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Validation of Monthly Data of Temperature and Precipitation over West Africa from Simulations of CORDEX-CORE Ensemble

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Abstract

We analysed nine simulations from dynamic downscaling to a horizontal resolution of approximately 25 km of three general circulation models (GCMs). These GCMs use three regional climate models (RCMs) that participated in the coordinated downscaling experiment (CORDEX-CORE). These simulations were compared to three datasets of reanalysis. The ERA5 for temperature at 2 metres and for precipitation, Climate Hazards Center InfraRed Precipitation with Stations (CHIRPS) and African Rainfall Climatology from the Famine Early Warning System (FEWS-ARC) were used. To give an overview of these nine model experiments, we presented and compared the results of the latter with the reanalysis taken into account for the period 1983 - 2005. The results indicated that the nine models correctly reproduced the temperature and rainfall in West Africa during the historical period. In the Guinean coast region, REMO-NorESM1 and RegCM4-MPI-MR models well simulated precipitation and temperature during the historical period. In the Savannah region, RegCM4-NorESM1, CCLM5-MPI-LR, REMO-NorESM1, CCLM5-NorESM1 and CCLM5-HadGEM2 model gave best result. In the Sahel region, the RegCM4-HadGEM2 model gave a good correlation. Using the Taylor diagram in the historical period, all CORDEX-CORE RCMs had a strong relationship with temperature.

Keywords

CORDEX-CORE, Regional Climate Model Evaluation, ERA5, CHIRPS, FEWS-ARC, West Africa

1. Introduction

All parts of our planet are affected by the phenomenon of climate change. The polar ice caps are melting as a result of rising temperatures and ocean water levels are increasing, giving rise to phenomena such as floods. Many regions face more frequent precipitation and extreme weather events, while others face increasingly intense heat waves and droughts. Adapting to the effects of climate change ensures that people, homes, businesses, livelihoods, infrastructure, and ecosystems are preserved. Africa is one of the poorest continents in the world, according to the latest World Bank Report (2024). This adaptation will be imperative for African countries living in extreme poverty. Furthermore, the GIEG (Intergovernmental Panel on Climate Change), responsible for taking stock of scientific, technical, and socio-economic knowledge concerning climate change, shows that, despite climate change mitigation measures, which firstly involve reducing greenhouse gas emissions, this is inevitable during this century. Based on the IPCC report, it would therefore be important and necessary to have a good, in-depth knowledge of future climate change in West Africa because of its rapid demographic growth and its economy which is highly dependent on rainfall agriculture (IPCC, 2023).

For a good understanding of the evolution of climate change on a regional scale, regional climate models (RCMs) are the most appropriate during this century. Therefore, developing climate change projections in this region is of paramount importance. These climate projections make it possible to measure the vulnerability of these regions and thus anticipate the harmful consequences that will result from them by implementing effective adaptation strategies. Climate change scenarios have often been carried out using global climate models (GCMs) in this region (Fotso-Nguemo et al., 2017). However, some authors have shown the presence of a strong dispersion between the scenarios produced by these models (Remedio et al., 2019). Indeed, the GCMs are consistent when it comes to simulating the distribution of changes in temperature or precipitation on a massive scale in a particular region; the differences are notable. The greatest disparity between models is the amplitude and geographic distribution of precipitation and this comes from the very small scale nature of rain events, difficult to represent in climate models. An additional difficulty arises when we want to predict the potential consequences of climate change. For these forecasts to have meaning and to lead to adaptation measures, they must be evaluated at regional or even local spatial scales. If we intend to obtain good climate change scenarios at high resolution and over very long periods within the framework of coordinated experiments, GCMs are not recommended because of the high cost of computing capacities required for such experiments. This is why regional climate models (RCMs) are increasingly indicated for the production of high-resolution climate change scenarios (Tamoffo et al., 2023).

As part of the World Climate Research Program (WCRP), the establishment of the Coordinated Regional Climate Downscaling Experiment (CORDEX) initiative (Giorgi et al., 2009) has considerably improved regional climate change scenarios (including the African continent) using latest generation RCMs and also to understand and analyze the uncertainties weighing on the future climate (Giorgi et al., 2009; Nikulin et al., 2012), to respond much more precisely to the growing demand for high-resolution information on regional climate change and its global impacts. CORDEX-CORE's mission is to provide essential data for the IPCC reports by providing a high-resolution dataset of regional climate information. These data come from the high-resolution dynamic and homogeneous downscaling reference data, forced by the European Center for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis (Dee et al., 2011), as well as only projections forced by chosen parameters. Research has mainly focused on past climatology, and very little has examined future precipitation and temperatures. In this study, our objective is to analyze monthly simulations of temperature and precipitation using the CORDEX-CORE ensemble over all of West Africa. Thus, three regional climate modeling centers participating in CORDEX–CORE use climate simulations to evaluate these two climate parameters throughout West Africa. It should be emphasized that these simulations respond to the increasing demand for climate services, providing scientifically validated data for decision-making on adaptation to climate change.

As previously reported, we employed three CORDEX CORE RCMs, namely REMO, RegCM, and CCLM, to dynamically downscale three CMIP5 GCMs and the ERA-Interin reanalysis dataset to a horizontal resolution of 0.22˚ × 0.22˚ in the CORDEX Africa domain and for the period from 1971 to 2100 (Ilori & Balogun, 2022). Due to the unreliability of ground observation datasets, the high vulnerability to climate change, and the low adaptive capacity of Africa, CORDEX has treated the African continent as one of its priorities. It is a key sector among other regions which cover the most populated land territories. The performance of CORDEX-CORE RCMs in West Africa has been analyzed in numerous studies (Klutse et al., 2016; Nikulin et al., 2012; Diallo et al., 2012; Sylla et al., 2013). However, the practice of using multi-model ensemble mean performance and its rapid acceptance over a single RCM to assess climate change and variability has raised concerns about the power of a single model to simulate precipitation and temperature in West Africa. The representation of characteristic precipitation over the study area was improved through the use of the multi-model ensemble mean. A climatological and statistical evaluation of CORDEX-CORE RCMs is offered in this study, with improved resolution for West Africa. The assessment began by examining seasonal climatology and statistically describing temperature and precipitation over the historical period in West Africa. Afterwards evaluating the performance of the nine models of three RCMs dynamically reduced from three GCMs and compared to the ERA5/FEWS-ARC/CHIRPS analysis data, this can be achieved. The next parts are organized as follows: the description of data and methodology, including information on the study area; following by the results and discussions and we concluded the study by offering perspectives for future research.

