

# Effectiveness of CORDEX-AFRICA Multi-Model Ensemble in Replicating Temperature and Associated Extremes over Côte d'Ivoire

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## Abstract

Developing reliable adaptation and mitigation strategies to combat climate change is necessary at regional and local scales. The present study analyses the ability of the multi-model ensemble (MME) composed of fourteen (14) CORDEX-Africa simulations to capture characteristics of the mean temperature for the present day (1979-2005) and associated extremes over Côte d'Ivoire. For this end, the analysis uses the mean variables of the temperature (*i.e.*, minimum temperature (TMIN), mean temperature (TMEAN) and maximum temperature (TMAX)) as well as associated extremes such as intra-period extreme temperature range (ETR), warm spell duration index (HWFI) and warm days index (TX90P) during January-February-March (JFM), April-May-June (AMJ), July-August-September (JAS) and October-November-December (OND) seasons. The results indicate that mean temperature variables (TMIN, TMEAN and TMAX) are underestimated by CORDEX MME in general, except TMEAN in the centre of Côte d'Ivoire. On the other hand, extreme temperature indices are overestimated over Côte d'Ivoire, except ETR in JAS with an underestimation of about 2°C and TX90P during JAS in the southern part of the country in JFM, AMJ and OND with an underestimation varying between 1% to 4%. In addition, CORDEX MME and observational datasets (CPC and NCEP) have a significant correlation in simulating temperature variables (TMIN, TMEAN, TMIN), while this correlation is not significant in general for extreme temperature, except ETR and HWFI. Furthermore, extreme temperatures (TX90P and HWFI) are characterized by more important

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interannual variability in the observations CPC and NCEP for ETR. Moreover, mean temperature variables (TMIN, TMEAN, TMAX) show slight interannual variability with respect to the observations CPC and NCEP, which are characterized by the most variability. Overall, CORDEX MME outperforms the seasonal and spatial variability of the temperature and associated extremes over Côte d'Ivoire, although some biases in representing their magnitudes. Thus, the results of the present study will help take appropriate adaptation and mitigation strategies against heatwaves and extreme temperature advent over Côte d'Ivoire as these climate extremes are projected to increase over the country.

### Keywords

Extreme Temperature Indices, Regional Climate Models Evaluation, CORDEX, Côte d'Ivoire

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## 1. Introduction

Africa is one of the most vulnerable regions to climate variability and change [1]. For this reason, it has received increasing attention from climate scientists in order to formulate some adaptation and mitigation policies to combat climate change drawbacks. To address this challenge, climate scientists are encouraged to use numerical tools like climate models, which will enable them to get realistic information on the climate of this region at regional and local scales. In the same vein, previous studies [2]-[4] revealed the incapability of Global Climate Models (GCMs) to simulate key features of the climate that could help resolve and understand some phenomena responsible for global warming and climate change locally. Consequently, these studies concluded that the use of Regional Climate Models (RCMs) could efficiently contribute to resolving this issue. RCMs are able to produce fine-scale and improved regional climate information [5]. Moreover, RCMs offer interesting frameworks for climate impact assessments which require high computing power and appropriate knowledge. Therefore, the RCMs are appropriate tools to investigate the West African climate, which is characterized by complex atmospheric dynamics and growing anthropogenic pressures, which, combined with climate change and variability, lead to many environmental impacts [6]. Several studies have shown the capability of RCMs to simulate surface air temperature over West Africa using CORDEX simulations [7] [8]. For example, Gbobayini *et al.* [7] showed the capability of the CORDEX simulations to reproduce the mean annual cycle of the temperature over West Africa, while Kim *et al.* [8] highlighted the high fidelity of the CORDEX simulations in representing mean and maximum temperature than the minimum. Considering the results of the different previous works, RCMs showed a good performance in simulating the mean temperature over West Africa, especially in the CORDEX framework [7] [8]. Nevertheless, some studies focused on the projected changes in temperature

and associated extremes revealed an increase in their frequency and intensity which will cause important environmental and health damage in West Africa [9]-[13]. For examples, Ringard *et al.* [10] underlined that trends in nocturnal and diurnal temperatures as well as heatwaves will be intense and frequent in the second half of the 20th century in West Africa. Moreover, Sylla *et al.* [12] showed that West Africa sub-region will be vulnerable to heat stress and human discomfort under 1.5°C and 2°C global Warming, while Yapo *et al.* [13] revealed a projected increase (about 10 and 20 days) in heatwave days for both the near (2031-2060) and far (2071-2100) future periods over the whole West African region under RCP4.5 and RCP8.5 emissions scenarios, respectively.

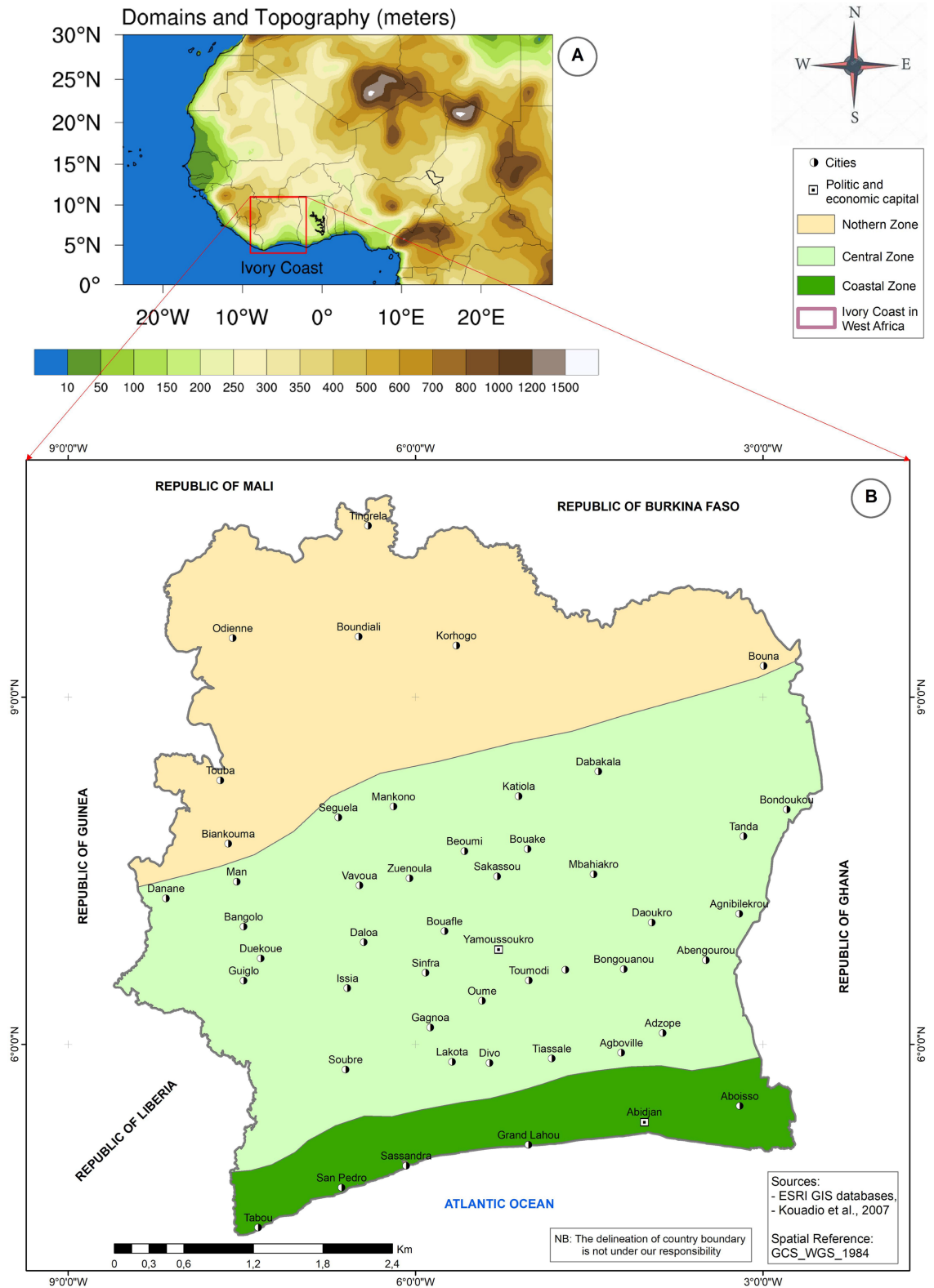
Most of these studies were discussed and focused on the West Africa sub-region using RCMs to investigate changes in temperature and associated extremes by evaluating the capability of the RCMs in simulating them. However, few studies were conducted over a particular domain, at the scale of a country (*i.e.*, Côte d'Ivoire) by validating the RCMs data used. Therefore, Yapo *et al.* [14] analyzed the projected changes in extreme temperature over Côte d'Ivoire for the twenty-first century using CORDEX simulations. Their results showed an increase in the warm extreme indices such as the warm spell days index (HWFI), very warm days frequency index (TX90P), and the warm nights frequency index (TN90P) over the entire country, under RCP4.5 and RCP8.5 scenarios, without discussing the strength of the different CORDEX simulations used. Therefore, the present study aims to evaluate the capability of the CORDEX multi-model ensemble (MME) simulations in replicating temperature and associated extremes at a local scale, particularly over Côte d'Ivoire during the 1979-2005 period. Section 2 of the paper describes the material and methods. Then, Section 3 presents the results and discussion. Finally, the summary of the main findings and the conclusion are given in Section 4.

## 2. Materials and Methods

### 2.1. Study Area

The study area is Côte d'Ivoire, a West African country geographically located between latitudes 4° and 11° North, and longitudes 8° and 2° West with a surface area of about 322,462 km<sup>2</sup>. For Kouadio *et al.* [15], the country is characterized by three types of climate with different rainfall variability (Figure 1). The Littoral climate area (along the Gulf of Guinea) is mainly dominated by abundant precipitation with two rainy seasons with a major peak in June (up to 500 mm) and a second maximum less pronounced (120 mm) in October [16]. The Centre climate zone is also characterized by two rainy seasons in June and September, while the North climate presents a unique rainy season in August. The country has been subject to climate change drawbacks in recent decades. For example, according to the National Meteorological Agency, the country faced a significant warming of about 0.5°C during the period 1962-2012 compared to the 1961-1990 normal period (reference period), while the 2001-2010 period was particularly hotter (0.8°C). In addition, 2010 was considered the hottest year of this period (2001-

2010) with a warming of about 1.2°C [14] [17].



**Figure 1.** The study domain: (A) Location of Côte d'Ivoire in West Africa; (B) The different climatic zones of Côte d'Ivoire adapted from [15] [16] [18].

## 2.2. Data

Two types of data were used in this study. First, the simulated daily minimum and maximum temperature derived from an ensemble of fourteen Coordinated Regional climate Downscaling Experiment (CORDEX-Africa) simulations [19]. The CORDEX simulations are available on the Earth System Grid Federation (ESGF) website (<https://esg-dn1.nsc.liu.se/projects/esgf-liu/>) at a resolution of  $0.44^\circ$  (about 50 km) and span the historical period 1950-2005 (Table 1). These simulations are used to provide climatic analysis and climate change impact studies using several parameters (*i.e.*, temperature, rainfall, wind, etc.). They are also available at daily time steps which enable their use to climate extreme analysis. Then, the observational daily mean temperature from the reanalysis of the National Center for Environmental Prediction (NCEP, [20]) as well as the daily minimum and maximum temperature from the Climate Prediction Center (CPC, [21]). The observational data (CPC and NCEP) are used to assess the ability of the CORDEX-Africa simulations to reproduce the temperature fields as well as the extreme temperature. These observational data have  $0.5^\circ$  (50 km) resolution and cover the period 1979-present (Table 2). Therefore, the analysis in this paper focuses on the common period of the different dataset, 1979-2005.

