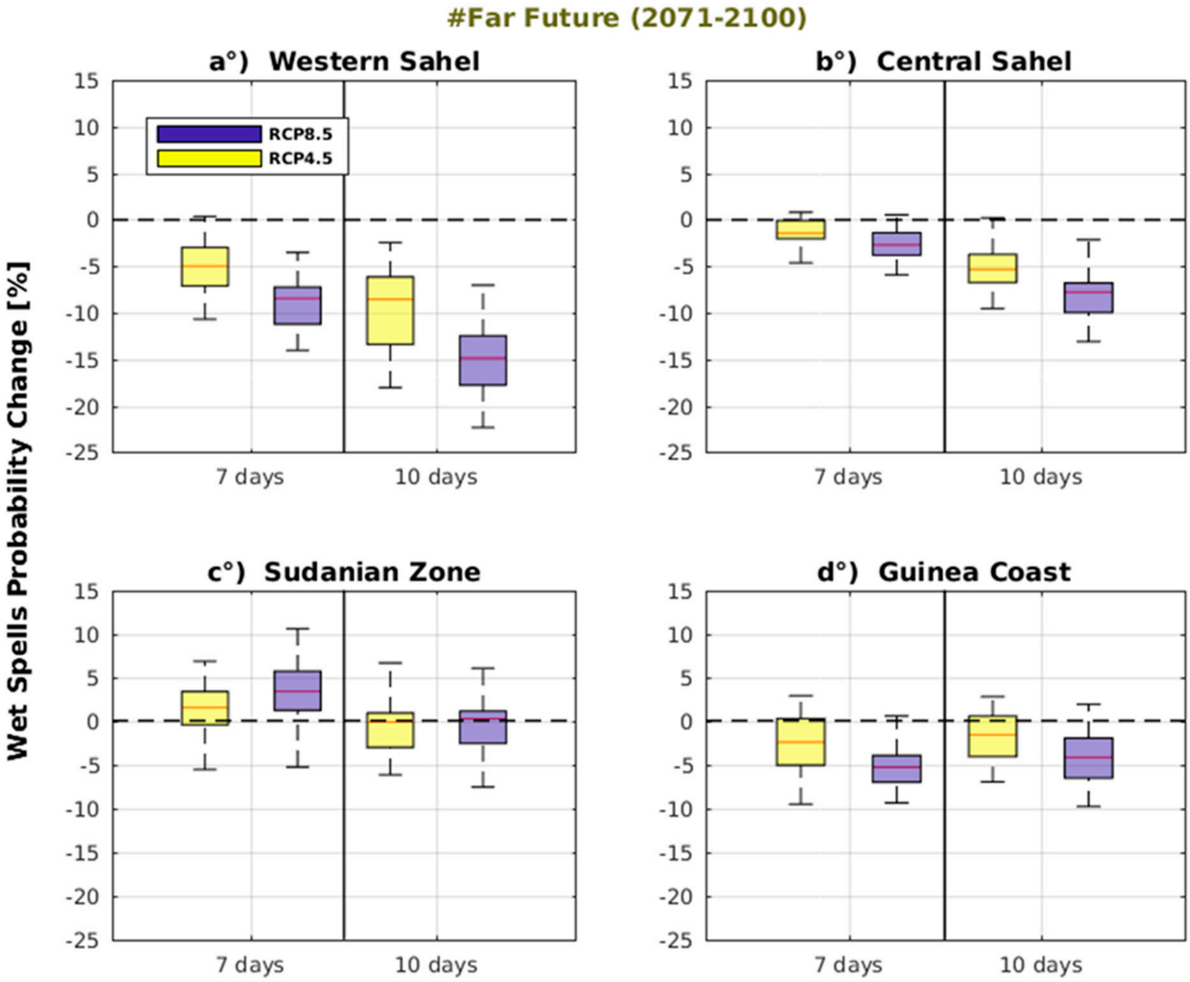

Figure 13. Same than in Figure 12, but for the far future.

