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Potential impacts of 1.5 °C and 2 °C global warming on rainfall onset, cessation and length of rainy season in West Africa

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Abstract

This study examines the potential impacts of 1.5 °C and 2 °C global warming (GWL15 and GWL20) on rainfall onset dates (RODs), rainfall cessation dates (RCDs), and length of the rainy season (LRS) in West Africa under RCP4.5 and RCP8.5 scenarios. Nineteen multi-model multi-ensemble simulation datasets from eight regional climate models that participated in the Coordinated Regional Climate Downscaling Experiment were used for the study. The ability of the model ensemble mean to reproduce the characteristics of RODs, RCDs and LRS for past climate were evaluated using two observed datasets. The impacts of GWL15 and GWL20 on each parameter were quantified and compared. The models reproduce the characteristics of RODs, RCDs, and LRS as observed in the historical climate over West Africa though with few biases. The models projected the western and eastern Sahel as hot-spots for a delayed ROD and reduced LRS in the 1.5 °C and 2 °C warmer climate under RCP4.5 and RCP8.5 scenarios. A delayed RCD and longer LRS are projected over the western part of the Guinea coast. The uncertainties associated with the projections are high for RCD but lower for ROD and LRS. While an increase in global warming from 1.5 °C–2 °C enhances late ROD over the entire West Africa under the RCP4.5, it fosters early ROD over the Sahel zone under the RCP8.5. It also encourages a decrease in the LRS over the Guinea zone and an increase in LRS over the Sahel zone, but produces opposite results under RCP8.5. The results of the study have application in reducing the impacts of global warming over West Africa.

1. Introduction

Understanding the characteristics of onset, cessation and length of the rainy season in West Africa is crucial. Many socio-economic activities of the people depend on rain-fed agriculture and most agricultural planning (e.g. land clearing, crop selection, seed planting and crop harvesting) requires the knowledge of rainfall onset and cessation. For instance, the rainfall onset controls the best planting dates (when the soil moisture is sufficient to sustain the crop from seed germination to maturity), while the cessation and length of rainy season determine the type of seed to plant (Marteau *et al* 2011, Mounkaila *et al* 2014, Amekudzi *et al* 2015). Therefore, agricultural activities and production becomes extremely vulnerable to the variability of the onset, cessation dates and length of the rainy season (Dodd and Jolliffe 2001). However, rainfall onset and cessation exhibit a large variability over West Africa due to the complexity of the West African monsoon system, which is driven by the temperature gradient between the sub-continent and the Atlantic Ocean. There are indications that the ongoing global warming may alter the temperature gradient because several studies have shown that the warming is more rapid over land than the oceans. This suggests that global warming may not only influence the characteristics of the West African monsoon system

(Abiodun *et al* 2012, Diallo *et al* 2012, Sylla *et al* 2015, Dosio and Panitz 2016, Sylla *et al* 2016), it may also enhance the variability of rainfall onset and cessation dates over the region. The impact of this on food security could aggravate the vulnerability of the region to climate change. Despite the numerous studies on future impacts of climate change in West Africa (e.g. Sylla *et al* 2015, Tall *et al* 2017), there is a dearth of information on how climate change could affect the onset, length of the rainy season and cessation of rainfall over West Africa. The present study intends to provide more information in this area.

To reduce the impacts of climate change, the United Nations Framework Convention on Climate Change (UNFCCC 2015) has proposed a mitigation goal to limit global warming to 1.5 °C and 2 °C above the pre-industrial levels. This proposal was accepted by majority of the parties of the convention at the 21st session of the Conference of the Parties (COP21) in 2015. Consequently, several studies have discussed how achieving this target could reduce the risks and impacts of climate change on global (e.g. James *et al* 2017) and regional scales (e.g. Vautard *et al* 2014, Riede *et al* 2016, Donnelly *et al* 2017). While some studies found a substantial difference in the impacts of 1.5 °C and 2 °C warming on regional climate variable (e.g. rainfall), others claimed that the difference is negligible when compared to the uncertainties associated with internal variability and model diversity (Karmalkar and Bradley 2017). Nevertheless, there are no known studies on how 1.5 °C and 2 °C warming may impact rainfall onset, length of the rainy season and cessation dates over West Africa in the future. Understanding the impacts will assist policy makers in making relevant decision on minimizing the associated risks.

