Projected changes in extreme precipitation intensity and dry spell length in Côte d'Ivoire under future climates

Article *in* Theoretical and Applied Climatology · May 2020

DOI: 10.1007/s00704-020-03124-4

10 authors, including:


Louis A. M. Yapo
University "Félix Houphouët-Boigny"
4 PUBLICATIONS **33** CITATIONS
SEE PROFILE


Fidèle Yoroba
University "Félix Houphouët-Boigny" of Cocody-Abidjan (UFHB) / Geophysical Sta…
17 PUBLICATIONS **92** CITATIONS
SEE PROFILE


Mouhamadou Bamba Sylla
African Institute for Mathematical Sciences Rwanda
122 PUBLICATIONS **4,786** CITATIONS
SEE PROFILE


Kouakou Kouadio
University "Félix Houphouët-Boigny"
23 PUBLICATIONS **207** CITATIONS
SEE PROFILE

Theoretical and Applied Climatology
https://doi.org/10.1007/s00704-020-03124-4

ORIGINAL PAPER

Projected changes in extreme precipitation intensity and dry spell length in Côte d'Ivoire under future climates

Assi Louis Martial Yapo[1] · Adama Diawara[1,2] · Benjamin K. Kouassi[1,2] · Fidèle Yoroba[1,2] · Mouhamadou Bamba Sylla[3] · Kouakou Kouadio[1,2] · Dro T. Tiémoko[1] · Dianikoura Ibrahim Koné[1] · Elisée Y. Akobé[1] · Kouassi P. A. T. Yao[1]

Received: 13 May 2019 / Accepted: 30 January 2020

Abstract

This study analyzes projected changes in seasonal extreme precipitation intensity and dry spell length in the investigation area (Côte d'Ivoire) under RCP4.5 and RCP8.5 forcing scenarios. To this end, a multi-model ensemble of fourteen CORDEX-Africa regional climate model simulations is used during the three stages of the West African Monsoon (WAM) season (April–June (AMJ), July–September (JAS), and October–December (OND)). The results indicate that Côte d'Ivoire is subject to a robust increase of cumulative intensity of precipitation associated with an amplification of extreme precipitation events during the WAM. In particular during JAS, a substantial increase in extreme precipitation reaching up to 50–60% compared to the reference mean value prevails in the western and coastal areas in the far future and under the RCP8.5 scenario. In addition, AMJ season is dominated by an increase in dry spell length of about 12% and 17% in the near future and 20% and 30% in the far future in the entire country under RCP4.5 and RCP8.5 scenarios, respectively, albeit considerable uncertainties. OND considered as the post-monsoon season is mostly characterized by a robust decrease in dry spell length more marked in the southwest in the RCP8.5 scenario during the far future. These results suggest that agricultural production and particularly cocoa plantations in the southwestern regions could be at the risk of flooding events and that water stress remains a threat for cocoa, coffee, and other cash crop plantations in the eastern regions.

1 Introduction

Climate change poses a major threat to the world today in view of its far-reaching implication for the environment, agriculture, natural resources, ecosystems, and social well-being (CCCR 2017). However, immediate damages to humans and their properties are not obviously caused by gradual changes in temperature or precipitation but mainly by extreme climate events (Sillmann and Roeckner 2008). Climate change induced by greenhouse gas (GHG) concentration will strongly result in intensification and a recurrence of extreme weather and climate events (IPCC 2012, 2013; Sillmann et al. 2013a, b). In the recent decades, West Africa has been affected by increased intense rainfall events and dry spells which often translate into hazards (FAO 2009; Tschakert et al. 2010; Odulami et al. 2018). Many West African countries such as Burkina Faso, Togo, Benin, and Ghana were affected by severe flooding and droughts causing many losses and damages (FAO 2009; Tschakert et al. 2010; Odulami et al. 2018). Likewise, during each rainy season, Côte d'Ivoire often faces numerous flooding events (Goula et al. 2007, 2012; Konate et al. 2016) co-existing with long dry spells in the southern and western parts where most of the cash crops are cultivated (Dibi and Mian 2016). It is thus evident that the country is particularly vulnerable to climate extremes and the related hazards putting the infrastructure and agricultural activities at risk. Agriculture, for example, accounts for 19% of the country's GDP and employs 70% of the population (Riquet et al. 2017). Climate change can thus substantially impact the country's economy.

To investigate trends and future changes of weather and climate extremes, the Expert Team on Climate Change Detection and Indices (ETCCDI) defined a set of 27 indices that provide a comprehensive overview of temperature and precipitation statistics for global application in studies on

✉ Assi Louis Martial Yapo
louismartialyapo@gmail.com

1 Laboratoire de Physique de l'Atmosphère et de Mécanique des Fluides, Université Félix Houphouët-Boigny, 22, BP 582, Abidjan, Côte d'Ivoire

2 Station Géophysique de Lamto, BP 31, N'Douci, Côte d'Ivoire

3 WASCAL Competence Center, West African Science Service Center on Climate Change and Adapted Land use (WASCAL), Ouagadougou, Burkina Faso

Published online: 10 February 2020

extreme events (Klein Tank et al. 2009). They describe particular characteristics of extremes including frequency, amplitude, and duration (Klein Tank et al. 2009). The assessment of their changes is important for many potential impacts (Schär et al. 2016). As a result, ETCCDI indices have been widely used in several studies in West Africa (Sylla et al. 2015; Menang 2017) and throughout the world (Frich et al. 2002; Alexander et al. 2006; Tebaldi et al. 2006; Klein Tank et al. 2009; Beniston et al. 2007; Sillmann and Roeckner 2008; Tommy 2009; Abdellatif et al. 2012; Donat et al. 2013; Sillmann et al. 2013a, b; Singh et al. 2015; Badsha et al. 2016). While it is clear that such events will substantially increase in terms of frequency and intensity globally and, to some extent, in West Africa, a detailed study on how these will change in the entire region of Côte d'Ivoire is not yet available. However, Balliet et al. (2016) showed in the Gôh region (central-western of Côte d'Ivoire) over the 1961–2010 period, using some precipitation indices, that the maximum total rainfall of 5 days (RX5DAY), very rainy days (R95P), and extremely rainy days (R99P) and the maximum consecutive dry days (CDD) increased, while the annual total rainfall (PRCPTOT) and the maximum number of consecutive wet days (CWD) decreased. In addition, other studies highlighted similar situations in some areas of Côte d'Ivoire, more specifically in the Korhogo region in the northern part of the country (Boko et al. 2016) during the 2009–2012 period and in the area of Adiaké and Enshi (i.e., Bia River basin) in the south-eastern region (Kouassi et al. 2010) during the period 1941–2000, where a significant downward trend is observed in the precipitation indices over the 1941–2000 period. In fact, these studies focused on the local scale and mostly during the present day and do not use multi-model ensemble. The present study aims to assess future changes in extreme precipitation events and the impacts of climate change on their intensity and frequency over the entire domain of Côte d'Ivoire under two Representative Concentration Pathway (RCP) forcing scenarios (i.e., RCP4.5 and RCP8.5) using the CORDEX-Africa regional climate model (RCM) simulations (Giorgi and Gutowski 2015). These simulations have been widely used in West Africa in many studies aimed at validating mean climate, its variability, and extreme events (Camara et al. 2013; Gbobaniyi et al. 2013; Klutse et al. 2015; Sarr et al. 2015; Nikiema et al. 2016; Gibba et al. 2018) and providing information about the future changes under different RCPs and global warming levels (Diallo et al. 2012; Sylla et al. 2012; Tall et al. 2016; Klutse et al. 2018; Sylla et al. 2018). In particular, our study will assess the future climate change signal and associated uncertainties in the intensity of extreme precipitation events and maximum length of dry spells during the three phases of the monsoon season (i.e., Sylla et al. 2015) for the near future (2031–2060) and the far future (2071–2100) relative to the reference period (1976–2005). Such information is very relevant for the resilience of urban infrastructure as well as cash crop farming in Côte d'Ivoire. The paper is organized as follows: we briefly describe the materials and methods in Section 2, discuss the results in Section 3, and summarize and provide conclusion in Section 4.

2 Materials and methods

2.1 Domain and experiment

The data used in the study is derived from the simulated daily precipitation outputs of an ensemble of fourteen (14) CORDEX-Africa RCM experiments available on the Earth System Grid Federation (ESGF) website (https://esg-dn1.nsc.liu.se/projects/esgf-liu/) at 0.44° of resolution. The data spans the historical period (1950–2005) and the future period (2006–2100) under RCP4.5 and RCP8.5 scenarios (see Table 1). These simulations are performed over a domain covering the whole Africa at 50 km of grid spacing. However, our domain of interest is Côte d'Ivoire (i.e., Fig. 1). Côte d'Ivoire is a relatively humid country located in West Africa along the Gulf of Guinea (9° W–2.5° W; 4° N–11° N). It consists of three climatic zones with different seasonal precipitation cycles (Kouadio et al. 2003, 2007, 2011): the northern climatic zone presents a unique rainy season occurring during the summer season from July to September with a peak in August; the central climate, with a hinted bimodal seasonal cycle peaking in June and September; and the littoral climatic zone located in the southern part of the country along the Gulf of Guinea is characterized by two rainy seasons with a major peak in June and a second maximum less pronounced in October.

2.2 Methodology

We used three daily precipitation–based indices from the ETCCDI to characterize extreme events in Côte d'Ivoire. The selected indices are as follows:

– The simple daily intensity index (SDII) is the ratio between the accumulated rainfall amount during wet days and the number of wet days (mm/day). Suppose R_i is the rainfall amount at a wet day ($R_i > 1$ mm) during period i and N is the number of wet days. SDII is given by

$$\mathrm{SDII} = \frac{\sum_{i=1}^{N} R_i}{N} \quad (1)$$

– The CDD index is the greatest length of dry spells (day). Suppose R_i is the daily rainfall amount in period i; then, counted is the maximum number of days with $R_i < 1$ mm. CDD is an indicator for drought.

Table 1 List of the 14 CORDEX-Africa phase 2 simulations used in the study

RCM	GCM	RCP	Status
SMHI-RCA4	CanESM2	4.5, 8.5	ESGF
	CNRM-CM5	4.5, 8.5	
	ES-EARTH-r12	4.5, 8.5	
	IPSL-CM5A-MR	4.5, 8.5	
CLMcom-CCLM4-8-17	MPI-ESM-LR	4.5, 8.5	ESGF
	ES-EARTH-r12	4.5, 8.5	
	HadGEM2-ES	4.5, 8.5	
	CNRM-CM5	4.5, 8.5	
DMI-HIRHAM5	EC-EARTH-r3	4.5, 8.5	ESGF
KNMI-RACMO22E	EC-EARTH-r1	4.5, 8.5	ESGF
		4.5, 8.5	
CCCma-CanRCM4	CanESM2	4.5, 8.5	CCCMA ftp
MPI-CSC-REMO2009	MPI-ESM-LR	4.5, 8.5	RCM group
CNRM-ALADIN52	CNRM-CM5	4.5, 8.5	RCM group (not all variables)
BCCR-WRF331	NorESM1-M	4.5, 8.5	RCM group

The simulations include the RCMs and the GCMs used as boundary data

– The precipitation intensity above the 95th percentile (R95PTOT) is the percentage of the precipitation due to very wet days by the total of precipitation accumulation (%). Suppose R_i is the daily precipitation amount on a wet day, PRCPTOT the total precipitation amount in period *i*, R95 the 95th percentile of the precipitation of daily precipitation amount of wet days for 1976–2005 used as reference period, and R95P the precipitation total above the 95th percentile ($R_i > \mathrm{R95}$) threshold. R95PTOT is given by

$$\mathrm{R95PTOT} = \frac{\mathrm{R95P}}{\mathrm{PRCPTOT}} \times 100 \quad (2)$$

R95PTOT is an indicator of extreme precipitation intensity that can trigger flooding.