2. Area of Study, Data and Methodology

2.1. Study Zone

West Africa, a broadly defined sub-region within the larger area of sub-Saharan Africa, which encompasses the western part of the Maghreb, covers a larger area of 6,140,000 km^2, representing approximately one-fifth of the African continent (**Figure 1**). Most of these lands are plains below 300 m above sea level, with isolated high points distributed across states along the southern coast of West Africa (**Figure 1**). West Africa, located between latitudes 0˚ - 20˚N and longitudes 20˚W - 20˚E, can be classified into three different agroclimatic zones, based on weather and climate conditions, similarity of land use/land cover and ecosystems: Guinea Coast (4˚ - 8˚N), Savannah (8˚ - 11˚N) and Sahel (11˚ - 16˚N) (Ilori & Ajayi, 2020; Omotosho & Abiodun, 2007). Located south of the Atlantic Ocean, north of the Sahara Desert, and east of the Cameroon highlands, the region has a seasonal cycle of precipitation caused by the south-north movement of the Intertropical Convergence Zone (ITCZ). The confluence of humid monsoon winds from the southwest and the dry Harmattan from the northeast is at the origin of this movement. According to Ilori and Ajayi (2020), average annual precipitation varies considerably, from more than 2500 mm in the south, near the Atlantic Ocean, to more than 400 mm in the north. According to studies carried out by Le Barbé et al. (2002), Sultan and Janicot (2000) and Lenouo et al. (2016), these zonal fluctuations are linked to the latitudinal movement of the zone of heaviest precipitation, called "monsoon jump," from the region towards the Sahel. Additionally, complex topography influences the climate of West Africa, including the Cameroon Highlands, Jos Plateau, and Fouta Djallon (Lenouo et al., 2016, 2021). According to Ndao et al. (2020), a correlation was observed between the West African monsoon (WAM) and monthly averages of boundary layer height (BLH). The greatest BLH variances occur in the tropics near the ITCZ.

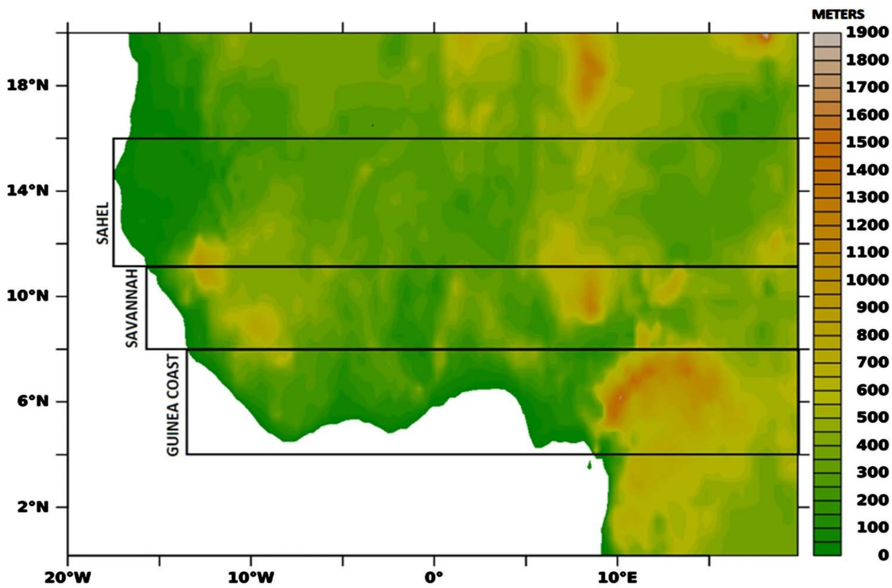

Figure 1. West Africa map showing the orography at an interval of 100 m and three homogenous climatic zones (Ilori & Ajayi, 2020).

2.2. Simulation and Reanalysis of Data

This study used nine monthly data sources, such as 2-meter average temperature and precipitation variables. This information comes from three RCMs, which were used to dynamically reduce three CMIP5 GCMs (**Table 1**). Historical ERA5 reanalysis data provided by ECMWF was also included. ERA5 provides global and hourly estimates of atmospheric variations, ocean variations, and land surface variations at a horizontal range of 31 km and 137 vertical levels from the surface to 0.01 hPa (approximately 80 km). Giorgi et al. (2009), Weber et al. (2018), and Endris et al. (2013) described the dynamics and physical parameters of these three RCMs (**Table 1**). All model data was extracted from the CORDEX archive (https://esgf-data.dkrz.de/projects/esgfdkrz) in the Africa domain (AFR-22). The new horizontal resolution of CORDEX-CORE is 0.22˚ (approximately 25 km) and it covers a period of 36 years (1970 - 2005) for the historical and 85 years (2006 - 2100) for the climate projections. Additionally, overall model performance was assessed using three institution-based ensemble averages: CCLM, REMO, and RegCM, as well as the grand ensemble average of the nine model combinations.

The old ERA-Interim was replaced by the ERA5 reanalysis, which served as the reference and standard data of temperature at 2 metres used in this study. The reference data used for climatological and statistical evaluation of all simulation datasets are enhanced by this approach. In 1998, the Climate Prediction Center (CPC) developed the Rainfall Estimator (RFE) (Herman et al. 1997) in response to the need for higher resolution operational daily rainfall estimates to support the humanitarian aid programs of USAID/Famine Early Warning Systems Network (FEWS-NET). In 2001, CPC implemented an advanced RFE algorithm (version 2.0, hereafter referred to as RFE2) based on the methods of (Xie & Arkin, 1996). Although the RFE2 product has served as the principal rainfall estimator

Table 1. Description of the CORDEX-CORE model combinations used for this study, with the RCMs REMO (at Climate Service Center Germany, GERICS), RegCM (at ICTP), and CLM (at KIT) and with GCM boundary conditions from three institutes UK Met Office Hadley Center (MOHC), Germany Max Planck Institute for meteorology (MPIM) and Norwegian Climate Center (NCC) (Adapted from Ilori & Balogun, 2022).

Institute	Driven GCM	RCM	RCM abbreviation	N°
Met Office Hadley center	MOHC-HadGEM2-ES	CLMcom-KIT-CCLM5	CCLM-HadGEM2	1
	MPI-M-MPI-ESM-LR	CLMcom-KIT-CCLM5	CCLM-MPI-LR	2
	NCC-NorESM1-M	CLMcom-KIT-CCLM5	CCLM-NorESM1	3
MPI for meteorology	MOHC-HadGEM2-ES	GERICS-REMO2015	REMO-HadGEM2	4
	MPI-M-MPI-ESM-LR	GERICS-REMO2015	REMO-MPI-LR	5
	NCC-NorESM1-M	GERICS-REMO2015	REMO-NorESM1	6
NCC	MOHC-HadGEM2-ES	ICTP-RegCM4-7	RegCM-HadGEM2	7
	MPI-M-MPI-ESM-MR	ICTP-RegCM4-7	RegCM-MPI-MR	8
	NCC-NorESM1-M	ICTP-RegCM4-7	RegCM-NorESM1	9

for USAID/FEWS-NET operations, the brevity of the dataset record (2001-present) does not allow users to derive meaningful rainfall anomalies to assess the current state and evolution of the climate over Africa. In 2004, the original Africa Rainfall Climatology (ARC1) was developed with the same algorithm used in the RFE2. The ARC1 dataset could not longer respond to current needs (higher number of years as well as inconsistencies in the original reprocessing) for operational climate monitoring. This has prompted us to utilize a new, long-term precipitation dataset for operational monitoring and climate analysis. The acquisition of historical, recalibrated IR imagery and daily summary gauge data has enabled reconstruction of the ARC climatology dataset from 1983, present, it is ARC2. ARC2 offers a number of advantages compared to other long-term climatological rainfall datasets that are widely used : high spatial resolution 0.1˚ (~10 km) and one day's temporal domain is from 0600 GMT through 0600 GMT, in the domain 20.0W - 55.0E and 40.0S - 40.0N. The Africa Rainfall Climatology from the Famine Early Warning System data version 2 (FEWS-ARC2) is a result of a project to create a satellite-estimated precipitation climatology over the Africa domain (Novella & Thiaw, 2013). Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a quasi-global (50S - 50N), (Schneider et al., 2013). land-only rainfall dataset with a range of temporal (daily, pentadal, and monthly) and spatial (0.05˚ or 0.1˚) resolutions, depending on the region and the time period. Dataset can be found at 6-hourly to seasonal time scales. The dataset begins in 1981 and extends to the near-present day. CHIRPS was developed to support the United States Agency for International Development Famine Early Warning Systems Network (FEWS NET).