Hence, the aim of this study is to examine and compare the future impacts of 1.5 °C and 2 °C global warming on rainfall onset, cessation and length of the rainy season in West Africa under two future climate forcing scenarios (RCP4.5 and RCP8.5). Section 2 describes the data and methods used in the study, section 3 presents and discusses the results and section 4 provides the conclusions and further recommendations to the study.

2. Data and method

2.1. Data

Observed and simulated rainfall datasets were analyzed for the study. The observation datasets are the African Rainfall Climatology version 2 (ARC2; Novella and Thiaw 2013) and the Climate Hazard Group Infrared Precipitation with Stations (CHIRPS; Funk *et al* 2014). ARC2 consists of daily precipitation estimation data over Africa at $0.1° \times 0.1°$ horizontal grid resolution for a period of 30 years (1983–2012), while CHIRPS consists of daily precipitation data over Africa at $0.05° \times 0.05°$ horizontal grid resolution for a period of 35 years (1981–2015). The observed datasets were used to evaluate the simulated rainfall datasets. For easy comparison, 30 years data were extracted from the observation datasets (ARC2: 1983–2012; CHIRPS: 1983–2012) and re-gridded to the resolution of the simulation datasets ($0.44° \times 0.44°$).

The simulated rainfall datasets are from the Coordinated Regional Climate Downscaling Experiment (CORDEX; Nikulin *et al* 2012). They are 19 multimodel simulation datasets produced by eight CORDEX Regional Climate Models (RCMs: ALADIN, RCA, CCLM, RACMO-V1, HIRHAM, REMO, RACMO-V2, and WRF). The RCMs and the GCMs they downscaled are given in table (1). For more detailed information on the CORDEX RCMs dynamics and configuration, as well as the CORDEX projections, readers are referred to Nikulin *et al* (2012, 2018). The simulation datasets cover the CORDEX-African domain at $0.44° \times 0.44°$ horizontal resolution and provide climate data for past and future periods (1951–2100) under two climate forcing scenarios (RCP4.5 and RCP8.5, i.e. the middle- and high-level emission scenarios). However, for the present study, 30 years data for past climate (1971–2000) and for future climate with 1.5 °C and 2 °C global warming above the pre-industrial levels for each RCP4.5 and RCP8.5 scenarios were analyzed. The 30 year future climate data have different periods depending on the global warming level, the model simulation, and the climate forcing scenario. The periods are shown in table (1) and how the periods were obtained is described in Déqué *et al* (2017).

2.2. Method

In this study, rainfall onset and cessation dates (ROD and RCD) are defined following the ROD definition of Stern *et al* (1981) and RCD definition of Omotosho *et al* (2000) (table 2). These popular definitions have been shown to give reliable RODs and RCDs over West Africa (see Dodd and Jolliffe 2001, Laux *et al* 2008, Mounkaila *et al* 2014). Here, we applied them on each dataset (observation and simulation) to obtain RODs and RCDs for past and future climates over each grid point in our study domain (West Africa; figure 1), and used the difference between the ROD and RCD (i.e. RCD minus ROD) as the length of rainy season (LRS) over the grid. The designation of the study area follows that of previous studies (e.g. Abiodun *et al* 2012, Diasso and Abiodun 2017). To evaluate the capability of the CORDEX simulations in reproducing these parameters (ROD, RCD and LRS), the simulated values were compared with the observed. In the evaluation, the simulation mean (and median) were compared with observation and the spread among the simulations were compared with uncertainty in the observed values. To quantify the impacts of a warming level on the parameters, we obtained the difference between the projected future values (for the warming level) and the historical values (i.e. future minus historical).