4. Conclusion and Perspectives

Future probabilities changes of dry and wet event in West Africa (WA) are examined using a combination of four CORDEX-Africa RCMs and two forcing scenarios (RCP4.5 and RCP8.5). The predicted seasonal for initial, transition and consecutive probabilities changes are evaluated by contrasting two future 30-year horizons (2021-2050 and 2071-2100) relative to the historical period (1976-2005) following the RCP4.5 and RCP8.5 scenarios. In addition, the time series of the interannual variability of the different probabilities are analyzed in the WA zones (Western Sahel, Central Sahel, Sudanian Area and Guinea Coast). Finally, the uncertainties are assessed by quantifying the dispersion of changes over each zone. The results indicate that a decrease in rainfall is expected in most of the northern regions of WA and an increase in the southern regions following the two scenarios and the two horizons. The changes are much more pronounced on the horizon to 2100, following the RCP8.5 scenario (more than 30%). An increase in the P_0 probabilities, the P_{00} probabilities and the P_{10} probabilities is predicted in the Sahelian regions under the RCP4.5 and RCP8.5 scenarios to about 20% by 2050 and more than 30% by 2100. However, a decrease in P_1 probabilities, P_{11} probabilities and P_{01} probabilities is projected in the Sahelian regions under the rcp45 and rcp8.5 scenarios to about -20% by 2050 and more than -30% by 2100. Over the Guinea Coast, a decrease in the P_0, P_{00} and P_{10} probabilities and an increase in the P_1, P_{11} and P_{01} probabilities are expected in the future and in the two scenarios.

Regarding the dry-spell probabilities, an increase in the Sahel is predicted during both periods and under both scenarios but the change magnitude and the spatial extension are more important on the horizon to 2100 under RCP8.5. Moreover, a decrease in these spells is expected in the Guinean regions, up to -50% for the 7-day dry-spell probabilities and up to -75% for the 10-day dry-spell

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probabilities on the horizon to 2100 under RCP8.5. When considering the probabilities of wet spells, a decrease of about -40% by 2050 and more than -60% by 2100 is projected in the Sahel under the RCP8.5 scenario, for the 7-day wet-spell probabilities. These changes are more important when considering the longer wet spells (i.e., 10-day wet spells). In addition, these characteristics are linked to a high variation in the various probabilities with larger amplitudes of variability in the projected climate in the different subregions. For rainfall, a decreasing trend is observed in the Western and Central Sahel over the whole period (1976-2100) and an increasing trend in the future over the Sudanian Area and over the Guinea Coast. The trends are more significant under RCP8.5. In addition, the Western and Central Sahel also show the trends of increasing of the P_0 probabilities, P_{00} probabilities, P_{10} probabilities and dry spells probabilities over the whole period considered with discernible differences between the two scenarios. In the Sudanian Area, the historical period is characterized by a decreasing trend of the P_0, P_{00} and P_{10} probabilities while an increasing trend is observed in the future. In addition, the dry spells probabilities show quite normal trends in the historical period and an increasing trend in the future.

Over the Guinea Coast, P_0 and P_{10} probabilities show decreasing trends during the whole period. The P_{00} probabilities shows low variability in the historical period and an increasing trend is observed in the future. For dry-spell probabilities, Guinea Coast is characterized by an increasing trend in the historical period and a decreasing trend in the future period. Furthermore, when assessing the projected changes in the dry-spell probabilities, it appears that the most prominent feature is its increase in the two future horizons and following the two scenarios in the Western Sahel. This increase in the probabilities of dry spells strengthens the risk of natural catastrophes such as droughts. This can have a substantial impact on agricultural production, which is, mainly rainfed in West Africa. This study suggests that decision makers should implement mitigation and adaptation policies to minimize the adverse effects of climate change. The results of this study on the dry and wet-spell probabilities in West Africa could be helpful for water conservation and for cultivation and hydropower sectors.