2.3. Methodology

The ability of CORDEX-CORE RCMs to simulate patterns and parameter characteristics such as temperature and precipitation in the West African region was evaluated using two methods. In the first approach, statistical techniques, such as Pearson's correlation coefficients (CC), standard deviation (STD) and root mean square error (RMSE) difference calculated using the Taylor diagram (Taylor, 2001), were employed to evaluate the performance and consistency of individual models in replicating climate parameters such as mean seasonal temperature and precipitation across the entire West African domain. The visual summary of the degree of agreement between observations (ERA5/FEWS-ARC2/CHIRPS2 used as reference data) and RCM experiments is presented in the Taylor diagram. Kalognomou et al. (2013), Akinsanola and Ogunjobi (2017), Dike et al. (2022), and Mbouna et al. (2022) have already used the Taylor diagram to evaluate different aspects of climate models. In equation (1), we then used the correlation coefficient (CC) to measure the degree of agreement between ERA5 and each model when simulating inter-annual variability of temperature and precipitation.

$$\mathrm{CC} = \frac{\sum\left(O_i - \overline{O_i}\right)\left(M_i - \overline{M_i}\right)}{\sqrt{\sum\left(O_i - \overline{O_i}\right)^2\left(M_i - \overline{M_i}\right)^2}} \tag{1}$$

$$\text{MB} = \frac{1}{N}\sum\left(M_i - O_i\right) \tag{2}$$

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum\left(M_i - O_i\right)^2} \tag{3}$$

O and M are the observed (ERA5) and simulated (CORDEX-CORE) values, *i,* are the pairs of annual climate parameters (temperature and precipitation) observed and simulated, and N is the total number of years taken into account.

In addition to Pearson's correlation coefficients (CC), one can also consider the mean bias (MB) as defined in equation (2) and the root mean square error (RMSE) as defined in equation. We used the statistical measurements (3) between ERA5 and the simulated climate parameters (temperature and precipitation) to evaluate the overall consistency of the entire model when simulating the annual climate parameters (temperature and precipitation) during the period history (1983 - 2005). The average difference between a model's predictive values and the actual values is one of the two major performance indicators of a regression model, thereby assessing the prediction of the target value (accuracy). Additionally, at a value of 5%, the Mann-Kendall trend test (Mann, 1945; Kendall, 1975; Ilori & Ajayi, 2020) was used to study changes in annual climate parameters (temperature and precipitation) simulated by all models at every grid point in West Africa. Then, we compared the results obtained with those of the ERA5/FEWS-ARC2/CHIRPS2 trend analysis for the whole of West Africa and the three sub-regions (**Table 2**).

3. Results and Discussion

The climatological and statistical analysis of CORDEX-CORE RCMs over West Africa is presented, including the assessment of seasonal climatology and the statistical analysis of precipitation and temperatures for past periods. Seasonal

Table 2. Correlation coefficients (CC), Mean Bias (MB), Root Mean Squared Error (RMSE), average (MEAN) and standard deviation (Std) between the nine CORDEX-CORE RCMs and the reference ERA5 during the historical period (1983 - 2005) over (A) Guinea Coast, (B) Savannah, (C) Sahel and (D) whole West Africa, for the variables: 2-meter mean temperature (2m-T), and precipitation (mm/day). The model combination number is defined in **Table 1**. Correlations are significant at the 10%.

(A) Guinea coast					
RCM	2m-T (˚C)				
	CC	MB	RMSE	MEAN	Std
1	0.87	−0.78	1.49	24.86	2.11
2	0.85	−0.09	1.56	25.55	2.36
3	0.93	−0.14	1.07	25.51	2.04
4	0.87	−0.80	1.61	24.84	2.08
5	0.89	−0.01	1.51	25.66	2.18
6	0.88	−0.07	1.27	25.57	2.08
7	0.89	−0.43	1.39	25.21	2.08

Continued

8	0.93	0.89	1.70	26.53	2.14
9	0.91	0.35	1.27	25.99	2.04
(B) Savannah					
RCM	2m-T (˚C)				
	CC	MB	RMSE	MEAN	Std
1	0.82	−1.46	2.12	25.29	2.52
2	0.80	−0.93	2.27	25.81	2.87
3	0.90	0.19	1.53	26.94	2.62
4	0.79	−1.60	2.29	25.14	2.40
5	0.80	−0.71	2.19	26.04	2.69
6	0.90	0.44	1.57	27.19	2.46
7	0.84	−1.09	2.06	25.66	2.55
8	0.92	0.54	2.15	27.30	2.86
9	0.86	1.03	1.93	27.79	2.60
(C) Sahel					
RCM	2m-T (˚C)				
	CC	MB	RMSE	MEAN	Std
1	0.79	−2.50	3.24	25.52	4.23
2	0.92	−1.22	2.59	26.81	4.58
3	0.87	0.61	2.27	28.63	3.34
4	0.68	−2.63	3.39	25.39	4.11
5	0.84	−0.88	2.56	27.14	4.37
6	0.87	0.63	2.12	28.66	3.15
7	0.66	−2.36	3.47	25.66	4.59
8	0.93	0.21	2.58	28.24	4.71
9	0.88	1.48	2.57	29.52	3.41
(D) Whole West Africa					
RCM	2m-T (˚C)				
	CC	MB	RMSE	MEAN	Std
1	0.89	1.56	2.59	24.12	5.75
2	0.89	−1.23	2.55	24.45	5.95
3	0.94	0.32	2.05	26.00	5.20
4	0.85	−1.64	2.73	24.05	5.54
5	0.86	−0.99	2.54	24.69	5.73
6	0.94	0.36	1.98	26.05	4.92
7	0.80	−1.73	3.06	23.95	5.85
8	0.83	−0.67	2.81	25.02	6.15
9	0.94	0.68	2.17	26.37	5.09

changes in climate parameters (temperature and precipitation) over the whole of West Africa over the historical period are shown in Figures 2-5 for all CORDEX-CORE simulations and ERA5 and FEWS-ARC2/CHIRPS2 observations for temperature and precipitation respectively. The sky-blue band in Figures 2-5 represents the standard deviation (Std) calculated from observations over the entire West Africa (Figure 2), Guinea (Figure 3), Savannah (Figure 4), and Sahel (Figure 5) zone. The average value of precipitation or daily temperature outside this band (STD) for a month considered indicates that the RCM experiment failed to simulate the observed climatology.

