AN ASSESSMENT OF FUTURE CLIMATE CHANGE IN NORTH WEST NIGERIA USING DOWNSCALED CLIMATE MODEL SIMULATIONS

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ABSTRACT

The sub-Saharan Africa has been classified vulnerable to climate change and variability. Northwestern Nigeria is located in this region and is expected to be disproportionately affected due to the vulnerability of its populations. Future climate change in northwestern Nigeria for two time slices was assessed using thirteen statistically downscaled global climate model projections from the Coupled Model Intercomparison Experiment Phase 5 (CMIP5) for Representative Concentration Pathway (RCP) 2.6, 6.0 and 8.5 scenarios. The results show that the ensemble mean captures the observed seasonal cycle and magnitude of maximum and minimum temperature, rainfall, and humidity with remarkable accuracy. In the near future (2020-2035) maximum temperature increases of about 0.5-1^{o}C are statistically significant ($p<0.01$), while in the far future (2060-2075) maximum temperature increases of 1-3^{o}C occur in 9-of-12 months ($p<0.01$), and increases are also significant ($p<0.1$ or 0.05) in the other three months. Humidity does not change significantly in the near or distant future except for a small but significant increase in December of about 1% ($p<0.10$; 2020-2035) to 2% ($p<0.05$; 2060-2075). While rainfall, exhibits statistically significant changes during December and January in both future periods but rainfall amounts is nearly zero during these months already, so the changes are almost imperceptible.

Key words: Climate change, CMIP5, Downscaling, North West Nigeria

INTRODUCTION

Many regions in Africa are classified as vulnerable to climate change and variability (Diffenbaugh and Giorgi, 2012). This change is expected to have substantial negative impacts on several aspects of human endeavors, such as change in the ecology and dynamics of some infectious diseases. The Sahel, including northwestern Nigeria, are areas identified as "hotspots" of climate change (Diffenbaugh and Giorgi, 2012), and are projected to be disproportionately affected due to the vulnerability of the populations (Suk and Sumenza, 2011).

The scientific evidence of the changing climate is clear and is likely to have negative impacts on efforts to achieve Nigeria's development objectives, including the targets set out in Nigeria Vision 20:2020 and the Sustainable Development Goals (SDGs). Climate change is expected to induce changes in the country, such as ecosystem degradation and reduced availability of water and food. It is also expected to become a major driver of increased human conflict, most especially the farmers – herders crisis which is majorly resource based that has direct link to climate change.

According to the Nigeria Meteorological Agency (NIMET), climate change is already having an impact in Nigeria. Weather-related disasters have become more frequent in the past four decades and the trend continues (NIMET, 2017). The nation's natural and agricultural ecosystems, including freshwater and coastal resources, are highly susceptible to the effects of climate change. These vulnerability factors make clear the urgent need to respond to the challenge of climate change in a comprehensive and systematic manner that, at the same time, addresses broader development priorities, taking account of the gender-differentiated needs and roles of the society.

Several efforts have been made to investigate the future changes of climate in Africa (Christensen et al., 2007; Giannini et al., 2008); the Sahel where northern Nigeria lies reveals more uncertainty in the future (Biasutti and Giannini, 2006) relatively due to the poor representation of the complex West African Monsoon (WAM) system. Despite these uncertainties, temperature in Africa is projected to increase in the future more than the global average (James and Washington, 2013) particularly in arid regions. In the case of rainfall, climate model simulations are showing increase in central Sahel and deficit in western areas (Fontaine et al., 2011; Monerie et al., 2012).

North West Nigeria is particularly vulnerable to climate change because of its physical and socioeconomic characteristics: widespread poverty, desertification, ecological disruption, high population growth rate and extreme weather events (NBS, 2015; NIMET, 2017). The region is suffering because many important issues of human and infrastructural development require urgent attention. Despite these glaring challenges, surprisingly, only few studies have been conducted on the potential future climate change in Nigeria, so not much is known about the most vulnerable region (northwest). The current study intends future climate change assessment in northwestern Nigeria for two time slices (2020-2035 and 2060-2075) using thirteen statistically downscaled global climate model projections from the Coupled Model Intercomparison Experiment Phase 5 (CMIP5) for Representative Concentration Pathway (RCP) 2.6, 6.0 and 8.5.