The indices are calculated on seasonal basis for each experiment before a multi-model ensemble is applied. Several studies revealed that the multi-model ensemble (MME) mean approach outperforms the individual RCM at different temporal and spatial scales, thus providing a more robust assessment (Druyan et al. 2010; Diallo et al. 2012; Nikulin et al. 2012; Camara et al. 2013; Gbobaniyi et al. 2013; Nikiema et al. 2016).

Future mean changes in the extremes are calculated for the three phases being April–June (AMJ), July–September (JAS), and October–December (OND) of the West African Monsoon (WAM) for two 30-year periods: the near future (2031–2060) and the far future (2071–2100) and under both RCP4.5 and RCP8.5 scenarios. The projected changes are performed by subtracting the projected value of the extreme index from that of the reference period (1976–2005). These changes are estimated as percentage relative to the reference period (1976–2005), and the statistical significance is evaluated using a Student's *t* test at 90% level. This technique uses a signal-to-noise ratio (*p* value) to assess the signal significance compared to noise. Following Decremer et al. (2014), the signal in this work is computed as the difference between the average of a climate index with external forcing and a hypothesized value (in a one-sample test) or the average of a climate index with basis forcing (in a two-sample test). This signal is defined as the changes in any specific climate index driven by an external forcing. It has been wildly used in many studies like Diawara et al. (2014), Yoroba et al. (2019), and Akinsanola and Zhou (2018), and it showed statistical great performance.

To have an idea about the trends of the changes, the analysis of anomalies is performed for each season for the entire country as well as for the three climatic zones. To gain some insights about the associated uncertainties, the box-and-whisker plots are considered to help quantify the intermodel spread of the changes.

3 Results and discussions

3.1 Mean spatial changes

3.1.1 Mean changes in SDII

Changes in the mean seasonal precipitation amount for wet days are reported in Fig. 2a–f for the different seasons and for both RCP4.5 and RCP.8.5 scenarios during the far-future period (2071–2100). In general, considering all seasons and scenarios, the tendency is towards no or positive changes of SDII. In the pre-monsoon season (AMJ), the southern regions and especially the coastal and mountainous areas experience an

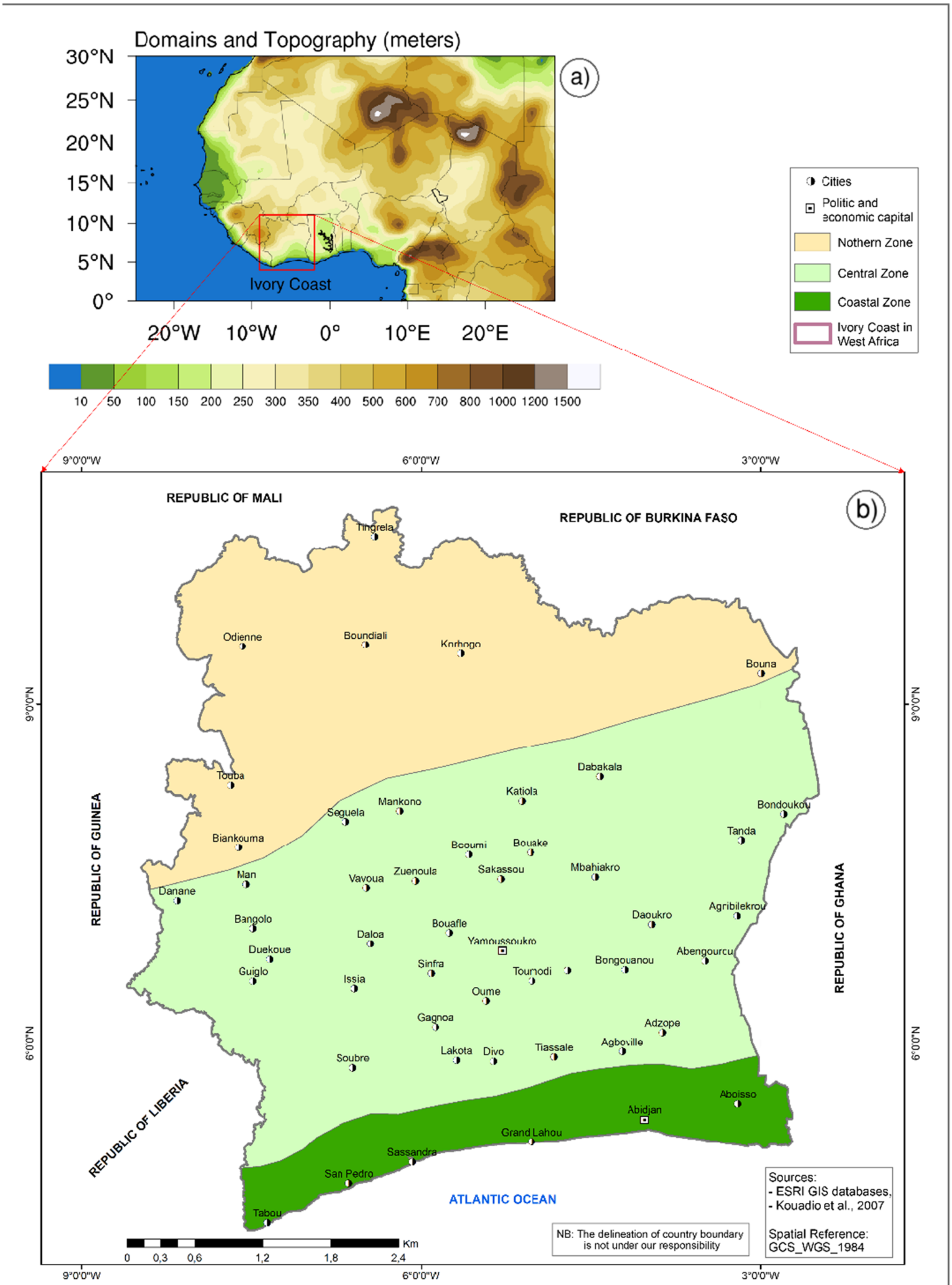

Fig. 1 **a** The domain and topography (m) of West Africa. **b** Côte d'Ivoire subdivided into three climatic zones (littoral, center, and north), adapted from Kouadio et al. (2007)

increase of rainfall intensity of about 10% in both scenarios relative to the mean value of the reference period. This intensification is stronger in the mature monsoon (JAS) phase where the highlands in the western part of the country are characterized by positive changes of more than 15% and 20% in the RCP4.5 and RCP8.5 scenarios, respectively. In

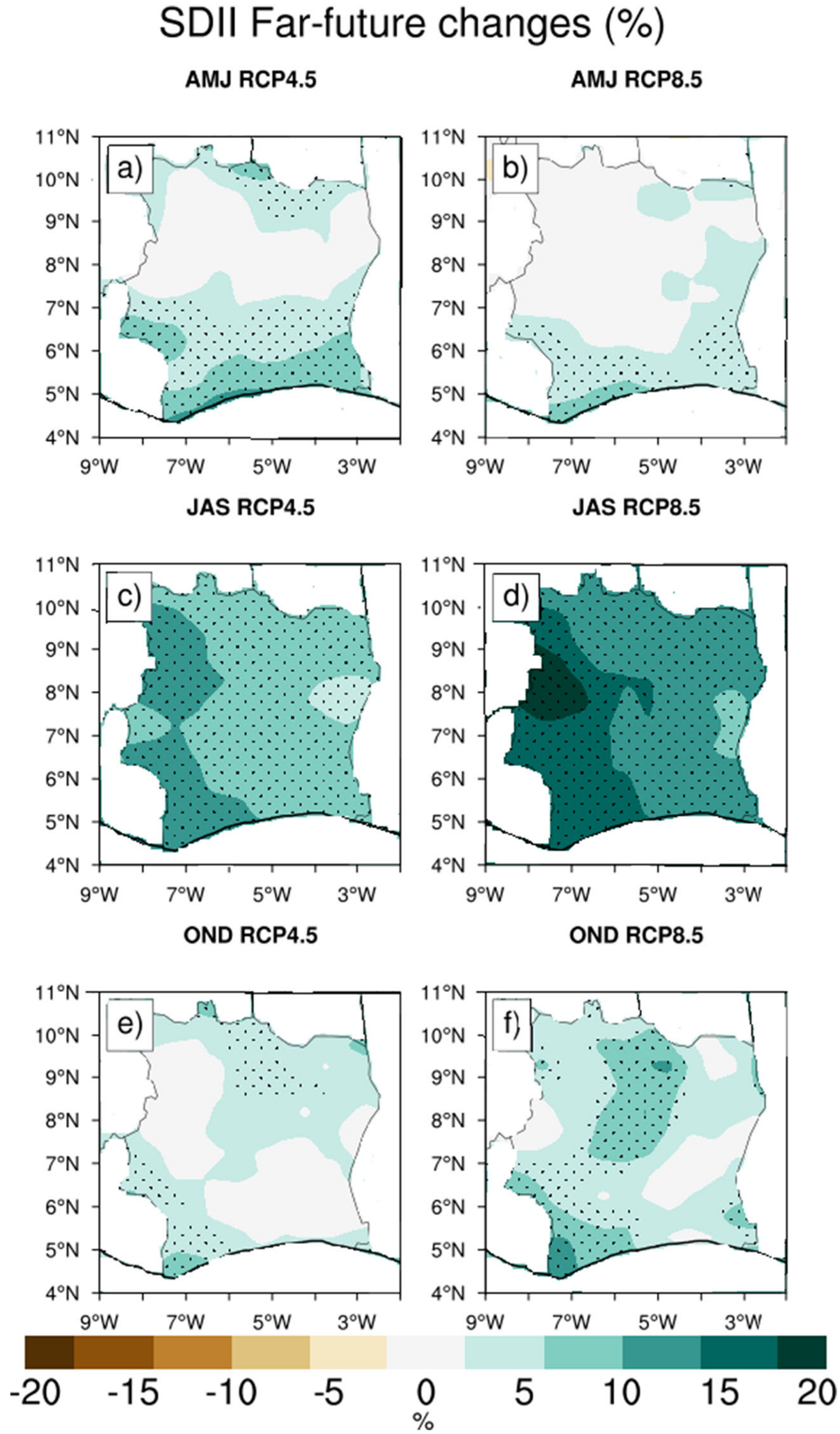

Fig. 2 Mean changes in AMJ, JAS, and OND seasons for the RCP4.5 scenario minus reference (**a**, **c**, **e**) and for the RCP8.5 scenario minus reference (**b**, **d**, **f**) in simple daily intensity index (SDII) from the multi-model ensemble mean of CORDEX-Africa simulations during the far-future period (2071–2100) in Côte d'Ivoire. Changes are estimated as percentage with respect to the reference period (1976–2005). Stippling indicate areas with changes are statistically significant (90% significance level using *t* test)

OND, similar magnitudes than AMJ are projected but with the maxima located in the northern and southwestern regions. Changes in the near future (i.e., Fig. 3a–f) show a generally less increase compared to the far future in JAS in the western regions. Nonetheless, a slight decrease about 7% and 2% is respectively projected in AMJ (in the north) under the RCP8.5 scenario and in OND (in the central and coastal areas) under both scenarios. These results are in line with previous studies in other regions of Africa such as Southern Africa (Pinto et al. 2016), Central Africa (Sonkoué et al. 2018; Fotso-Nguemo et al. 2019), and West Africa (Sylla et al. 2015; Akinsanola and Zhou 2018) showing an increase in SDII under climate change. It is thus clear that in general, Côte d'Ivoire, as most part of the world, is subject to an increased intensity of precipitation events under future climates, suggesting an amplification of extreme precipitation events.