Table 1. The 30 year periods of 1.5 °C and 2 °C global warming levels (GWL15 and GWL20) in RCP4.5 and RCP8.5 simulations used in the study. The method for calculating the periods are described in Déqué *et al* (2017).

RCMs	GCMs	RCP4.5		RCP8.5	
		GWL15 Period	GWL20 Period	GWL15 Period	GWL20 Period
RCA	CCCMA	2002–2031	2017–2046	1999–2028	2012–2041
	CNRM	2021–2050	2042–2071	2015–2044	2029–2058
	CSIRO	2020–2049	2033–2062	2018–2047	2030–2059
	ICHEC-r12	2010–2039	2031–2060	2005–2034	2021–2050
	HADGEM	2016–2045	2032–2061	2010–2039	2023–2052
	IPSL-MR	2002–2031	2020–2049	2002–2031	2016–2045
	MIROC	2026–2055	2059–2088	2019–2048	2034–2063
	MPI-LR	2006–2035	2029–2058	2004–2033	2021–2050
	NCCN	2027–2056	2062–2091	2019–2048	2034–2063
CCLM	CNRM	2021–2050	2042–2071	2015–2044	2029–2058
	ICHEC-r12	2010–2039	2031–2060	2005–2034	2021–2050
	HADGEM	2016–2045	2032–2061	2010–2039	2023–2052
	MPI-LR	2006–2035	2029–2058	2004–2033	2021–2050
ALADIN	CNRM	2021–2050	2042–2071	2015–2044	2029–2058
HIRHAM	ICHEC-r3	2009–2038	2030–2059	2006–2035	2023–2052
REMO	MPI-LR	2006–2035	2029–2058	2004–2033	2021–2050
RACMO-V1	ICHEC-r1	2006–2035	2028–2057	2003–2032	2021–2050
RACMO-V2	HADGEM	2016–2045	2032–2061	2010–2039	2023–2052
WRF	NCCN	2027–2056	2062–2091	2019–2048	2034–2063

Table 2. Definition of ROD, cessation and length of rainfall dates over West Africa.

Parameter	Definition	Reference
Rainfall Onset Date (ROD)	The total of at least 25 mm of rainfall within 5 days. The starting day and at least two other days in this 5 day period must be wet (at least 0.1 m m rainfall recorded), followed by a no dry period of seven (7) or more consecutive days occurring in the following 30 days.	Stern *et al* (1981)
Rainfall Cessation Date (RCD)	Any day from 1st September after which there are 21 or more consecutive days of rainfall less than 50% of the crop-water requirement.	Omotosho *et al* (2000)
Length of Rainy Season (LRS)	The period between rainfall onset and cessation dates (i.e. RCD minus ROD)	Omotosho *et al* (2000) and Mugalavai *et al* (2008)