THE STUDY AREA

Nigeria is located in the West Africa region. It has an area of about 1 million square kilometers comprising 36 states and the Federal Capital Territory (FCT) (Figure 1). Currently the population of the country is over 190m people, with an average annual growth rate of 2.5% (World Bank, 2017). According to the recent World Bank data, Nigeria has an average life expectancy of about 50 years, a national poverty line of 54.7% and only about 35% of its total population have access to pipe-borne water. Social statistics obtained from the Nigeria's National Bureau of Statistics (NBS, 2015) corroborate these figures, with the highest level of poverty and lower adult literacy in the northern part of the country. These environmental and social characteristics qualify the northwest region of the country to be more susceptible to the impacts of climate change.

The northwest region currently has an estimated population of over 41 million people, and comprise seven states (Figure 1). The regional climate is characterized by two seasons, a short wet season from June to September, and a prolonged dry season for the remainder of the year. Daytime maximum temperatures remain consistently high throughout the year with maxima during March-May (up to 47°C), while relative humidity is low during the dry season, and increases during the wet season (NIMET, 2012). These mean regional climate conditions are mainly a consequence of the WAM system, which exhibits large spatiotemporal variability (Cornforth, 2012), especially with respect to regional rainfall distributions. The WAM is a large-scale wind system characterized by moist northward flow from the Gulf of Guinea during the wet season and a dry and dusty southward flow (Harmattan) during the dry season.