3.1.2 Mean changes in seasonal R95PTOT

Mean seasonal changes in the contribution of extreme precipitation events under RCP4.5 and RCP8.5 scenarios for the far future are presented in Fig. 4a–f. An increase in R95PTOT occurred in the far-future period under both forcing scenarios, during all the WAM stages, i.e., pre-monsoon (AMJ), mature monsoon (JAS), and post-monsoon (OND). The most substantial increases, up to 50–60% of reference period mean value, are projected to take place during the mature monsoon phase (i.e., JAS) over the entire country and under the RCP8.5. Other seasons experience changes about 20% located in central regions in AMJ and in the northeastern region in OND. Compared to the changes in SDII, it can be concluded that most of the increases of precipitation amount for wet days

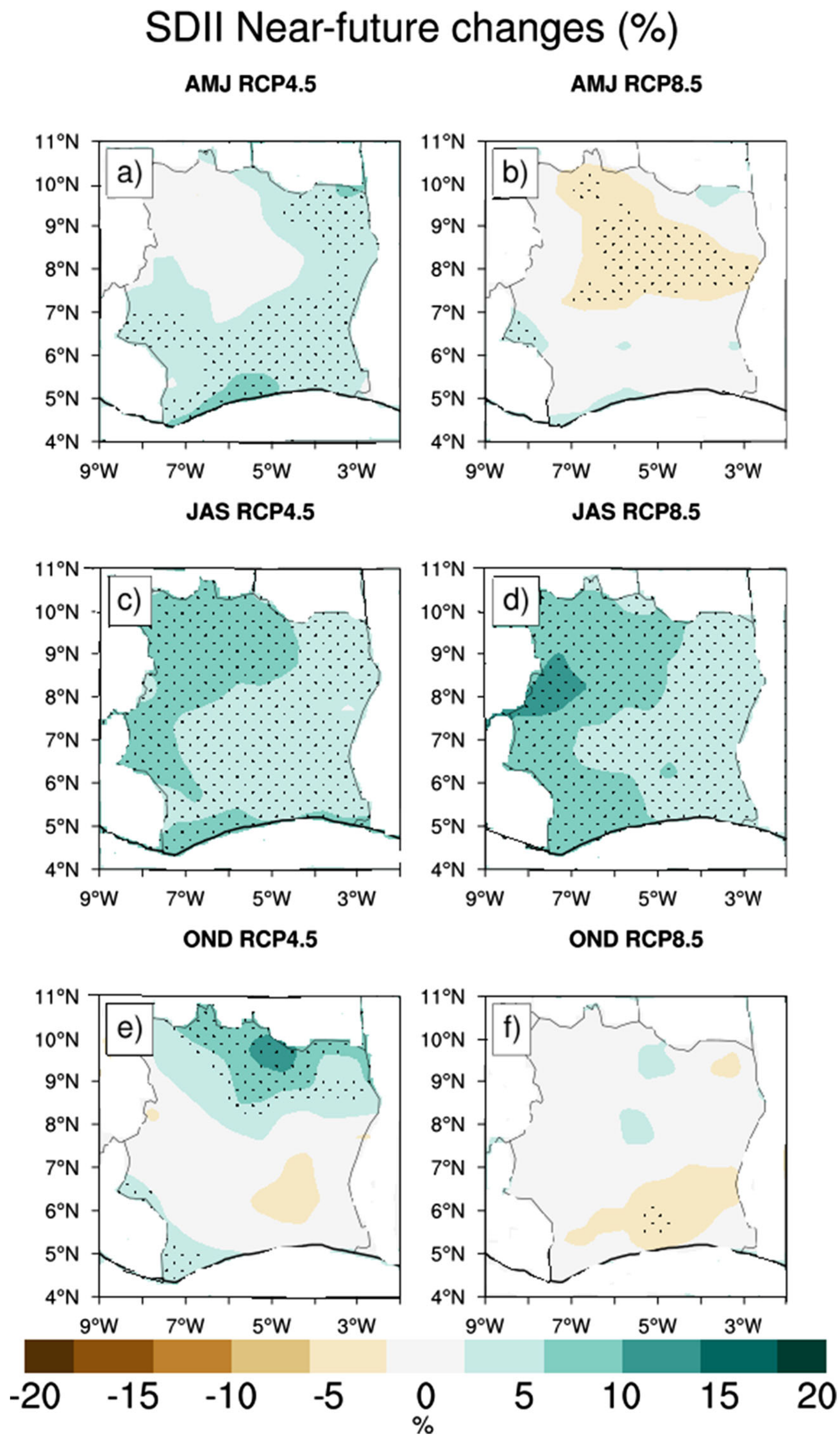

Fig. 3 Same as Fig. 2, but during the near-future period (2031–2060)

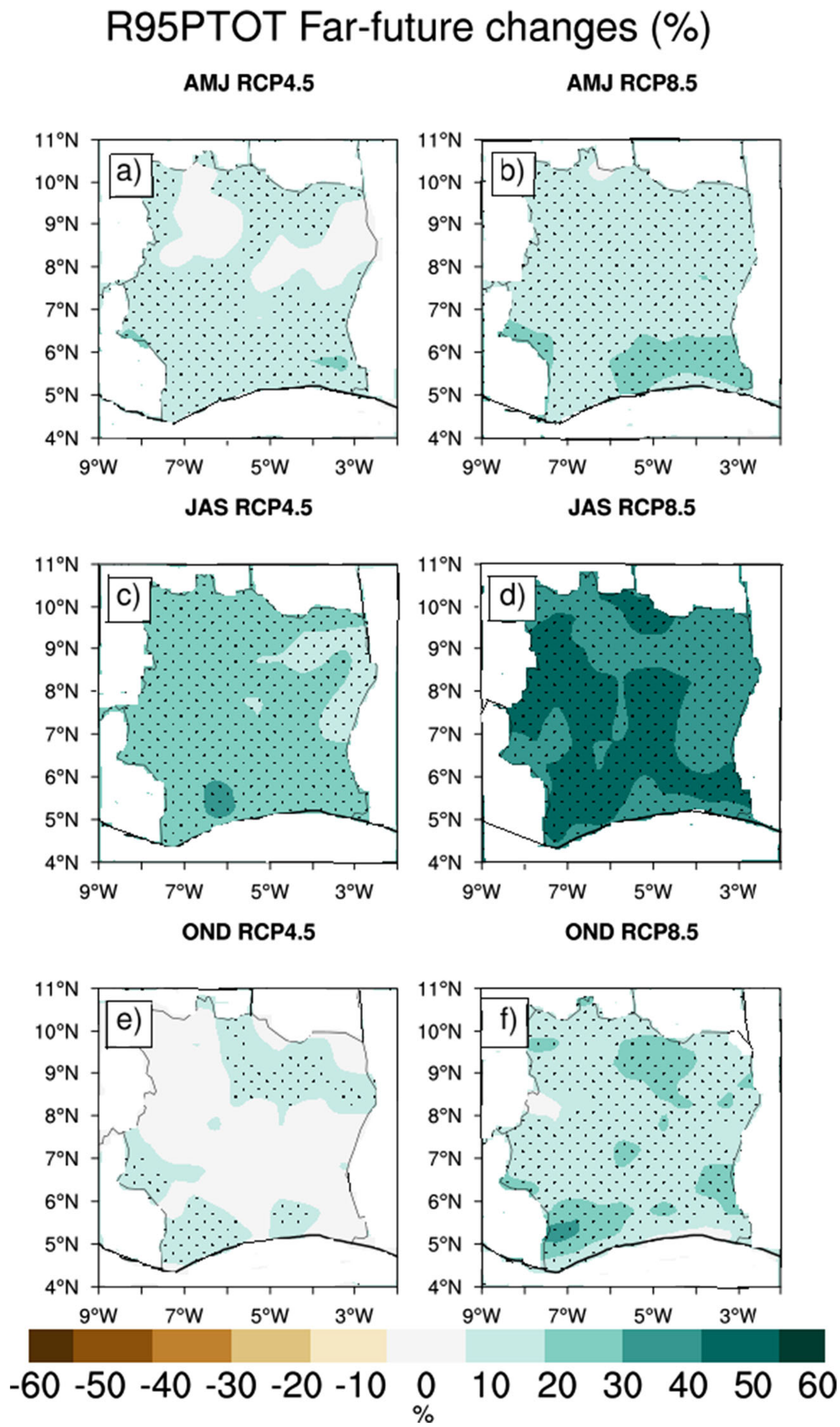

Fig. 4 Same as Fig. 2, but for the extreme precipitation above the 95th percentile (R95PTOT) during the far-future period (2071–2100)

are due to an intensification of extreme precipitation events. Previous studies have linked this intensification to the decrease in the frequency of wet days and a subsequent increase of low-level atmospheric water content (Sylla et al. 2012, 2015; Diallo et al. 2016). This can considerably impact changes in dry spells. Changes in the near future indicate a general increase, but to a lesser extent compared to the far future. These positive changes during the near future occur during all seasons (AMJ, JAS, and OND) with the most considerable increase (i.e., up to 20%) arising in JAS. However, it is worth noting a slight decrease about 10% is projected in the northeastern areas in AMJ under the RCP8.5 scenario and in the central areas during OND under the RCP4.5 scenario (Fig. 5a–f).

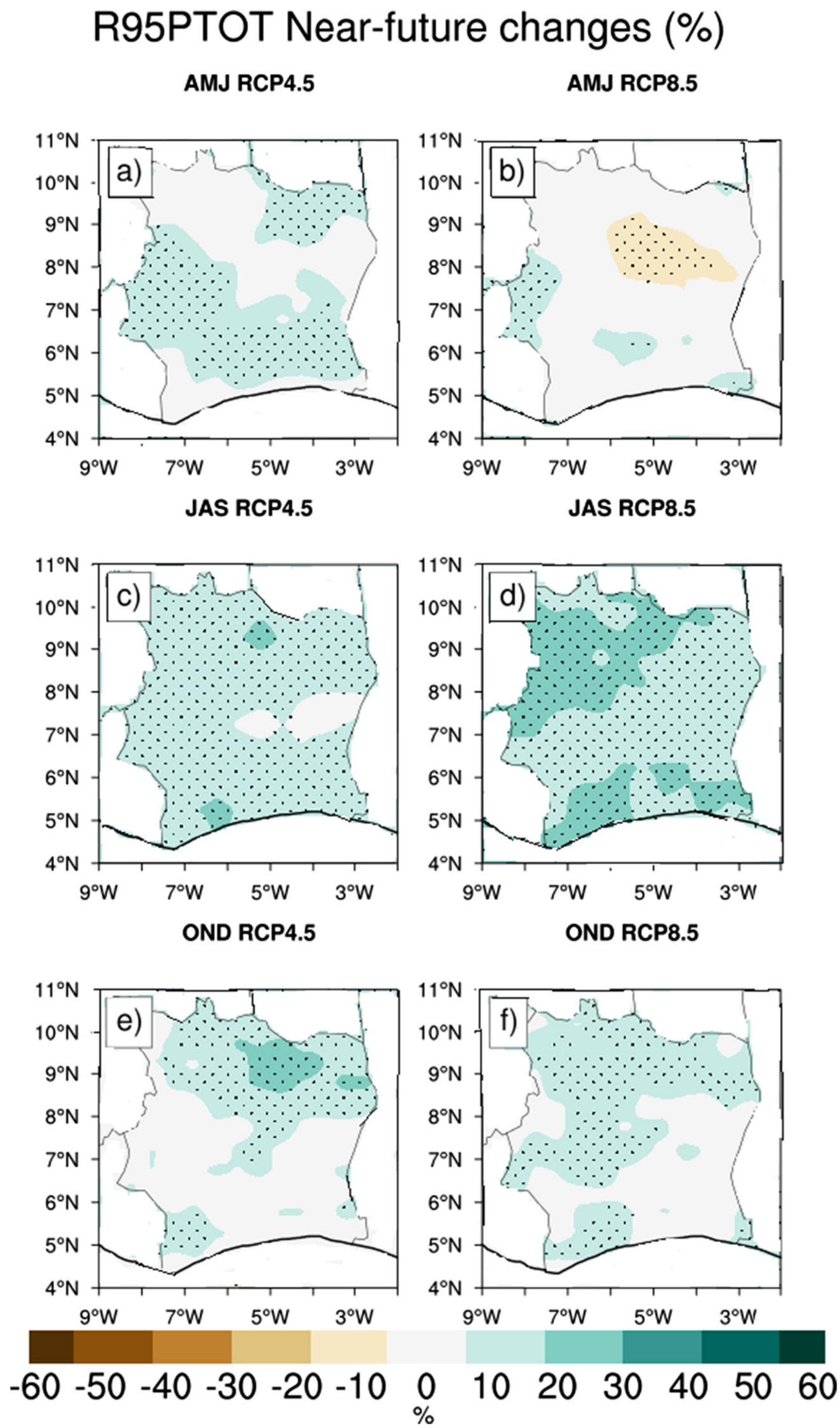

Fig. 5 Same as Fig. 2, but for the extreme precipitation above the 95th percentile (R95PTOT) during the near-future period (2031–2060)