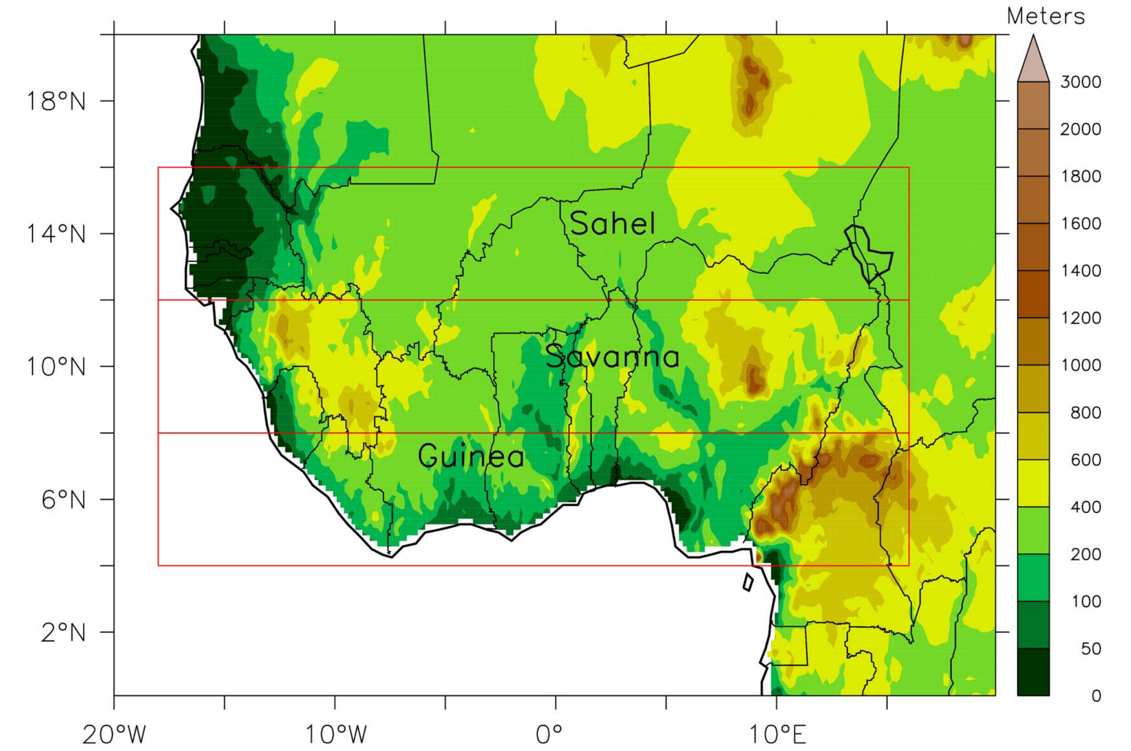

Figure 1. West African domain showing the topography and regions designated as Guinea, Savanna and Sahel zones.

