

Assessment of Projected Temperature Over West Africa Using CORDEX Regional Climate Models

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Abstract

This study assessed the projections of temperature over West Africa using the simulated daily temperatures which were output of two (2) Coordinated Regional Climate Downscaling Experiment (CORDEX) models, include historical runs (1951-2005) and two (2) concentration pathways scenarios (RCP 4.5 from 2006-2100 and RCP 8.5 from 2006-2070) obtained from Earth System Grid Federation (ESGF) and Copernicus Climate Change Service (C3S-Climate Data Store) with spatial resolution of 0.22°. Results show that over West Africa under the Representation Concentration Pathways (RCP 4.5) scenario, there is a strong agreement between the distribution of model and observed PDF for the maximum temperature as the probability density functions (PDF) increases between 0.1 to 0.2 within the range of maximum temperature of 32.5°C to 36.0°C, the observed and MPI-CCLM5 revealed an agreement while the CCCma-CanRCM4 overestimated the PDF with a spike of 0.45 in March, April and May from 1979-2018. The validation of the PDF yielded skill score for the maximum temperature revealed at 0.86 and 0.81 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 4.5 scenario in March, April and May from 1979-2018 over West Africa. In June, July, August and September from 1979 to 2018 under the RCP 4.5 scenario, there is a fair agreement between the distribution of model and observed PDF for the maximum temperature as the PDF increases from 0.1 to 0.15 with the MPI-CCLM5 model in fair agreement with the observed while the CCCma-CanRCM4 model overestimated the observed with a spike PDF value of 0.47. The validation of the PDF yielded skill score for the maximum temperature revealed at 0.89 and 0.86 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 4.5 scenario in June, July, August and September from 1979-2018 over West Africa. The findings revealed a warming trend in the possible future climate of West Africa and the temperature increase could pose a serious threat on socioeconomic activities, which necessitates a call to action for possible climate adaption and mitigation pathways for planners and policymakers.

Keywords: Temperature, RCP, PDF

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1. Introduction

Alexander et al. (2006) and New et al. (2006) revealed a significant increase, at regional level, in the temperatures of both warmest and coldest days, and in the duration and frequency of warm spells especially in South and West Africa. Donat et al. (2013) reported a global analysis of climate extreme indices based on station data since the beginning of the twentieth century: although the station density over Africa is very scarce, significant trends in the number of warm days and nights and duration of warm spells are reported for e.g. South Africa. Based on the same dataset and reanalysis data, a comprehensive analysis of climate extreme indices simulated by Global Circulation Models (GCMs) was presented by Sillmann et al. (2013a).

On the basis of reanalysis dataset for the period 1979–2011, Fontaine et al. (2013) reported an increased occurrence of hot days and heat waves in Northern Africa, associated to specific atmospheric anomalies over Morocco and the Western Sahara. Under global warming, the occurrence and intensity of extreme events, defined by IPCC (2012) as a value of a weather or climate variable above or below a threshold value near the upper or lower ends of the range of observed values, are expected to change, as reported by e.g. Tebaldi et al. (2006), Russo and Sterl (2011), Orłowsky and Seneviratne (2011), and Sillmann et al. (2013b).

Model evaluations reported by Collins et al. (2006), Johns et al. (2006) and Delworth et al. (2006) revealed detailed assessments of the strengths and weaknesses of some major climate models based on seasonal and annual time scales. Many other studies have assessed GCM performance using monthly to annual time-scale data (e.g. Knutti et al., 2006; Chiew et al., 2009; Mitchell, 2003; Whetton et al., 2005; Suppiah et al., 2007; Masanganise, 2010; Masanganise et al., 2013). In this paper, we evaluated CORDEX GCMs based on daily climatology. As Perkins et al. (2007) point out, an assessment of the capacity of models to simulate climate on daily time scales is valuable because climate on time scales of days has a direct impact on human health and activities. Some studies have evaluated GCMs based on the climatological mean (see Watterson, 1996; Taylor, 2001; Murphy et al., 2004; Ramirez-Villegas et al., 2013). However, studies by Alexander et al. (2006) and Dessai et al. (2005) revealed the importance of considering climate statistics other than means to evaluate model performance.

This study focused on use of probability density functions (PDFs) according to Millard (2013) to assess model performance and skill score developed by Siebert (2017) for forecast verification routines for weather and climate.

2. Data and methodology

2.1 Study locality

The domain of the study lies within Latitude 0°N - 20°N and Longitude 20°W - 20°E , it is bounded in the south by Atlantic Ocean, north by Sahara Desert and Cameroon highland in the east.

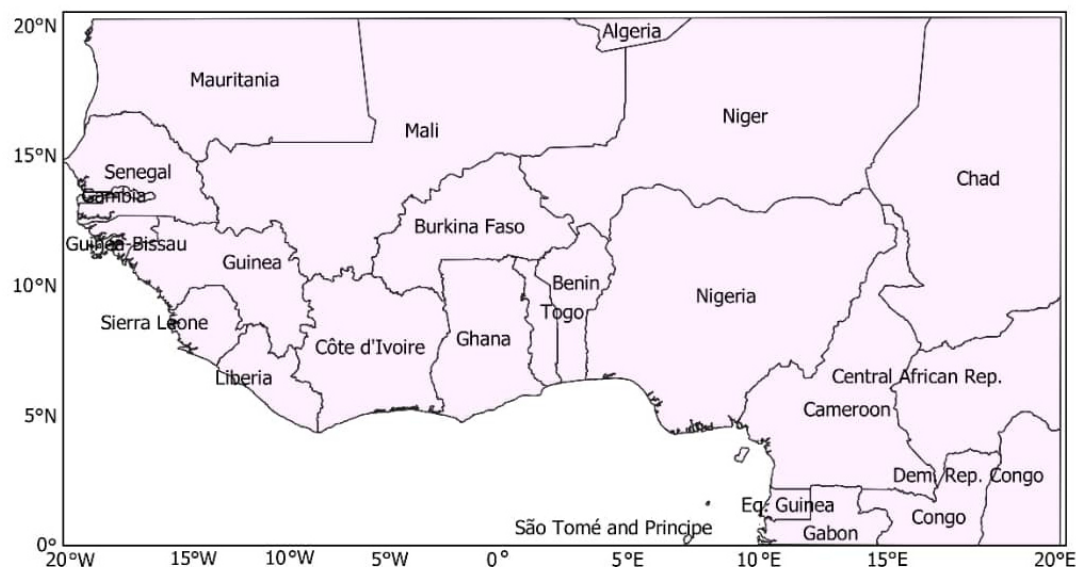


Figure 1: Map of West Africa showing the domain of study

2.2 Methodology

The simulated daily temperatures were output of two (2) Coordinated Regional Climate Downscaling Experiment (CORDEX) models which include historical runs (1951-2005) and two (2) concentration pathways scenarios (RCP 4.5 from 2006-2100 and RCP 8.5 from 2006-2070) obtained from Earth System Grid Federation (ESGF) and Copernicus Climate Change Service (C3S-Climate Data Store) with spatial resolution of 0.22° .