The results of Figure 2(a) show that precipitation from CHIRPS2 has the same

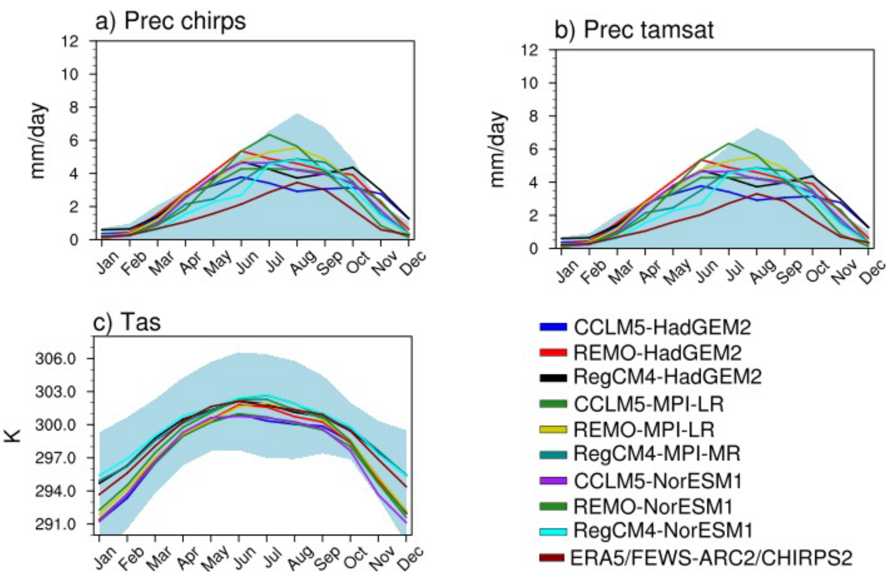

Figure 2. Seasonality of mean (1983 - 2005) of precipitation (a from CHIRPS2 and b from TAMSAT) and (c) temperature at 2 metres from ERA5 over the entire of West Africa.

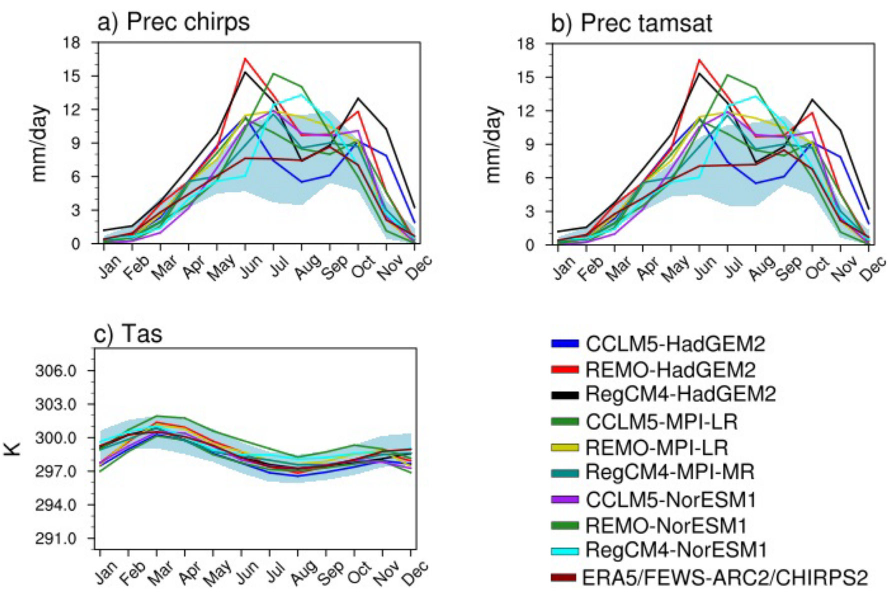

Figure 3. The same as Figure 2 for Guinea coast zone

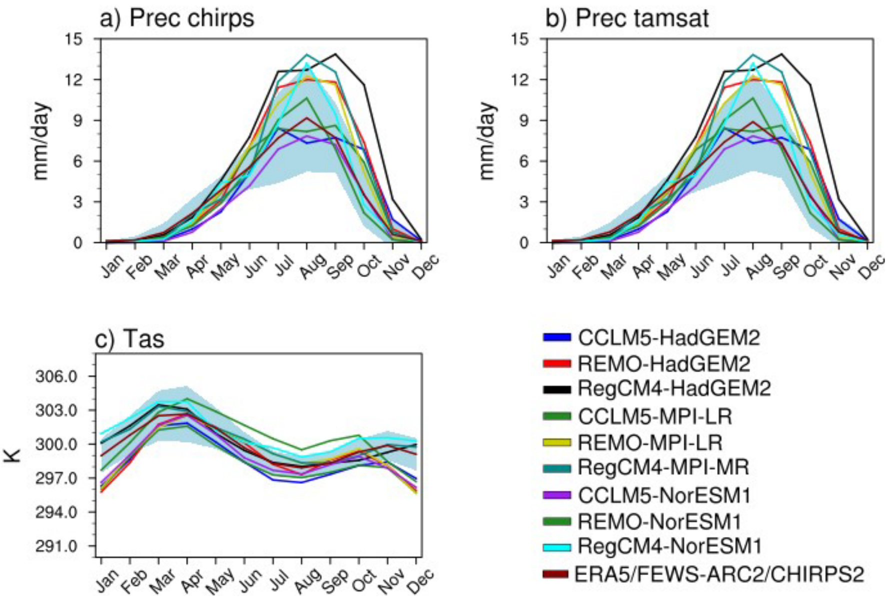

Figure 4. The same as **Figure 2** for Savannah zone.

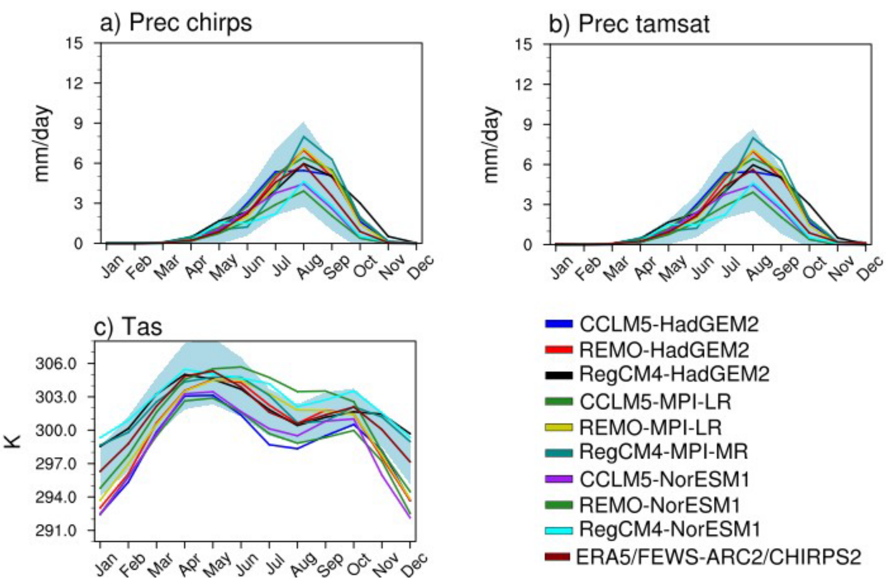

Figure 5. The same as **Figure 2** for Sahel zone.