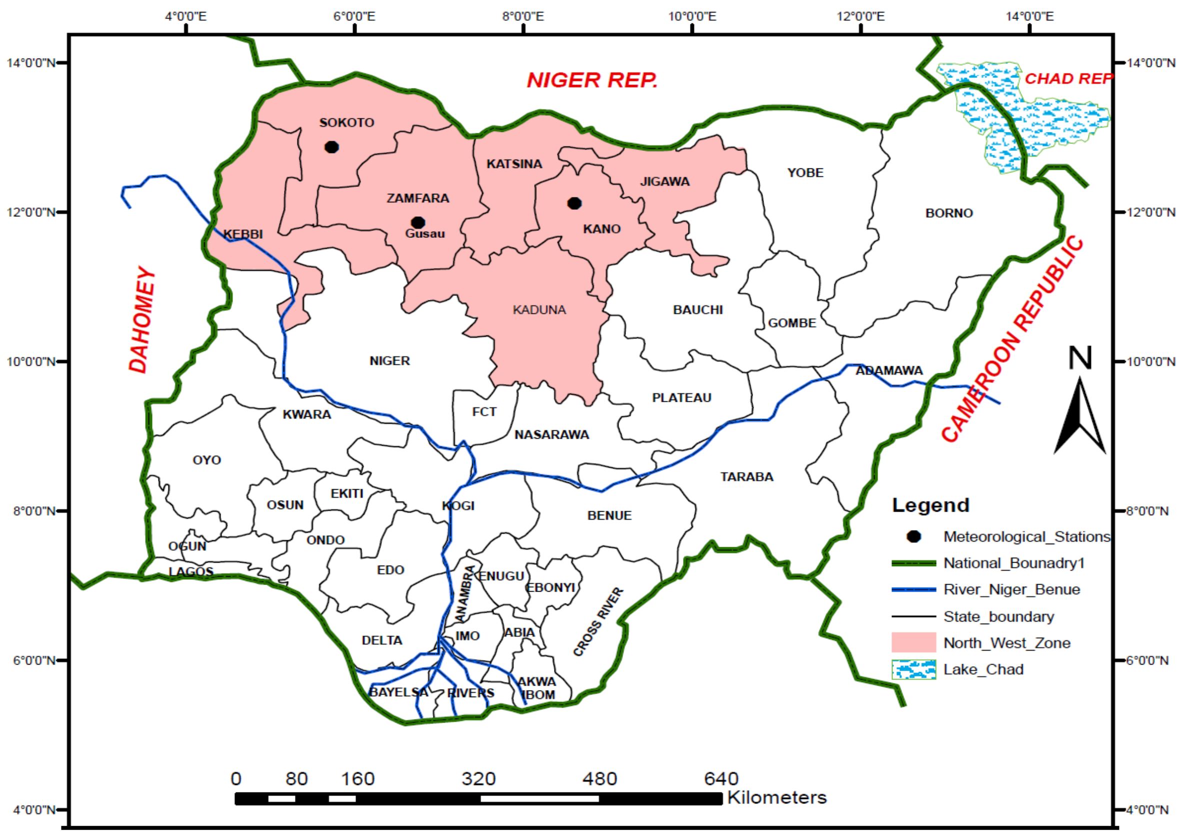

Figure 1: Nigeria showing the Northwest Region and selected Stations

MATERIALS AND METHODS

Station data

Digital records of daily maximum and minimum temperature, rainfall, and humidity for three selected synoptic meteorological stations (Sokoto, Gusau, and Kano) in the north-western region of Nigeria were obtained from the Nigerian Meteorological Agency between 1971 and 2014. Data were quality controlled to ascertain validity.

Climate model simulations

In this study, a wide range of climate models output were employed, monthly output from thirteen coupled AOGCM that participated in the CMIP5 were employed (Table 1). These sets of models have undergone a few changes and improvement, if compared with the former CMIP3.

This is in addition to the new climate change scenarios introduced – the family of "Representative Concentration Pathways" (RCP) (van Vurren et al., 2011) that reflected the importance of potential GHG emission mitigation (Taylor et al., 2012).

Model fields were obtained from the Earth System Grid - Program for Climate Model Diagnosis and Intercomparison (ESG-PCMDI, 2013) gateway at Lawrence Livermore National Laboratory (http://pcmdi3.llnl.gov/esgcet/home.htm). Model scenarios used in this study include the historical simulation and three future projections. The historical simulation was forced by observed natural and anthropogenic atmospheric composition changes spanning 1861-2005 in all of the models; it was used to provide a baseline against which to assess climate change in the three future projections. The future projections were distinguished by the values of their RCPs. In this study the RCP2.6, RCP6.0 and RCP8.5 scenarios for 2006-2100 were used, with the numbers representing the globally-averaged top-of-the-atmosphere radiative imbalance (in W m^{-2}) in 2100 (Moss et al., 2010). Compared to the Special Report on Emissions scenarios (SRES) that informed the climate projections for the previous CMIP experiment (CMIP3), the CO_2 concentration in RCP2.6 is below B1, in RCP6.0 is slightly above A1B, and in RCP8.5 exceeds A2. Therefore, a broad range of potential GHG trajectories for the 21st century were represented by the three chosen scenarios. Generally, multiple ensemble members are available for each CMIP5 scenario for the given model. Assuming to have sufficient models in the ensemble to get reliable estimates of a potential climate change signal, only one ensemble member (the first) from each CMIP5 model and scenario is used here. The variables used include near surface maximum and minimum temperature, precipitation, and relative humidity, a comparison of the annual cycle of the historical AOGCM simulations versus observations for some climatic variables relevant to the present study was also evaluated.

The AOGCM outputs were statistically downscaled to each of the three cities where the stations are located (Kano, Sokoto and Gusau). A variety of statistical downscaling techniques of varying complexity are available (e.g., Gutiérrez et al., 2012; Wilby and Dawson, 2012). In this study, the following steps were taken in the downscaling process: (1) bilinearly interpolating the AOGCM output to the coordinates of each city; (2) computing the AOGCM climate change signal for a given variable for a specified future RCP period (e.g., 2020-2035) relative to the AOGCM historical period that overlaps with the observational record (1990-2005); and (3) adding this change signal (which includes changes in the mean and the variance) to the 1990-2005 observational record to compute the downscaled future climate in 2020-2035 or 2060-2075 for a given variable and city.

