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Projecting Future Changes in Precipitation and Temperature Anomaly in Nigeria

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Abstract
This paper examined current and future trends with change detection in temperature and rainfall in the three agro-climatic zones of Nigeria. The datasets are of Historical period of 1961 to 2000 and projection period of 2020–2099 with ensemble mean of seven different Regional Climate Models (RCMs). Three statistical change point detection techniques were adopted to identify accurate change in the climate parameters and trends at 5% significant level. The ensemble-mean evaluation performed for the historical period (1961–2000) using Centre for Research Unit (CRU) dataset revealed that the change point occurred with precipitation and temperature series in the 1970s and 1980s, while there were significant increasing trend observed with temperature in all the three climatic zones.
Homogeneity characterized projected precipitation with change-point detection and as well as positive significant change point is expected to occur with temperature for all climatic zones under RCP4.5 and RCP8.5 for future period of (2020–2099) with increase in the mean annual temperature trend 0.026–0.38 ℃ Projected relative change in seasonal cycle shows that winter months may witness increase in precipitation amounts under RCP4.5 but could significantly dry under RCP8.5 in near and far-future as temperature is expected to rise in certain months of the year. Decadal precipitation anomaly projects the Sahel to have a reduced amount of precipitation compared to other zones as temperature anomaly reveals a continuous increase in all the zones under the two RCPs. The results of this study show and affirm that climate variability and change will intensify in Nigeria in the near and far future.
***Keywords**: evaluation, precipitation, simulation, temperature and winter*

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I. Introduction

Natural processes and most especially human-induced forces have been responsible for the modification of climate pattern (IPCC 2007a) in Africa and in particular Nigeria. This is due to increase in Green House Gases (GHGs) emission through bush burning, unlawful dump sites, unguided grazing, and uncontrolled automobile exhaust fumes and as well as constant burning of fossil fuel. These in turn have results into increase in the occurrence of extreme weather and climate events (Akinsanola and Zhou 2018; Gbode et al. 2019) such as increase in air temperature above average of 1.5^{o}C (IPCC AR5, 2013), changes in spatio-temporal pattern of rainfall and temperature (Sylla et al. 2016) and sea level rise (IPCC, 2013). According to the fifth assessment report of the Intergovernmental Panel on Climate Change (IPCC AR5, 2013), projected average air temperature over Africa could exceed the twentieth-century range of variability by 2047 and 2069, under Representative Concentration Pathways (RCPs) RCP8.5 and RCP4.5, respectively (Niang *et al*. 2015).

More so, Collins (2011) reported that in Africa and Nigeria in particular the temperature has been increasing at about 0.15 °C per decade. It is important to point out that the extent of change in temperature, precipitation, and all other climatic variables are not spatially and temporally uniform across the world (IPCC 2014; Yue and Hashino 2003). This regional variation is as a result of the differences in surface albedo, types of land surfaces, evapotranspiration and Green House Gas (GHGs) emission rate among many other factors affecting the climate in many forms (Meissner et al. 2003; Synder et al. 2004).. Evidences have also shown that the durations and intensities of rainfall have increased in some parts of the country, producing large runoffs and flooding in many places in Nigeria. Most climatic regions for instance have continued to experience precipitation anomaly patterns and which is quite noticeable during exreme precipitation which induces flood conditions based on interannual and intraseasonal time scale (Nicholson, 2013).

However, only very few studies had examined trends and change point detection in climate variables. Hence, this study aimed at using ensemble mean of seven Regional Climate Model (RCMs) adopted for the Co-Ordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi *et al.* 2009) to assess trends and change point detection in precipitation and temperature over Nigeria from 1961 to 2099 for both historical and the future projection. The ensemble mean of seven RCMs and individual RCMs replicates the pattern of Nigeria climate and features such as summer monsoon very well though with varying degree of skills (Lambert and Boer 2001; Kim et al. 2014; Akinsanola et al. 2015).