structure as the sky-blue band, almost centered in the middle of this band and having a unimodal rainfall around the month of August, which captures the pic of the band, it is linked to the arrival of Monsoon over Africa. All CORDEX-CORE RCM simulations are in the STD domain (except CCLM5-HadGEM2 and RegCM4-HadGEM2 which leave the STD domain around mid-October), which implies that the RCM experiments successfully simulated the observed climatology. All CORDEX-CORE RCMs overestimate the seasonal cycle of Prec_chirps except CCLM5-HadGEM2. Most simulations are unimodal CCLM5-HadGEM2 and RegCM4-HadGEM2 and have almost the same structures as the observations, with the exception of CCLM5-HadGEM2 and RegCM4-HadGEM2 which are bimodal. The majority of model outputs simulate their peak two months earlier (June) while the CCLM5-MPI-MR output simulates its peak one month earlier (July). REMO-MPI-MR, RegCM4-MPI-MR, and RegCM4-NorESM1 model outputs capture the peak of observations (ERA5/FEWS-ARC2/CHIRPS2) and overestimate it much more. This shows us that for the months of June, July and August have a maximum precipitation according to different models that correspond to the rainy season in the entire region.

Precipitation for all models and observations oscillates in the interval [0; 0.5] for January and February and all simulations and observations in this interval remain almost constant. From the beginning of February, the rains increase rapidly up to the maximum of ERA5, and all RCMs then decrease until the month of December (December, January and Febuary show the minima, that correspond to dry season in West Africa) except CCLM5-HadGEM2 and RegCM-HadGEM2 which have particular simulations (these simulations have three extrema: June, August, and October). For most of these model outputs, they remain linked to the observations despite some observed differences. **Figure 2(b)** presents a similar structure to that of **Figure 2(a)**. However, apart from the two model outputs (CCLM5-MPI-LR and REMO-HadGEM2) that partially falls out of the STD domain. These 2 models outputs simulate their maximums as in **Figure 2(a)**, except that their peaks form outside the sky-blue band. We found that more model outputs successfully simulated the climatology of Prec_chirps (**Figure 2(a)**) than for Prec_tamsat (**Figure 2(b)**). We remarked that most models are colder than ERA5, except for RegCM4-MPI-MR and RegCM4-NorESM1. However, Precipitation variations slightly diminish in August for CCLM5-HadGEM2 and RegCM4-HadGEM2 models. Climatological monthly means of precipitation over West Africa can be found in Ndao et al. (2019).

Figure 2(c) shows that all simulations and observations have almost the (parabolic) structures similar to that of the sky-blue band and most of these simulations and observations are centered almost in the middle of the band, which indicates all RCMs CORDEX-CORE succeeded in almost correctly simulating the observed climatology. The majority of model outputs underestimate observations except RegCM4-MPI-LR and RegCM4-NorESM1. The maximum of observations from REMO-HadGEM2, REMO-NorESM1, CCLM5-MPI-LR, and RegCM4-HadGEM2 corresponds to the month of June (temperature ~ 28.85˚C). REMO-NorESM1 and RegCM4-HadGEM2 capture the maximum of observations very well while CCLM5-MPI-LR and REMO-HadGEM2 underestimate it. CCLM5-HadGEM2 and CCLM5-NorESM1 simulate their maximum one month (May) earlier, and CCLM5-MPI-LR, REMO-MPI-LR, and RegCM4-NorESM1 theirs one month (July) later. The average temperature for the month of January for all RCMs and observations oscillates in the interval [17,85˚C; 21,85˚C], we can see the same variation of temperature in Betant et al. (2024) that is linked to the climatology of West Africa. During the annual cycle, this temperature increases rapidly until reaching the maximum of observations, and all models then decrease rapidly until the month of December.

Despite some disparities between the models on the one hand and between the observations and all the models on the other hand, we noted that the RCM and ERA5/FEWS-ARC2/CHIRPS2 remain strongly linked because the differences between them are small (between and 0 and 5K). We noted that in Guinean coast area (**Figure 3**), **Figure 3(a)** (Prec chirps) and **Figure 3(b)** (prec-tamsat) are exactly the same. They present unimodal rainfall in the month of September for the observations. The observations have the same structure as that of the sky-blue band and are almost centered in the middle of this band. For all CORDEX-CORE MCRs, rainfall is bimodal around June and mid-September, except REMO-MPI-LR, CCLM5-MPI-LR, and RegCM4-NorESM1. A similar work has been done in Central Equatorial Africa by Tamoffo et al. (2022). All RCMs simulate their first peak two to three months earlier and their second peak one month later. All RCMs overestimate (mostly hugely) ERA5 (Tamoffo et al., 2023). The majority of RCMs failed to simulate the observed climatology. **Figure 3(c)** shows that all RCMs simulations and observations are similar to those in **Figure 3(a)** and **Figure 3(b)**. All models are strongly linked to each other and then between ERA5. The majority of RCMs overestimate observations and all models succeeded in correctly simulating the observed climatology, this is in agreement with the work of Kouassi et al. (2022), they show that optimizing RCMs configuration allow accurate climate simulations. The average temperature of the annual heat cycle oscillates in the interval] 22.85˚C; 26.85˚C [. The warmer month of the annual cycle of observations is around February (~26.85˚C), and for all RCMs, one month later (in the interval [25.85˚C, 28.85˚C]). This shows the climatology of Guinean Coast according to previous study (Kouassi et al., 2022)

In the Savannah zone (**Figure 4**), For Prec_chirps (**Figure 4(a)**), we found that the observations are unimodal, having the same structure as that of the sky-blue band and located in the middle of it. CCLM5-MPI-LR, RegCM4-NorESM1, and REMO-NorESM1 successfully simulated the observed climatology because these outputs are located in the STD domain. This is sync with the work of Safari et al (2022) in Rwanda. The peak rainfall of observations and the majority of RCMs is located around October. CCLM5-NorESM1, CCLM5-MPI-LR, REMO-MPI-LR, RegCM4-NorESM1, and RegCM4-MPI-LR do not capture the peak (~9 mm/day) of the observations well. The peak of the observations is overestimated by most model outputs having the same structures as that of the observations. The majority of RCMs overestimate observations. Zero precipitation for January, February, and December for most RCMs, indeed it is a dry season in Savannah zone (Dia-Diop et al., 2020). For some model releases, total drought begins in November and ends in March. **Figure 4(b)** is similar to that of **Figure 4(a)**, but the RegCM4-NorESM1 peak falls outside the STD domain. For **Figure 4(c)**, the average temperature increases from January to March for certain model outputs and from January - April for observations and other model outputs, then it decreases from March (or April) to approximately mid-June (or August), and in the end, it remains increasing for certain outings until the month of December and for others, it increases until the month of October (for observations, until the month of November) and then it decreases. The average temperature oscillates from January – December in the interval [21.85˚C; 31.85˚C].