Table 1: Description of the CORDEX RCMs

Institute	Driven GCM	RCM	RCM Abbreviation
Canadian Centre for Climate Modelling and Analysis, Canada	CCCma CanESM2	CCCma- CanRCM4	CCCma- CanRCM4
Climate Limited-Area Modeling (CLM) Community, Germany	MPI-M-MPI- ESM-LR	CLMcom- KIT-CCLM5	MPI-CCLM5

Table 2: CORDEX RCMs Characteristics (Nikulian et al. 2012; Scinocca et al. 2015)

	CCma-CanRCM4	CLMcom-KIT-CCLM5
Institute	CCCma, Canada	CLM Community, Germany (https://www.clmcommunity.eu)
Short name	CCCma	CCLM
Projection Resolution	Rotated pole 0.22°	Rotated pole 0.22°
Vertical Coordinate/Level	Hybrid Sigma-pressure	Terrain Following/3.5
Advection	Semi-Lagrangian Hydrostatic	Fifth-order upwind, Baldauf and Schulz (2004)
Time step (s)	600 seconds	240 seconds
Convective Scheme	Mass flux scheme for shallow and deep convection	Tiedtke (1989)
Turbulence Vertical Diffusion	Bulk Richardson Formulation	Herzog et al. (2002), Buzzi et al. (2011)
Cloud Microphysics Scheme	Prognostic cloud liquid water and ice, statistical cloud scheme, interactive with aerosols	Doms et al. (2007), Baldauf and Schulz (2004)
Land Surface Scheme	CLASS2.7; J. Scinocca et al. (2015)	TERRA-ML; Doms et al. (2007)

Probability density function (PDF) were used to assess how the climate models reproduced the temperature

in present climatic conditions, and also its change under climate change.

$$\Pr [a \leq X \leq b] = \int_a^b f_x(x) dx \quad (1)$$

Millard (2013) developed EnviStats on R Package and the tool was used to analyze the Probability density function. Siegert (2017) developed SpecsVerification(R-Project) for forecast verification routines for ensemble forecast of weather and climate and it was used to test the skill score of the pdf results.

Regional Climate Models' projections under Representative Concentration Pathways (RCP 4.5 and RCP 8.5) scenarios were used to evaluate future temperature over West Africa. Pyferret was used for visualization of the RCP 4.5 and RCP 8.5 respectively.

3. Results and discussion

3.1 Probability Density Function and Skill Score

3.1.1 March, April and May

(a) Minimum Temperature

Model and observed PDF fairly agree at the distribution as the PDF tend to increase from 0.1 to 0.5 and there is an evident agreement of the MPI-CCLM5 and the observed where the PDF value is less than 0.1. The CCCma-CanRCM4 indicated high level of deviation from the observed as the PDF value increases to 0.38 with range of the minimum temperature from 17°C to 25°C on RCP 4.5 in March, April and May over West Africa (Figure 2). The validation of the PDF yielded skill score for the minimum temperature revealed at 0.91 and 0.87 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 4.5 scenario in March, April and May from 1979-2018 over West Africa (Figure 10).

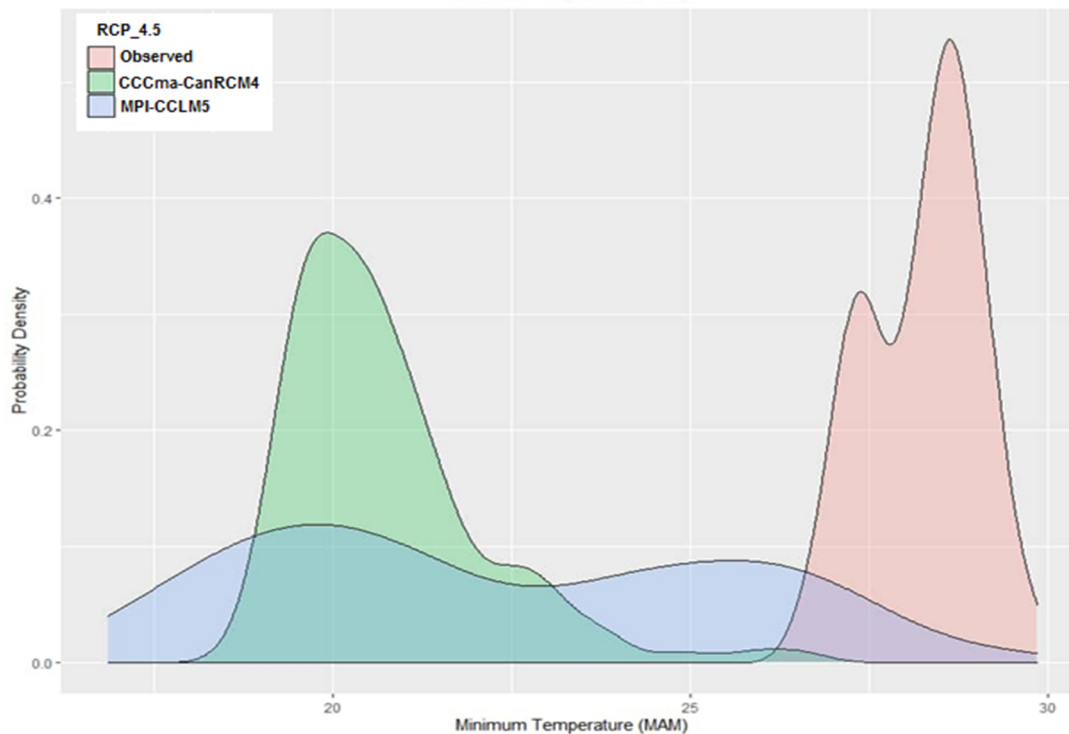


Figure 2: Probability Density Function of minimum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 4.5 in March, April and May over West Africa

Under the RCP 8.5 scenario (Figure 3), the models and observed PDF disagreed at the distribution as the PDF tend to increase from 0.1 to 0.3 with gap from the observed as the models (CCCma-CanRCM4 and MPI-CCLM5) underestimated the observed minimum temperature ranging from 17°C to 30°C, although both models are in consensus in their underestimation with a spike in CCCma-CanRCM4 for PDF value ranging from 0.1-0.35 in March, April and May from 1979-2018 over West Africa. PDF yielded skill score for the minimum temperature revealed at 0.9 and 0.88 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 8.5 scenario in March, April and May from 1979-2018 over West Africa. (Figure 11).