**Table 1.** Details of the different CORDEX-Africa simulations.

MCR	MCG
SMHI-RCA4	CanESM2
	CNRM-CM5
	ES-EARTH-r12
	IPSL-CM5A-MR
CLMcom-CCLM4-8-17	MPI-ESM-LR
	ES-EARTH-r12
	HadGEM2-ES
	CNRM-CM5
DMI-HIRHAM5	EC-EARTH-r3
KNMI-RACMO22E	EC-EARTH-r1
CCCma-CanRCM4	CanESM2
MPI-CSC-REMO2009	MPI-ESM-LR
CNRM-ALADIN52	CNRM-CM5
BCCR-WRF331	NorESM1-M

**Table 2.** Summary of the datasets used in the study (periods and horizontal resolutions).

	Horizontal resolution	Variables	Period (Temporal coverage)
CORDEX-Africa	$0.44^\circ$ (~50 km)	Minimum and maximum temperature	1950-2005
CPC	$0.5^\circ$ (~50 km)		1979-present
NCEP		Mean temperature	

### 2.3. Methods

In addition to the mean, maximum and minimum temperature, we selected four extreme temperature-based indices defined by the Experts Team of Climate Change Detection and Indices (ETCCDI, [22]) and [23] suitable for the purposes of the study (Table 3). The indices include:

- Warm spells duration index (HWFI) which counts when at least six (6) consecutive days with daily maximum temperature is greater than 90th percentile ( $T_{Gi} > T_{Gn90}$ ).
- Intra period extreme temperature range (ETR) is the difference between the maximum of the maximum temperature and the minimum of the minimum temperature ( $ETR = TX_{xi} - TN_{Ni}$ ).
- Warm days (TX90P) is the percentage of days when daily maximum temperature is greater than 90th percentile ( $TX_i > T_{Xn90}$ ).
- Warm nights (TN90P) is the percentage of days when daily minimum temperature is greater than 90th percentile ( $TN_i > T_{Nn90}$ ).

**Table 3.** Summary of the extreme temperature indices used in the study [22] [23].

Index (Definition)	Expression	Unit
HWFI	$T_{Gi} > T_{Gn90}$	Days
ETR	$ETR = TX_{xi} - TN_{Ni}$	°C
TX90P	$TX_i > T_{Xn90}$	%
TN90P	$TN_i > T_{Nn90}$	%

The computation of the above mentioned extreme climate temperature indices is made using Climate Data Operators software (CDO version 1.7.0; [24]) for each simulation before applying the bilinear interpolation method to remap all indices derived from the observations (CPC, and NCEP) and models into a common grid (50 km × 50 km). Interpolating all the datasets into a common grid helps comparing the spatial distribution of temperature and associated extremes indices derived from observations and simulations (CORDEX) and to get existing biases between them [25]-[29]. In addition, we applied the multi-model ensemble (MME) approach to the different indices calculated from the individual simulations of CORDEX-Africa using Equation (1). This approach consists of the use of an ensemble of simulations instead of ones to reduce uncertainties between them. Biases were estimated as percentages (%) or absolute values, using Equations (2) and (3).

$$MME = \frac{1}{N} \sum_{i=1}^N \text{SIMULATION}_i \quad (1)$$

where  $\text{SIMULATION}_i$  and  $N$  represent the simulated variables (indices) derived from the different CORDEX-Africa simulations and the number of simulations, respectively.

$$\text{bias (absolute)} = \text{MME} - \text{observation} \quad (2)$$

$$\text{bias (\%)} = \frac{\text{MME} - \text{observation}}{\text{observation}} \times 100 \quad (3)$$

where MME denotes the value of the variable (index) derived from the multi-model ensemble (CORDEX) and observation indicating the value of the variable derived from the observational data (CPC and NCEP).

In order to best evaluate the performance of the CORDEX MME to simulate temperature variables and associated extremes, we applied the correlation coefficient method. Correlation coefficient methods assess the strength or the weakness of the relationship existing between two variables. This method also refers to the degree to which a pair of variables are linearly relating, thus indicating the significance of the correlation. In this study, we estimated the correlation between the observational and simulated variables and evaluated its significance. Indeed, correlation is statistically significant if the p-value is less than 0.05 (95% significance level using t test).

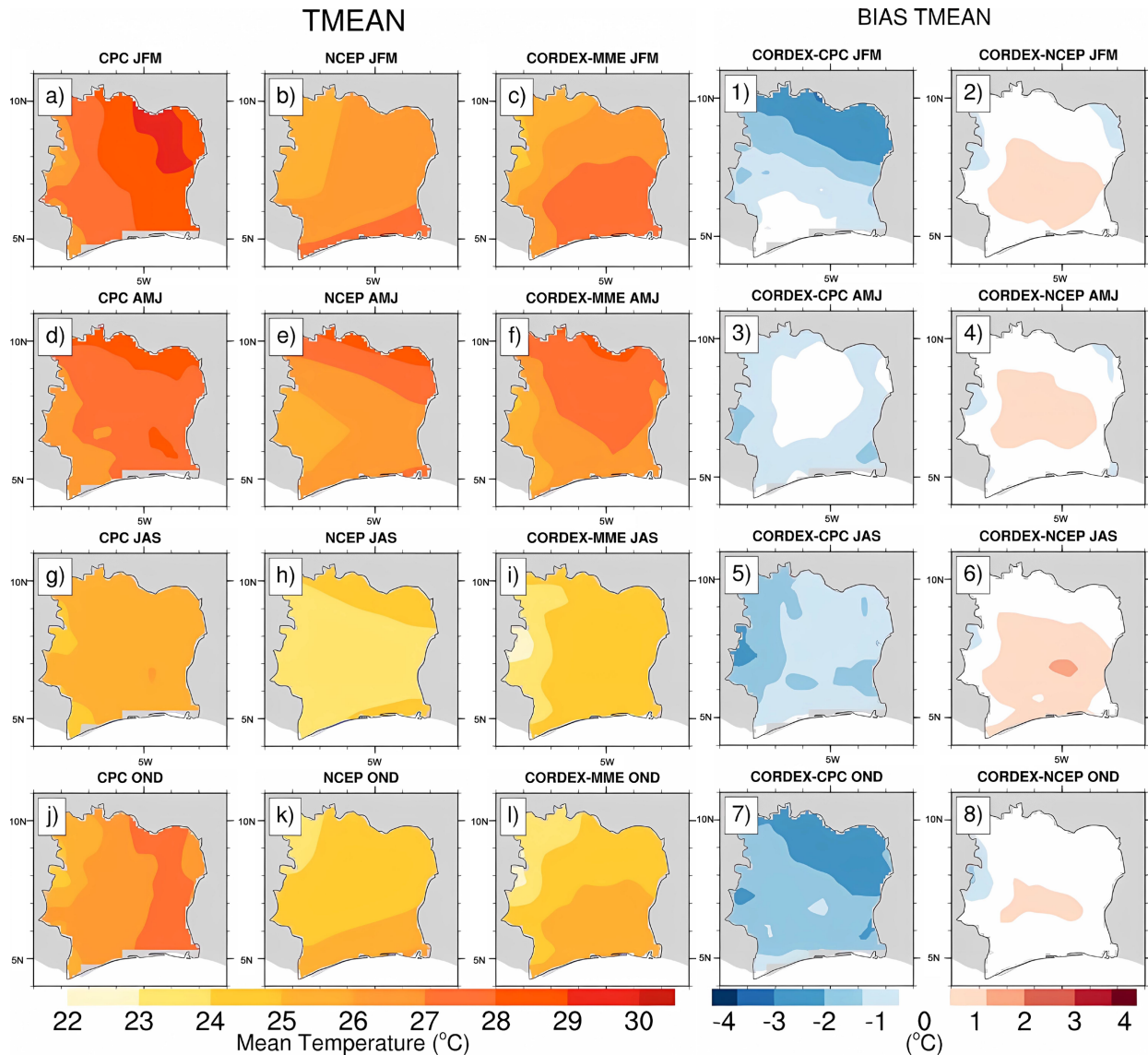
### 3. Results and Discussion

#### 3.1. Spatial Variability and Biases

##### 1) Daily Mean Temperature (TMEAN)

**Figure 2** shows the seasonal and spatial variability **Figures 2(a)-(l)** of the mean temperature (TMEAN) for CPC, NCEP and the CORDEX MME as well as the associated biases **Figures 2(1)-(8)** over Côte d'Ivoire during the period 1983-2005. These spatial variabilities present different gradients depending to the season (JFM, AMJ, JAS, OND). While JFM and OND in general, experience a north-south gradient of mean temperature with maxima about 26°C and 30°C located in the southern part of Côte d'Ivoire in NCEP and CORDEX MME, AMJ and JAS exhibit south-north gradient with maxima about 30°C and 24°C located in the northern part of the country as shown by CPC, NCEP and CORDEX MME. In general, the spatial variability of TMEAN is well represented by the CORDEX MME (**Figures 2(a)-(l)**) with some biases (**Figures 2(1)-(8)**). However, TMEAN is overestimated about 1°C, located in the center of Côte d'Ivoire when compared to reanalysis NCEP. This warm bias located in the center of the country is observed during JFM, AMJ and OND and extends toward the coastal area in JAS. However, MME shows cold bias in comparison to CPC over Côte d'Ivoire. This cold bias shows maxima about 2°C, located in the north during JFM and OND seasons. These results are in agreement with the findings of Gbobayini *et al.* [7] and Russo *et al.* [28] who showed cold bias about 2°C of the temperature prevailing along the Gulf of Guinea by regional climate models (CORDEX, RegCM, HadRM3P, etc.). Moreover, the fact that CORDEX MME underestimates mean temperature (TMEAN) in comparison to CPC observation in the one hand and overestimates TMEAN in comparison to NCEP in the other hand, indicates that uncertainties exist between observation products. Furthermore, uncertainties in

observation products were highlighted by Diaconescu *et al.* [29] in their studies by evaluating daily precipitation statistics and monsoon onset/retreat over western Sahel in multiple datasets.