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Appendix A

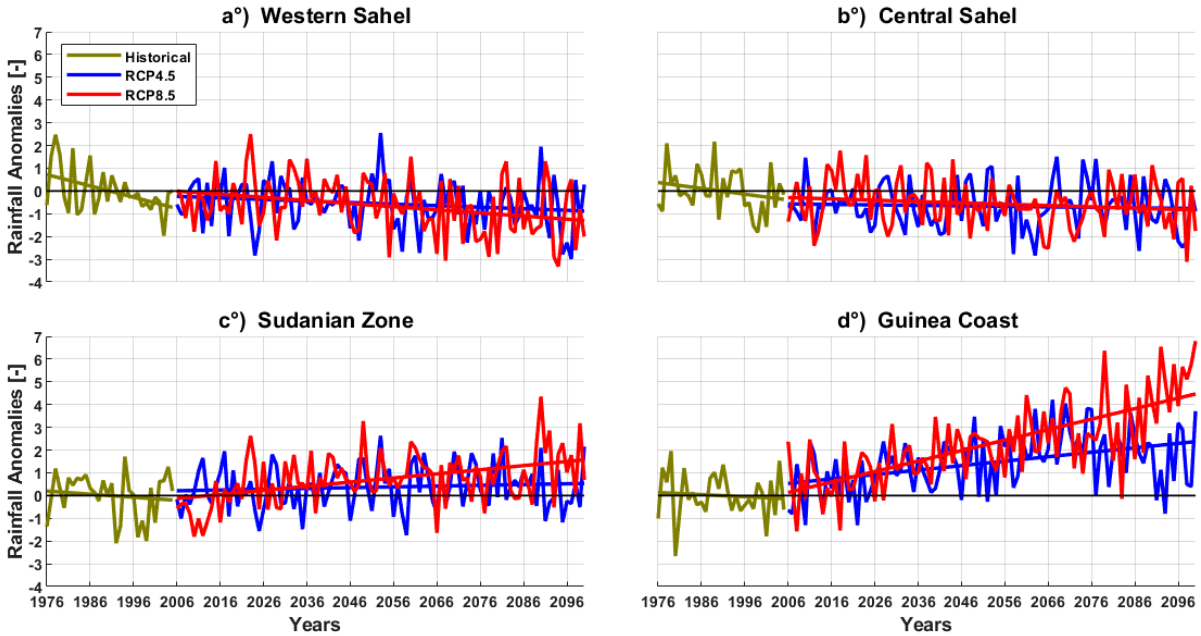

Figure A1. Temporal evolution of rainfall anomalies: a°) Western Sahel, b°) Central Sahel, **c°)** Sudanian zone and **d°)** Guinea Coast during the WAM (JAS) season under the RCP4.5 and RCP8.5 scenarios.