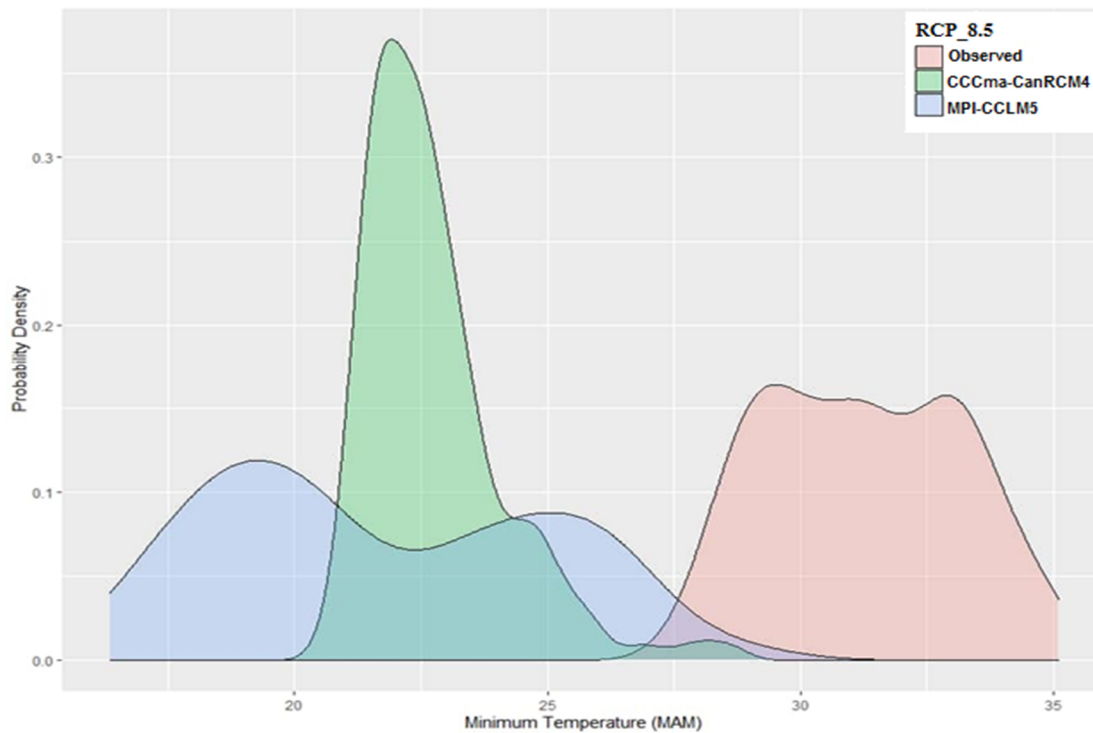


Figure 3: Probability Density Function of minimum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 8.5 in March, April and May over West Africa.

(b) Maximum Temperature

Over West Africa under the RCP 4.5 scenario, there is a strong agreement between the distribution of model and observed PDF for the maximum temperature as the PDF increases between 0.1 to 0.2 within the range of maximum temperature of 32.5°C to 36.0°C where the observed and MPI-CCLM5 revealed an agreement while the CCCma-CanRCM4 overestimated the PDF with a spike of 0.45 in March, April and May from 1979-2018 (Figure 4). The validation of the PDF yielded skill score for the maximum temperature revealed at 0.86 and 0.81 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 4.5 scenario in March, April and May from 1979-2018 over West Africa (Figure 10).

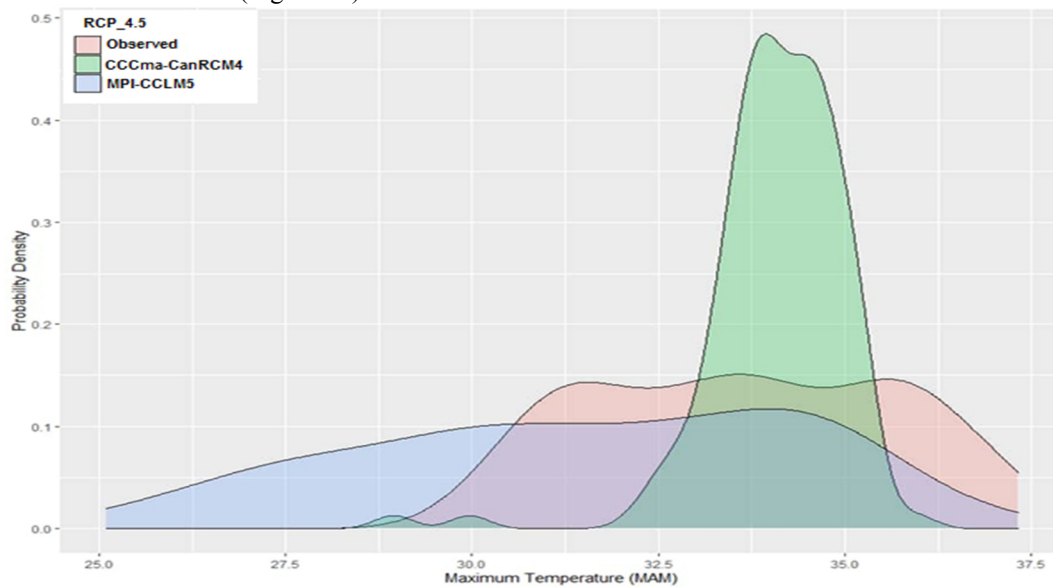


Figure 4: Probability Density Function of maximum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 4.5 in March, April and May over West Africa

Under the RCP 8.5 scenario (Figure 5), the models and observed PDF strongly agree at the distribution as the PDF tend to increase 0.1 to 0.5 within the range of maximum temperature of 33°C to 37°C while the CCCma-CanRCM4 overestimated with a spike in the PDF of 0.48 in March, April and May from 1979-2018 over West Africa. The PDF yielded skill score for the maximum temperature revealed at 0.87 and 0.85 for CCCma-CanRCM4

and MPI-CCLM5 models respectively under RCP 8.5 scenario in March, April and May from 1979-2018 over West Africa (Figure 11).

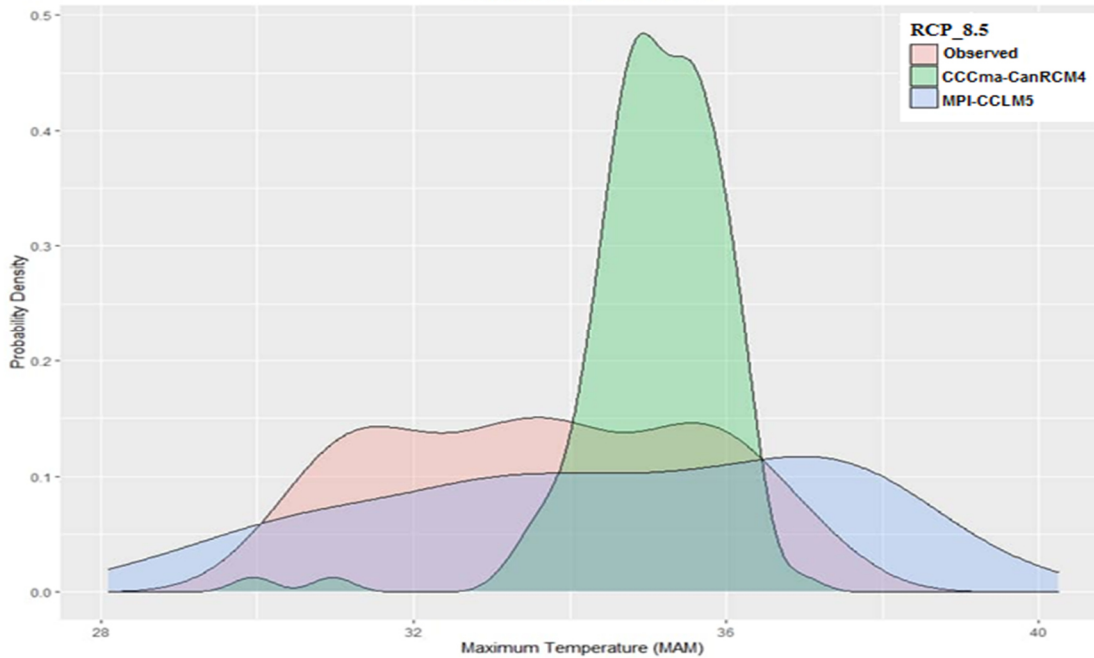


Figure 5: Probability Density Function of maximum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 8.5 in March, April and May over West Africa