3.1.3 Mean changes in seasonal CDD

Mean seasonal changes of the maximum number of consecutive dry days are shown in Fig. 6a–f for RCP4.5 and RCP8.5 scenarios during the pre-monsoon (top panel), mature monsoon (middle panel), and post-monsoon (bottom panel) for the far-future period. An increase in the maximum length of dry spells is projected during the pre-monsoon (AMJ) in the whole country. This increase is more pronounced under the RCP8.5 scenario in the northern regions where maxima reach 30%. Under the RCP4.5 scenario, the increase is limited to about 20% and is mostly located in the eastern part of the country. During the other seasons (i.e., JAS and OND), the consecutive dry days index is projected to decrease (about 20% of the reference period mean value), except in the south-eastern, the eastern, and the northern parts of the country. In fact, in these latter regions, there is a slight increase of about 10% during the mature monsoon phase (i.e., JAS) and under

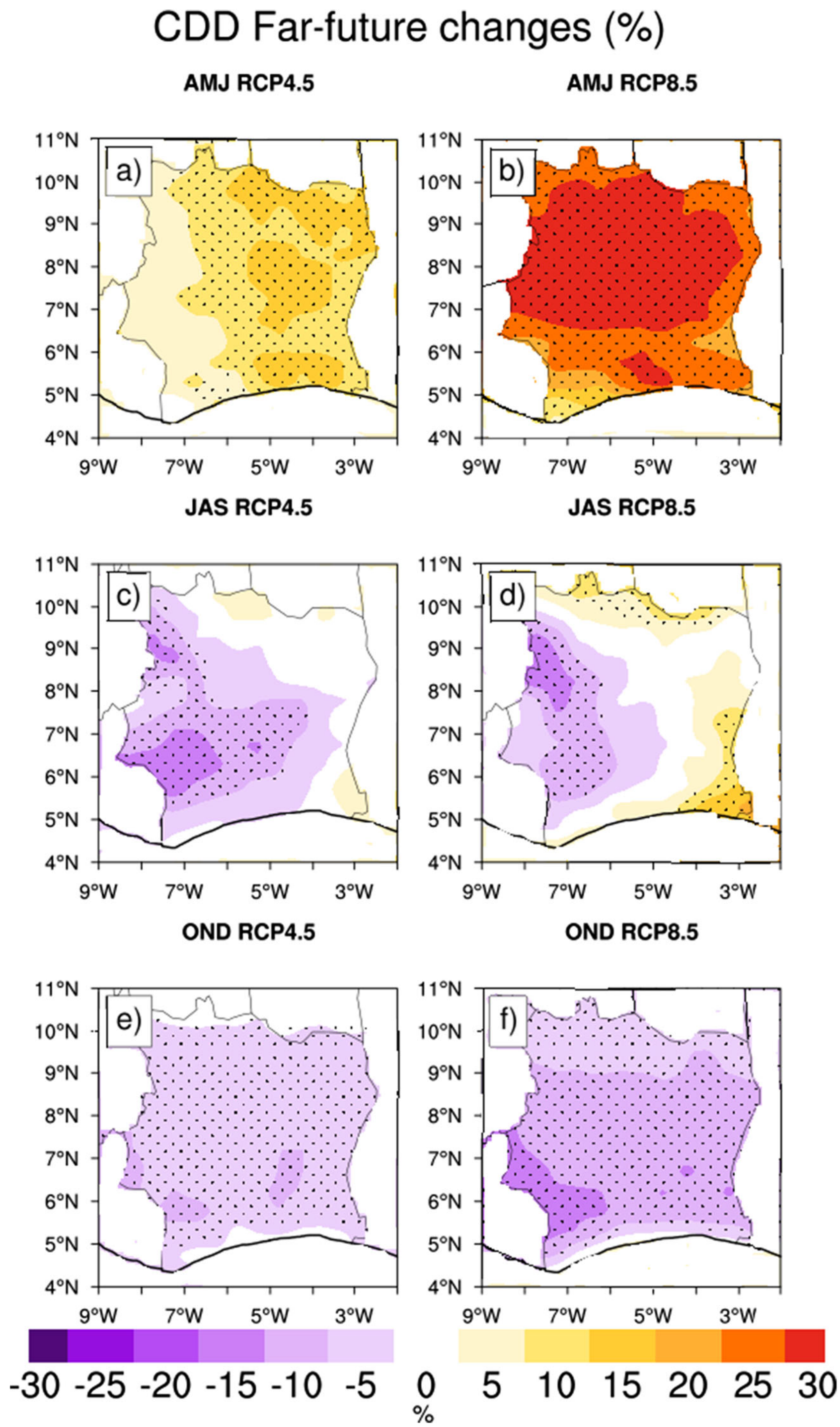

Fig. 6 Same as Fig. 2, but for the consecutive dry days (CDD) index during the far-future period (2071–2100)

the RCP8.5 scenario. This situation is also the same in the near-future period, where the pre-monsoon (AMJ) is characterized by an increase in dry spell length about 12% and 17% under RCP4.5 and RCP8.5 scenarios, respectively. However, the two other seasons (i.e., JAS and OND) are both characterized by a decrease in dry spell length of about 18% and 12% in the western part of the country under RCP4.5 and RCP8.5 scenarios, respectively (Fig. 7a–f).

3.2 Mean seasonal changes in regionally average values

The quantitative values of the seasonal changes over the different subregions of Côte d'Ivoire (i.e., littoral, center, and north) are reported in Tables 2, 3, and 4 for CDD, SDII, and R95PTOT indices, respectively. As indicated in Table 2, CDD is projected to increase during the AMJ season over the three

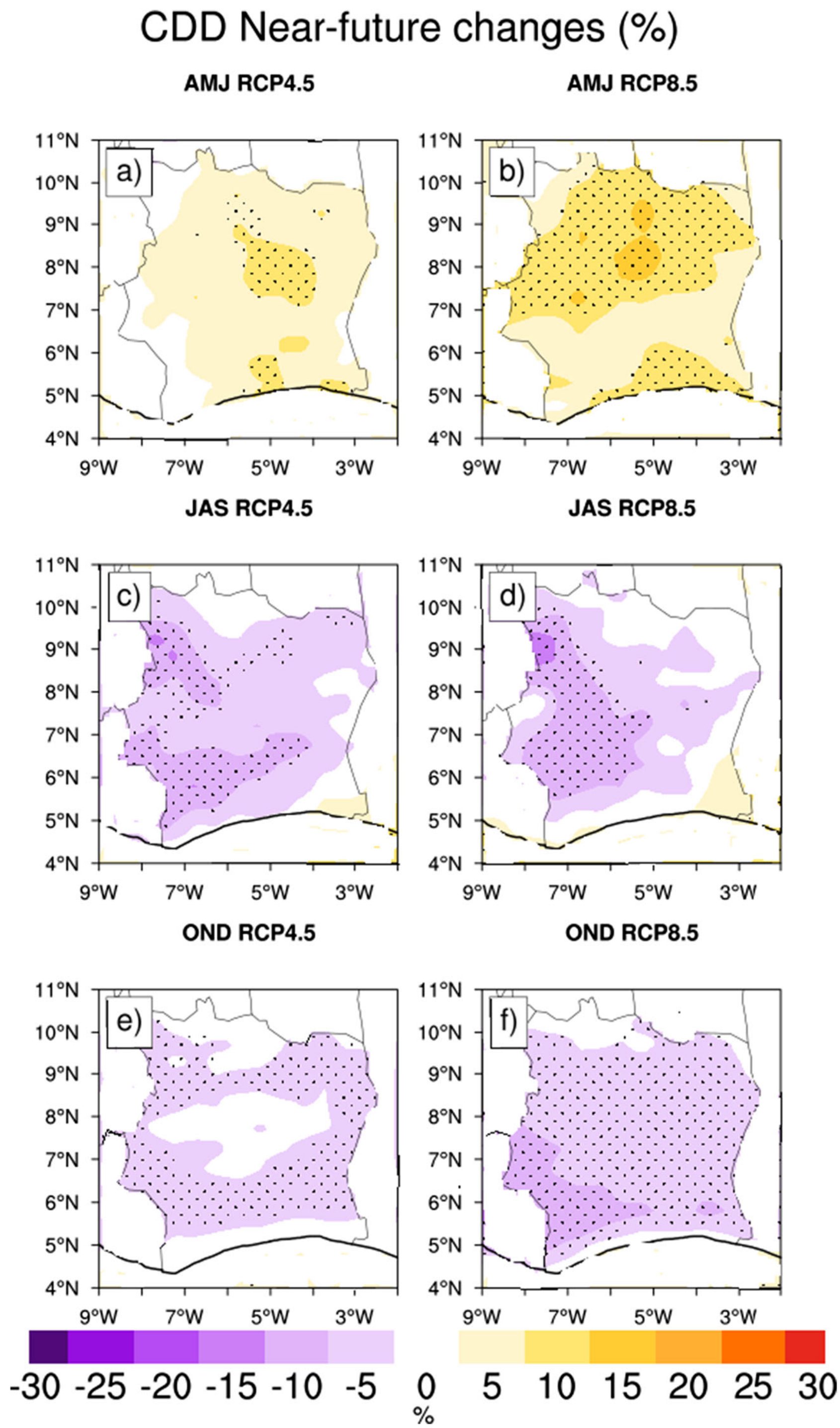

Fig. 7 Same as Fig. 2, but for the consecutive dry days (CDD) index during the near-future period (2031–2060)

subregions with maxima of about 20% in the littoral under the RCP8.5 scenario. In the contrary during OND, the regional changes are characterized by a decrease in dry spell length with maxima reaching about 7.05% in the littoral and 10.27% in the center during the 2031–2060 and 2071–2100 periods, respectively, and under the RCP8.5 scenario. Changes during JAS over the northern regions are extremely small (nearly 0.0%) for both scenarios during the near-future period. However, for the far future, they increase for about 7.38% for the RCP8.5 scenario.