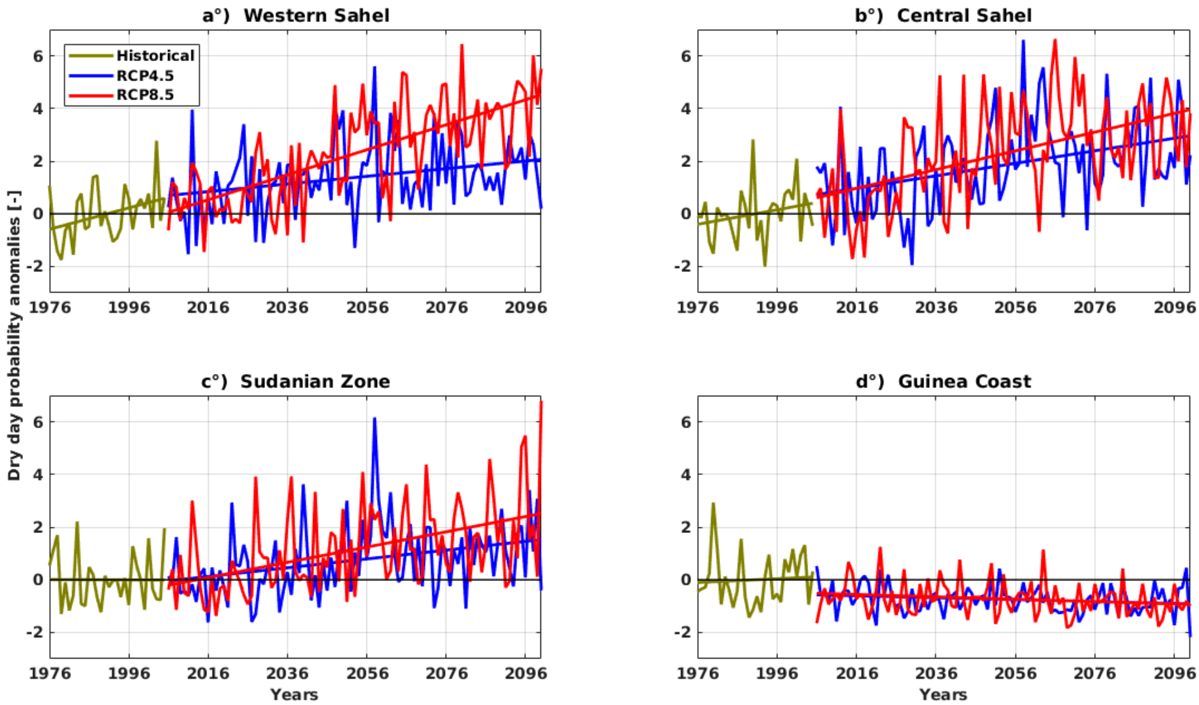

Figure A2. Same than in Figure A1, but for the dry day probabilities.

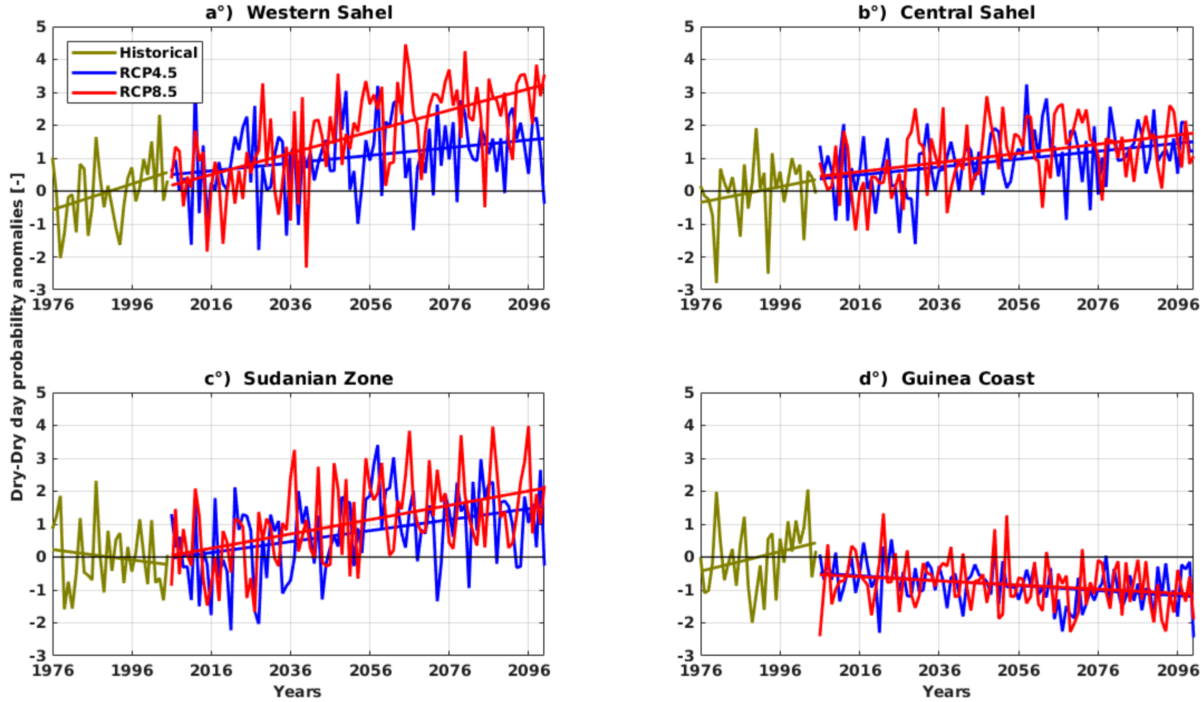

Figure A3. Same than in Figure A1, but for the dry day preceded by a dry day probabilities.

