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The effect of climate change on solar radiation in Nigeria

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Abstract

In this study, global solar radiation over Nigeria was simulated under an enhanced atmospheric CO_2 level using the International Centre for Theoretical Physics (ICTP) Regional Climate Model version 3 (RegCM3) for the period 1981 to 2100 with ECHAM5 GCM as the lateral boundary conditions. The simulated seasonal global solar radiation bias for the RegCM3 with NIMET and NASA observed datasets in the control period are of similar magnitudes and showed a mixture of persistent positive and negative biases ranging between −10% and 30%. The model generally underestimates solar radiation (biases −10% to −30%) across the whole country in most of the months. In addition, it overestimates radiation (biases +2–30%) over the northern region of the country. Alongside the present climate (1981–2010), three future periods were considered viz: period 1 (2011–2040), period 2 (2041–2070) and period 3 (2071–2100) for the potential future changes. The seasonal potential future changes in period 1 (i.e. potential future changes with respect to 2040) showed a reduction in the range of 0% (North) to 3.27% (South) whereas more reduction in global solar radiation is observed in period 2 (i.e. 2041–2070 minus present climate) having general decrease ranging from 0.11% to 3.39% with the least value in April (Middle-belt) and the largest in the South zone (March). Potential future changes in period 3 (i.e. 2071–2100 minus present climate) is generally characterized with mixed increase and decrease in global solar radiation across the country than the previous two periods (1 and 2). For the annual potential future changes, RegCM3 model predicted a decrease in solar radiation towards the end of the century with more reduction found in the South zone and the least in the North region. Furthermore, future changes in global solar radiation across the zones in all the periods are however found to be insignificant at $p \leqslant 0.01$.

Keywords: Climate change; Global solar radiation; Regional climate model; General circulation model

1. Introduction

Solar radiation (a renewable energy resource) has direct impact on energy generation in addition to agriculture and water resources. The energy resource was observed to be affected by climate changes induced by CO_2 emissions (Pan et al., 2004). With enormous solar potential across Nigeria, a moderate seasonal effect of climate change can have significant socio-economic impacts; change of solar radiation in future climate is thus of considerable interest (Pan et al., 2004). High resolution reliable projections of 21st century climate change are of great importance to

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assess related impacts on renewable energy resources (directly on solar energy and indirectly on wind and hydro power), human activities and natural ecosystem over the country. African countries are shown to be among the most vulnerable to climatic changes expected for the next decades of the 21st century due to increasing concentrations of atmospheric greenhouse gases (IPCC, 2007; Mariotti et al., 2011). Furthermore, among African regions, West Africa is found as one of the world most exposed to the negative effects of climate variability (Tchotchou and Kamga, 2010). In Nigeria, Climate change is the latest challenge to sustainable human development and is leading to more frequent and more severe climate-related impacts that may deter efforts to achieve the country's development objectives, including the targets of the Nigeria Vision 20:2020 and the Millennium Development Goals (MDGs) NEST and Tegler, 2011; NASPA-CCN, 2011; the challenges being multifaceted (social, economic, environmental), its impact on infrastructure will be significant because infrastructure provides a critical platform for the effective functioning of the Nigerian economy (NEST and Tegler, 2011). Climate change is also expected to negatively affect the already limited electrical power supply through impacts on the existing hydroelectric and thermal generation; service interruption is also expected to result from damage to transmission lines and substation equipment impacted by sea level rise, flash floods, and other extreme weather events (NASPA-CCN, 2011).

Climate change was discussed in (Li et al., 2012) to have effect on weather parameters (wind speed, solar radiation, precipitation, mean temperature, maximum and minimum temperatures etc.) that constitute the renewable resources. Several authors have also shown that potential climatic changes due to increased atmospheric greenhouse gases might affect the availability of renewable resources in West Africa in the future. However, changes (increase or decrease) in resource potentials resulting from climate change consequences may affect power generation from renewable energy resources and can consequently affect the potential contribution to future electricity output. There is also the tendency of a reduction or increase in magnitude of the several weather parameters (global solar radiation, dry-bulb temperature (mean, maximum and minimum), relative humidity, precipitation, and wind speeds) that contribute to building comforts (through heat gain and loss in buildings) in the advent of a changing climate (Ohunakin et al., 2013).

However, study of the physical mechanisms underlying climate variability and the quantification of the relative contributions of each of the driving factors, require long time series of observations. The long range of observed data is a disability in West Africa because of the relatively few observation stations, and most times, poor quality of available data; these necessitate the use of climate models whose outputs constitute consistent datasets of atmospheric variables. Climate models (global and regional circulation models) are thus the primary tools that aid in our understanding of the many processes that govern the climate systems (Pal et al., 2007). A number of simulations have been carried out using Global Circulation Models (GCMs). Climate models with GCMs have been found to have difficulties reproducing various atmospheric variables of interest and thus generating unrealistic outputs (some examples are in the results as given in the following: Community Climate Model version 3-CCM3 in the work of (Jenkins and Mikovitz, 2003); Laboratoire de Météorologie Dynamique (LMD) GCM and also the Centre for Ocean-Land-Atmosphere (COLA) GCM as reviewed in the work of (Tchotchou and Kamga, 2010).

In (Anyah and Semazzi, 2007), regional climate modelling is presently one of the fundamental techniques used to downscale global (large scale) climate information for regional applications. The Regional Climate Models (RCMs) have proven to be very essential tools for regional climate downscaling through the detailed representation of regional climate variability when nested within global analyses of observations or the GCM outputs, needed for the initial and time dependent lateral boundary conditions (e.g. previous work as listed in (Anyah and Semazzi, 2007); they have higher spatial resolution and can potentially better simulate finer structures of circulation and precipitation distribution by taking into account steep topography and resolving orographic features, such as isolated reliefs, lakes, coastlines and sharp gradients in vegetation, temperature, and soil moisture (Semazzi et al., 1993). Several studies demonstrated to determine the sensitivities of RCMs to dynamic configuration and the physical parameterizations proved RCMs to have better performance than GCMs with even drastic reduction in errors associated with large scale simulations (Anyah and Semazzi, 2007; Kgatuke et al., 2008). In (Mariotti et al., 2011), the RCM solution is determined by a dynamical equilibrium between the information being derived from the lateral boundary conditions and that produced by the internal model dynamics and physics. As a result, more realistic output regimes can be expected by adapting the model physics to the region of interest (Tchotchou and Kamga, 2010). RCMs are also expected to be dynamically configured and customized in their simulation for sensitivity of climates over different domains/regions for their optimum performance (Anyah and Semazzi, 2007; Giorgi et al., 1993; Seth and Giorgi, 1998; Sun et al., 1999; Denis and Laprise, 2002; Giorgi and Mearns, 1999). In line with this assertion, several works were carried out, many on mid-latitude climates and very few covering some regions and sub-regions of Africa as discussed in literatures.

Several versions of RCMs exist including the International Centre for Theoretical Physics (ICTP) Regional Climate Model versions 2, 2.5, 3, 4 and respectively tagged as RegCM2, RegCM2.5, RegCM3 and RegCM4 (most recent version and model still under evaluation) etc. In (Sylla et al., 2010), the performance of