3.1.2 June, July, August and September

(a) Minimum Temperature

Model and observed PDF strongly agree at the distribution as the PDF tend to increase from 0.1 to 0.47 and there is an evident in more agreement of the CCCma-CanRCM4 and the observed where the PDF is between 0.1 to 0.25 while the MPI-CCLM5 indicated some deviation from the observed by underestimating as the PDF of the minimum temperature as the PDF increases on RCP 4.5 in June, July, August and September over West Africa (Figure 6). The validation of the PDF yielded skill score for the minimum temperature revealed at 0.87 and 0.82 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 4.5 scenario in June, July, August and September from 1979-2018 over West Africa (Figure 12).

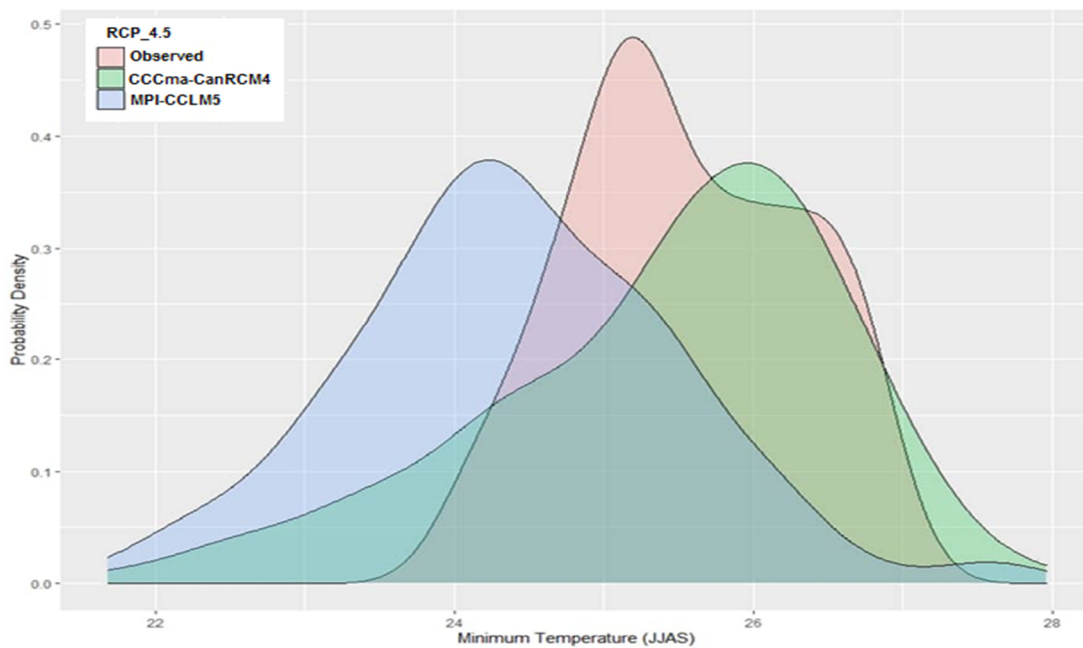


Figure 6: Probability Density Function of minimum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 4.5 in June, July, August and September over West Africa

Under the RCP 8.5 scenario (Figure 7), the models and observed PDF fairly agree at the distribution as the PDF tend to 0.1 to 0.4 where the CCCma-CanRCM4 overestimated the PDF with minimum temperature above 30°C and the observed agreed with MPI-CCLM5 model revealed PDF value of 0.1 to 0.38 in June, July, August and September over West Africa. The PDF yielded skill score for the minimum temperature revealed at 0.88 and 0.84 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 8.5 scenario in June, July, August and September from 1979-2018 over West Africa (Figure 13).

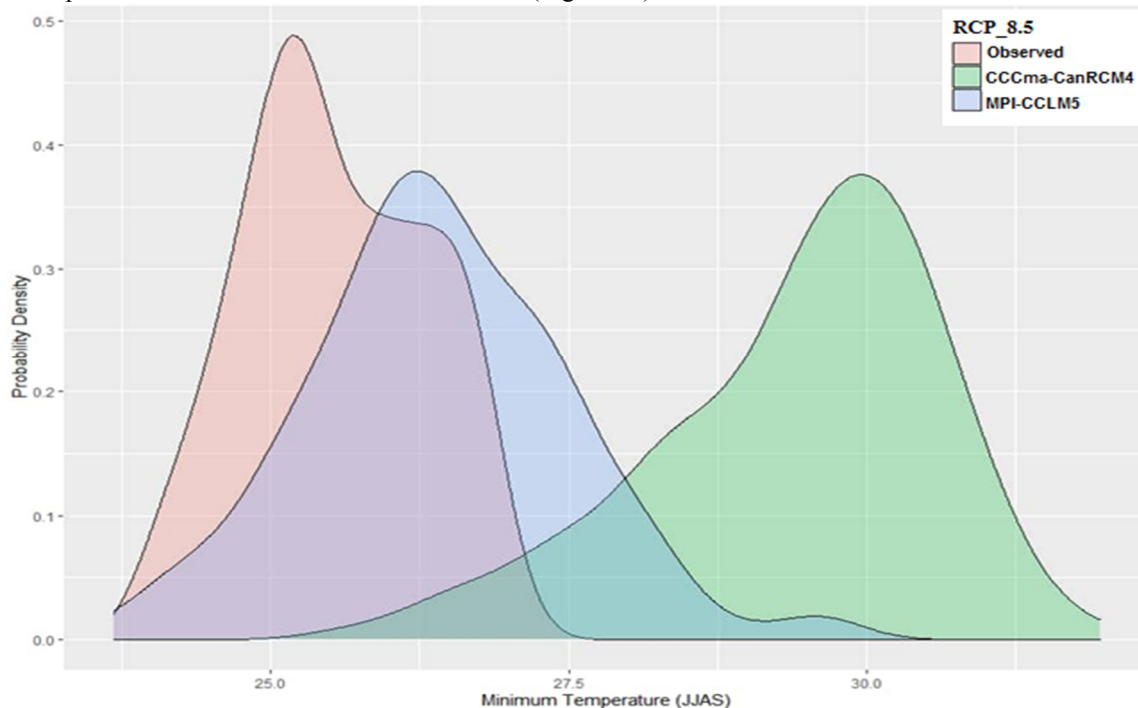


Figure 7: Probability Density Function of minimum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 8.5 in June, July, August and September over West Africa

(b) Maximum Temperature

Over West Africa under the RCP 4.5 scenario, there is a fair agreement between the distribution of model and observed PDF for the maximum temperature as the PDF increases from 0.1 to 0.15 with the MPI-CCLM5 model in fair agreement with the observed while the CCCma-CanRCM4 model overestimated the observed with a spike PDF value of 0.47 in June, July, August and September from 1979 to 2018 (Figure 8). The validation of the PDF yielded skill score for the maximum temperature revealed at 0.89 and 0.86 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 4.5 scenario in June, July, August and September from 1979-2018 over West Africa (Figure 12).