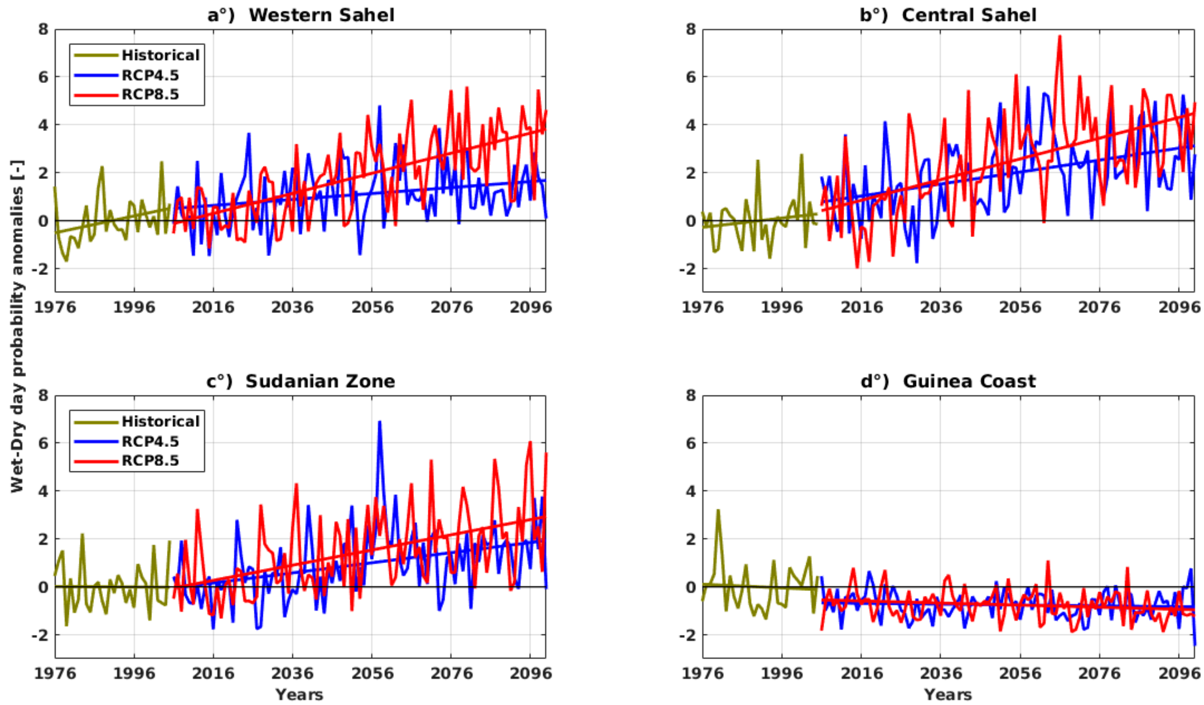

Figure A4. Same than in Figure A1, but for the dry day preceded by a wet day probabilities.

References

1. Afouda A, Adisso P (1997). Etude stochastique des structures de séquences sèches au Bénin. Sustainability of Water Resources under Increasing Uncertainly (Proceedings of the Rabat Symposium S1) IAHS Publication 240 Rabat Maroc
2. Akinsanola AA, Zhou W (2020). Understanding the variability of West African summer monsoon rainfall: contrasting tropospheric features and monsoon index. Atmosphere 11:309. https://doi.org/10.3390/atmos11030309.