The warmest month is April for observations and some model outputs while other outputs simulate theirs a month earlier. Almost all simulations and observations have the same structures as the sky-blue band. The majority of simulations and observations are bimodal. RegCM4-HadGEM2, RegCM4-MPI-MR, and RegCM4-NorESM1 successfully simulated the observed climatology. The observations are in the center of the sky-blue band and are overestimated for some outings and underestimated for others. In the Sahelian zone (**Figure 5**), for Prec_chirps (**Figure 5(a)**), we almost have all RCMs succeeded in simulating the observed climatology, except RegCM4-HadGEM2. The observations appear to be centered in the area of STD. All simulations and observations have the same structures as that of the sky-blue band and are unimodal, except RegCM4-HadGEM2. The month with the most rain is August for all RCMs and observations except for the RegCM4-HadGEM2, output which has July – September. Tamoffo et al., 2023 observed the trend in their work on "Understanding the diversity of the West African monsoon system change projected by CORDEX-CORE regional climate models". Not all of these models capture the peak in observations well and most model outputs overestimate it while others underestimate it. The rainfall amount from November until the end of March is ~ 0 mm/day (Nicholson; 2013, Wane et al., 2023). From April onwards, precipitation increases until it reaches its peak and then decreases until December. It should still be noted that for the months of March and November, there are only traces of rain (Ilori & Balogun, 2022). **Figure 5(b)** is similar to that of 5a, with the only small difference that the RegCM4-MPI-MR output goes slightly out of the sky-blue band. **Figure 5(c)** (Tas) shows that, the average temperature fluctuates in the interval [18.85˚C; 32.85˚C]. All simulations have almost the same structures as that of the observations. The average temperature of December is similar to that of January for all RCMs and observations, the observations are bimodal. The first peak is around May and it is the high temperature of the year and the second peak is mainly in October (Sultan et al., 2015). The two peaks are assimilated and are not well captured by the RCMs. There are only two model outputs (RegCM4-HadGEM2 and RegCM4-MPI-MR) that successfully simulated the observed climatology.

Taylor plots for the monthly average by area in the period 1983 - 2005 are shown over the entire West Africa (**Figure 6**), Guinea (**Figure 7**), Savannah (**Figure 8**), and Sahel (**Figure 9**) zone. The standard deviation is indicated by the radial coordinate, and the correlation between the RCMs and the reference data is shown by the azimuthal axis. It should be emphasized that the Taylor plot establishes a reference point for the observation, with a correlation of 1 and an RMSE of 0. Thus, if the simulated point is closely aligned with the observed point, this indicates similarity in terms of standard deviation, a high correlation, and an RMSE close to zero. Another important feature of the Taylor diagram is the relationship between ERA5 values and those generated by the RCMs. A higher ratio suggests

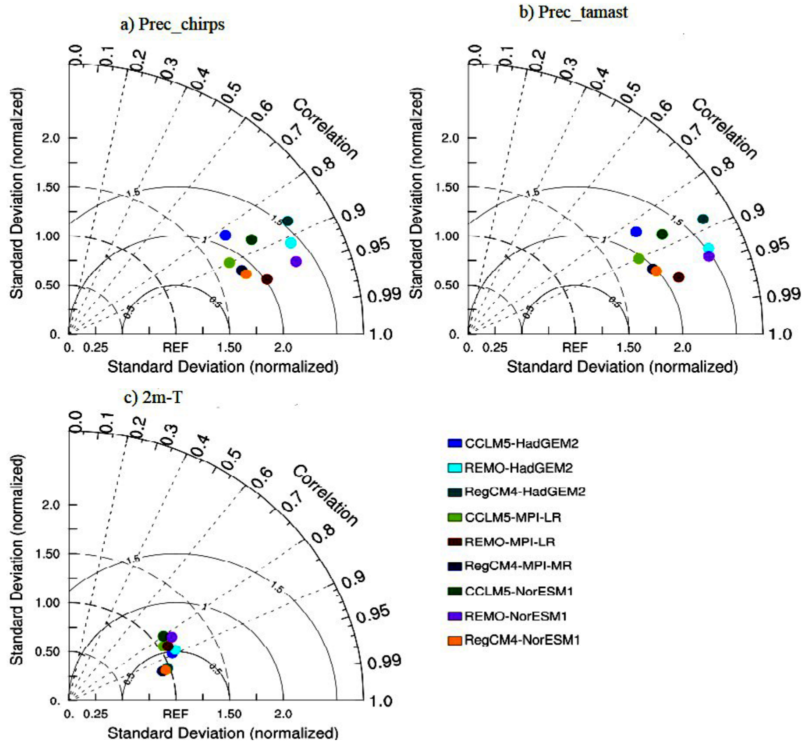

Figure 6. Taylor diagrams for area-averaged monthly (a) mean temperature at 2 meters (2m-T), (b) precipitation (Prec-chirps) and (c) precipitation (Prec-tamsat) during the historical period (1983 - 2005). The radial coordinate shows the standard deviation. The azimuthal axis shows the correlation between the RCMs and the reference data. The centred root-mean square error is indicated by the dashed grey semi-circles about the reference point.

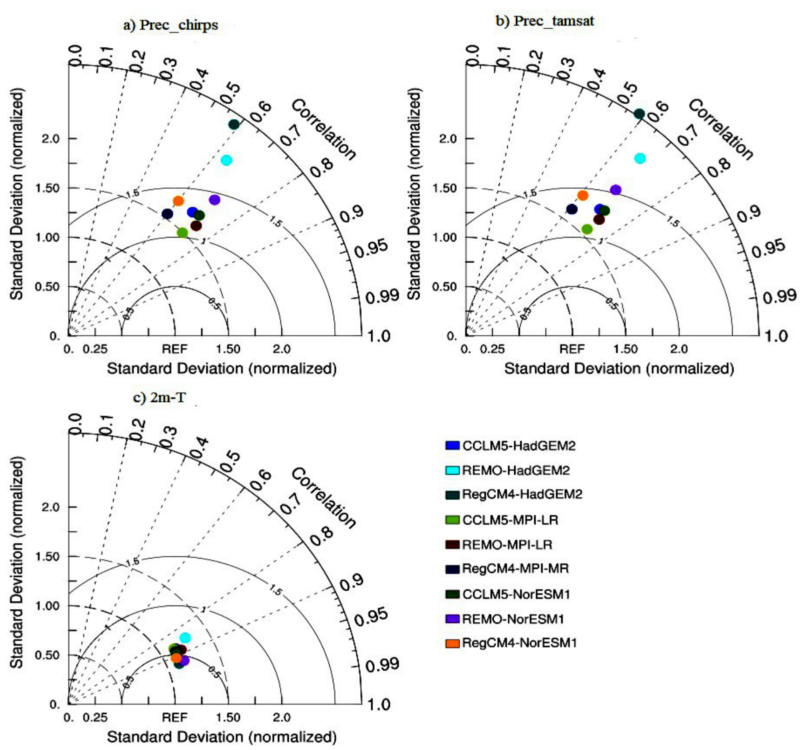

Figure 7. The same as **Figure 6** for Guinea coast zone.