$$X_{f_{m,y}} = \left[\bar{X}_{p,obs_m}\right] + \left[\bar{X}_{f,gcm_m} - \bar{X}_{p,gcm_m}\right] + \left[X_{p,obs_{m,y}} - \bar{X}_{p,obs_m}\right] \times \left[1 + \frac{\bar{\sigma}_{f,gcm_m} - \bar{\sigma}_{p,gcm_m}}{\bar{\sigma}_{p,gcm_m}}\right].$$

Where $X_{f_{m,y}}$ is the downscaled future value of variable X for a given month, m, and year, y. Downscaled variables include maximum temperature, minimum temperature, rainfall, relative humidity. $\bar{X}_{p,obs_m}$ is the mean present-day observed climate for a given month averaged across all years of the historical period (1990-2005), as calculated from weather station in each city. $\bar{X}_{f,gcm_m}$ and $\bar{X}_{p,gcm_m}$ are the mean future (e.g., 2020-2035 or 2060-2075) and present-day (1990-2005) averages, respectively, for a given month in the AOGCM. $X_{p,obs_{m,y}}$ is the observed climate for a given year and month. $\bar{\sigma}_{f,gcm_m}$ and $\bar{\sigma}_{p,gcm_m}$ are the mean future and present-day standard deviations from the monthly mean over the period, respectively, for a given month in the AOGCM.

Table 1: List of Climate Models used in this Study

Model	Modeling centre	Institution
BCC-CSM1.1	BCC	Beijing Climate Center, China Meteorological Administration
CESM1-CAM5	NSF-DOE-NCAR	National Center for Atmospheric Research
CSIROMk3.6.0	CSIRO-QCCCE	Commonwealth Scientific and Industrial Research Organization in collaboration with the Queensland Climate Change Centre of Excellence.
GFDL-ESM2G	NOAA GFDL	Geophysical Fluid Dynamics Laboratory
GFDL-ESM2M	NOAA GFDL	Geophysical Fluid Dynamics Laboratory
GISS-E2-R	NASA GISS	NASA Goddard Institute for Space Studies
HadGEM2-ES	MOHC	Met Office Hadley Centre
IPSL-CM5ALR	IPSL	Institute Pierre-Simon Laplace
MIROC5	MIROC	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology
MIROC-ESM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MIROC-ESMCHEM	MIROC	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies
MRI-CGCM3	MRI	Meteorological Research Institute
NorESM1-M	NCC	Norwegian Climate Centre

Therefore, the above equation is in essence a Reynolds averaging approach: the monthly mean AOGCM change signal (bracketed term 2) is added to the present-day observed monthly mean (bracketed term 1), then the observed perturbation for each year and month is added back to the mean change signal (bracketed term 3). First, however, the perturbation term is multiplied by the fractional change in the standard deviation (bracketed term 4) prior to adding it back to the mean, in order to account for changes in the variability of a given variable in the future. This was done so on a fractional basis to account for the fact that variability in a AOGCM may be dampened or enhanced compared to the observed variability due to the coarse spatial resolution and physical assumptions of the AOGCM. Adjusting the observed perturbation on a fractional (rather than absolute) basis accounts for such differences. Likewise, the change in the mean of variable X, expressed in bracketed term 2, was modified slightly when downscaling rainfall. Finally, student's t-tests was used to test for significance between the observed present-day climatic variables. The tests account for the uncertainty due to the interannual variability within each period, and the uncertainty due to the climate model projections.

RESULTS AND DISCUSSION

Climate Projection and Evaluation

The annual cycle of the historical AOGCM simulations versus observations for the climatic variables relevant to the present study were evaluated. Although the range of historical simulations about the observed annual cycle is large, the ensemble mean captures the observed seasonal cycle and magnitude of maximum and minimum temperature, rainfall, and humidity with remarkable accuracy. This lends confidence that the statistically downscaled climate projections are based on models that, on average, reasonably simulate the climate of northwest Nigeria on this time scale.