II. Data and Methodology

2.1.Data

This section focuses on different type of datasets used for this study. An ensemble mean of seven Regional Climate Models (RCMs) were computed and driven by five different coupled Modelling Intercomparison Project (CMIP5) Global Circulation Model in the CORDEX framework (Nikulin *et al*. 2018). The observations from the performance evaluation of the RCMs datasets used in simulating temperature and precipitation variability over Nigeria shows that the selected RCMs as shown in Table 1 performed better in replicating the pattern of temperature and precipitation (Nikulin et al. 2012; Gbobaniyi et al. 2014; Akinsanola et al. 2015; Ajayi and Ilori 2020). The study period is from 1961 to 2000 for the historical datasets and the time scale slice for near-future from 2020 to 2059 and far-future from 2060 to 2099 respectively. The selected RCMs dynamically downscaled seven GCM simulations at a horizontal resolution of 0.44° × 0.44° (Dieterich et al. 2013; Panitz et al. 2014). Also, the daily temperature and precipitation datasets from CORDEX were converted to monthly data format and were utilized over the three climatic zones of Nigeria. An evaluation of all seven CORDEX datasets was performed based on ensemble mean with the gridded dataset of Climate Research Unit (CRU: Harris et al. 2014) version v4.03 to simulate seasonal cycle of temperature and precipitation, trend and change point detection. Table 1 highlight all the RCMs used and their driven GCMs.

Table 1. List of seven Regional Climate Models employed in the study

S/N	INSTITUTE	GCMs	Downscaling RCMs
1	Norwegian Climate Centre (Norway)	NCC-NorESM1-M	HIRHAM5
2	NOAA Geophysical Fluid Dynamics Laboratory, USA	NOAA-GFDL-GFDL-ESM2G	REMO
3	National Institute for Environmental Studies, And Japan Agency For Marine-Earth Science and Technology (MIROC), Japan	MIROC-MIROC5	RCA4
4	Consortium of European Research Institution and Researchers	ICHEC-EC-EARTH	RACMO
5	Max Planck Institute for Meteorology (Germany)	MPI-M-MPI-ESM-LR	CCLM4
6	Canadian Centre For Climate Modeling and Analysis (Canada)	CCCma-CanESM2	CRCM5
7	Institute Pierre-Simon Laplace, France	IPSL-IPSL-CM5A-MR	RCA4

2.2. Methodology

Performance evaluations of the ensemble mean were used with different parameters to ascertain how well the simulation data replicate the precipitation and temperature over the country Nigeria. The parameter observed includes Mean Bias Error (MBE), Mean Gross Error (MGE), correlation coefficient (r), and Nash-Sutcliffe Efficiency (NSE). Change point detection test was also performed using the Pettit's test, Standard Normal Homogeneity Test (SNHT), Buishand's range test over the three homogeneous climatic zones at 5% significant level while Mann-Kendall trend test was used to examine trend in temperature and precipitation spatially over Nigeria and over the agro-climatic zones at 5% significant level. The standardized Rainfall Anomaly Index (SRAI) was also adopted to examine the degree of dryness and wetness of each year in the reference, near-future and far-future periods while Standardized Temperature Anomaly Index (STAI) was used to access the extent of warmth and cold relative to the near-future and far-future respectfully.

III. Results And Discussion

It can be seen that ensemble mean reproduced precipitation and temperature pattern over the three climatic zones but overestimates and also underestimate in some months. This can be associated to different parameterization schemes used in the various RCMs that made up the ensemble mean (Afiesimama et al. 2006; Diallo et al. 2012).

Table 2: Results of the statistical evaluation between the observation and ensemble mean precipitation over the three agro-climatic zones of Nigeria

CLIMATIC ZONE	NSE	MBE	MGE	r
GUINEA COAST	0.84	23.9	31.73	0.89
SAVANNAH	0.85	14.04	24.14	0.93
SAHEL	0.89	11.67	26.25	0.95

TABLE 3: Results of the statistical evaluation between the observation and ensemble mean temperature over the three agro-climatic zones of Nigeria

CLIMATIC ZONE	NSE	MBE	MGE	*r*
GUINEA COAST	0.84	12.57	16.09	0.92
SAVANNAH	0.79	14.86	13.25	0.89
SAHEL	0.80	-14.01	15.37	0.88

The change-point detection (HGN) is observed for both RCP4.5 and 8.5, an indication that no change occure in the precipitation time serie for all the three climatic zones as observed in Table 6. However, for the temperature series under RCP4.5, a change point expected to occur over the Guinea Coast and the Sahel by the year 2038 and 2036 respectively and that may be as a result of the projected increase in the annual mean of temperature within the range of 0.56–0.91 ℃ in the near future as observed in Table 6. There is posibility of positive shift in the mean annual temperature which is likely to take place in Guinea ncoast and Savannah climatic zones by the year 2044 within the range of 1.26 and 1.16 ℃ in the near-future under RCP8.5 emission scenario.