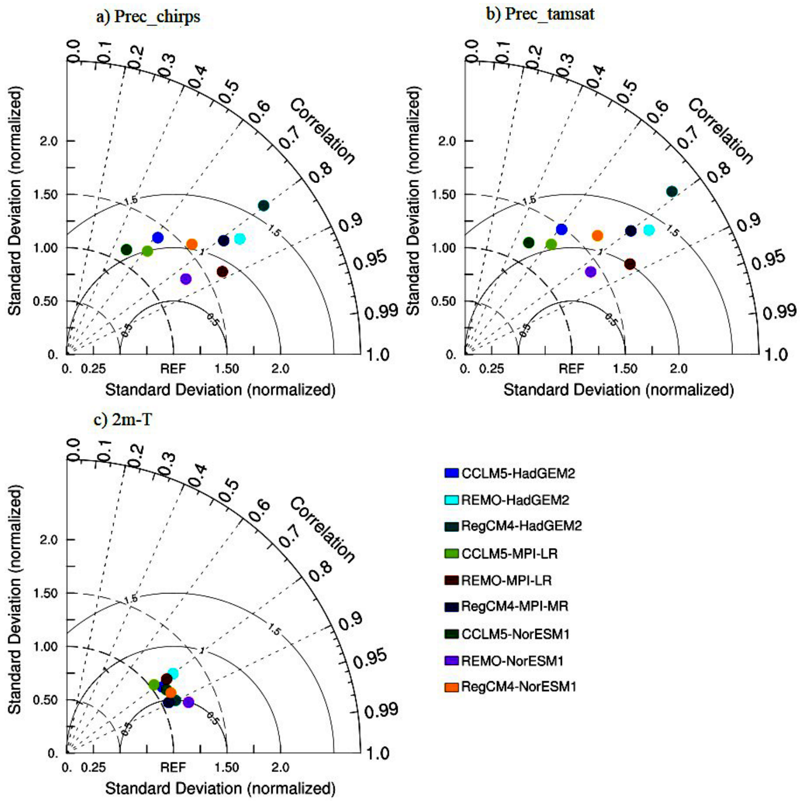

Figure 8. The same as **Figure 6** for Savannah zone.

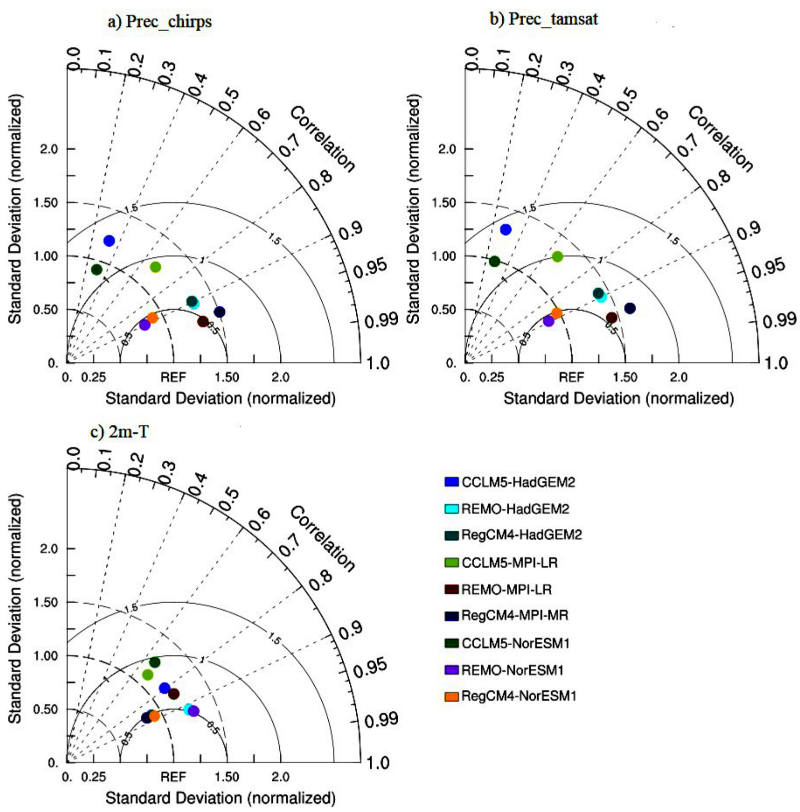

Figure 9. The same as **Figure 6** for Sahel zone.

greater agreement between the ERA5 and RCMs runs.

Throughout West Africa (Figure 6), we observed in Figure 6(a) that CC values vary between 0.81 and 0.97 (CC is very high for all models), RMSE is between 0.5, and 1.5 and the highest value of std is 1.5. Then we can say there is a strong relationship between ERA5 and CCLM5-MPI-LR (because cc ≈ 0.9) and stronger between ERA5 and REMO-NorESM1, RegCM4-NorESM1, RegCM4-MPI-MR, REMO-MPI-LR, RegCM4-HadGEM2 and REMO-HadGEM2. Therefore, all CORDEX-CORE RCMs suggest a stronger agreement. RegCM4-NorESM1 and REMO-NorESM1 are the best fit for observations, with approximately the same RMSE. The CCLM5-HadGEM2 model is one of the worst-performing models, with low model correlation. Although the REMO-NorESM1, RegCM4-NorESM1, RegCM4-MPI-MR, REMO-MPI-LR, RegCM4-HadGEM2 and REMO-HadGEM2 models have approximately the same correlation with the ERA5 reanalyses, the REMO-NorESM1 model simulates the magnitude of the variations much better (i.e. standard deviation) than the RegCM4-NorESM1 model, resulting in a lower RMSE. The same trend is noted for Prec_tamsat (Figure 6(b)), ($0.2 < CC < 0.97$, $0.5 < RMSE < 1.75$; and $0.75 < Std < 1.75$). Figure 6(c) shows that CC is very high for all models with the maximum of 0.97. The RMSE value varies between 0.75 and 1.5; and the Std values are also large for 2m temperature all over West Africa. All CORDEX-CORE RCMs suggest a stronger agreement. RegCM4-NorESM1, RegCM4-HadGEM2, and RegCM4-MPI-MR are best suited to the observations, with approximately the same RMSE. Although the RegCM4-NorESM1, RegCM4-HadGEM2, and RegCM4-MPI-MR models have approximately the same correlation with the ERA5 reanalyses, the RegCM4-MPI-MR model simulates the magnitude of the variations much better (i.e. standard deviation) than the RegCM4-NorESM1 and RegCM4-HadGEM2 models, resulting in a lower RMSE. The worst-performing model is CCLM5-NorESM1. It is important to note that the majority of RCMs, higher for West Africa, provide relatively satisfactory results for studying short-term (2030 - 2060) and long-term (2070 - 2021) developments. The MBs are negative for temperature at 2 metres (Table 2) except for CCLM-HadGEM2 (1), CCLM-NorESM1 (3) and REMO-NorESM1 (6) and RegCM-MPI-LR (8).