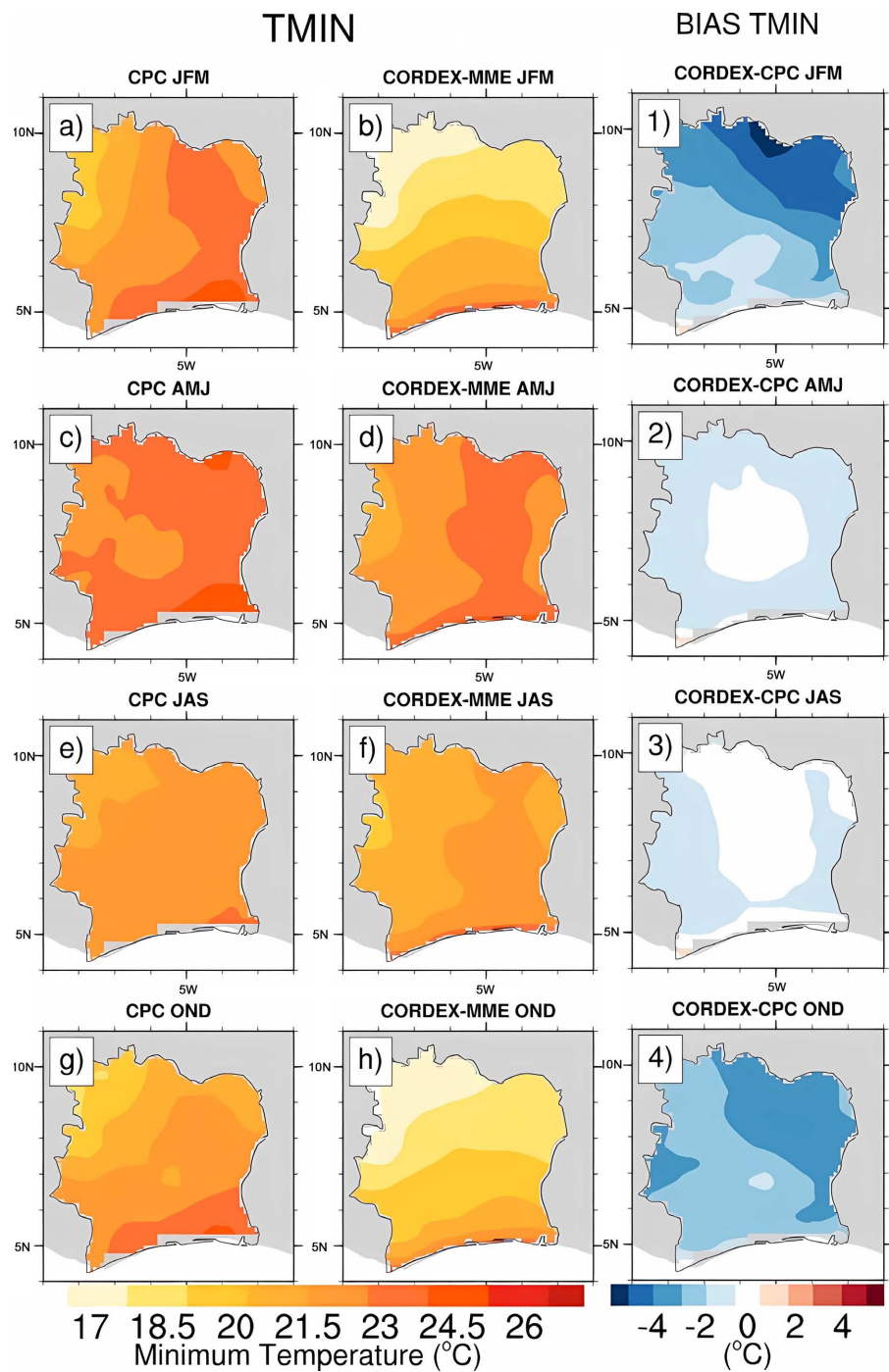


**Figure 2.** Spatial variability of seasonal (JFM, AMJ, JAS, OND) mean temperature (TMEAN) (a-l) and biases (1-8) relative to the observations (CPC and NCEP) during the period 1983-2005 over Côte d'Ivoire.

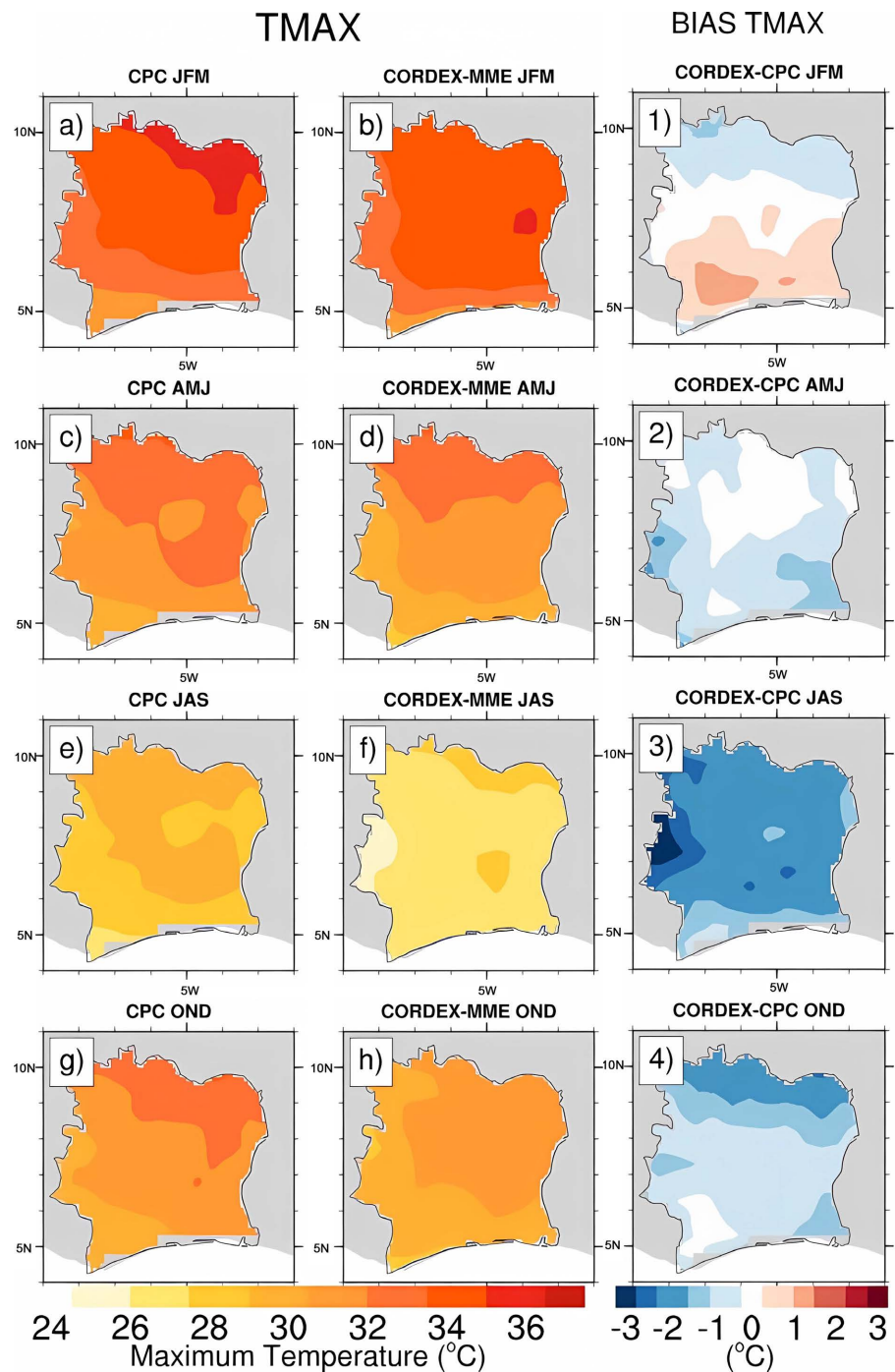
## 2) Daily Minimum Temperature (TMIN)

Daily minimum temperature shows south-north gradient variability during JFM and OND and east-west gradient during AMJ and JAS seasons as simulated by the CORDEX MME and the observation CPC in Côte d'Ivoire (**Figures 3(a)-(h)**). Maxima about 26°C is mainly located in the coastal areas during JFM and OND and in the eastern during AMJ and JAS. This spatial distribution of the minimum temperature (TMIN) is the same in the observation CPC as well as in the CORDEX MME but with some biases. CORDEX MME presents in general a cold

bias in representing TMIN over Côte d'Ivoire as shown in **Figure 3(1)-(4)**. This cold bias presents maxima about 3°C located in the north-eastern part of the country during JFM and OND seasons. During AMJ and JAS seasons, the magnitude of TMIN is well represented by the CORDEX MME in the country center with no bias (0°C).



**Figure 3.** Spatial variability of seasonal (JFM, AMJ, JAS, OND) minimum temperature (TMIN) (a-h) and biases (1-4) relative to the observation (CPC) during the period 1983-2005 over Côte d'Ivoire.

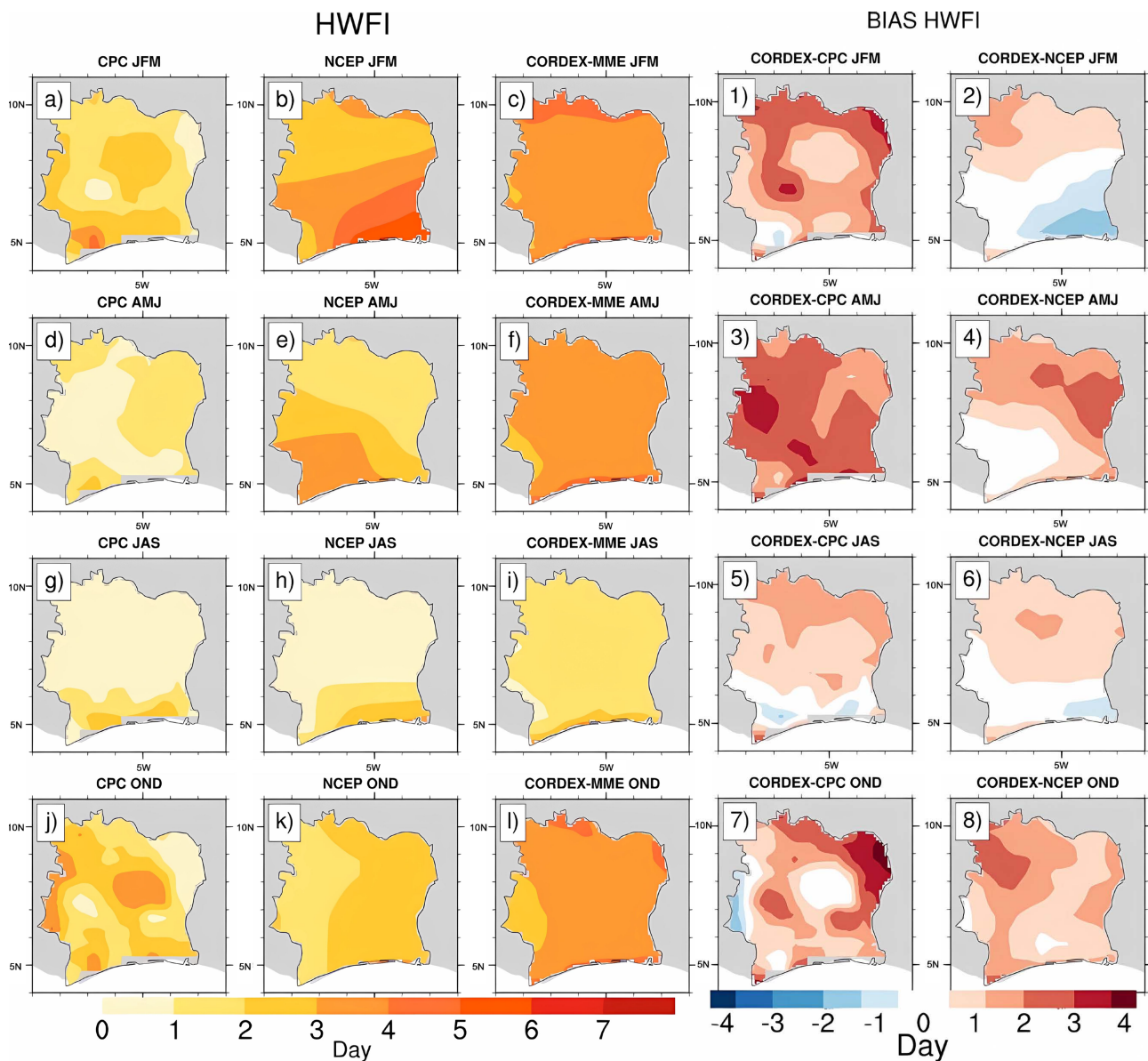


**Figure 4.** Spatial variability of seasonal (JFM, AMJ, JAS, OND) maximum temperature (TMAX) (a-h) and biases (1-4) relative to the observation (CPC) during the period 1983-2005 over Côte d'Ivoire.

### 3) Daily Maximum Temperature (TMAX)

During the period 1983-2005, the maximum temperature (TMAX) is characterized by a north-south gradient distribution in both observation CPC and CORDEX MME for the four seasons (JFM, AMJ, JAS, OND) over Côte d'Ivoire (**Figures 4(a)-(h)**). Maxima about 40°C and 32°C, are observed in the northern

part of the country in (JFM, AMJ, OND) and JAS seasons, respectively. This means that northern regions of Côte d'Ivoire experience hotter days compared to the southern areas. This situation could be explained by the transportation of the humidity flux of the ocean towards the coastal areas. Nevertheless, CORDEX MME shows in general a cold bias in representing the magnitude of the maximum temperature (TMAX) over Côte d'Ivoire as shown in **Figure 4(1)-(4)**. The seasons JFM, AMJ, JAS and OND are characterized by a cold bias with maxima reaching about 2°C in the north during OND and in the west in JAS, except a warm bias about 1°C, located in the southern region of the country during JFM season. Soil moisture scarcity in the northern regions of Côte d'Ivoire could explain the cold biases observed in the model ensemble as underlined by [30].