Table 3 presents the mean seasonal changes of regionally averaged values for SDII. A common future is the general increase projected over the littoral, the central, and the northern regions for both scenarios and periods and for all seasons. A larger increase of more than 15% occurs during 2071–2100 in JAS and under the RCP8.5 scenario in the central region.

Table 2 Changes (%) in CDD with respect to the mean value of the reference 1976–2005 period in the different subregions of Côte d'Ivoire

	AMJ		JAS		OND		AMJ		JAS		OND	
Littoral	4.84	8.13	− 0.77	1.73	− 4.09	− 7.05	6.18	19.58	0.24	8.41	− 5.63	− 9.29
Center	3.03	5.56	− 0.38	1.69	− 3.58	− 6.42	4.46	18.85	− 0.07	5.09	− 6.71	− 10.27
North	1.59	3.61	− 0.70	− 0.39	− 3.11	− 3.41	4.65	19.16	0.63	7.38	− 4.68	− 6.98
Scenarios	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Periods	2031–2060						2071–2100					

For other regions and seasons during the same period, changes range from 1.16 to 6.50%. During the 2031–2060 period, changes are not significant. Regional changes in R95PTOT (Table 4) present positive values over the three subregions during the near future (2031–2060) and the far future (2071–2100) and under both scenarios. The maximum values 21.69%, 50.12%, and 18.69% are projected particularly in the littoral during the 2071–2100 period under the RCP8.5 scenario in AMJ, JAS, and OND seasons, respectively. These results indicate that the littoral could be significantly affected by the risk of floods, specifically during the mature monsoon season (JAS) in the far future.

3.3 Temporal evolution of the extreme indices' anomalies

The temporal evolution analysis is conducted during the different monsoon phases (AMJ, JAS, and OND) for each extreme index from the historical (1976–2005) period (black line) to the future (2006–2100) period under RCP4.5 and RCP8.5 scenarios (blue and red lines), respectively. The temporal evolution of the anomalies is done for Côte d'Ivoire as well as for the three climatic areas (Figs. 8, 9, and 10).

Figure 8a–l displays the temporal evolution of the SDII anomalies relative to the reference period (1976–2005). The pre-monsoon (AMJ) season is characterized by a fluctuation of SDII with a succession of positive and negative anomalies during the whole period (1976–2100) for the country and the three climatic areas. During the present day, the range of fluctuation is around − 10% to 10%, while for the future, it reaches 15% indicating a stronger variability as greenhouse gas forcing increases. During the mature monsoon (JAS) phase, in addition to a stronger variability, a substantial increasing tendency in SDII is projected under both scenarios with RCP8.5 yielding greater values in 2100. This increasing tendency is simulated for the whole country as well as for the three climatic areas with the northern region experiencing the largest changes (more than 20% under the RCP8.5 scenario). The post-monsoon (OND) season exhibits a behavior of anomalies similar to that of the pre-monsoon season. However, the variability is stronger, and the magnitude of fluctuations is greater than during AMJ especially in the northern climate area where they reach more than 20%.

The temporal evolution of the anomalies of the intensity of precipitation events above the 95th percentile hereafter referred as intensity of extreme precipitation is shown in Fig. 9a–l for the whole country and the three climatic areas during AMJ, JAS, and OND, respectively. Generally, during the different phases of the monsoon season, there is strong variability of extreme precipitation intensity in future climates although most of the anomalies are positive. During AMJ, the anomalies exhibit a slight increasing tendency from 2060 in both scenarios with amplitudes reaching 30% in 2100 over the whole country and in the northern and central regions but without any discernable differences between RCP4.5 and RCP8.5 scenarios. In JAS, an increasing tendency of extreme precipitation intensity that starts as early as 2020 prevails for the whole country and over the different regions. The RCP8.5 scenario yields higher intensities compared to the RCP4.5 scenario. Thus, around the end of the century 2100, the projected anomalies range mostly from 30 to 60% compared to the mean of the reference period. In OND in the whole country and for each of the regions, although no increasing tendency is noted, the anomalies are mostly positive during the future periods, indicating the occurrences of more intense precipitation events.

Table 3 Same as Table 2, but for SDII (%)

	AMJ		JAS		OND		AMJ		JAS		OND	
Littoral	3.89	0.57	5.65	6.35	0.60	− 1.20	6.50	4.58	9.10	14.11	2.88	6.28
Center	3.00	− 1.12	4.28	6.25	0.62	0.44	3.02	2.03	7.52	15.31	1.72	4.78
North	1.42	− 1.61	5.56	6.76	5.37	1.84	1.87	1.16	8.03	14.37	3.49	6.82
Scenarios	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Periods	2031–2060						2071–2100					

Table 4 Same as Table 2, but for R95PTOT

	AMJ		JAS		OND		AMJ		JAS		OND	
Littoral	6.31	4.23	17.42	22.93	5.63	5.98	15.29	21.69	29.15	50.12	9.50	18.69
Center	7.42	3.38	11.67	18.75	5.87	8.06	10.50	19.60	22.58	48.25	3.40	15.33
North	5.62	2.25	13.80	19.34	12.50	10.37	8.10	16.39	23.06	46.01	5.24	16.23
Scenarios	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5	RCP4.5	RCP8.5
Periods	2031–2060						2071–2100					

The corresponding times series for the maximum length of CDD index anomalies are shown in Fig. 10a–l for Côte d'Ivoire and the three climatic regions during the pre-monsoon, mature monsoon, and post-monsoon seasons, respectively. In AMJ, stronger variabilities, larger amplitudes, and a tendency towards increasing length of dry spells compared to the reference are projected in Côte d'Ivoire but also in the three climatic regions. As in the case of the intensity of extreme events, the RCP8.5 scenario leads to larger changes (at least 50% in all regions and in the country) compared to the RCP4.5 scenario (30% in the southern region and 0% to 10% in Côte d'Ivoire and in the central and northern regions), suggesting dry spells will be longer during the pre-monsoon season as greenhouse gas increases. However, it is worth noting that the two forcing scenarios show divergence only from 2080. In JAS and for all regions and Côte d'Ivoire, although stronger fluctuations are projected, the amplitudes are lower compared to the reference period and anomalies are mostly below normal, indicating that the dry spells tend to be shorter in future climates. During OND, although the amplitudes are quite similar to those of the reference period, anomalies are mostly below normal and a tendency towards a decreasing length of dry spells is predominant in future climates. In this region, the seasonal changes range mostly between 0% and − 20% in the last two decades of the twenty-first century.

Globally in future climates, the cumulative intensity of precipitation events will generally increase in Côte d'Ivoire and in the three climatic regions as a result of more variable and larger extreme precipitation intensity occurring in all seasons. In particular during JAS, a clear and discernable tendency towards increasing extreme intensity with a higher variability is projected with the higher-level forcing scenario (i.e., RCP8.5) leading, by the end of century, to changes of up to 60% while the middle-range RCP4.5 forcing scenario limits the increase to 30%. In contrast during AMJ, a slightly increasing trend of extreme precipitation intensity anomalies with larger variability is concurrent with an increasing tendency of dry spell length more marked in the RCP8.5 scenario. Finally, during OND, predominant and highly variable positive anomalies of extreme precipitation intensity co-exist with a slight decreasing tendency of dry spell length. It is thus clear that the country will be threatened more by (1) increasing trend of both extreme precipitation intensity and dry spell length during AMJ, (2) only extreme precipitation intensity increasing tendency during JAS, and (3) an increasing length of dry spells although the extreme precipitation intensity's amplitudes are larger than those during the reference period. These results are in line with the findings of Diedhiou et al. (2018) over the wetter regions of the Guinea Coast and Central Africa where models project the highest increase in heavy rainfall at a global warming temperature of 1.5 °C.

3.4 Uncertainties

For a more quantitative assessment and to have a picture of the extent to which CORDEX-Africa models agree on projected changes, the mean seasonal changes of country-wide average values and intermodel spread for each index (i.e., SDII, CDD, and R95PTOT) are shown as a box-and-whiskers plot and tables for the two future periods, i.e., the near future (2031–2060) and far future (2071–2100) under RCP4.5 and RCP8.5 scenarios for the whole country (Figs. 11, 12, and 13).

For the SDII, the most prominent feature is the projected increase of the intensity for both the near-future and the far-future periods and both RCP4.5 and RCP8.5 scenarios during JAS. The magnitude ranges from 5% during 2031–2060 under the RCP4.5 scenario to 15% during 2071–2100 under the RCP8.5 scenario. In addition, the interquartile range tends to increase, suggesting that the regional response of the individual RCMs tends to become larger as the greenhouse gas forcing strengthens. However, the median and both the lower (25th percentile) and upper (75th percentile) quartiles are positive, indicating the increase in intensity of precipitation events is a robust result. During AMJ and OND, the interquartile ranges span both positive and negative values except in 2071–2100 and for the RCP8.5 scenario. In this latter, most of the RCMs agree in the sign and imply robust increased precipitation event intensity as well during the last decades of the twenty-first century (Fig. 11). For the extreme precipitation intensity (i.e., R95PTOT), the most striking feature is the positive projected changes in all seasons, future periods, and forcing scenarios with largest changes in JAS during 2071–2100 and the RCP8.5 scenario. Changes are quite uncertain during AMJ and OND for both periods in the RCP4.5 scenario and during 2031–2060 for the RCP8.5 scenario as the interquartile ranges span both positive and negative values. In