Figure 2 shows that the models capture the seasonal cycle of maximum and minimum temperature, rainfall, and relative humidity, as measured by the ensemble mean values. For maximum temperature during the hottest months (February – April), the ensemble mean of the models is nearly perfect, and there is a 1.5-2 degree cold bias during April and May. The models exhibit a larger standard deviation and range than the observations because there were more data points used for the statistics: for the observations there are 16 data points for each month (because there are 16 years of data for 1990-2005). For the models there are 13 times as many data points, since there are 13 models. In summary, these plots indicate that, collectively, the models are able to capture the seasonal cycle and magnitude of the key meteorological variables, albeit with some small biases. This indicates the models are resolving key atmospheric processes, which in turn suggests that the models' climate change projections for 2020-2035 and 2060-2075 may have reasonable fidelity.

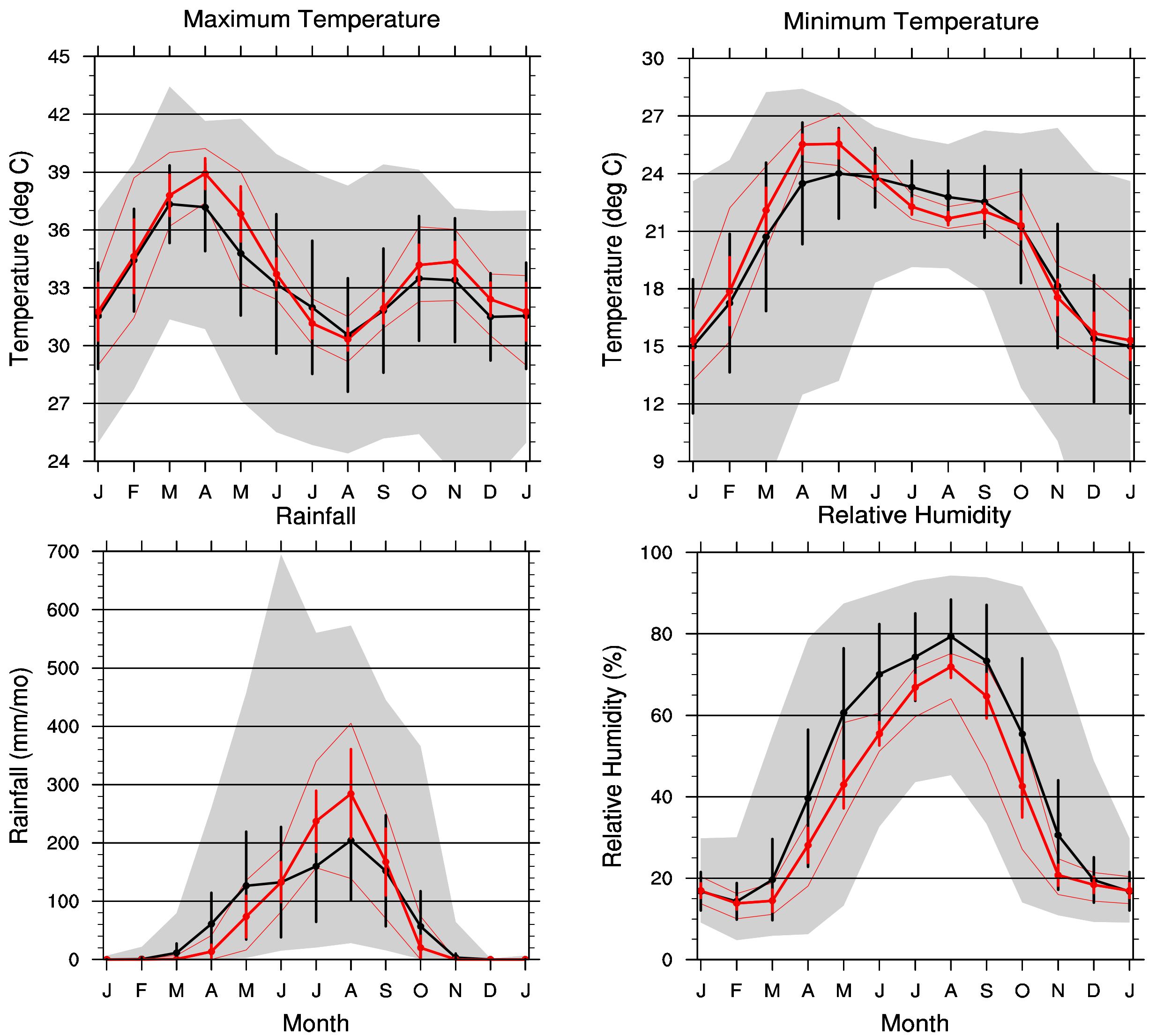

Figure 2: Annual Cycle of the Observed Present Day (1990-2005) Parameters Averaged for the Selected Cities (Sokoto, Gusau, and Kano), in Comparison with the Ensemble of Historical AOGCM Simulations for the same 16-year Period.

Figure 3 shows the annual cycle of the observed present day maximum temperature, rainfall and relative humidity for the aggregate of the three cities, in comparison with the RCP6.0 simulations for 2020-2035 and 2060-2075. Even in the near future (2020-2035) maximum temperature increases of about 0.5-1^{o}C are statistically significant ($p<0.01$) compared to 1990-2005 in 7-out-of-12 months, including those months from February-April. In the far future (2060-2075), statistically significant ($p<0.01$) maximum temperature increases of 1-3^{o}C occur in 9-of-12 months, and increases are also significant ($p<0.1$ or 0.05) in the other three months.