**Figure 5.** Spatial variability of seasonal (JFM, AMJ, JAS, OND) warm spells duration index (HWFI) (a-l) and biases (1-8) relative to the observations (CPC and NCEP) during the period 1983-2005 over Côte d'Ivoire.

#### 4) Warm Spells Duration Index (HWFI)

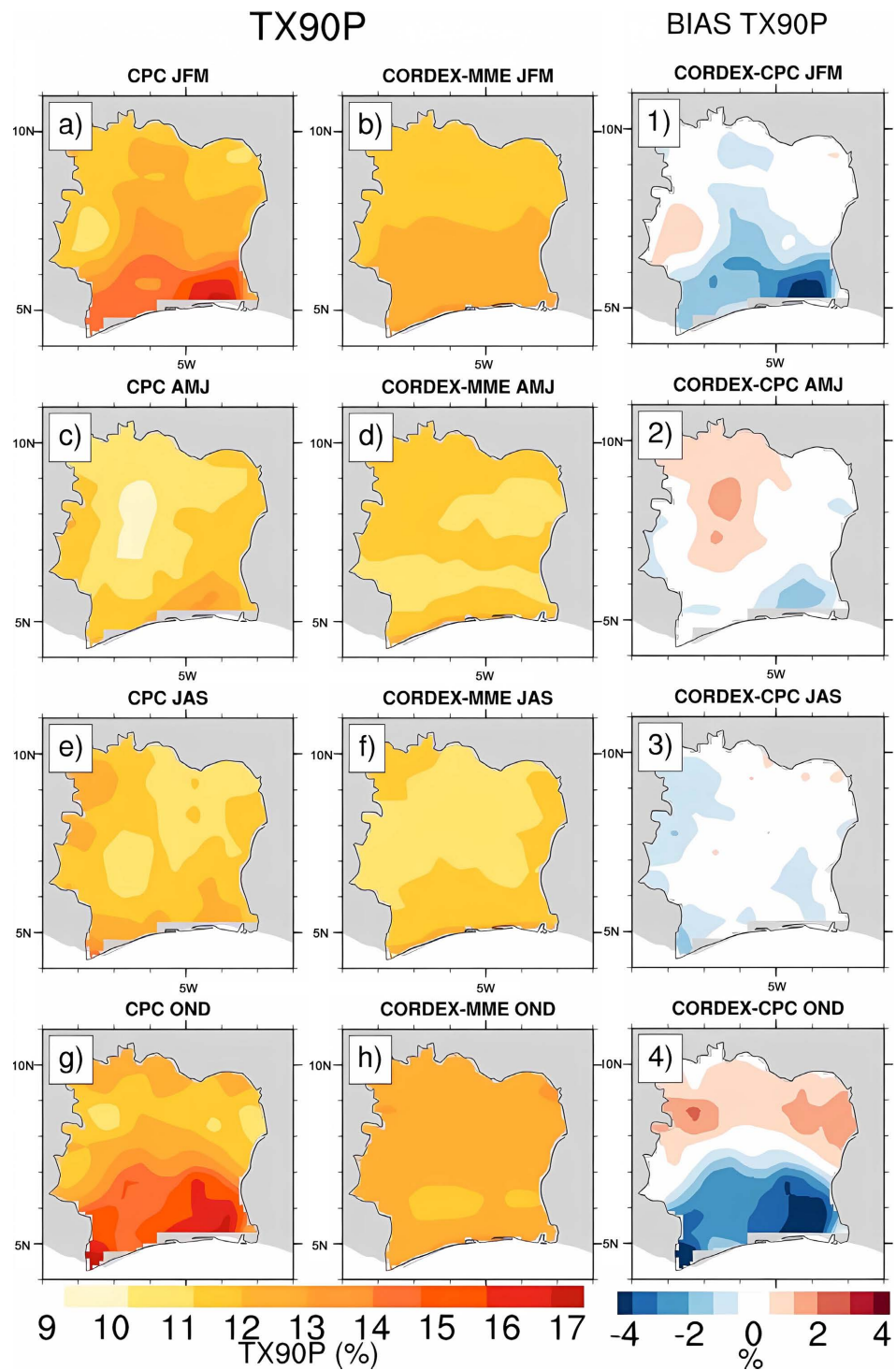
The spatial variability of the seasonal (JFM, AMJ, JAS and OND) warm spells duration index (HWFI) in the observations (CPC and NCEP) and the CORDEX MME are compared in **Figures 5(a)-(l)**. During JAS, HWFI presents the same spatial distribution in the three dataset (CPC, NCEP and CORDEX MME) with maxima about 4 days located in the coastal area of Côte d'Ivoire. During JFM, AMJ and OND seasons, the spatial distributions are different in the three dataset, but closer to the reanalysis NCEP. However, CORDEX MME generally overestimates the magnitude of the warm spells duration index in comparison to the observations CPC and NCEP over Côte d'Ivoire about three days during all the seasons (**Figures 5(1)-(8)**). In the south-eastern part of Côte d'Ivoire, CORDEX MME underestimates the magnitude of the HWFI about 2 days with respect to the reanalysis NCEP in JFM, while in the south-west in AMJ and in the coastal area in JAS, it outperforms its magnitude.

#### 5) Warm Days (TX90P)

**Figure 6** shows in the one hand the comparison of the spatial variability of the warm days percent (TX90P) over Côte d'Ivoire in the observation CPC and the CORDEX MME (**Figures 6(a)-(h)**). In the other hand, the biases of the CORDEX MME in replicating TX90P with respect to the CPC are also displayed (**Figures 6(1)-(4)**). TX90P presents a north-south gradient in the observation CPC where maxima are localized along the coastal area. This spatial distribution is well captured by the CORDEX MME, except during OND, where maxima are rather located in the north of the country. However, MME CORDEX presents some biases in replicating TX90P over Côte d'Ivoire. TX90P is underestimated about 4% in the south during JFM and OND and overestimated about 2% in the north during AMJ and OND, then in the west during JFM. Moreover, JAS is characterized by a slight underestimation (about 1%) of the CORDEX MME in the west, north-west, south-west and south-east of Côte d'Ivoire. In general, CORDEX MME outperforms the magnitude of TX90P in the centre of Côte d'Ivoire. The cold bias observed in the coastal area could be caused by the incapability of the CORDEX models to simulate the moisture flux from the ocean associated with evapotranspiration.

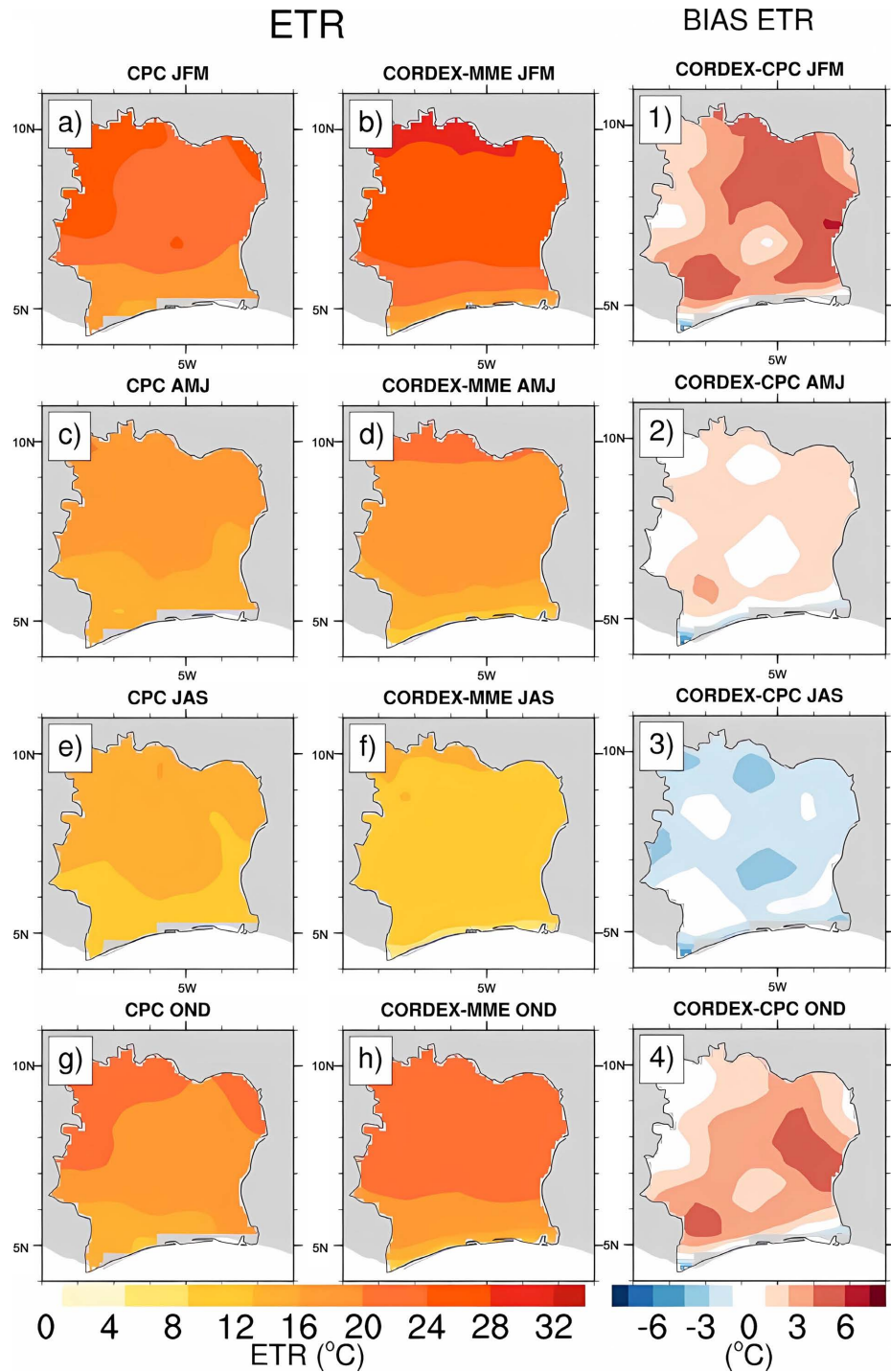
#### 6) Intra Period Extreme Temperature Range (ETR)

The spatial variability of the seasonal intra period extreme temperature range (ETR) in the observation CPC and the CORDEX MME during the four seasons (JFM, AMJ, JAS and OND) of the period 1983-2005 over Côte d'Ivoire is presented in **Figures 7(a)-(h)**. The biases of the CORDEX MME with respect to the observation CPC are also highlighted (**Figures 7(1)-(4)**). In both data; the observation CPC and the CORDEX MME, ETR exhibits a north-south gradient with maxima localized in the north of the country. In general, the amplitude of ETR is greater in JFM and OND than in AMJ and JAS in Côte d'Ivoire. In addition, the seasonal distributions show that ETR can increase and reach about 28°C and 23°C, in JFM and OND, respectively in the north, then decrease to reach about 12°C and 9°C in AMJ and JAS, respectively along the coastal area. The results



**Figure 6.** Spatial variability of seasonal (JFM, AMJ, JAS, OND) warm days (TX90P) (a-h) and biases (1-4) relative to the observation (CPC) during the period 1983-2005 over Côte d'Ivoire.

show a weak variability in the amplitude of temperature extreme along the coastal areas, compared to the northern areas, while important amplitude of extreme temperature occurs during JFM and OND in Côte d'Ivoire. This could be caused by a decrease in the soil humidity, mainly observed in dry seasons. These results



**Figure 7.** Spatial variability of seasonal (JFM, AMJ, JAS, OND) intra period extreme temperature range (ETR) (a-h) and biases (1-4) relative to the observation (CPC) during the period 1983-2005 over Côte d'Ivoire.

collaborate the findings of [31] in tropical regions. In addition, the ETR characteristic over Côte d'Ivoire is similar to that observed by [32] who suggested a northward increase from the equator reaching maxima ( $\sim 40^{\circ}\text{C}$ ) in northern regions of Africa [14]. Moreover, it's worth noting that the CORDEX MME

outperforms the seasonal and spatial variability of ETR over Côte d'Ivoire although some biases. Indeed, ETR is overestimated during JFM, AMJ and OND seasons with maxima reaching about 4°C in JFM and underestimated about 2°C in JAS (Figures 7(1)-(4)).