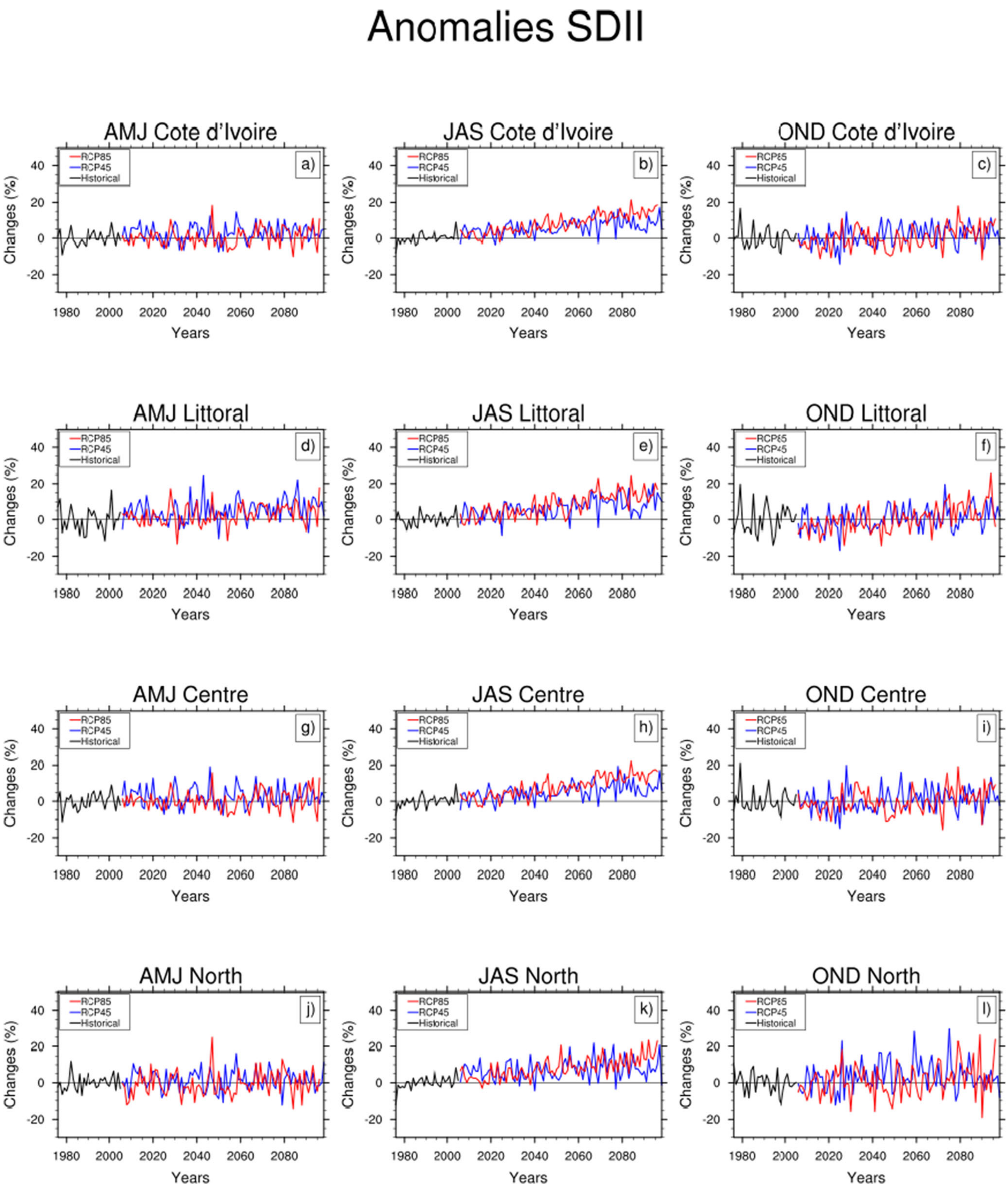

Fig. 8 Temporal evolution of the SDII anomalies in Côte d'Ivoire (**a**–**c**) and in the littoral (**d**–**f**), the center (**g**–**i**), and the north (**j**–**l**) climatic zones during WAM seasons: AMJ (**a**, **d**, **g**, **j**), JAS (**b**, **e**, **h**, **k**), and OND (**c**, **f**, **i**, **l**)

all JAS seasons, median, interquartile ranges, and lower and higher quartiles as well the maxima and minima are all above 0, implying that the projected increased extreme precipitation intensity is substantially robust (Fig. 12). For the dry spell

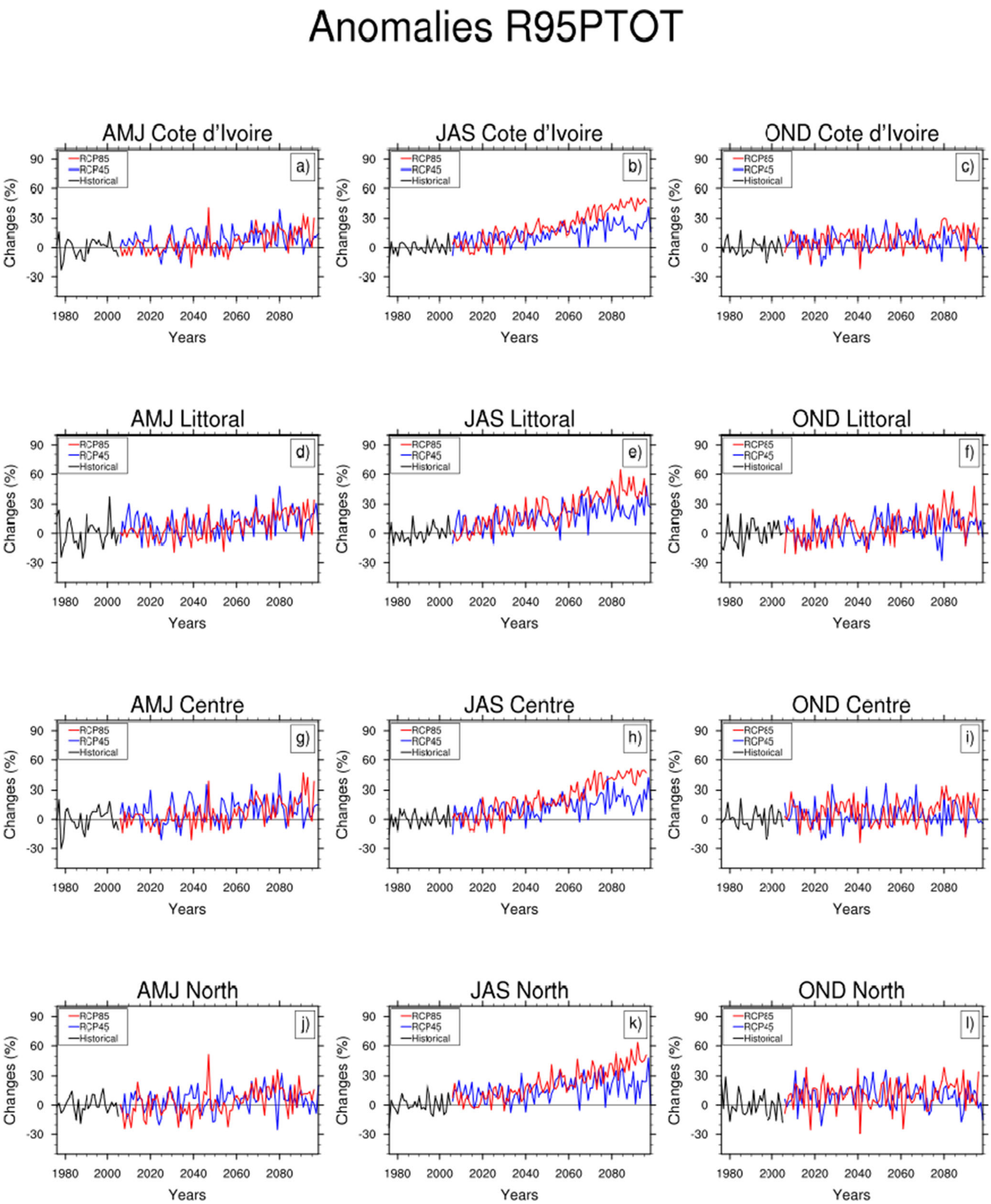

Fig. 9 Same as Fig. 8, but for R95PTOT

length index, considerable uncertainties prevail during AMJ and JAS as intermodel spread span both positive and negative values. However, it is thus clear that Côte d'Ivoire will face robust changes indicating the occurrences of more intense extreme precipitations with generally a higher variability than the reference period in all seasons and

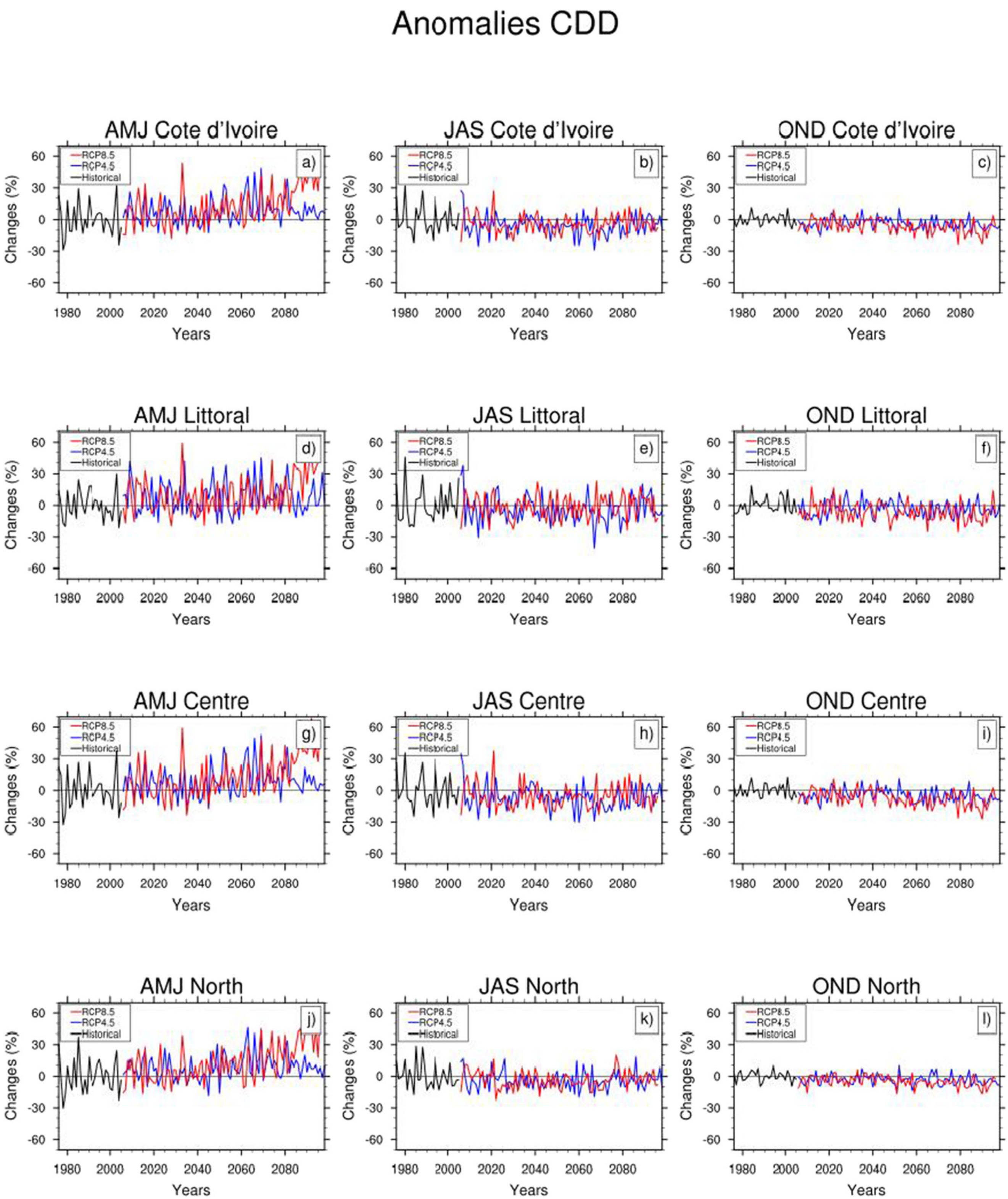

Fig. 10 Same as Figs. 8 and 9, but for CDD

periods peaking in 2071–2100 during JAS considering the RCP8.5 forcing scenario. In addition, dry spell tends to be less short in future climates, but these changes are robust only during OND (Fig. 13).