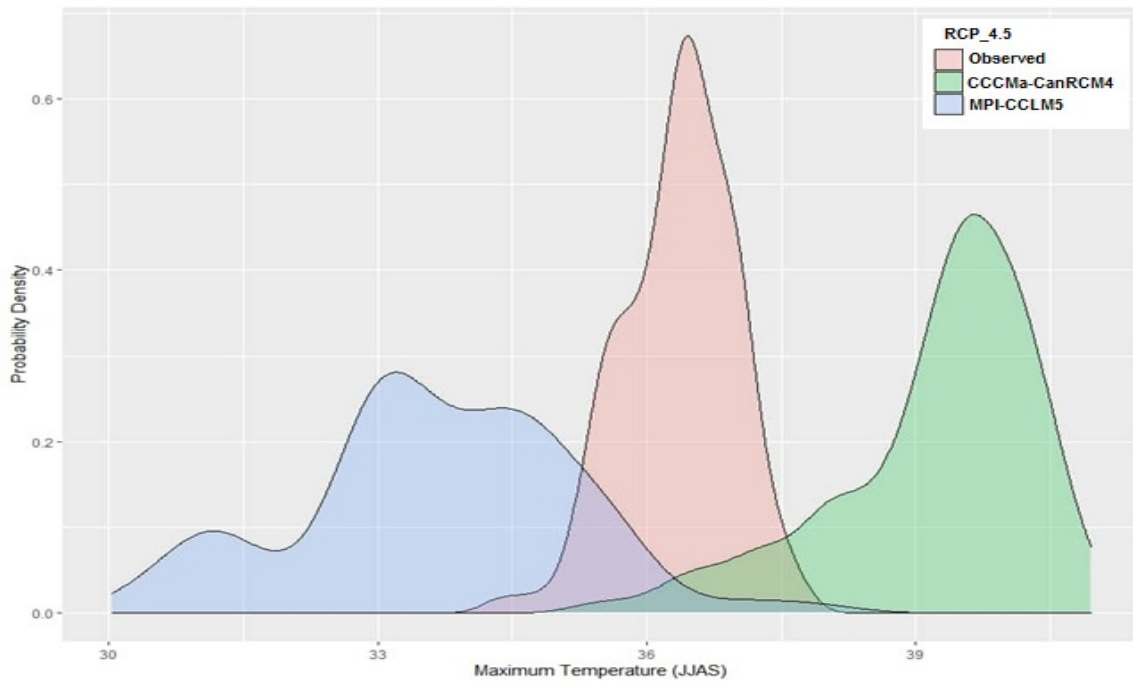


Figure 8: Probability Density Function of maximum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 4.5 in June, July, August and September over West Africa

Under the RCP 8.5 scenario (Figure 9), the models and observed PDF fairly agree at the distribution as the PDF tend to increase from 0.1 to 0.3 where CCCma-CanRCM4 model agreed with the observed and the MPI-CCLM5 model underestimated with the PDF value of 0.1 to 0.28 with maximum temperature range from 27°C to 35°C relatively low compared with CCCma-CanRCM4 and the observed from 1979 to 2018 in June, July, August and September from 1979-2018 over West Africa. The PDF yielded skill score for the maximum temperature revealed at 0.86 and 0.85 for CCCma-CanRCM4 and MPI-CCLM5 models respectively under RCP 8.5 scenario in June, July, August and September from 1979-2018 over West Africa (Figure 13).

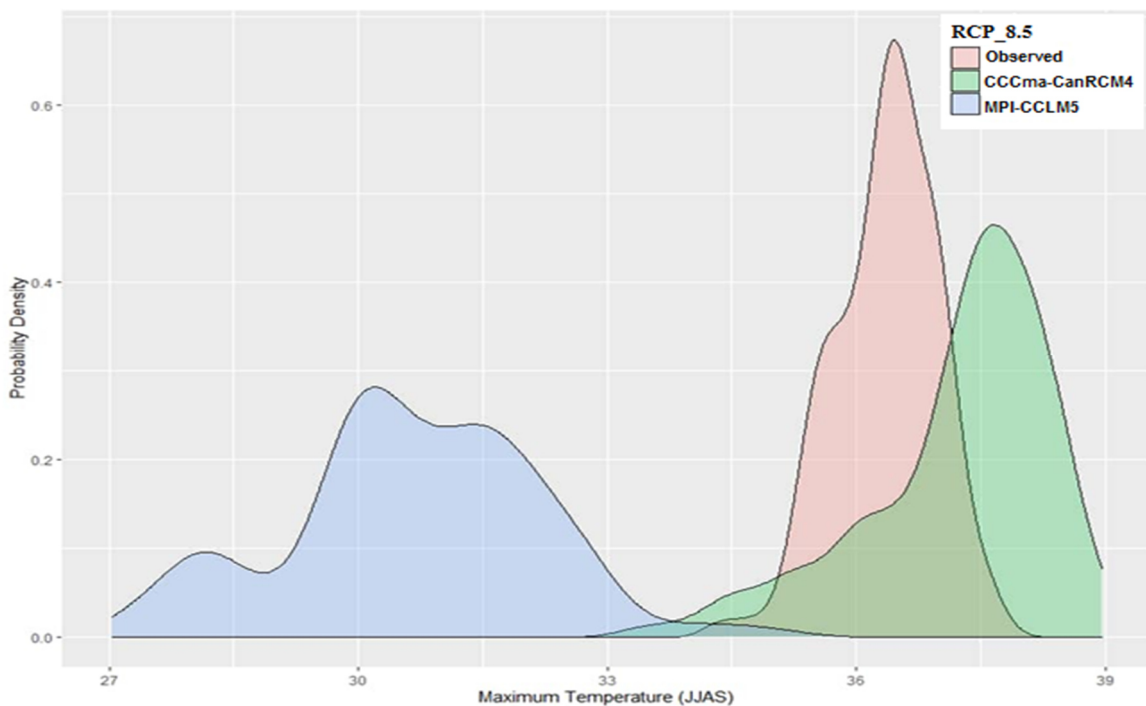


Figure 9: Probability Density Function of maximum temperature for Observed, CCCma-CanRCM4 and MPI-CCLM5 on RCP 8.5 in June, July, August and September over West Africa