The near-future precipitation trends under RCP4.5 indicate that there are indication of significant precipitation trends nearly in all three climatic zones of Nigeria excepts for the Guinea coast where there are insignificant trends of precipitation and this is due to homogeneity of precipitation pattern in the region but for the projected precipitation under RCP8.5 there are indication of more insignificant precipitation trends seen especially in the Savannah and Sahel region of the country. This means there is likely more drought events in the near future in the Savannah and Sahel region of Nigeria in relation to (IPCC, 2013) hypothesis that some regions will become warmer in sub-Sahara Africa.

Mean temperature under RCP4.5 shows very significant trends in the Savannah and Sahel region of Nigeria than the Guinea coast region with an annual average temperature change of 0.034 but with less varying degree in the Coastal region while the mean temperature under RCP8.5 shows greater significant change from Coastal area to the Sahel with varying degree of about 0.038 in the Sahel region. This means that mean temperature will still be under the base line of 1.5^{o}C under RCP4.5 in the near future but likely to exceed the target of 1.5^{o}C in far future under RCP8.5 scenario.

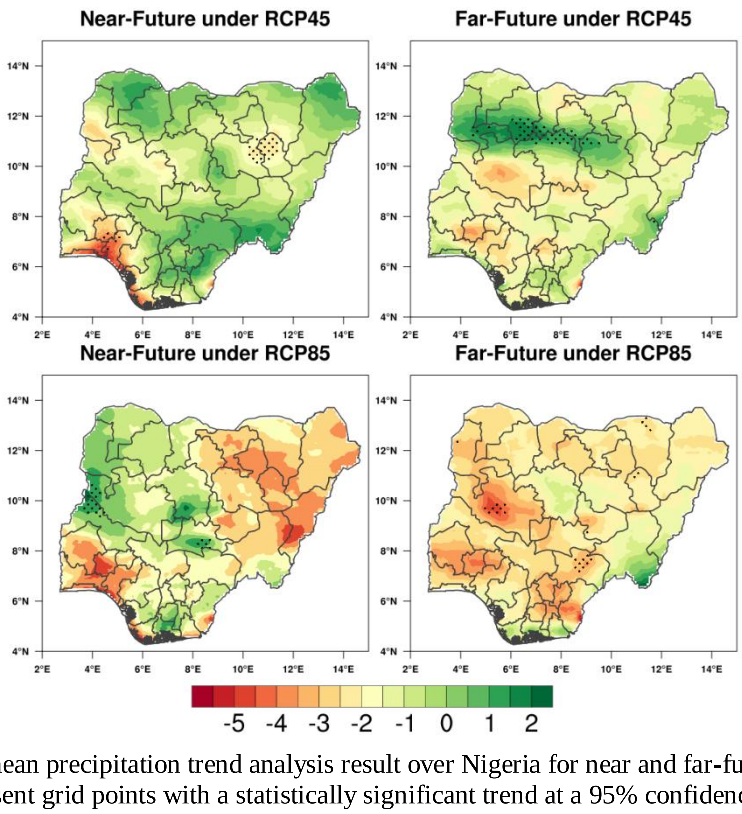

Figure3. Annual mean precipitation trend analysis result over Nigeria for near and far-future Stipples on the plot represent grid points with a statistically significant trend at a 95% confidence interval.