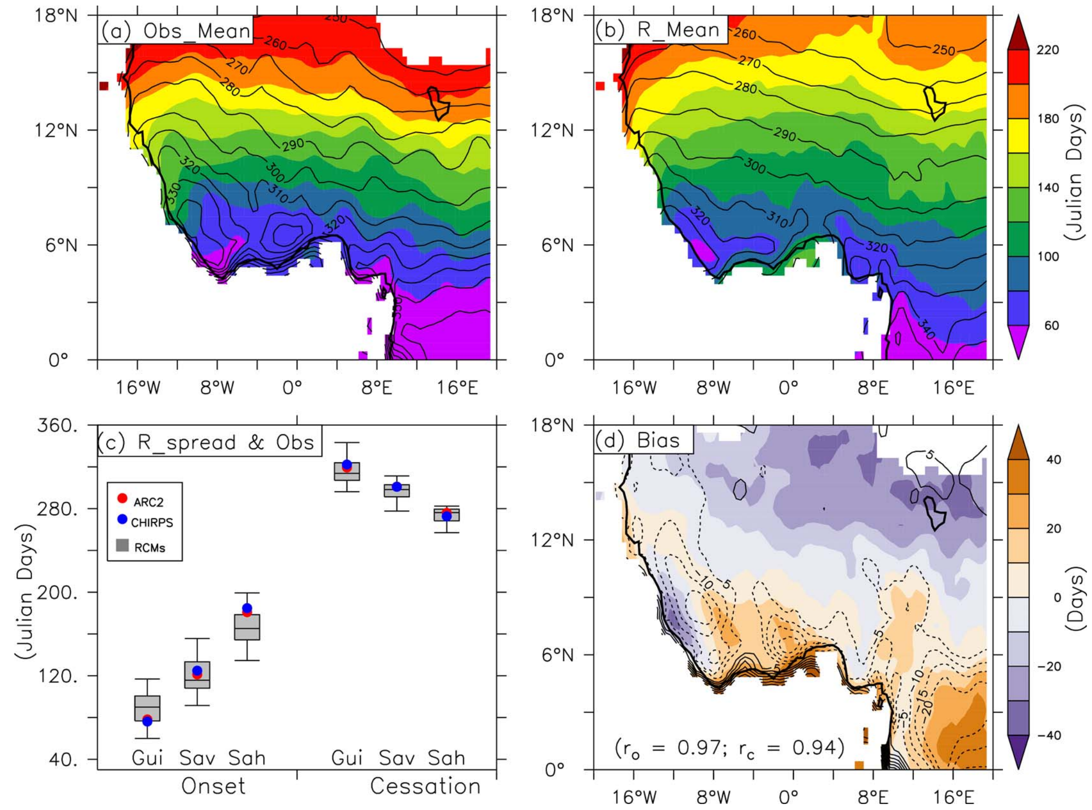

Figure 2. The climatology of rainfall onset and cessation dates (shaded and contour, respectively) over West Africa, as observed (panel a; average of ARC2 and CHIRPS observations) and simulated (panel (*b*); RCMs ensemble mean). Panel (*d*) shows the simulation bias and the correlation between the observed and simulated values (r_o and r_c, respectively). The average values over each climatic zone in West Africa (i.e. Guinea, Savanna, and Sahel) are shown in panel (*c*). Each box plot indicates the minimum, 25th percentile, median, 75th percentile and maximum values of the RCMs ensemble.

The difference in impacts of the two global warming levels was also quantified under the RCP4.5 and RCP8.5 scenarios.

3. Results and discussion

3.1. Model evaluation

The RCM ensemble reproduces the spatial distribution of rainfall onset dates (RODs) over West Africa well (figure 2). The correlation between the simulated and observed values is high ($r_o = 0.97$) and all the essential features in the observed pattern are well reproduced by the models (figures 2(*a*) and (*b*)). As observed, the RCMs simulate a northward progression of RODs, from 1st March (i.e. Julian Day 60) along the coast to about 15th June (Julian Day 200) around 18°N. This progression corresponds to the northward transport of moisture (from the Gulf of Guinea into the subcontinent) by the West African Monsoon (WAM; Omotosho *et al* 2000, Sylla *et al* 2013). However, the simulated ROD is too early (about 30 days early) over the western part of the Guinea zone and too late (about 20 days late) over the central and eastern part of the zone (figure 2(*d*)). This bias may be because the RCMs overestimate the influence of the south-west mountain range (i.e. orographic lifting between Sierra Leone, Liberia, and Cote d'Ivoire). That is, the RCMs may produce too much rainfall west of the mountain (causing too early onset) and transport less moisture for rainfall east of the mountain (leading to late onset). Nonetheless, more than 50% of the simulations overestimate the average ROD over the Guinea zone. In contrast, more than 75% of the models underestimate the average ROD over the Sahel zone, where the model ensemble produce too early onset dates (about 20 days early). The oppose sign in the simulation bias over Guinea and Sahel suggests that the mechanism for producing rainfall during the early stage of rainy season in the models is too weak over the Guinea, but too strong over the Sahel zone. On the other hand, the RCMs feature their best performance over the Savanna zone, where the model bias is less than 10 days and the observed onset dates are between the 2nd and 3rd quartile of the model spread.