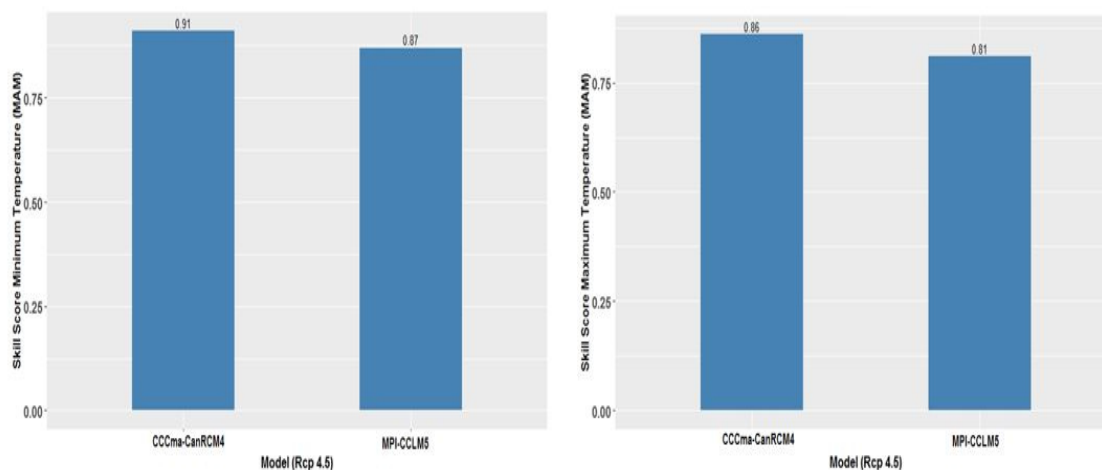


Figure 10: PDF-based skill score for the models for simulating minimum and maximum temperature for March, April and May under RCP 4.5.

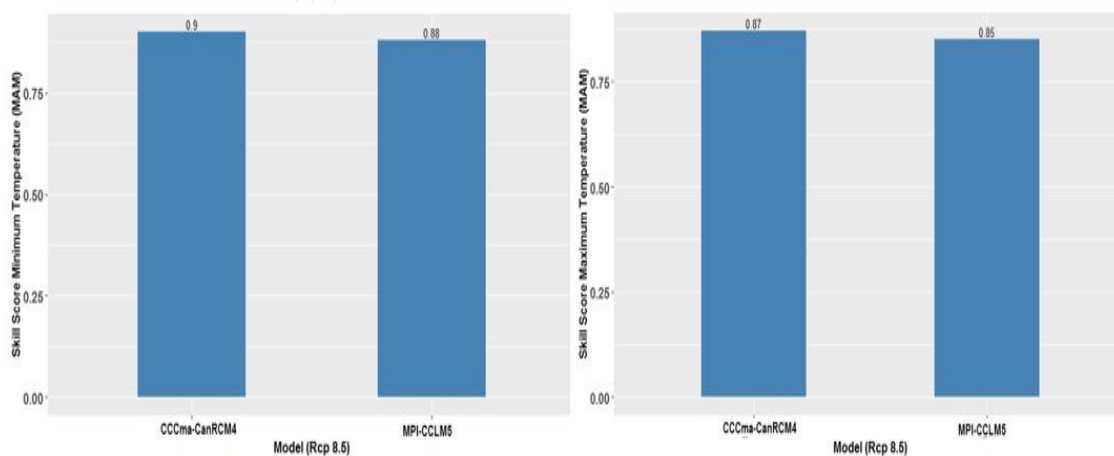


Figure 11: PDF-based skill score for the models for simulating minimum and maximum temperature for March, April and May under RCP 8.5.

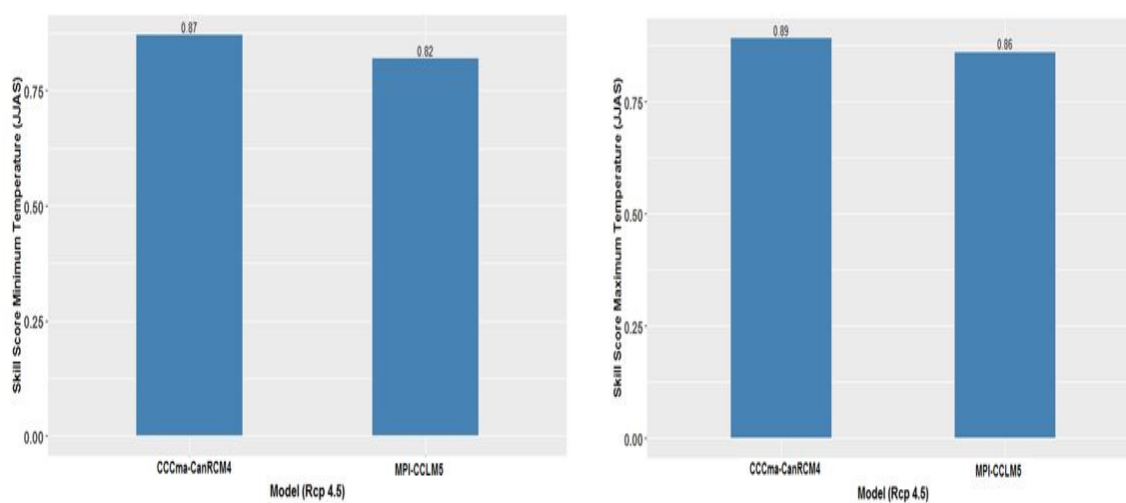


Figure 12: PDF-based skill score for the models for simulating minimum and maximum temperature for June, July, August and September under RCP 4.5.

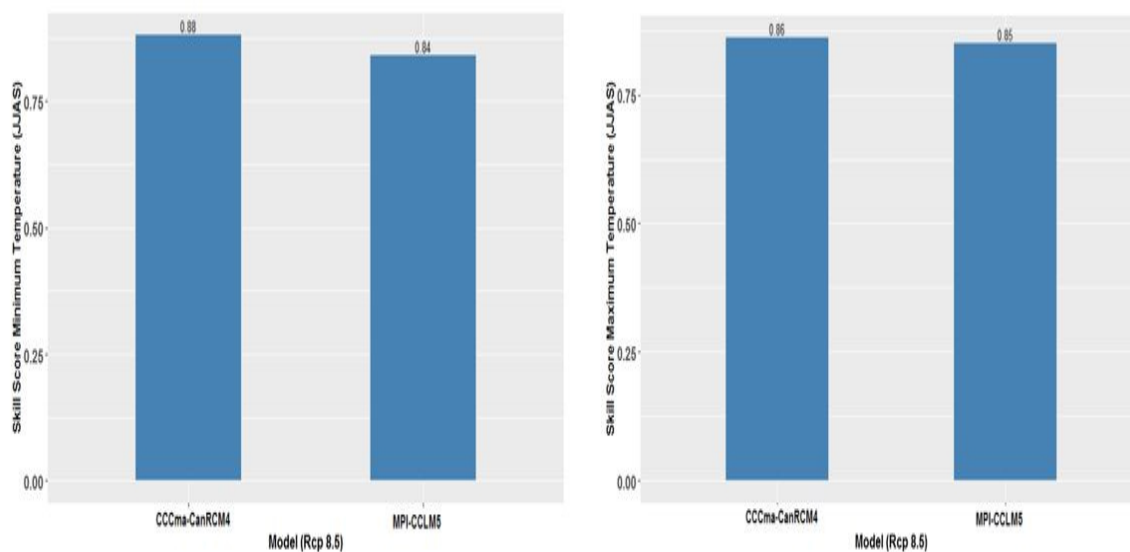


Figure 13: PDF-based skill score for the models for simulating minimum and maximum temperature for June, July, August and September under RCP 8.5.