### 3.2. Quantitative Biases Estimation and Correlation

**Table 4** indicates the quantitative biases values of the CORDEX multi-models ensemble (MME) in replicating temperature variables (TMEAN, TMIN, TMAX) and temperature extremes (HWFI, TX90P, ETR) over Côte d'Ivoire with respect to the observations CPC and NCEP during the period 1983-2005. It's worth noting that Temperature variables are all underestimated by the CORDEX MME over Côte d'Ivoire, except the mean temperature (TMEAN) which is overestimated about 0.36°C with respect to reanalysis NCEP during JAS season. Nevertheless, temperature extremes are overestimated, except ETR in JAS and TX90P in JFM, JAS and OND which are underestimated. The CORDEX MME biases with respect to NCEP for TMEAN and HWFI are lower than CPC ones, this suggests that MME CORDEX simulates the mean temperature (TMEAN) and warm spells duration index (HWFI) closer to reanalysis NCEP. This could be explained by the fact that CORDEX simulations are forced by reanalysis data like ERA-Interim (ERAINT) as underlined by [33] and [23].

**Table 4.** Estimated quantitative biases of temperature variables (TMIN, TMEAN, TMAX) and associated extremes (HWFI, TX90P, ETR) over Côte d'Ivoire during JFM, AMJ, JAS and OND seasons.

Seasons and parameters	BIASES			
	JFM	AMJ	JAS	OND
TMEAN(°C) (CPC)	-1.64	-0.70	-1.22	-1.93
TMEAN (°C) (NCEP)	-0.08	-0.11	0.36	-0.11
TMIN(°C) (CPC)	-3.17	-0.89	-0.59	-2.73
TMAX(°C) (CPC)	-0.11	-0.52	-1.85	-1.13
HWFI (day) (CPC)	1.98	2.33	1.04	1.82
HWFI (day) (NCEP)	0.45	1.47	0.70	1.54
TX90P (%) (CPC)	-0.50	0.17	-0.25	-0.42
ETR (°C) (CPC)	3.07	0.93	-1.78	1.95

The correlation existing between the observed (CPC and NCEP) and simulated (CORDEX MME) temperature variables (TMIN, TMEAN and TMAX) and associated extremes (ETR, HWFI and TX90P) are summarized in **Table 5** and **Table 6**, with significant correlation coefficients using t-test at 95% significance level being in bold. There is a significant correlation between observations (NCEP, CPC) and CORDEX MME in replicating temperature variables (TMIN, TMEAN

and TMAX) during the period 1979-2005 in Côte d'Ivoire, except TMAX in JFM (Table 5) and TMEAN in OND (Table 6). Nevertheless, for extreme temperatures, the correlation is not significant in general although there is an important value of the correlation (about 0.546 for TX90P). But an exception is made for ETR and HWFI, characterized by significant correlation with respect to CPC in AMJ and JAS seasons for HWFI and during all the seasons for ETR (Table 5). JAS is characterized by negative and significant correlations for TMAX, ETR and TMEAN indicating that CORDEX MME and observation show opposite relationships for simulating these variables.

**Table 5.** Correlation coefficients between CPC and CORDEX MME in simulating temperature variables (TMIN, TMEAN, TMAX) and associated extremes (ETR, TX90P, HWFI) with p-values in brackets. Significant correlation at 95% interval level are marked in bold.

Variables	JFM	AMJ	JAS	OND
TMIN	<b>0.362</b> ( $2.6 \times 10^{-17}$ )	<b>0.336</b> ( $4.7 \times 10^{-9}$ )	<b>0.490</b> ( $2.06 \times 10^{-6}$ )	<b>0.530</b> ( $5.83 \times 10^{-17}$ )
TMEAN	<b>0.428</b> ( $4.51 \times 10^{-15}$ )	<b>0.321</b> ( $3.18 \times 10^{-9}$ )	<b>0.282</b> ( $2.31 \times 10^{-21}$ )	<b>0.570</b> ( $4.37 \times 10^{-18}$ )
TMAX	0.354 (0.538)	<b>0.205</b> ( $1.331 \times 10^{-5}$ )	<b>-0.05</b> ( $1.86 \times 10^{-25}$ )	<b>0.398</b> ( $2.68 \times 10^{-11}$ )
ETR	<b>-0.085</b> ( $3.12 \times 10^{-12}$ )	<b>0.409</b> ( $2.46 \times 10^{-7}$ )	<b>-0.129</b> ( $2.16 \times 10^{-11}$ )	<b>0.062</b> ( $5.99 \times 10^{-7}$ )
TX90P	0.546 (0.72)	0.448 (0.90)	0.516 (0.82)	0.594 (0.74)
HWFI	0.403 (0.069)	<b>0.072</b> ( $2.11 \times 10^{-5}$ )	<b>0.637</b> (0.012)	0.408 (0.192)

**Table 6.** Correlation coefficients between NCEP and CORDEX MME in simulating mean temperature (TMEAN) and Warm Spells Duration Index (HWFI) with p-values in brackets. Significant correlation at 95% interval level are marked in bold.

Variables	JFM	AMJ	JAS	OND
TMEAN	<b>0.02</b> (0.03)	<b>0.180</b> (0.029)	<b>-0.086</b> ( $2.34 \times 10^{-10}$ )	0.415 (0.899)
HWFI	0.142 (0.75)	-0.051 (0.08)	-0.080 (0.074)	0.097 (0.120)

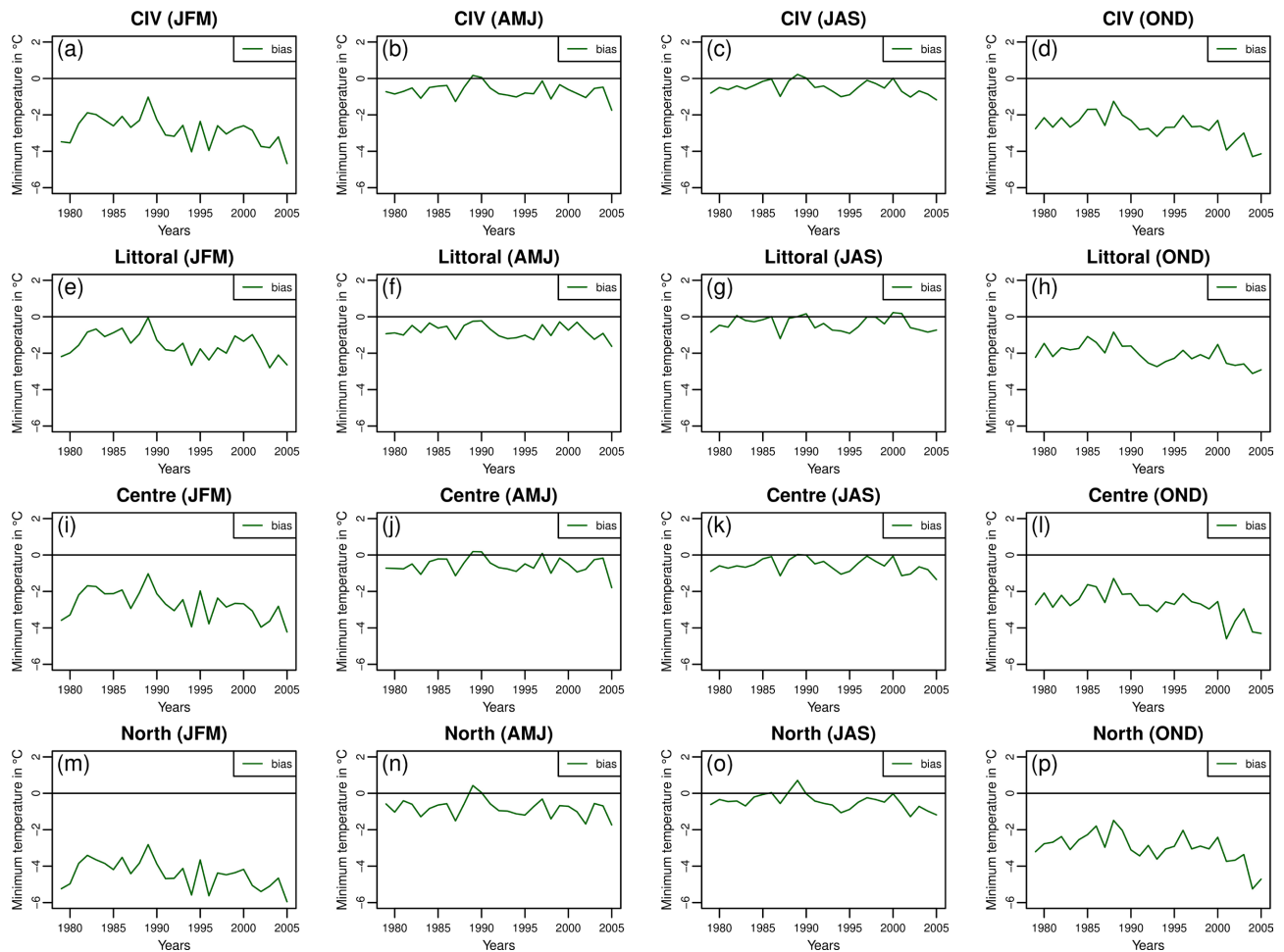
### 3.3. Interannual Variability of Seasonal Biases

In this paragraph, the interannual variability of the seasonal biases of the CORDEX MME with respect to the observations CPC and NCEP for the different temperature variables (TMIN, TMEAN, TMAX) and associated extremes (ETR, HWFI, TX90P) are analyzed for the entire domain of Côte d'Ivoire (a-d) and for the three climatic zones (Littoral, Centre and North), (e-p).

#### 1) Minimum Temperature (TMIN)

Minimum temperature (TMIN) is underestimated by the CORDEX MME in comparison to the observation CPC over Côte d'Ivoire during the study period (1983-2005). But this underestimation largely depends on the season and the climatic zone. JFM and OND are characterized by an important cold biases reaching about 5°C, especially in the north climate zone of Côte d'Ivoire. However, CORDEX MME outperforms the interannual variability of TMIN during AMJ

and JAS seasons with slight biases of about 1 °C, over the different climatic zones and the entire domain of Côte d'Ivoire (**Figure 8**).