The models also give a credible simulation of rainfall cessation dates (RCDs) over West Africa, where the simulated RCD pattern strongly correlates with the observed ($r_o = 0.94$; figure 2). The simulations agree with observations on the zonal distribution and southward increase of the RCDs. The southward decrease depicts the southward retreat of the WAM with its moisture-laden air over the region (e.g. Nicholson 2013, Vellinga *et al* 2013). The simulated RCDs

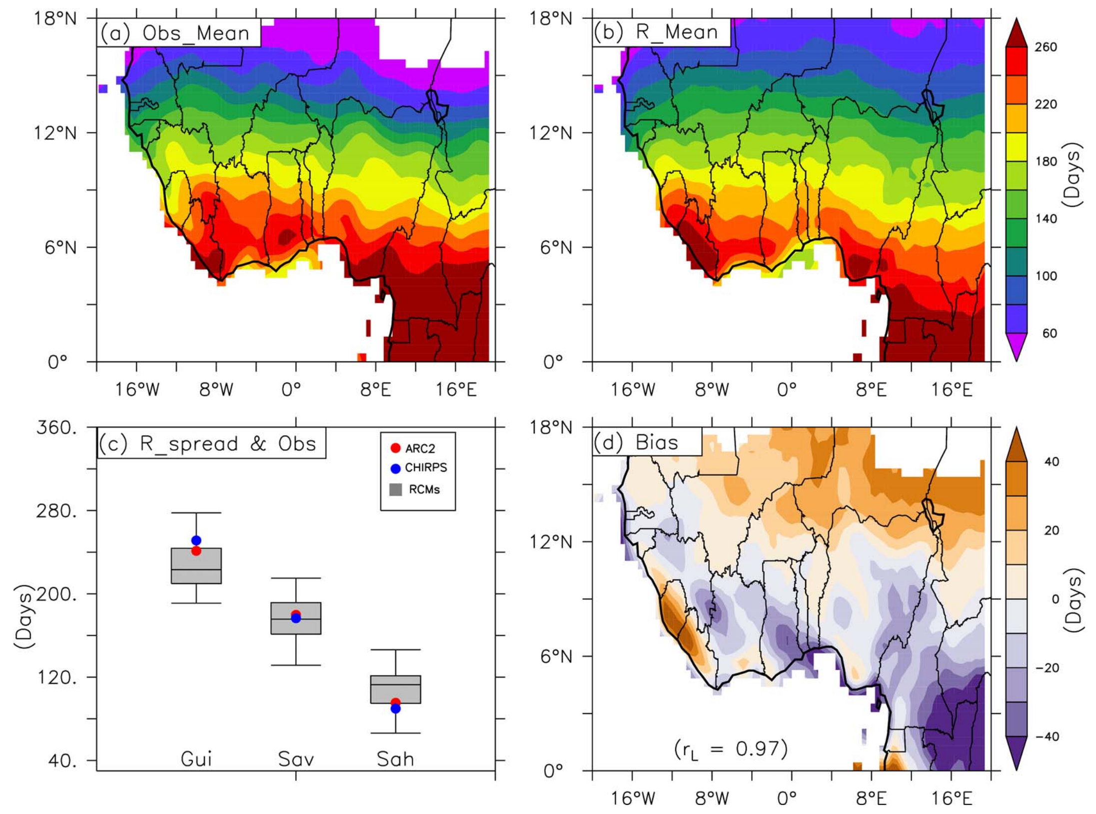

Figure 3. The climatology of length of rainy season over West Africa as observed (panel (*a*); average of ARC2 and CHIRPS observations) and simulated (panel (*b*); RCMs ensemble mean). Panel (*d*) shows the simulation bias and the correlation between the observed and simulated values (r_L). The average values over each climatic zone in West Africa (i.e. Guinea, Savanna, and Sahel) are shown in panel (*c*). Each box plot depicts the minimum, 25th percentile, median, 75th percentile and maximum values of the RCMs ensemble.

range from 7th September (Julian Day 250) over the Sahel to 16th November (Julian Day 320) over the Guinea zone. These dates are almost the same with the observed dates over the Sahel and Savanna, though they are too early over the Guinea zone. Over each zone, the observed mean RCD is within 1st and 3rd quartile of the model simulation (figure 2(*c*)). The simulated RCD bias is generally smaller than that of the simulated ROD. It is less than 5 days in the Sahel and Savanna zone, but up to 10 days in the Guinea zone (especially over the south-west mountain range). This bias suggests that the RCMs also struggle in reproducing the mechanisms that induces rainfall during the late-rainy season (September-November) over the Guinea zone. This may be attributed to too shallow moisture depth or too weak convection triggering mechanism in the models.