3. Ayanlade A, Radeny M, Morton JF, Muchaba T (2018). Rainfall variability and drought characteristics in two agro-climatic zones: An assessment of climate change challenges in Africa. Science of the Total Environment 630:728-737
4. Barredo JI, Caudullo G, Mauri A (2017). Mediterranean habitat loss under RCP4.5 and RCP8.5 climate change projections. Assessing impacts on the Natura 2000 protected area network, EUR 28547 EN, doi: 10.2760/622174
5. Basse J, Camara M, Diba I, Diedhiou A (2021). Probability of dry and wet spells over West Africa during the summer monsoon season - Scientific Research and Essays. 16(3): 20-35. Doi: 10.5897/SRE2021.6718
6. Biao EI, Alamou EA (2018). Stochastic Modelling of Daily Rainfall for Decision Making in Water Management in Benin (West Africa). Research journal of Advance Environmental Science 1: 12-21
7. Bichet A, Diedhiou A (2018a). West African Sahel has become wetter during the last 30 years but dry spells are shorter and more frequent. Climate Research 75(2):155-162
8. Bichet A, Diedhiou A (2018b). Less frequent and more intense rainfall along the coast of the Gulf of Guinea in West and Central Africa (1981-2014). Climate Research 76(3):191-201
9. Coulibaly N, Coulibaly T, Mpakama Z, Savané I (2018). The impact of climate change on water resource availability in a trans-boundary basin in West Africa: the case of Sassandra. Hydrology 5, 12. https://doi.org/10.3390/hydrology5010012
10. Diba I, Camara M, Sarr AB, Basse J, Sabaly HN, Diedhiou A (2021). Caractérisation des extrêmes composés de précipitation et de température au Sénégal: climat présent et futur -Afrique Science, 18(1): 12-30
11. Diba I, Camara M, Sarr AB (2016). Impacts of the Sahel-Sahara Interface Reforestation on West African Climate: Article ID 3262451, 20 Intraseasonal Variability and Extreme Precipitation Events. Advances in Meteorology, Volume 2016, pages.
12. Didi SRM, Ly M, Kouadio K, Bichet A, Diedhiou A, Coulibaly HSJ, Kouadio KKA, Coulibaly TJH, Obahoundje S and Savané I (2020). Using the CHIRPS Dataset to Investigate Historical Changes in Precipitation Extremes in West Africa. Climate 8(7):1b-1b.
13. Diedhiou A, Janicot S, Viltard A P de Felice (1998). Evidence of two regimes of easterly waves over West Africa and the tropical Atlantic. Geophysical Research Letters 25(15):2805-2808
14. Diedhiou A, Janicot S, Viltard A, De Felice P, Laurent H (1999). Easterly wave regimes and associated convection over West Africa and tropical Atlantic: results from the NCEP/NCAR and ECMWF reanalysis. Clim Dyn 15:795–822
15. Diedhiou A, Bichet A, Wartenburger R, Seneviratne SI, Rowell DP, Sylla MB, Diallo I, Todzo S, Touré NE, Camara M, Ngatchah BN, Kane NA, Tall L, Affholder F (2018). Changes in climate extremes over West and Central Africa at 1.5°C and 2°C global warming. Environ. Res. Lett. 13 (2018) 065020
16. Fall CMN, Lavaysse C, Kerdiles H, Dramé MS, Roudier P, Gaye AT (2021). Performance of dry and wet spells combined with far sensing indicators for crop yield prediction in Senegal Stern. Nat. Hazards Earth Syst. Sci., 21, 1051–1069, 2021https://doi.org/10.5194/nhess-21-1051-2021
17. FAO (2009). FAOSTAT online statistical service. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy
18. Froidurot S, Diedhiou A (2017). Characteristics of wet and dry spells in the West African monsoon system. Atmospheric Science Letters 18(3):125-131
19. GIEC (2013) Climate Change 2013. The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change. Chapter 9: Evaluation of Climate Models - Final Draft Underlying Scientific-Technical Assessment. [G. Flato, J. Marotzke, B. Abiodun, P. Braconnot, S. Chan Chou,W.Collins, P.Cox, F. Driouech, S. Emori, V. Eyring, C. Forest, P. Gleckler, E. Guilyardi, C. Jakob, V. Kattsov, C. Reason, M.Rummukainen], 207 p.
20. Giorgi F, Jones C, Asrar GR (2009). Addressing climate information needs at the regional level: The CORDEX framework. WMO Bull., 58, 175-183
21. Hewitson BC, Lennard C, Nikulin G, Jones C (2012). CORDEX-Africa: a unique opportunity for science and capacity building. CLIVAR Exchanges, 17(3), 6-7
22. Jones CG, Giorgi F, Asrar G (2011). The Coordinated Regional Downscaling Experiment (CORDEX); An international downscaling link to CMIP5. CLIVAR Exchanges, International CLIVAR Project Office, No. 56, Southampton, United Kingdom, 34-40
23. Klein Tank AMG, Zwiers FW, Zhang X (2009). Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. Climate data and monitoring WCDMP-No. 72, WMO-TD No. 1500, pp. 56
24. Koffi B, Brou AL, Kouadio KJO, Ebodé VB, N'guessan KJY, Yangouliba GI, Yaya K, Brou D, Kouassi KL (2023). Impact of climate and land use/land cover change on Lobo reservoir inflow, West-Central of Côte d'Ivoire. Journal of Hydrology: Regional Studies 47 (2023) 101417. https://orcid.org/0000-0002-4835-2975
25. Kouadio KY, Ochou DA, Servain J (2003). Tropical Atlantic and rainfall variability in Côte d'Ivoire. Geophysical Research Letters, 30:1-15