In coastal Guinea (Figure 7), Precipitation chirps (Figure 7(a)) and Precipitation tamsat (Figure 7(b)), have the same trend. The CC value varies between 0.59 and 0.77, the std value is very large and RSME is 1.5 and 2. All CORDEX-CORE RCMs suggest a strong agreement. This means that the spatial distributions of the CORDEX-CORE simulation are similar to the ones of the ERA5 reanalysis. The CCLM5-HadGEM2 model is one of the worst performing models and the CCLM5-MPI-LR model simulates the magnitude of variations much better (i.e., standard deviation) than all the other models, resulting in a lower RMSE for both parameters. For 2 metres temperature (Figure 7(c)), we see that all CORDEX-CORE RCMs suggest a stronger agreement because CC is very high ($0.84 \le CC < 0.95$). The correlation is very strong between ERA5 and all these models. The most suitable model for the simulations is RegCM4-MPI-MR (Std values are very large between 0.75 and 1, it is the same trend for RMSE) and the least efficient model is REMO-HadGEM2 because its correlation is the lowest. The MBs are generally negative (**Table 2**) except for the RegCM-MPI-MR (8) and RegCM-NorESM1 (9) for the temperature at 2metres. In Savannah region we noted the same observations for Precipitation chirps (**Figure 8(a)**) and Precipitation tamsat (**Figure 8(b)**). RSME and Std have almost the same trend (vary between, 1.5 and 3.5) and we can note the CC is also high in Savannah: between 0.5 and 0.88. There is a strong relationship between ERA5 and all these models, so the spatial distributions of the CORDEX-CORE simulation are similar to the ones of the ERA5 reanalysis. The most suitable model for the simulations of the two parameters is CCLM5-MPI-LR and the least suitable is RegCM4-HadGEM2. For 2 m temperature (**Figure 8(c)**), we noted that CC remains very high, RMSE and Std also have a same trend (1 and 1.5). All CORDEX-CORE RCMs are strongly linked to ERA5. All models are recommended for simulations. In the Sahel region (**Figure 9**), Precipitation chirps (**Figure 9(a)**) and Precipitation tamsat (**Figure 9(b)**), show that they have the same trend for CC (between 0.29 and 0.96), RSME (between 1 and 3), and Std (1 < Std < 3.5). All CORDEX-CORE RCMs have a strong relationship with ERA5, except CCLM5-NorESM1 and CCLM5-HadGEM2. The model most suitable for simulations is REMO-NorESM1 and the ones that are not recommended are CCLM5-NorESM1 and CCLM5-HadGEM2. In **Figure 9(c)**, the correlations of all CORDEX-CORE RCMs are strong (0.76< CC < 0.95), so there is a strong relationship between all these models and ERA5. The MB are also generally negative (**Table 2**) except for CCLM-NorESM1 (3), REMO-NorESM1 (6), RegCM-NorESM1 (8) and RegCM-NorESM1 (9).

4. Conclusion

Weather and climate conditions in West Africa are strongly influenced by temperature and precipitation (Ndao et al., 2019; Seetha et al., 2023). Member of the CORDEX community of the World Climate Research Program (WCRP), the objective of this study was to analyze and, above all, to document the data on climate change provided by the CORDEX-CORE simulation ensemble. Average annual and monthly data on climate change in West Africa are presented for two parameters: temperature and near-surface precipitation. Overall, we observed a strong influence of mesoscale sea breeze and land breeze circulations on temperature and precipitation in this region, as confirmed by previous research (Ndao et al., 2020; Seetha et al., 2023). CORDEX-CORE participants used three regional climate models—REMO, RegCM, and CCLM, to dynamically downscale three CMIP5 GCMs to a resolution of 0.22˚ × 0.22˚. We compared the global mean of two observations using different statistical methods and climatological descriptions at seasonal and annual scales, thereby simulating the spatial distribution of mean seasonal temperature and precipitation in West Africa. According to our results, all three CMIP5 GCMs showed superior performance than the ERA5 reanalysis in reproducing temperature and precipitation.

Throughout history, ENS-RCM has recorded CC values ranging from 0.80 to 0.94 for 2m-T across the West Africa region, with lower MB and RMSE values and predominantly negative MB values. Additionally, typical means and deviations differed very little between different models and observations. There were no regional differences between the different climatic regions of West Africa. This observation can be explained by the parameters used, namely temperature and precipitation because when analyzing these variables in this area, slight variations were noted (Ilori & Balogun, 2022).

To give an overview of these nine model experiments, we present and compare the results of the latter with the ERA5/FEWS-ARC2/CHIRPS2 reanalysis taken into account for the period 1983 - 2005. The results indicate that the nine models correctly reproduce the temperature and rainfall in West Africa during the historical period. In the Guinean coast region, there are only REMO-NorESM1 and RegCM4-MPI-MR which adequately simulate Prec chips and Prec tamsat on the other hand, all the outputs almost correctly simulate Tas during the historical period. In the Savannah region, only the RegCM4-NorESM1, CCLM5-MPI-LR, REMO-NorESM1, CCLM5-NorESM1 and CCLM5-HadGEM2 model outputs adequately simulate Prec chips and Prec tamsat and For Tas, there is only CCLM5-HadGEM2, RegCM4-MPI-MR and RegCM4-HadGEM2 which correctly simulate during the historical period. In the Sahel region, all model outputs normally simulate Prec chirps and Prec tamsat except RegCM4-HadGEM2 and for Tas, there is only RegCM4-HadGEM2, RegCM4-MPI-MR and RegCM4-NorESM1 which simulate correctly during the historical period. Using the Taylor diagram in the historical period, we make the following observations: In any region of West Africa, the CCLM5-MPI-LR model simulates the magnitude of variations much better (i.e. say the standard deviation) than all the other models for 2m-T and Prec_chirps and the most suitable model for the simulations for Prec_tamsat is RegCM4-MPI-MR (0.75< RMSE < 1 and 0.75 < Std < 1).

In the Guinean coast region, the most suitable model for the 2m-T and Prec_chirps simulations is CCLM5-MPI-LR and for Prec_tamsat, all CORDEX-CORE RCMs are strongly linked to ERA5. Therefore, all models are recommended for simulations. In the Savannah region, for 2m-T and Prec_chirps, all CORDEX-CORE RCMs have a strong relationship with ERA5, except CCLM5-NorESM1. But the most suitable model for simulations is REMO-NorESM1 and for Prec_tamsat, all models are suitable for simulations. In the Sahel region, for 2m-T and Prec_chirps, the REMO-NorESM1 model simulates better and the RegCM4-MPI-MR model is most adequate for Prec_tamsat. This work was carried out to validate this data for their later use in AquaCrop for the production of wheat in Cameroon to limit the importation of the latter using seasonal and monthly variations in temperature and precipitation in West Africa at the beginning (2030 - 2060) and at the end (2071 - 2099) of the 21st century under the scenario RCP 2.6 and RCP 8.5.

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Conflicts of Interest

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

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