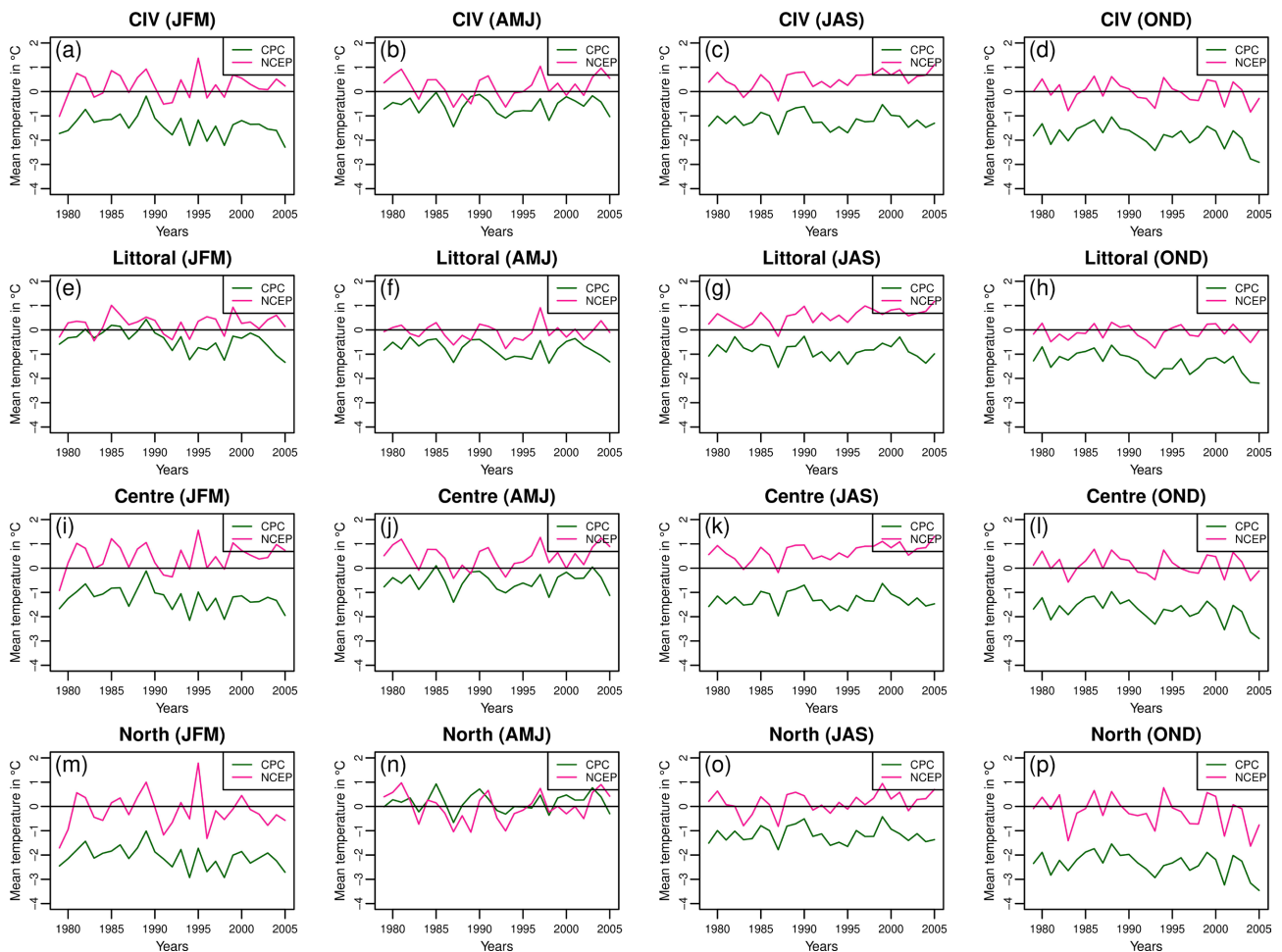


**Figure 8.** Interannual variability of the MME biases in simulating minimum temperature (TMIN) with respect to the observation CPC (green) over Côte d'Ivoire (a-d), the Littoral (e-h), the Centre (i-l) and the North (m-p) climatic zones during JFM, AMJ, JAS and OND seasons. The horizontal line indicates the reference.

## 2) Mean Temperature (TMEAN)

**Figure 9** shows the comparison of the interannual variability of the CORDEX MME biases with respect to the observations CPC (green) and NCEP (pink) in representing the mean temperature (TMEAN) over the entire domain of Côte d'Ivoire (**Figures 9(a)-(d)**) and the three climatic zones (**Figures 9(e)-(p)**) for the four seasons (JFM, AMJ, JAS, OND) of the period 1979-2005. In general, CORDEX MME underestimates the mean temperature (TMEAN) with respect to CPC over Côte d'Ivoire, except in the North climate during AMJ season. Furthermore, it tends to overestimate TMEAN in comparison to NCEP over Côte d'Ivoire during the period 1979-2005, particularly in the centre climate zone for the four seasons. It's worth noting that the interannual variability of the seasonal bias of TMEAN is characterized by an important fluctuation during JFM and OND seasons, particularly in the centre and the north climatic zones. Also, the biases of the

CORDEX MME with respect to the observations CPC and NCEP have almost the same interannual variability with different amplitudes, particularly in the north climatic area during AMJ season. This could be explained by the fact that CORDEX MME outperforms the spatial variability of the mean temperature over Côte d'Ivoire in comparison to CPC and NCEP.

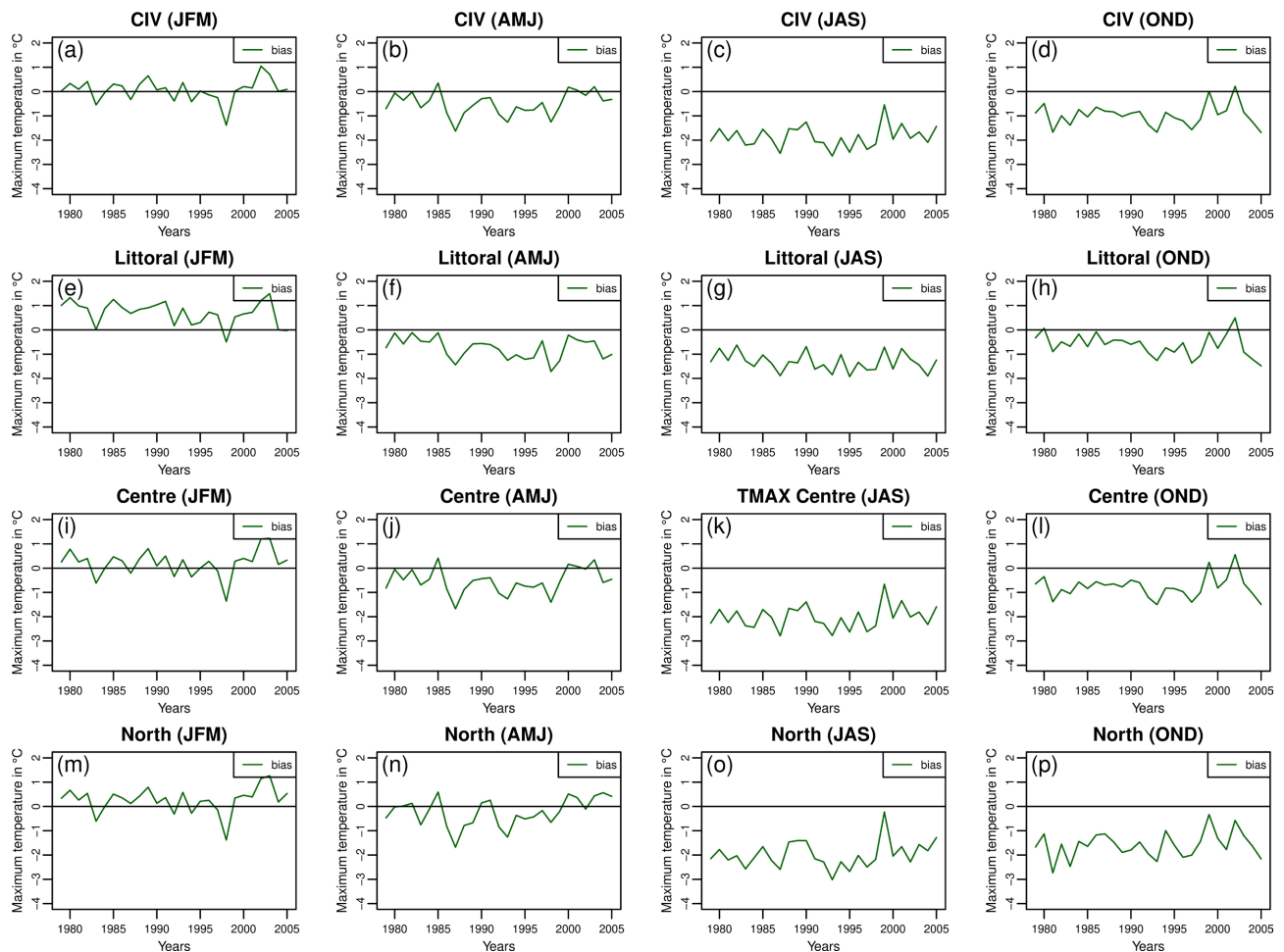


**Figure 9.** Interannual variability of the MME biases in simulating mean temperature (TMEAN) with respect to the observations CPC (green) and NCEP (pink) over Côte d'Ivoire (a-d), the Littoral (e-h), the Centre (i-l) and the North (m-p) climatic zones during JFM, AMJ, JAS and OND seasons. The horizontal line indicates the reference.

### 3) Maximum Temperature (TMAX)

The interannual variability of the CORDEX MME biases with respect to the observation CPC in simulating the maximum temperature (TMAX) over Côte d'Ivoire and the three climatic areas is displayed in **Figure 10**. In general, CORDEX MME underestimates TMAX, except in the littoral climatic area during JFM where TMAX is overestimated (about 1°C). Moreover, during the same season (JFM), CORDEX MME's bias fluctuates around 0°C (between positive and negative values) over the centre and the north climatic zones, indicating that TMAX's magnitude is well captured by the CORDEX MME. Nevertheless, important cold biases (about 3°C) are observed during JAS over the whole country and particularly

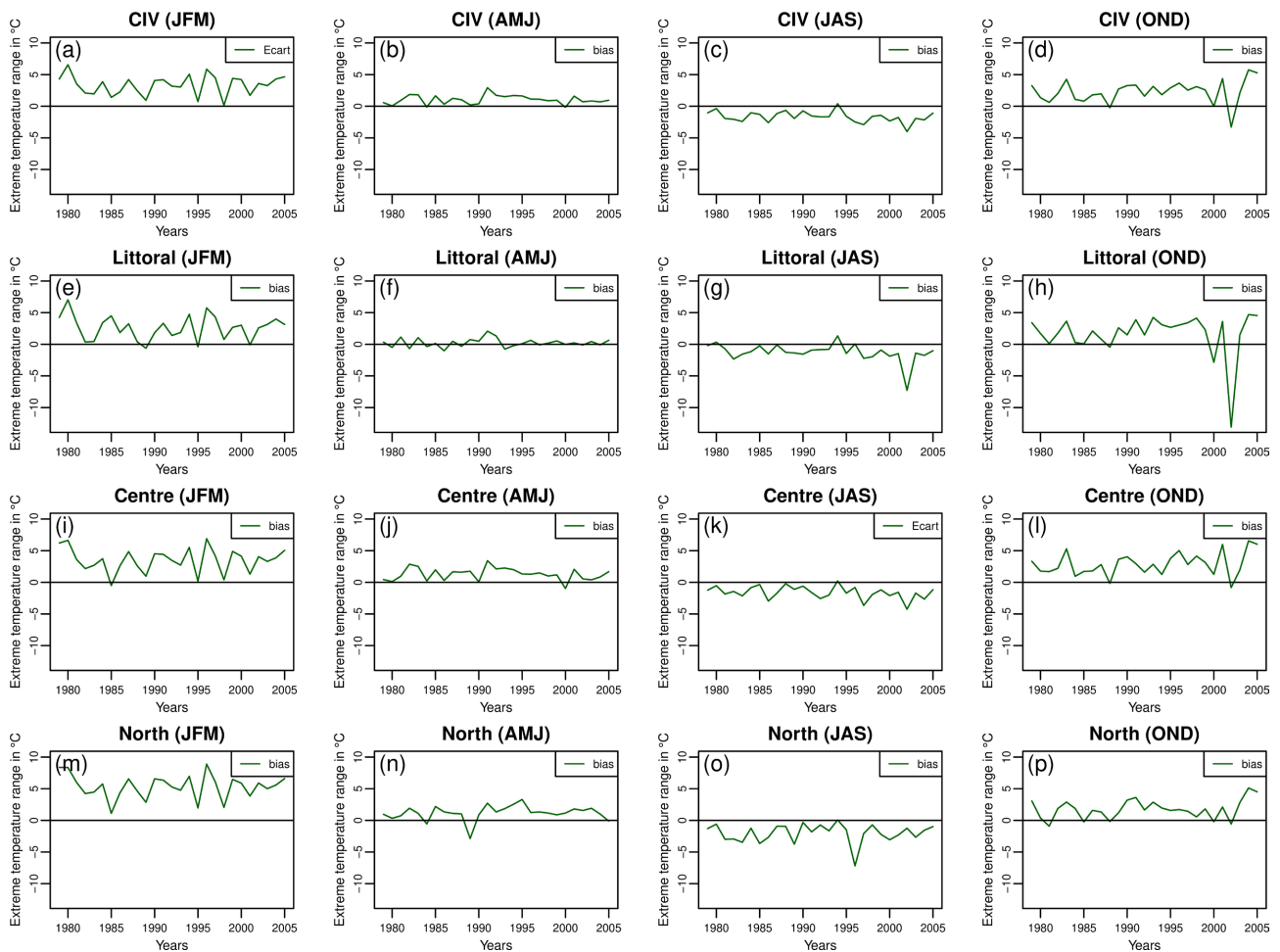
in the north climate area during OND.