26. Kouadio KCA, Amoussou E, Coulibaly TJH, Diedhiou A, Coulibaly HSJ-P, Didi R, Savané I (2020). Analysis of hydrological dynamics and hydropower generation in a West African anthropized watershed in a context of climate change. Model. Earth Syst. Environ. 6, 2197–2214. https://doi.org/10.1007/s40808- 020-00836-4
27. Kulkarni A, Deshpande N, Kothawale DR, Sabade SS, Ramarao MVS, Sabin TP, Patwardhan S, Mujumdar M, Krishnan R (2017). Observed climate variability and change over India. In: Krishnan R, Sanjay J (eds) Climate change over India-an interim report
28. Lawin AE, Hounguè R, N'Tcha M'Po Y, Hounguè NR, Attogouinon A, Afouda AA (2019). Mid-century climate change impacts on Ouémé River discharge at bonou outlet (Benin). Hydrology 6, 72. https://doi.org/10.3390/hydrology6030072
29. Mbaye ML Sylla MB, Tall M (2019). Impacts of 1.5 and 2.0 °C Global Warming on Water Balance Components over Senegal in West Africa. Atmosphere, 10, 712; doi: 10.3390/atmos10110712.
30. Moon SE, Ryoo SB, Kwon JG (1994). A markov chain model for daily precipitation occurrence in South Korea. International Journal of Climatology 14(9):1009-1016. Doi: 551.577.2 (519.5):519.217
31. Nikulin G, Jones C, Giorgi F, Asrar G, Büchner M, Cerezo-Mota R, Christensen OB, Déqué M, Fernandez J, Hänsler A, van Meijgaard E, Samuelsson P, Sylla MB, Sushama L (2012). Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. J Clim, 25:6057–6078
32. Nkrumah F, Vischel T, Panthou G, Klutse NAB, Adukpo DC, Diedhiou A (2019). Recent Trends in the Daily Rainfall Regime in Southern West Africa. Atmosphere; 10(12):741. https://doi.org/10.3390/atmos10120741
33. Nuga OA, Adekola LO (2018). A Markov chain analysis of rainfall distributions in three south western cities of Nigeria. Research Journal of Physical Sciences 6(4): 1-5
34. Ogega OM, Gyampoh BA, Mistry MN (2020). Intraseasonal Precipitation Variability over West Africa under 1.5 °C and 2.0 °C Global Warming Scenarios: Results from CORDEX RCMs. Climate 2020, 8(12), 143; https://doi.org/10.3390/cli8120143
35. Ouédraogo PLA, Zorom M, Niang D, Fossi S (2013). Prédétermination des séquences sèches et intérêt de l'information climatique sur la production céréalière en zone sahélienne. Institut International d'Ingénierie, Ouagadougou, BF, mémoire master en ingénierie, 61 pages
36. Pandarinath N (1991). Markov chain model probability of dry and wet weeks during monsoon periods over Andhra Pradesh, Mausam, 42, 4, 393-400
37. Raheem MA, Yahya WB, Obisesan KO (2015). A Markov chain approach on pattern of rainfall distribution. Journal of Environmental Statistics 7(1):1-13
38. Raheem MA, Ezepue PO (2016). A Three-State Markov Model for Predicting Movements of Asset Returns of a Nigerian Bank. CBN Journal of Applied Statistics 7(2):77-99
39. Ray M, Biswasi, Sahoo, Patro H (2018). A Markov Chain Approach for Wet and Dry Spell and Probability Analysis. International Journal of Current Microbiology and Applied Sciences, Special Issue-6: 1005-1013.