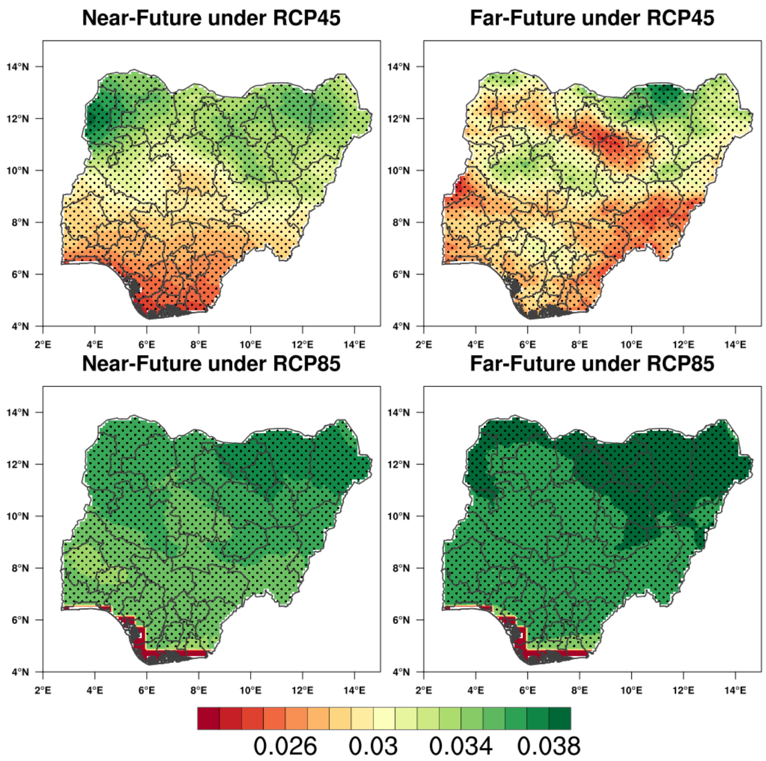

Figure4. Mean annual temperature trend analysis result over Nigeria for near and far future. Stipples on the plot represent grid points with a statistically significant trend at a 95% confidence interval

Table 3.Trend analysis over the three climatic zones for near-future

Scenario	CLIMATIC ZONE	PRECIPITATION		TEMPERATURE	
		P-value	Sen's Slope	*P*-value	Sen's Slope
RCP4.5	GUINEA COAST	0.6025	-0.824	**0.0011**	0.022
	SAVANNAH	0.5012	0.689	**0.0001**	0.029
	SAHEL	0.7142	0.266	**0.0026**	0.035
RCP8.5	GUINEA COAST	0.5010	2.502	**0.0019**	0.062
	SAVANNAH	0.1575	1.977	**0.0013**	0.068
	SAHEL	0.2736	0.814	**0.0003**	0.071

The relative change in decadal rainfall in Guinea coast under RCP4.5 in figure 5a projects moderately wet and dry years in the first decade 2020-2030 and as well as moderate wet years with no significant dry years in the second decades of 2030-2040 while there are projected extreme wet and dry years in 2040-2050 and mildly dry years in last decades of 2050-2060 respectively

Standardized Rainfall Anomaly Index (SRAI) under RCP8.5 for the near-future projects moderately decadal dry years from 2030-250 in the Guinea coast and with moderately extreme wet years in the first and last decades of 2050-2060. In the same vein, there are projected moderately dry years of precipitation for two decades of 2030-2050 in the Savannah (Figure 5b) with moderate and severe precipitation in 2020-2030 and 2050-2060 respectively. In Sahel, the decadal precipitation pattern takes the same pattern with Savannah except the high intensity of dryness in the decades of 2030-2050 with moderate precipitation in the first and the middle of last decades. In all, there are projected dry years in the near future with high decadal precipitation variation across the three climatic zones of Nigeria.

Figure 3 revealed that over the three homogeneous climatic zones, the temperature is projected to be warmer than the historical period under RCP4.5 and RCP8.5 with the later higher than the former. Also, the rate of increase in temperature relative to historical mean was noticed to be higher under RCP8.5 when compared to lower emission scenarios (RCP4.5). Since the warmer atmosphere can hold larger moisture (Lenderink and Meijgaard 2010), the projected increase in rainfall relative to the historical mean over the Guinea Coast and Savannah may be associated with the expected increase in temperature.

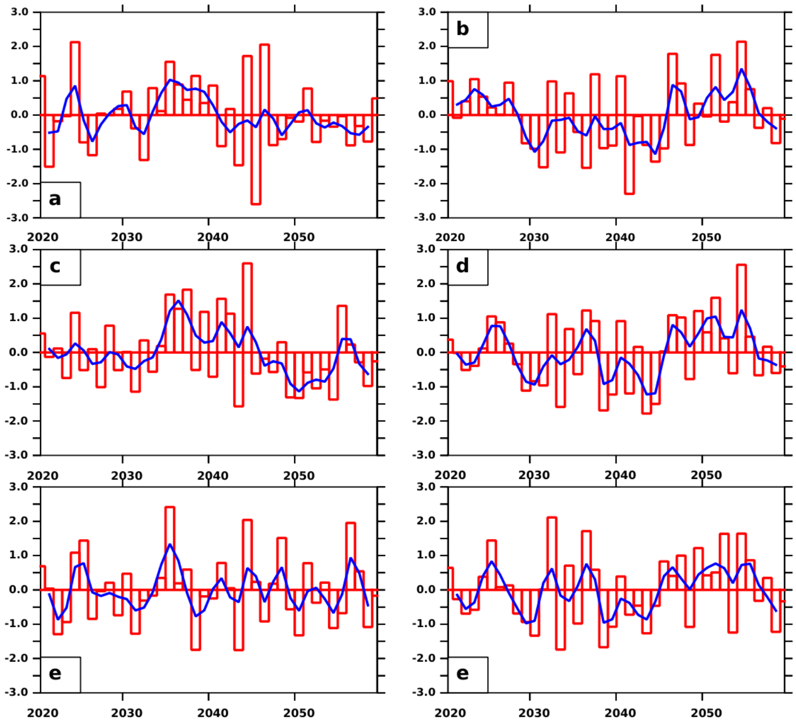

Figure 5. Standardized Rainfall Anomaly Index (SRAI) for the near-future under RCP4.5 (left panels) and RCP8.5 (right panels) over the Guinea Coast (a,b), Savannah (c,d) and Sahel (e,f) relative to the reference period (1961-2000) mean. Blue curve on each plot depicts non-linear trend of two years moving average