**Figure 10.** Interannual variability of the MME biases in simulating maximum temperature (TMAX) with respect to the observation CPC (green) over Côte d'Ivoire (a-d), the Littoral (e-h), the Centre (i-l) and the North (m-p) climatic zones during JFM, AMJ, JAS and OND seasons. The horizontal line indicates the reference.

#### 4) Intra Period Extreme Temperature Range (ETR)

The interannual variability of the CORDEX MME's biases with respect to the observation CPC in simulating the intra period extreme temperature range (ETR) over Côte d'Ivoire and its three climatic areas is presented in **Figure 11**. During JFM, AMJ and OND, ETR is overestimated about 5°C, 1°C, 5°C, respectively; while during JAS, we notice an underestimation about 1.5°C, over the different climatic zones of Côte d'Ivoire. In addition, important biases (about 5°C) are observed during JFM and OND, while slight biases (about 2°C) occurred in AMJ and JAS. In the littoral climatic area, there is an important bias characterized by a peak (about 10°C) around the year 2002 which impacted the other climatic zones during OND season. Nevertheless, CORDEX MME, in general outperforms the magnitude of ETR in comparison to CPC better in AMJ and JAS than in JFM and OND over the three climatic zones, particularly over the littoral climatic area in AMJ.



**Figure 11.** Interannual variability of the MME biases in simulating the intra period extreme temperature range (ETR) with respect to the observation CPC (green) over Côte d'Ivoire (a-d), the Littoral (e-h), the Centre (i-l) and the North (m-p) climatic zones during JFM, AMJ, JAS and OND seasons. The horizontal line indicates the reference.

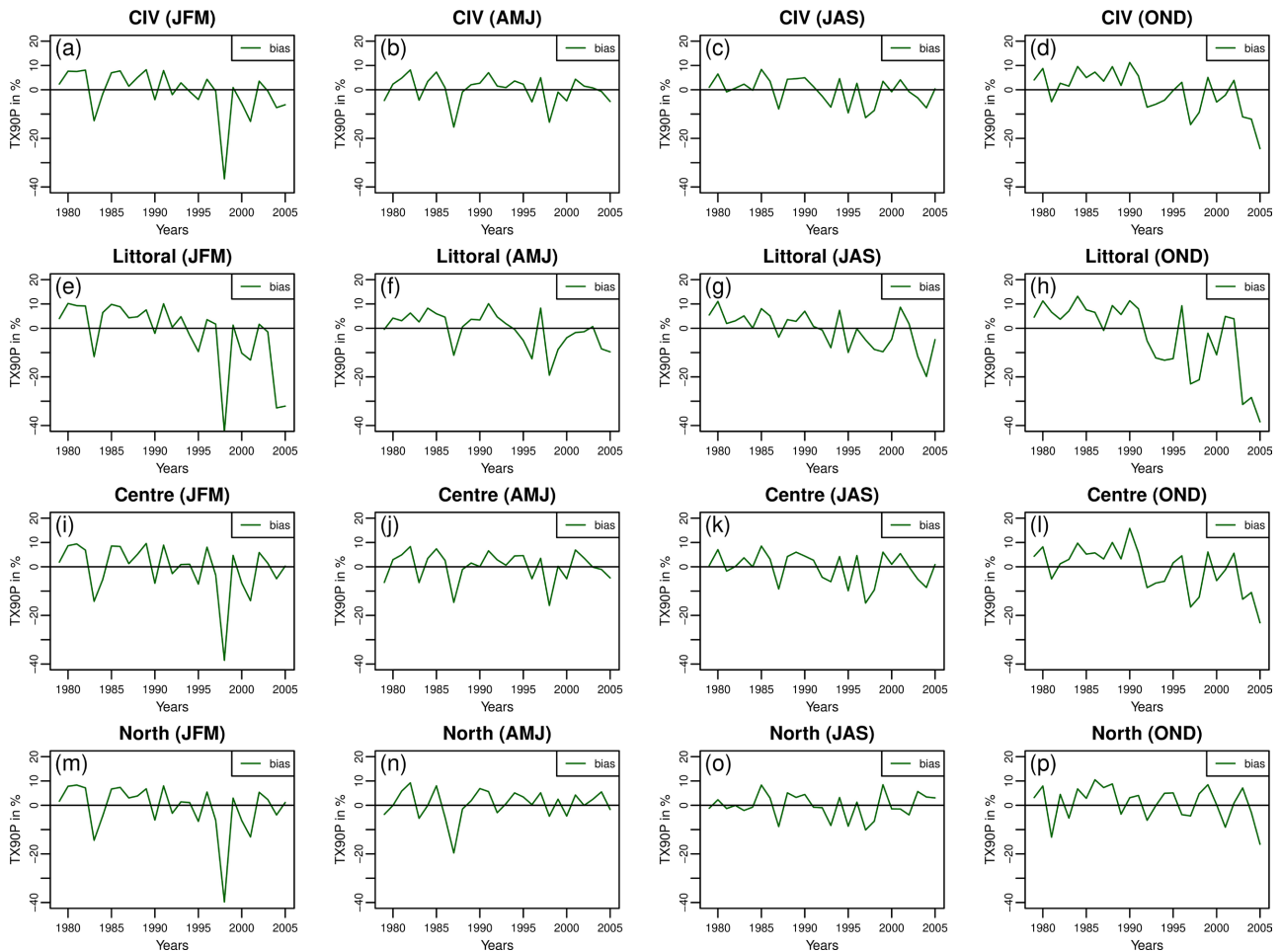
#### 5) Warm Days (TX90P)

**Figure 12** shows the interannual variability of seasonal (JFM, AMJ, JAS, OND) biases of the CORDEX MME in replicating warm days percent (TX90P) with respect to CPC observation over Côte d'Ivoire and the three climatic zones (Littoral, Centre, North). The analysis indicates important fluctuations of TX90P biases between  $-40\%$  and  $15\%$  in JFM and OND seasons for the three climatic zones of Côte d'Ivoire. Moreover, CORDEX MME presents significant cold biases (about  $40\%$ ) for the year 1998 during JFM over the three climatic zones. We also noticed that during the period 1997-2005, CORDEX MME underestimated TX90P with respect to CPC overall climatic areas and seasons, except the north climate zone in AMJ.

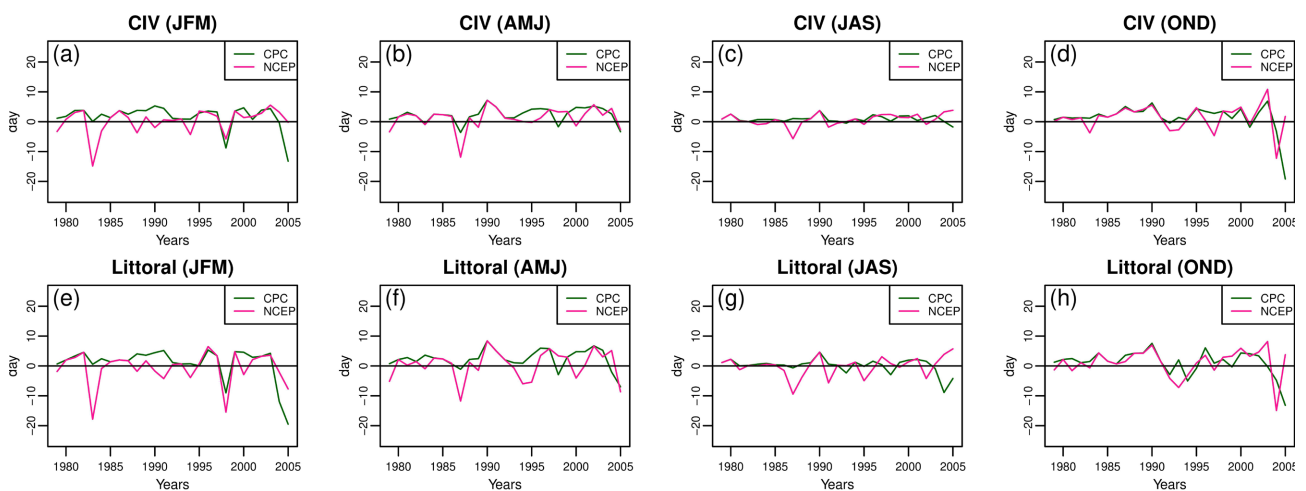
#### 6) Warm Spell Duration Index (HWFI)

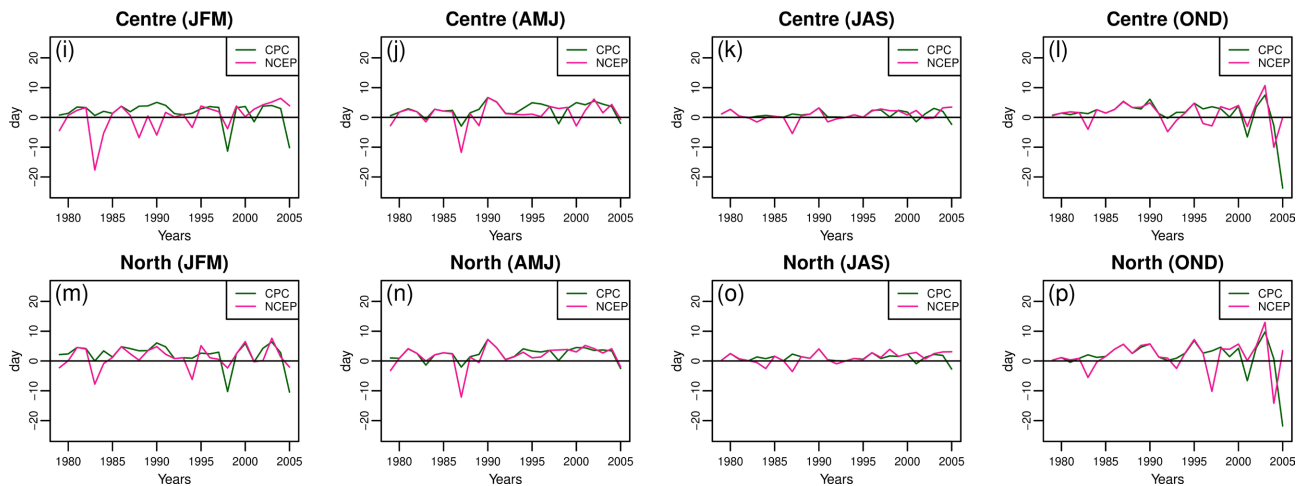
The interannual variability of seasonal (JFM, AMJ, JAS, OND) biases of the CORDEX MME in replicating the warm spells duration index (HWFI) with respect to the observations CPC (green) and NCEP (pink) over the entire domain of Côte d'Ivoire and its three climatic areas, is shown in **Figure 13**. CORDEX MME biases is characterized by a fluctuation comprised between  $-10$  days and  $10$

days, indicating, negative and positive biases during the period 1979-2005. JFM and OND are characterized by important fluctuations, compared to AMJ and JAS seasons. In addition, during JAS season, CORDEX MME indicates slight biases



**Figure 12.** Interannual variability of the MME biases in simulating the warm days percent (TX90P) with respect to the observation CPC (green) over Côte d'Ivoire (a-d), the Littoral (e-h), the Centre (i-l) and the North (m-p) climatic zones during JFM, AMJ, JAS and OND seasons. The horizontal line indicates the reference.