Humidity does not change significantly in the near or distant future except for a small but significant increase in December of about 1% ($p<0.10$; 2020-2035) to 2% ($p<0.05$; 2060-2075). While rainfall exhibits statistically significant changes during December and January in both future periods but rainfall amounts is nearly zero during these months already, so the changes are almost imperceptible. Likewise, July-August rainfall is projected to increase in the future, a result consistent with Vizy et al. (2013).

Given that projected climate changes in northwestern Nigeria are similar for other regions of the Sahel (Chou et al., 2013), these results may be broadly applicable throughout Sahelian Africa. It is noteworthy that the WAM which brings about precipitation in the Sahel is not well simulated in climate models (Bock et al., 2011; Marsham et al., 2013); however the AOGCMs have vigorously improved if compared with the previous GCMs; they now include the representation of the ocean, atmospheric chemistry, vegetation, carbon cycle, land surface, aerosols, and sea ice at a finer spatial resolution (McMichael et al., 2006). This reduces uncertainties that may affect the results of this study.

Finally, changes in climate extremes may have more adverse impact than that of the mean climate (which was investigated here). For example, increase in the intensity and occurrences of heat events may increase the risk of heat mortality. Likewise, occurrence of extreme rainfall may increase the risk of flooding. As such, it is pertinent to further investigate the potential future impact of these events, this will help to further identify the climatic effects that otherwise may be obscured by the mean values.