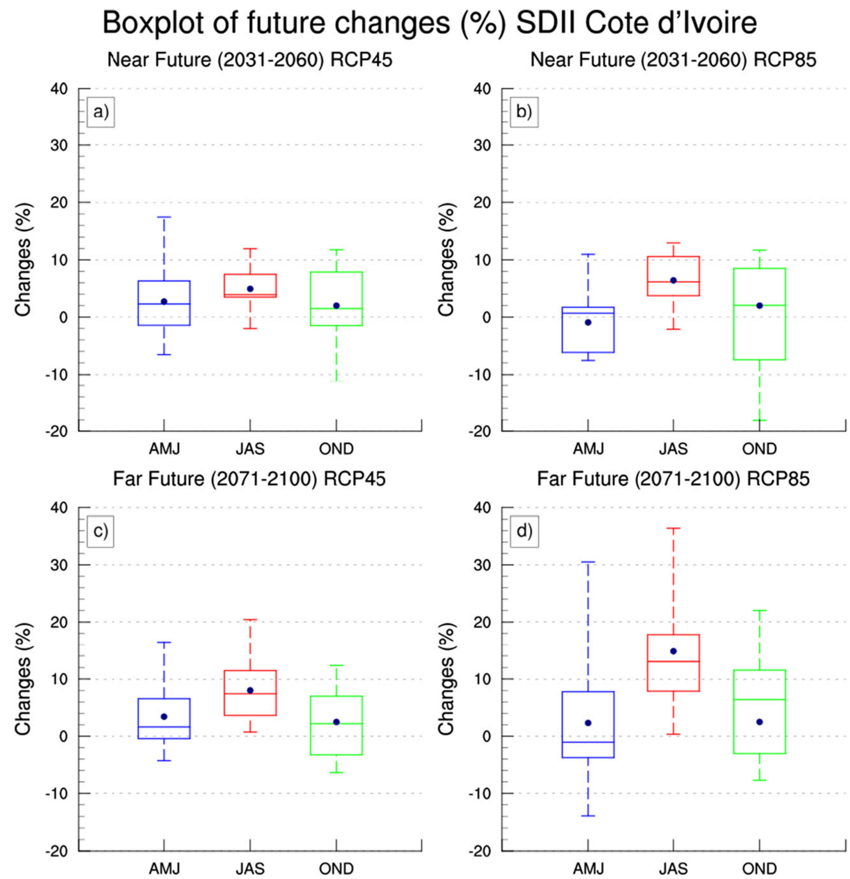

Fig. 11 Quantitative assessment of the CORDEX-Africa model agreement on the projected changes for the SDII in the near-future (**a**, **b**) and the far-future (**c**, **d**) periods, under RCP4.5 (**a**, **c**) and RCP8.5 (**b**, **d**) scenarios during AMJ (blue), JAS (red), and OND (green) seasons in Côte d'Ivoire. Dots indicate the ensemble mean of the CORDEX-Africa models

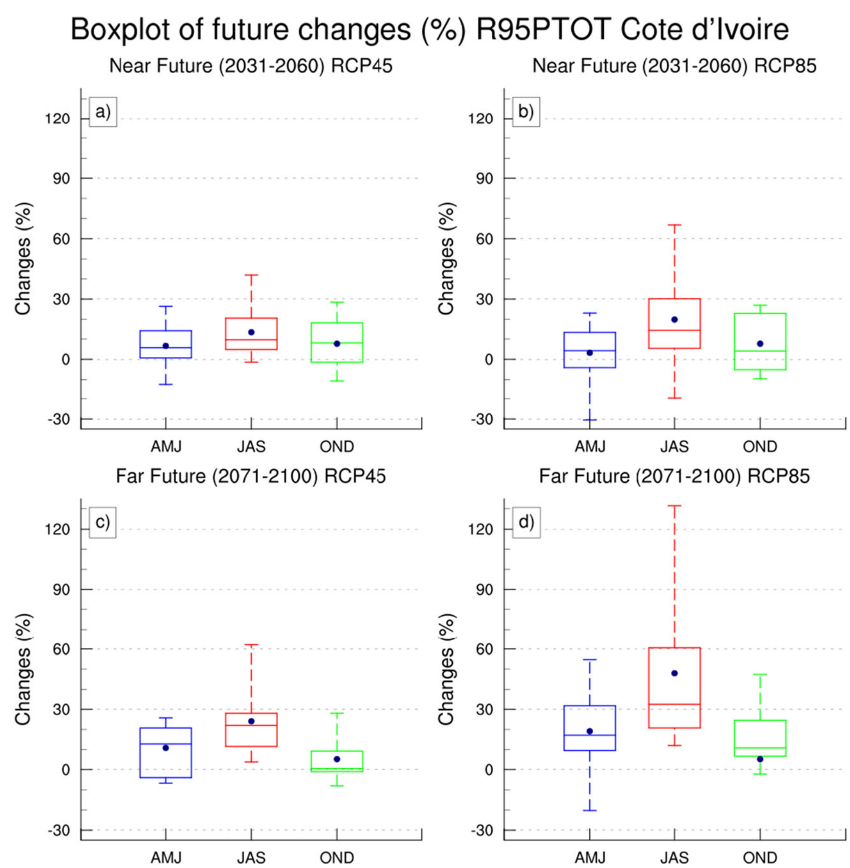

Fig. 12 Same as Fig. 11, but for R95PTOT

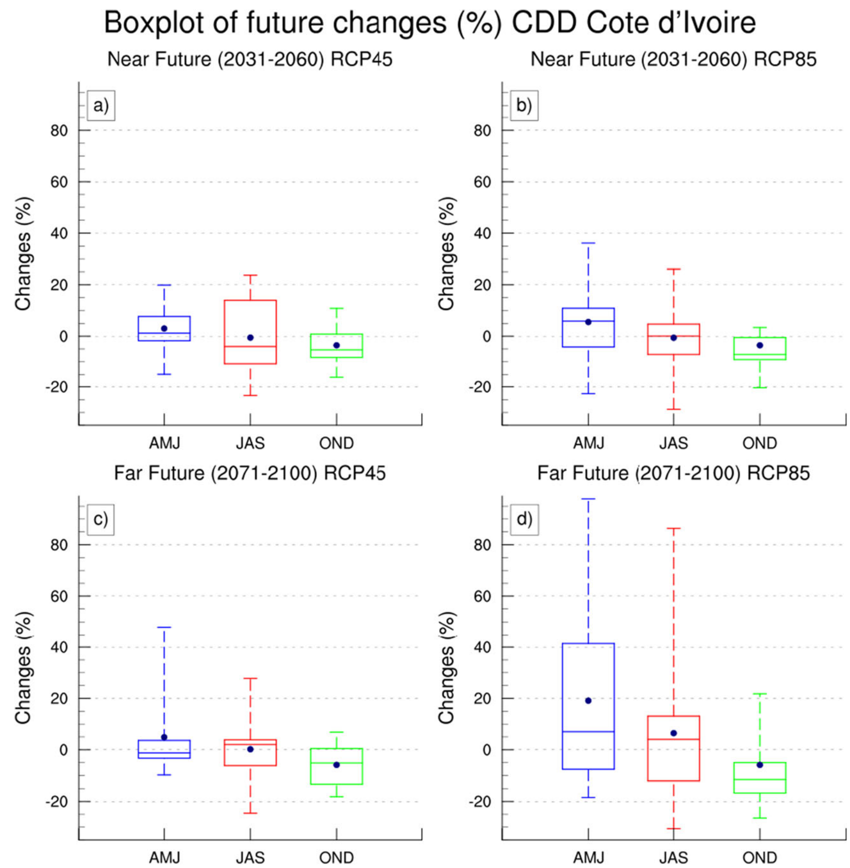

Fig. 13 Same as Figs. 11 and 12, but for CDD

4 Summary and conclusions

In this paper, future changes in extreme precipitation intensity and dry spell length in Côte d'Ivoire are investigated using an ensemble of 14 CORDEX-Africa RCMs and two forcing scenarios (RCP4.5 and RCP8.5). The projected seasonal changes in the extreme precipitation intensity (SDII and R95PTOT) and dry spell length (CDD) are assessed by comparing two future 30-year periods (near future and far future; 2031–2060 and 2071–2100, respectively) with the reference time period (1976–2005), under RCP4.5 and RCP8.5 scenarios. In addition, the time series of the interannual variability of the different indices (i.e., SDII, R95PTOT, and CDD) are analyzed over the entire country (Côte d'Ivoire) and in the different climatic areas (littoral, center, and north). Finally, uncertainties are evaluated by quantifying the intermodel spread of the changes over Côte d'Ivoire. The results indicate that during each of the three stages of the WAM seasons (i.e., AMJ, JAS, OND), a general increase in rainfall intensity (SDII) and extreme precipitation intensity (R95PTOT) is observed in Côte d'Ivoire, considering both scenarios and periods. Moreover, the most substantial increase is projected to take place during the mature monsoon (JAS) phase, where the highlands in the western parts of the country will be characterized by positive changes estimated about 15% and 20% under RCP4.5 and RCP8.5 scenarios, respectively. Also, an increase up to 50–60% with respect to the mean value of the reference period (1976–2005) of the extreme precipitation intensity will occurred over the entire country and under the RCP8.5 scenario. Meanwhile, an increasing dry spell length (CDD) about 30% and 20% is projected during the pre-monsoon (AMJ) in the country, under RCP8.5 and RCP4.5 scenarios, while other seasons (JAS and OND) experience a decrease. Furthermore, these features are associated with a strong variability of the different indices with the magnitudes of fluctuation greater in future climate in the whole country as well as in the climatic areas. For SDII, greater magnitude of fluctuation reaching more than 20% is observed especially in OND, whereas an increasing tendency is predominant in JAS. R95PTOT therefore exhibits positive anomalies during the three stages of the WAM, and AMJ and JAS show an increasing tendency starting in 2060 and 2020, respectively. The amplitude of the fluctuation can reach about 30% in AMJ and between 30% and 60% in JAS with discernable differences between RCP4.5 and RCP8.5 scenarios. However, no increasing tendency is noticed in OND. Consequently, CDD presents a stronger variability, larger amplitudes, and a tendency towards increasing dry spell length during AMJ, whereas JAS and OND show quite similar amplitude associated with a tendency towards a decreasing dry spell length. In addition, when assessing the projected changes in the different indices, one can notice that the most prominent feature in SDII is the projected increase of the intensity for both the near-future and the far-future periods and under both RCP4.5 and RCP8.5 scenarios during JAS, as a robust result. Although the positive projected changes in all seasons, future periods, and forcing scenarios for R95PTOT are substantially robust in all JAS seasons under both scenarios. For the dry spell length index (CDD), considerable uncertainties prevail during AMJ and JAS seasons, but these changes are robust only during OND. Finally, it is thus clear that in general, Côte d'Ivoire as most part of the world is subject to an increased intensity of precipitation events under future climates, suggesting an amplification of extreme precipitation events. This considerably impacts changes in dry spell length. The high increase in the extreme precipitation intensity associated to an extension of dry spell length increases the risk of the occurrence of natural disasters such are floods and droughts. This can substantially impact agricultural production, particularly cocoa and coffee for which Côte d'Ivoire is the first and the third world's producer, respectively. In addition, in the southwestern and eastern regions where the precipitation indices (CDD, SDII, R95PTOT) determine the water availability, cocoa and coffee plantations could be differently affected. For example, the southwestern areas could be at risk of flood while the eastern regions would face drought episodes, thus altering the socioeconomic stability. It is worth noting that important changes in the extremes in Côte d'Ivoire are related to high-level radiative forcing. This should encourage decision-makers to implement policies for mitigating the greenhouse gas effects to minimize the drawbacks of climate change.

Acknowledgments The authors thank the "Programme d'Appui Stratégique à la Recherche Scientifique en Côte d'Ivoire" (PASRES), the Geophysical Station of LAMTO, the Centre for Science & Technology of the Non-Aligned and Other Developing Countries (NAM S&T Centre) through the Research Training Fellowship for Developing Country Scientists (RTF-DCS), the "Centre d'Excellence African en Changement Climatique, la Biodiversité et l'Agriculture Durable" (CEA-CCBAD), and the West African Science Service Center on Climate Change and Adapted Land use (WASCAL) Competence Centre (Ouagadougou) for their technical and financial supports. They thank also Dr. Chabi Adéyèmi for his help. Finally, the authors thank the anonymous reviewers for their contribution to improving the quality of the paper.