The good performance of the models in reproducing ROD and RCD is reflected in the simulated length of rainy season (figure 3). The level of agreement between the observed and simulated LRS is also high ($r_L = 0.97$). In both observation and simulation, the LRS is longest (about 240 days) over the Guinea zone (where the ROD is earliest and RCD is latest) and shortest (about 60 days) over the Sahel zone (where the ROD is latest and RCD is earliest). However, the pattern of the simulated LRS bias is a mirror image of that of ROD, because of the larger simulation bias in ROD than in RCD. Hence, the models overestimate the length of rainy season (by up to 25 days) over central and eastern part of the Guinea zone, but underestimate it (by up to 25 days) over the western part of same zone and over the west part of the Sahel. However, the level of agreement between the observed and simulated ROD shows that the model generally captures the dynamics of the monsoon system that drives the onset and cessation of rainfall over West Africa. The results further corroborate the findings of previous studies on the reliability of CORDEX simulation datasets for studying West African climate (e.g. Nikulin *et al* 2012, Mounkaila *et al* 2014, Klutse *et al* 2016, Sylla *et al* 2016, Diasso and Abiodun 2017).

3.2. Future projections of rainfall onset, cessation and length of rainy season

3.2.1. RCP4.5 projection

The RCM ensemble mean projects a delay in future RODs (figure 4). Although the horizontal distribution of the projected delay is similar under both GWLs (GWL15 and GWL20), the period of the delay is generally higher under GWL20 than GWL15 (figures 4(*a*) and (*d*)). Under both warming, the maximum delays (about 4 days in GWL15 and 6 days in GWL20) are located over the eastern and western part of Sahel zone, as well as the western mountain range in the