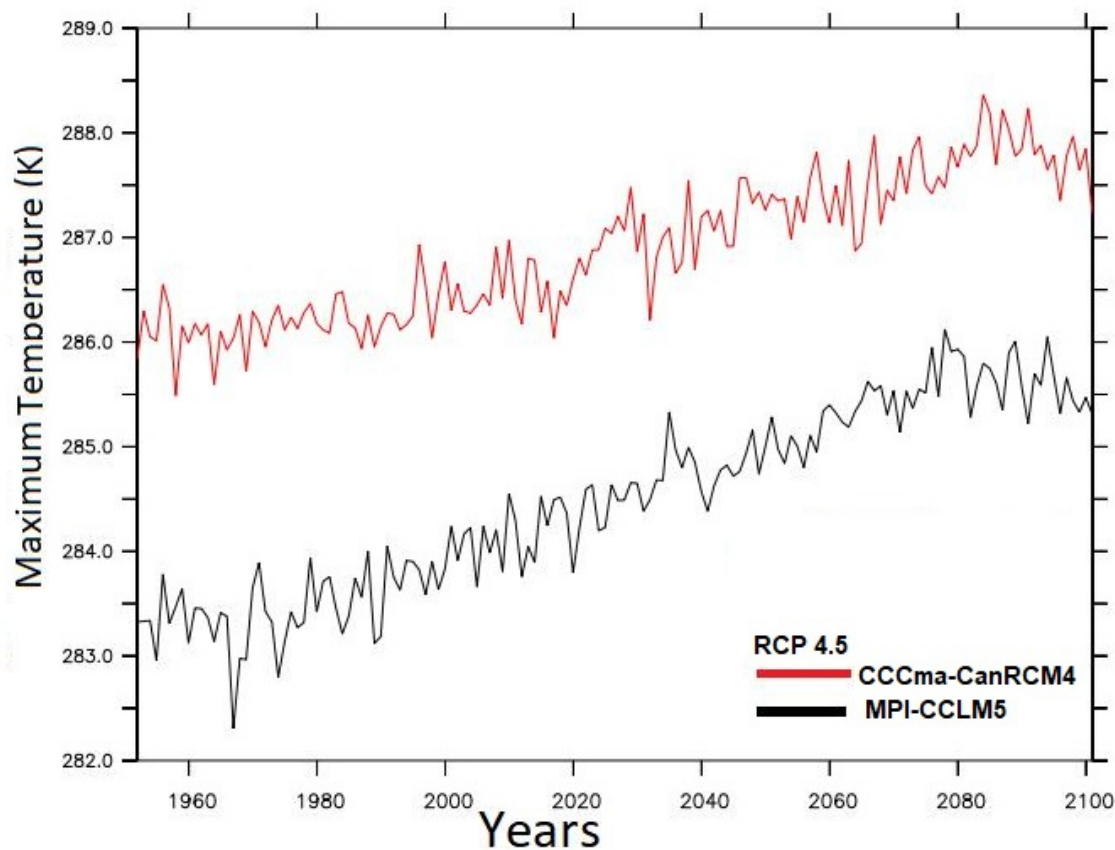


Figure 14: Maximum temperature for CCCma-CanRCM4 and MPI-CCLM5 under RCP 4.5 over West Africa

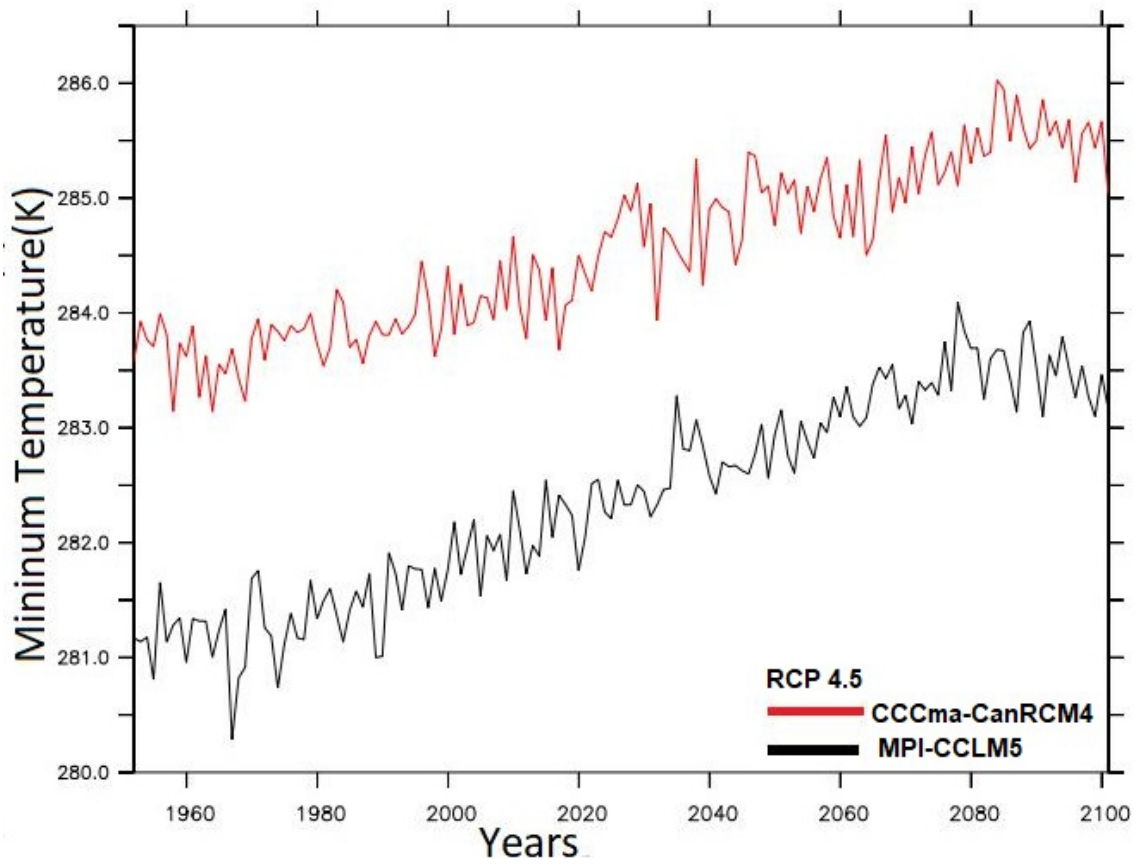


Figure 15: Minimum temperature for CCCma-CanRCM4 and MPI-CCLM5 under RCP 4.5 over West Africa