References

Abdellatif M, Atherton W, Alkhaddar R (2012) Climate change impacts on the extreme rainfall for selected sites in North Western England. Open J Modern Hydrol 2(p):49–58

Akinsanola A, Zhou W (2018) Projections of West African summer monsoon rainfall extremes from two CORDEX models. Clim Dyn:12. https://doi.org/10.1007/s00382-018-4238-8

Alexander LV et al (2006) Global observed changes in daily climate extremes of temperature and precipitation. J Geophys Res-Atmos 111:1–22. https://doi.org/10.1029/2005JD006290

Badsha MAH et al. (2016) Analysis of the trends in temperature and precipitation variables for Sylhet City of Bangladesh using Rclimdex toolkit, Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development (ICCESD), p. 7 pages

Balliet R et al (2016) Évolution Des Extrêmes Pluviométriques Dans La Région Du Gôh (Centre-Ouest De La Côte d'Ivoire). Eur Sci J 12: 74–87. https://doi.org/10.19044/esj.2016.v12n23p74

Beniston M et al (2007) Future extreme events in European climate: an exploration of regional climate model projections. Clim Chang 81: 71–95. https://doi.org/10.1007/s10584-006-9226-z

Boko ANN et al (2016) Croyance locales et stratégies d'aptation aux variations climatiques à Korhogo (Côte d'Ivoire). Tropicultura 34: 40–46

Camara M et al (2013) Analyse de la pluie simulée par les modèles climatiques régionaux de CORDEX en Afrique de l'Ouest. Secheresse 24:14–28. https://doi.org/10.1684/sec.2013.0375

Centre for Climate Change Research (2017) 'Climate Change over INDIA: An Interim Report', ESSO-Indian Institute of Tropical Meteorology, Ministry of Earth Sciences, Govt. of India, p. 38 pages

Decremer D et al (2014) Which significance test performs the best in climate simulations? Tellus A: Dyn Meteorol Oceanogr 66:1–14. https://doi.org/10.3402/tellusa.v66.23139

Diallo I et al (2012) Multimodel GCM-RCM ensemble-based projections of temperature and precipitation over West Africa for the early 21st century. Int J Geophys 2012:19. https://doi.org/10.1155/2012/972896

Diallo I et al (2016) Projected changes of summer monsoon extremes and hydroclimatic regimes over West Africa for the twenty-first century. Clim Dyn. Springer Berlin Heidelberg 47:3931–3954. https://doi.org/10.1007/s00382-016-3052-4

Diawara A et al. (2014) Climate variability in the Sudano-Guinean transition area and its impact on vegetation: the case of the Lamto region in Côte d'Ivoire, Advances in Meteorology, 2014, p. 11 pages

Dibi K, Mian (2016) Analyse Agroclimatique de la Zone Cacaoyère en Cote d'Ivoire. Revue de Géographie de l'Université Ouaga I Pr Joseph KI-ZERBO 2(p):45–68

Diedhiou A et al (2018) Changes in climate extremes over West and Central Africa at 1.5°C and 2°C global warming. Environ Res Lett 13:11

Donat MG et al (2013) Updated analyses of temperature and precipitation extreme indices since the beginning of the twentieth century: the HadEX2 dataset. J Geophys Res-Atmos 118(p):2098–2118. https://doi.org/10.1002/jgrd.50150

Druyan LM et al (2010) The WAMME regional model intercomparison study. Clim Dyn 35(1):175–192. https://doi.org/10.1007/s00382-009-0676-7

FAO (2009) FAO's role in the Burkina Faso Flash Appeal 2009, Food and Agriculture Organization of the United Nations (FAO)

Fotso-Nguemo T., Diallo, I., Diakhaté M., Vondou, D., Mbaye, M., Haensler, A., Gaye, A., Tchawoua, C. (2019) 'Projected changes in the seasonal cycle of extreme rainfall events from CORDEX simulations over Central Africa', Climatic Change, p. 19. https://doi.org/10.1007/s10584-019-02492-9

Frich P et al (2002) Observed coherent changes in climatic extremes during the second half of the twentieth century. Clim Res 19(3): 193–212. https://doi.org/10.3354/cr019193

Gbobaniyi E et al (2013) Climatology, annual cycle and interannual variability of precipitation and temperature in CORDEX simulations over West Africa. Int J Climatol 34(p):2241–2257. https://doi.org/10.1002/joc.3834

Gibba, P., Sylla, M. B., Okogbue, E. C., Gaye, A. T., Nikiema, M., Kebe, I. (2018) 'State-of-the-art climate modeling of extreme precipitation over Africa : analysis of CORDEX added-value over CMIP5', Theoretical and Applied Climatology, p. 17 pages

Giorgi F, Gutowski WJ (2015) Regional dynamical downscaling and the CORDEX initiative. Annu Rev Environ Resour 40:24. https://doi.org/10.1146/annurev-environ-102014-021217

Goula A et al (2007) Estimation des pluies exceptionnelles journalières en zone tropicale: cas de la Côte d'Ivoire par comparaison des lois lognormale et de Gumbel Estimation des pluies exceptionnelles journalières en zone tropicale: cas de la Côte d' Ivoire par comparai. Hydrol Sci J 52(p):49–67. https://doi.org/10.1623/hysj.52.1.49

Goula ABT, Gneneyougo Soro E, Kouassi W, Srohourou B (2012) Tendances et ruptures au niveau des pluies journalières extrêmes en Côte d'Ivoire (Afrique de l'Ouest). Hydrol Sci J 57(6):1067–1080. https://doi.org/10.1080/02626667.2012.692880

IPCC (2012) Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp

IPCC (2013) Climate change 2013: the physical science basis. Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change, Intergovernmental Panel on Climate Change, Working Group I Contribution to the IPCC Fifth Assessment Report (AR5) (Cambridge Univ Press, New York), p. 1535. doi: https://doi.org/10.1029/2000JD000115

Klein Tank AMG, Zwiers FW, Zhang X (2009) 'Guidelines on Analysis of extremes in a changing climate in support of informed decisions for adaptation', World Meteorological Organization, p. 56 pages

Klutse NAB et al (2015) Daily characteristics of West African summer monsoon precipitation in CORDEX simulations. Theor Appl Climatol 123(p):369–386. https://doi.org/10.1007/s00704-014-1352-3

Klutse NAB et al (2018) Potential impact of 1.5 °C and 2 °C global warming on consecutive dry and wet days over West Africa. Environ Res Lett 13:7. https://doi.org/10.1088/1748-9326/aab37b

Konate L et al (2016) Caractérisation des pluies journalières intenses et récurrences des inondations: apport des totaux glissants trois (3) jours à la détermination d' une quantité seuil d' inondation (District d'Abidjan au Sud-Est de la Côte d' Ivoire). Int J Innov Appl Stud 17(p):990–1003

Kouadio YK, Ochou DA, Servain J (2003) Tropical Atlantic and rainfall variability in Côte d'Ivoire. Geophys Res Lett 30:4. https://doi.org/10.1029/2002GL015290

Kouadio KY et al (2007) Etude de la prédictibilité de la pluviométrie en Côte d'Ivoire durant la période de Juillet à Septembre. Rev Ivoir Sci Technol 10:117–134

Kouadio KY et al (2011) Rainfall variability patterns in West Africa: case of Côte d' Ivoire and Ghana. J Environ Sci Eng 5(p):1229–1238

Kouassi AM et al (2010) Analyse de la variabilité climatique et de ses influences sur les régimes pluviométriques saisonniers en Afrique de l'Ouest: cas du bassin versant du N'zi (Bandama) en Côte d'Ivoire, Cybergeo. Eur J Geogr [En ligne], Environ Nat Paysage 513:31. https://doi.org/10.4000/cybergeo.23388

Menang KP (2017) Climate extreme indices derived from observed daily precipitation and temperature data over Cameroon: the need for further assessments. Meteorol Appl 24(p):167–171. https://doi.org/10.1002/met.1628

Nikiema PM et al (2016) Multi-model CMIP5 and CORDEX simulations of historical summer temperature and precipitation variabilities over West Africa. Int J Climatol 37:2438–2450. https://doi.org/10.1002/joc.4856

Nikulin G et al (2012) Precipitation climatology in an ensemble of CORDEX-Africa regional climate simulations. J Clim 25:6057–6078. https://doi.org/10.1175/JCLI-D-11-00375.1

Odulami RC, Abiodun BJ, Ajayi AE (2018) Modelling the potential impacts of afforestation on extreme precipitation over West Africa. Clim Dyn. Springer Berlin Heidelberg, p. 16 pages. https://doi.org/10.1007/s00382-018-4248-6

Pinto I et al (2016) Evaluation and projections of extreme precipitation over southern Africa from two CORDEX models. Clim Chang 135:14. https://doi.org/10.1007/s10584-015-1573-1

Riquet C, Musiime D, Marita C (2017) National Survey and segmentation of smallholder households in Côte d'Ivoire: understanding their demand for financial, agricultural, and digital solutions, Working Paper, CGAP, p. 110 pages

Sarr AB, Camara M, Diba I (2015) Spatial distribution of Cordex regional climate models biases over West Africa. Int J Geosci 6(p):1018–1031

Schär C et al (2016) Percentile indices for assessing changes in heavy precipitation events. Clim Chang 137:201–216. https://doi.org/10.1007/s10584-016-1669-2

Sillmann J, Roeckner E (2008) Indices for extreme events in projections of anthropogenic climate change. Clim Chang 86:83–104. https://doi.org/10.1007/s10584-007-9308-6

Sillmann J, Kharin VV, Zhang X et al (2013a) Climate extremes indices in the CMIP5 multimodel ensemble: part 1. Model evaluation in the present climate. J Geophys Res-Atmos 118:1716–1733. https://doi.org/10.1002/jgrd.50203

Sillmann J, Kharin VV, Zwiers FW et al (2013b) Climate extremes indices in the CMIP5 multimodel ensemble: part 2. Future climate projections. J Geophys Res-Atmos 118:2473–2493. https://doi.org/10.1002/jgrd.50188

Singh D, Gupta RD, Jain SK (2015) Study of daily extreme temperature indices over Sutlej Basin, N-W Himalayan region, India. Global Nest J 17(p):301–311

Sonkoué D et al (2018) Evaluation and projected changes in daily rainfall characteristics over Central Africa based on a multi-model ensemble mean of CMIP5 simulations. Theor Appl Climatol 137(p):2167–2186

Sylla MB, Gaye AT, Jenkins GS (2012) On the fine-scale topography regulating changes in atmospheric hydrological cycle and extreme rainfall over West Africa in a regional climate model projections. Int J Geophys 2012:15. https://doi.org/10.1155/2012/981649

Sylla MB et al (2015) Projected changes in the annual cycle of high-intensity precipitation events over West Africa for the late twenty-first century. J Clim 28:6475–6488. https://doi.org/10.1175/JCLI-D-14-00854.1

Sylla MB, Faye A, Giorgi F, Diedhiou A, Kunstmann H (2018) Projected heat stress under 1.5 °C and 2 °C global warming scenarios creates unprecedented discomfort for humans in West Africa. Earth's Future 6:16. https://doi.org/10.1029/2018EF000873

Tall M et al (2016) Projected impact of climate change in the hydroclimatology of Senegal with a focus over the Lake of Guiers for the twenty-first century. Theor Appl Climatol 129(p):655–665. https://doi.org/10.1007/s00704-016-1805-y

Tebaldi C et al (2006) Going to the extremes: an intercomparison of model-simulated historical and future changes in extreme events. Clim Chang 79(p):185–211. https://doi.org/10.1007/s10584-006-9051-4

Tommy K (2009) Comparaison Des Sécheresses Estivales De 1976 et 2003 en Europe Occidentale à l' aide d' Indices Climatiques. BSGLg 53(p):75–86

Tschakert P et al (2010) Floods in the Sahel: an analysis of anomalies, memory, and anticipatory learning. Clim Chang 103(p):471–502. https://doi.org/10.1007/s10584-009-9776-y

Yoroba F et al (2019) Evaluation of rainfall and temperature conditions for a perennial crop in tropical wetland: a case study of cocoa in Côte d'Ivoire. Adv Meteorol 2019:10