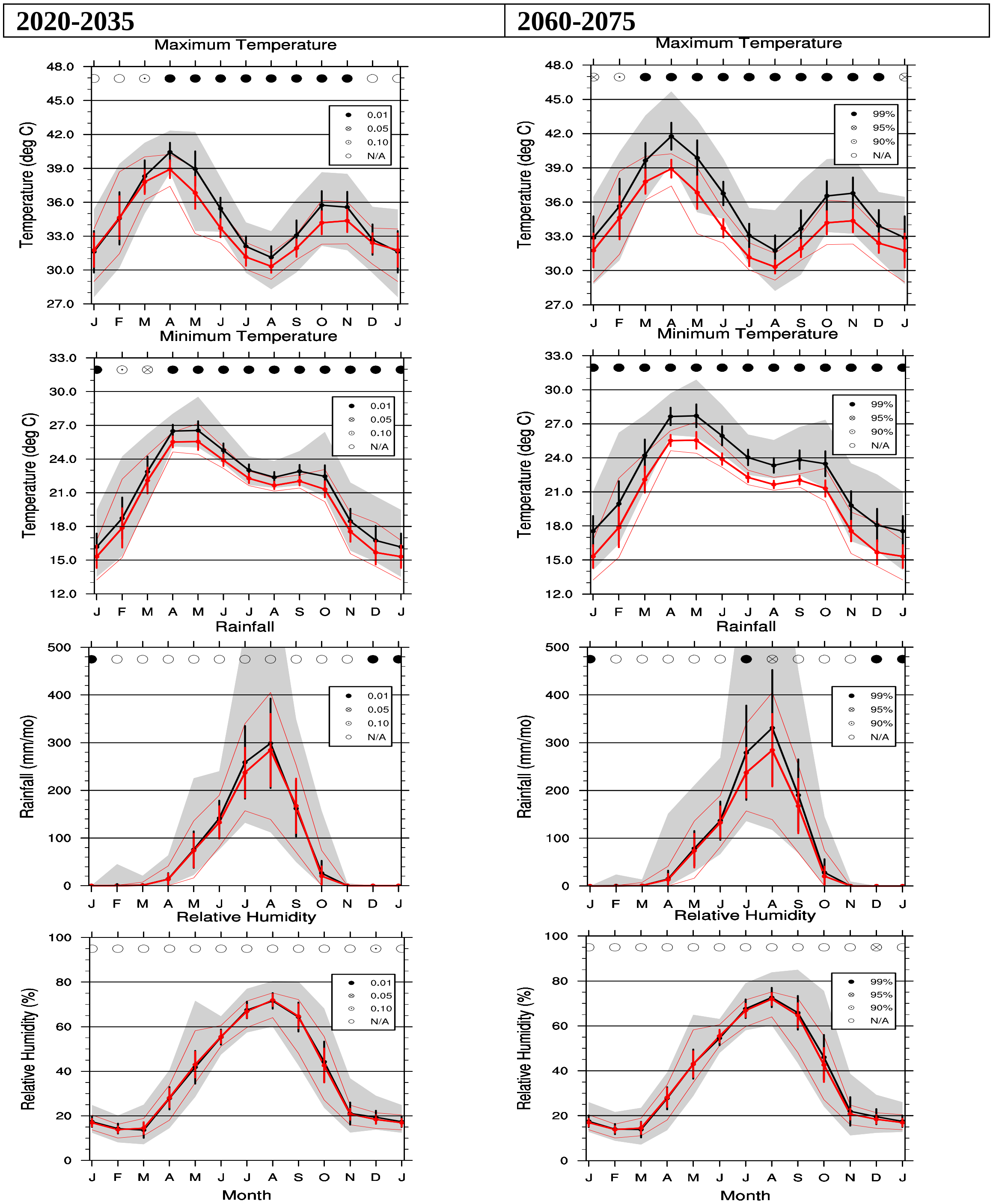

Figure 3: Annual cycle of the observed present day (1990-2005) Parameters averaged for the three cities (Sokoto, Gusau, and Kano), in comparison with the ensemble of downscaled RCP6.0 AOGCM projections in 2020-2035 and 2060-2075

CONCLUSION

This study uses the most recent and improved AOGCMs simulations from CMIP5 project. Evaluations shows that the models capture the seasonal cycle of maximum and minimum temperature, rainfall, and relative humidity, as measured by the ensemble mean values. The study reveals that both in the near and far future maximum temperature shows a statistically significant increases of about 0.5-1^{o}C and 1-3^{o}C respectively. Rainfall also, exhibits statistically significant changes during December and January in both future periods but rainfall amounts is nearly zero during these months already, so the changes are almost imperceptible.

It is recommended that future studies should consider the use of high resolution Regional Climate Models (RCM) data. This may help in reducing uncertainties that might be inherited from climate models, because this model has the advantage of having high resolution outputs, and it also allows for the representation of small scale processes such as soil characteristics and coastal sizes etc.

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