**Figure 13.** Interannual variability of the MME biases in simulating warm spell days index (HWFI) with respect to the observations CPC (green) and NCEP (pink) over Côte d'Ivoire (a-d), the Littoral (e-h), the Centre (i-l) and the North (m-p) climatic zones during JFM, AMJ, JAS and OND seasons. The horizontal line indicates the reference.

around 1 day in simulating HWFI over the centre and north climate areas of Côte d'Ivoire. Consequently, CORDEX MME outperforms the magnitude of HWFI, particularly during JAS.

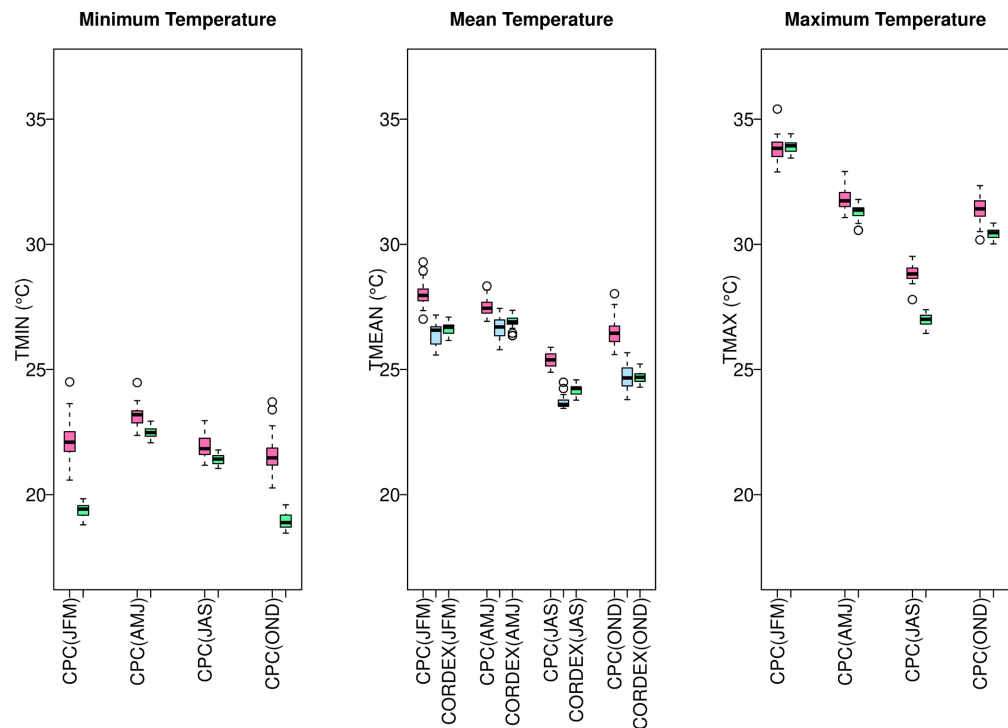
### 3.4. Interannual Variability in the Multi-Model Ensemble

In this paragraph, the comparison of the interannual variability of the CORDEX multi-model ensemble (MME) and the observations CPC and NCEP in representing temperature variables (TMIN, TMEAN and TMAX) as well as associated temperature extremes (TX90P, HWFI and ETR) over Côte d'Ivoire during the period 1979-2005 are presented in **Figure 14** and **Figure 15** as box-and-whisker plots.

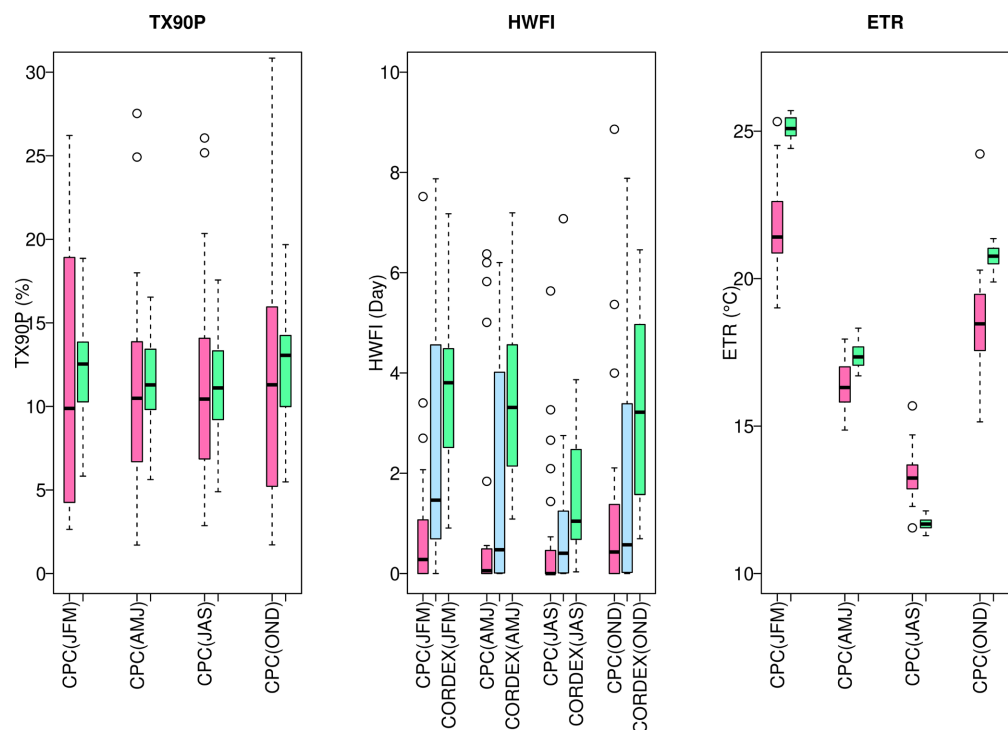
#### 1) Minimum, Mean and Maximum Temperature (TMIN, TMEAN and TMAX)

CORDEX MME generally underestimates the minimum temperature (TMIN) in comparison to the observation CPC over Côte d'Ivoire during the period 1979-2005 with almost the same interquartile spread. This cold bias is most important during JFM and OND seasons. However, for mean temperature (TMEAN), the observational data (CPC and NCEP) show high variability compared to CORDEX MME with an important interquartile spread. Moreover, CORDEX MME overestimates TMEAN with respect to NCEP while TMEAN magnitude is underestimated with respect to CPC during AMJ and JAS. During JFM and OND, CORDEX MME outperforms the interannual variability of TMEAN in comparison to NCEP with the same median (about 27°C). Finally, maximum temperature (TMAX) is characterized by the same interannual variability in the CORDEX MME and in the observation CPC during the period of study (1979-2005). Nevertheless, CORDEX MME underestimates the magnitude of TMAX during AMJ, JAS and OND seasons while during JFM, TMAX is well captured with almost the same median (about 34°C).

#### 2) Temperature Extremes (TX90P, HWFI and ETR)



**Figure 14.** Quantification of the inter-annual spread of the minimum, mean and maximum temperature (TMIN, TMEAN and TMAX) as simulated by the MME (CORDEX-green) and the observations (CPC-pink, NCEP-blue) during the period 1983-2005 over Côte d'Ivoire.



**Figure 15.** Quantification of the inter-annual spread of the warm days percent (TX90P), the warm spells duration index (HWFI) and the intra period extreme temperature range (ETR) as simulated by the MME (CORDEX-green) and the observations (CPC-pink, NCEP-blue) during the period 1983-2005 over Côte d'Ivoire.

In general, extreme temperature indices (TX90P and HWFI) present large scale interannual variability over Côte d'Ivoire during the period 1979-2005 in the observations CPC and NCEP as well as in the CORDEX MME. This interannual variability is more important in CPC compared to CORDEX MME for TX90P, while NCEP and CORDEX MME show high variability in HWFI compared to CPC. However, ETR is characterized by a relatively slight variability in CPC and CORDEX MME, compared to TX90P and HWFI over Côte d'Ivoire with CPC having a higher interquartile range, compared to CORDEX MME. Overall, CORDEX MME overestimates the magnitude of the temperature extremes (TX90P, HWFI, ETR) over the period 1979-2005 in Côte d'Ivoire (**Figure 15**). The differences between the observations and the CORDEX multi-model ensemble (MME) in simulating the interannual variability of temperature and associated extremes could be caused by the different atmospheric circulation responses in the individual models [34].

#### 4. Summary and Conclusions

Climate change is considered one of the great challenges to face in the West Africa region because of the recurrence and intensity of climate based precipitation and temperature extremes in each of its different countries. This study assessed the effectiveness of the multi-model ensemble (MME) of fourteen CORDEX-Africa simulations to replicate the spatial and interannual variability of the temperature variables (TMIN, TMEAN and TMAX) and associated extremes (ETR, TX90P and HWFI) over Côte d'Ivoire during the period 1979-2005. The analysis is conducted during the four seasons: January-February-March (JFM), April-May-June (AMJ), July-August-September (JAS) and October-November-December (OND) of the period 1979-2005. Our results indicate that the CORDEX MME outperforms the basic features of the spatial variability of temperature variables and associated extremes over Côte d'Ivoire; however, they show different patterns and magnitudes of bias regarding the observations CPC and NCEP. In general, CORDEX-Africa MME underestimates the temperature variables (TMIN, TMEAN, TMAX), while extreme temperatures (TX90P, ETR and HWFI) are overestimated. Considering the mean temperature (TMEAN), the spatial variability is captured well by the CORDEX MME with different magnitudes in both CPC and NCEP observations. A cold bias is indicated by the CORDEX MME with respect to CPC, while a dry bias is observed with respect to NCEP, thus underlining the uncertainties existing between the observations CPC and NCEP. For minimum and maximum temperature (TMIN and TMAX), CORDEX MME shows a cold bias over Côte d'Ivoire in comparison to NCEP, except in the southern region during JFM, where TMAX is overestimated (about 1°C) by CORDEX MME. The analysis of the spatial variability of extreme temperature indicates that HWFI is overestimated by CORDEX MME in both observational datasets (NCEP and CPC), while TX90P and ETR are in general, underestimated and overestimated, respectively. On the other hand, the analysis of the correlation between CORDEX

MME and the observational datasets (CPC and NCEP) revealed in general, a statistically significant relationship in simulating temperature variables (TMIN, TMEAN and TMAX) over Côte d'Ivoire during the period 1979-2005. Nevertheless, for extreme temperatures, the correlation is not significant in general, although important values reach about 0.594 for TX90P in OND, except ETR and HWFI with significant correlation. In addition, observations (CPC and NCEP) and CORDEX-Africa MME showed low interannual variability in representing temperature variables (TMIN, TMEAN, TMAX), while extreme temperature is characterized by an important interannual variability in the observations (CPC and NCEP) datasets as well as in the CORDEX MME. Consequently, observations datasets showed high interannual variability compared to CORDEX MME in simulating extreme temperature over Côte d'Ivoire, except for warm spells duration index (HWFI), characterized by an important interannual variability in CORDEX MME than in observation CPC. The differences observed among the observations (CPC and NCEP) and the CORDEX MME could be caused by the different atmospheric circulation responses in the individual models, such as soil moisture, humidity flux coming from the ocean, and the evapotranspiration phenomenon. Overall, CORDEX Africa MME showed good performance in reproducing the temperature and associated extremes over Côte d'Ivoire under the present-day climate conditions (1979-2005). Thus, this study could be considered as a warning for government, stakeholders and decision makers about the reliability of the projected changes in warm extreme temperatures over Côte d'Ivoire as revealed by previous studies. It is worth noting that if nothing is done to minimize greenhouse gas emissions, the country will face exceptional warm extremes like heatwaves and drought episodes which could alter the socioeconomic stability. Consequently, further work will involve the ability of the different CORDEX simulations to replicate temperature and precipitation variability over Côte d'Ivoire and identify the climate scenario followed by the current climate change in the future.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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