40. Rockström J, Barron J, Fox P (2002). Rainwater management for increased productivity among small-holder farmers in drought prone environments. Physics and Chemistry of the Earth, Volume 27, Issues 11-22, Pages 949-959. https://doi.org/10.1016/S1474-7065(02)00098-0
41. Salack S, Klein C, Giannini A, Sarr B, Worou ON, Belko N, Bliefer-nicht J, Kunstman H (2016). Global warming induced hybrid rainyseasons in the Sahel.Environmental Research Letters: ERL11:104008
42. Sarr AB, Camara M, Diba I (2018) Multi-model Analysis of the West African Monsoon: Seasonal Evolution and the Monsoon Onset. Journal of Scientific Research & Reports, 20(2): 1-17.
43. Sarr AB, Camara M (2017) Evolution des indices pluviométriques extrêmes par l'analyse de modèles climatiques régionaux du programme CORDEX : Les projections climatiques sur le Sénégal. European Scientific Journal. Vol.13, No.17 ISSN: 1857-7881 (print)e - ISSN 1857- 7431. Doi:10.19044/esg. 2017.v13n17p206
44. Sen Z (2015) Regional Wet and Dry spell analysis with heterogeneous probability occurrences. Journal of Hydrologic Engineering 20
45. Sonnadara DUJ, Jayewardene DR (2015). A Markov chain probability model to describe wet and dry patterns of weather at Colombo. Theoretical and Applied Climatology 119(1):333-340 Doi: 10.1007/s00704-014-1117-z
46. Stern RD, Cooper PMJ (2011). Assessing climate risk and climate change using rainfall data: a case study from Zambia. Experimental Agriculture 47(2):241-266
47. Sylla MB, Giorgi F, Pal JS, Gibba P, Kebe I, Nikiema M (2015) Projected changes in the annual cycle of high intensity precipitation events over West Africa for the late 21st century. Journal of Climate, 28, 6475-6488. Doi:10.1175/JCLI-D-14-00854.1
48. Ta S, Kouadio KY, Ali KE, Toualy E, Aman A, Yoroba F (2016) West Africa Extreme Rainfall Events and Large-Scale Ocean Surface and Atmospheric Conditions in the Tropical Atlantic Advances in Meteorology, vol. 2016, Article ID 1940456, 14 pages. https://doi.org/10.1155/2016/1940456
49. Todzo S, Bichet A, Diedhiou A (2020) Intensification of the hydrological cycle expected in West Africa over the 21st century. Earth Syst Dyn 11:319-328. https://doi.org/10.5194/esd-11-319-2020

50. Tschakert P, Sagoe R, Ofori-Darko G, Codjoe SN (2010) Floods in the Sahel: an analysis of Anomalies, memory, and anticipatory learning. Climatic Change 103, 471-502. https://doi.org/10.1007/s10584-009-9776-y
51. Wu MLC, Reale O, Schubert SD (2013) A characterization of African easterly waves on 2.5-6 day and 6-9 day time scales. Journal of Climate 26(18):6750-6774
52. Yapo ALM, Diawara A, Kouassi BK, Yoroba F, Sylla MB, Kouadio K, Tiémoko DT, Koné DI, Akobé EY, Yao KPAT (2020) Projected changes in extreme precipitation intensity and dry spell length in Côte d'Ivoire under future climates. https://doi.org/10.1007/s00704-020-03124-z