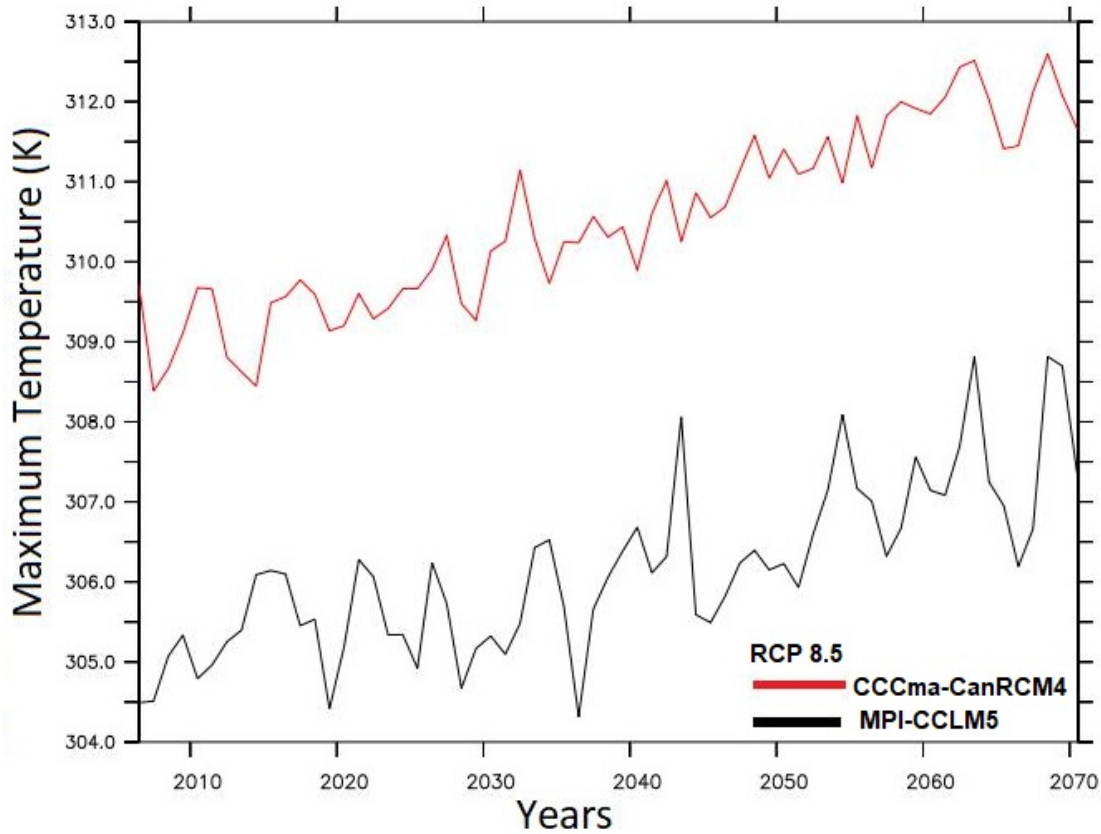


Figure 16: Maximum temperature for CCCma-CanRCM4 and MPI-CCLM5 under RCP 8.5 over West Africa

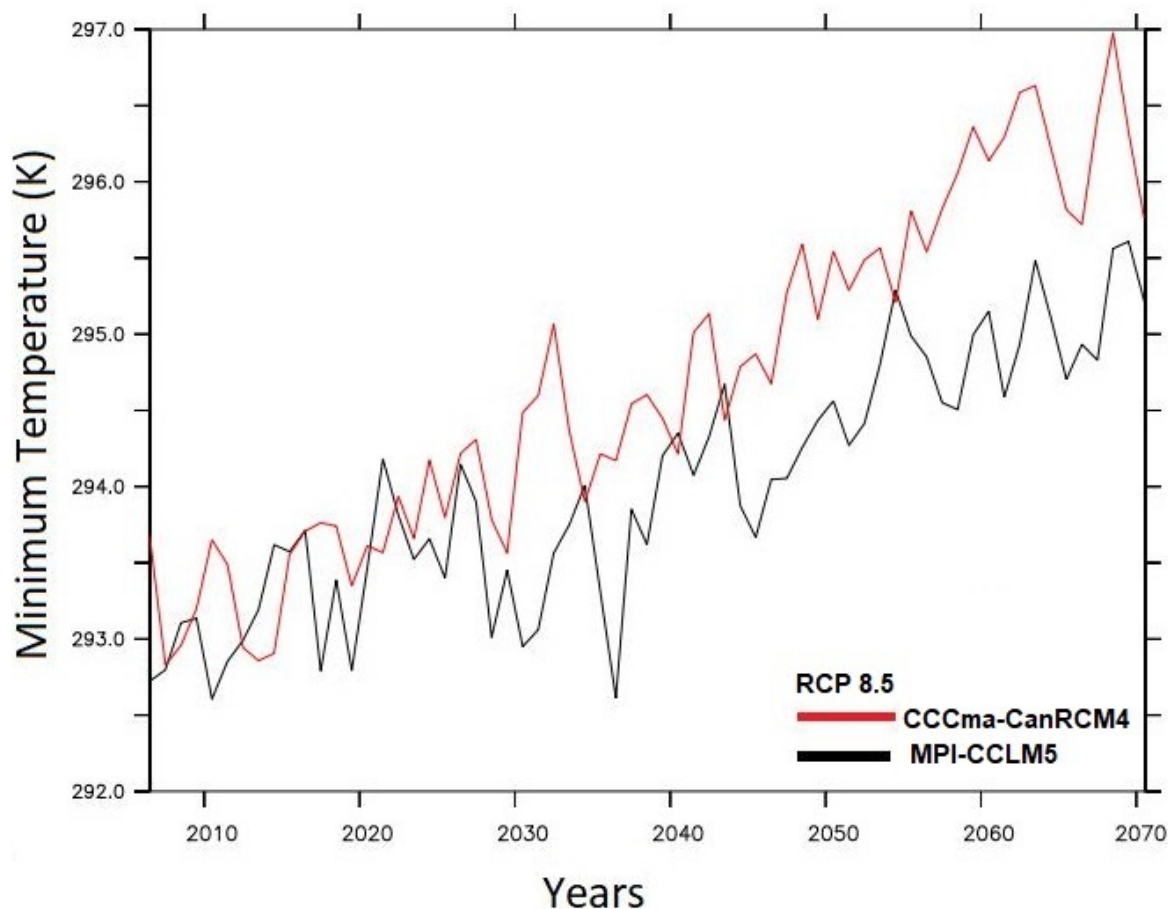


Figure 17: Minimum temperature for CCCma-CanRCM4 and MPI-CCLM5 under RCP 8.5 over West Africa

There is an evident warming trend as shown on (Figure 14-17) for CCCma-CanRCM4 and MPI-CCLM5 under RCP 4.5 and RCP 8.5 scenarios over West Africa. CCCma-CanRCM4 model projections under RCP 4.5 and RCP 8.5 was on the high side progressively above MPI-CCLM5 model, although both models revealed warming temperature conditions over West Africa which is in agreement with the report of Intergovernmental Panel on Climate Change (IPCC) working Group I (2021) of code red for humanity as the internationally agreed threshold of 1.5°C is perilously close.

Conclusion

The results from the study under RCP 4.5 and RCP 8.5 scenarios revealed an increasing temperature pattern with the observed, CCCma-CanRCM4 and MPI-CCLM5 in agreement, pointing towards a possible warmer climate over West Africa and this condition will negatively impact agricultural productivity, health and socio-economic activities over the region. This calls for possible climate adaptation and mitigation for a sustainable future to avoid migration and heightening on insecurity over West Africa.

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