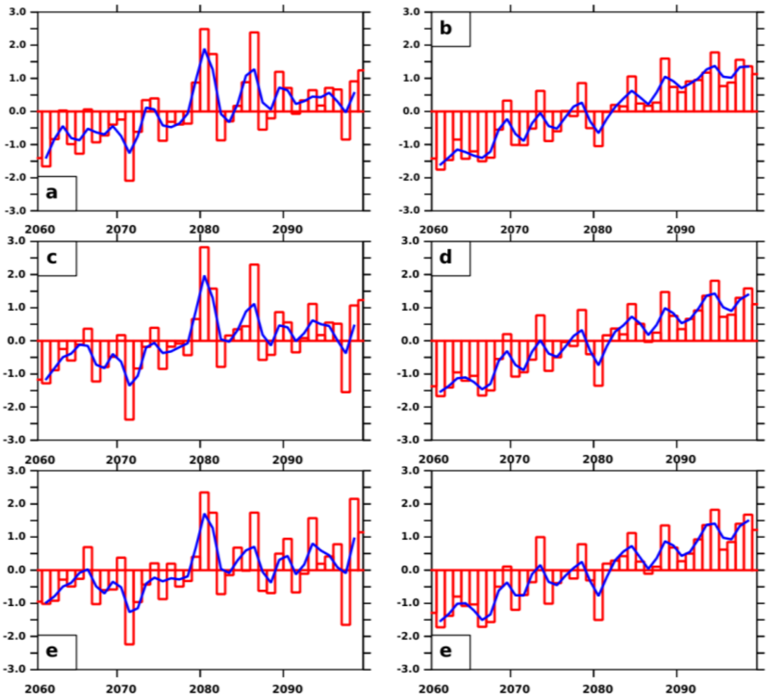

Figure 7. Standardized Temperature Anomaly Index (STAI) for the far-future under RCP4.5 (left panels) and RCP8.5 (right panels) over the Guinea Coast (a,b), Savannah (c,d) and Sahel (e,f) relative to the reference period (1961-2000) mean. Blue curve on each plot depicts non-linear trend of two years moving average

IV. Summaries and Conclusion

The capabilities of the ensemble mean of the RCMs to detect change point and reproduce seasonal cycle was firstly assessed by comparing its results to that of CRU for the historical period.. The results are summarized as follows:

- The ensemble mean used reproduced the observed seasonal variation and pattern of rainfall and temperature as seen from the CRU over the three agro-climatic zones.
- At a 5% significant level, both the ensemble mean and CRU observation agree that a significant change point in temperature and rainfall occurred in the 1970s and 1980s decades in all three climatic zones. These are well-known decades with prolonging droughts over Nigeria as a statistical significant increase in temperature was observed in the two datasets.
- Projected change in seasonal cycle relative to the historical period for the near-future revealed that winter months will receive more rainfall under RCP4.5 while the temperature will be warmer in all the months under both pathways with more warming under RCP8.5. Annual anomaly relative to historical long-term mean projects Guinea Coast and Savannah to have increased rainfall amount under RCP4.5, rainfall in the Sahel will be reduced under the two emission scenarios as temperature expected to be warmer than the historical period under RCP4.5 and RCP8.5.
- In the far-future, rainfall expected will remain homogeneous under the two emission scenarios, change point expected to occur by 2077 under RCP4.5 while it will be between 2080 and 2081 under RCP8.5 in all the zones. A positive shift in the temperature means that could reach 1.67 ℃ projected across the three climatic zones under the two emission scenarios as increasing temperature trend will be statistically significant.
- Projected change in temperature seasonal cycle relative to the historical period will be warmer under the two RCPs in all climatic zones. Also, rainfall anomaly revealed that the Sahel will continue to have a lesser amount of rainfall as the annual mean temperature will continue to rise under the two scenarios till the end of the twenty-first century in all the three climatic zones of West Africa.

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