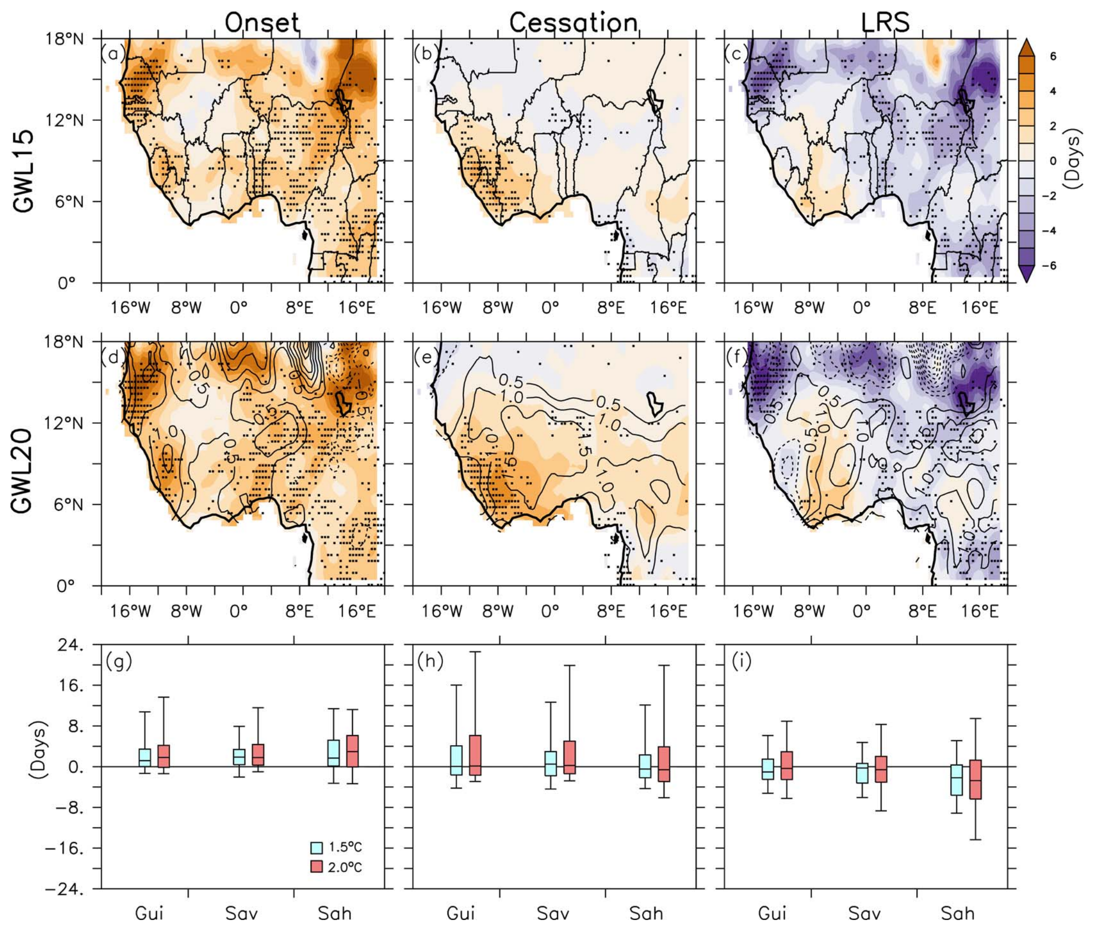

Figure 4. The future projection of RODs (panel (*a*) and (*d*)), cessation dates (panel (*b*) and (*e*)) and LRS (panel (*c*) and (*f*)) over West Africa (shaded) for GWL15 and GWL20 (top and middle panels) under RCP4.5 scenario. The future projections over each climatic zone over West Africa (i.e. Guinea, Savanna, and Sahel) are shown in panels ((*g*), (*h*) and (*i*), respectively). Each box plot indicates the minimum, 25th percentile, median, 75th percentile and maximum values of the RCMs ensemble. The contours represent the difference between GWL15 and GWL20. The significant areas are indicated with dots, showing where at least 15 (79%) of the models agree on the sign of change.

Guinea zone. The major difference between GWL15 and GWL20 ROD delays also occur over these locations. Hence, these locations are suggested as hotspots of global-induced delay in ROD. Nevertheless, there is a discrepancy among the simulations on the sign mean ROD changes over each zone. While some simulations suggest an increase (up to 10 days delayed) in the ROD, others suggest no change or a decrease (up to 3 days early). The level of uncertainty is higher with GWL20 than with GW15, especially over the Guinea and Savanna zones. This notwithstanding, more than 75% of the models agree on delayed ROD over the zones for both GWL15 and GWL20 (figure 4(*g*)).

The impact of global warming on rainfall cessation dates (RCDs) is weaker than on ROD (figure 4). In comparison with ROD, the magnitude of the RCD change is low and the maximum change is confined over the western part of Guinea zone, where the RCM ensemble projects up to 6 days delay in RCD. However, the magnitude and area of the RCD delay increases with the warming level. For instance, over the central part of Guinea and Savanna zones, the delay is 2 days longer under GWL20 than GWL15. This suggests that, with a moist soil condition over West Africa during the later southward retreat of WAM, a warmer boundary (induced by the global warming) could enhance evaporation and make the boundary layer moister for more convection, thereby extending the RCD. Nevertheless, the mean RCD projection over each zone is associated with a large uncertainty, because there is a weak agreement among the models on the projected mean RCD over the zones (figure 4(*h*)). Over each zone, irrespective of the warming level, almost half of the simulations disagree with an increase in RCD following the global warming. The degree of the uncertainty is higher with GWL20 than GWL15. This disagreement may be attributed to differences in sensitivity of convection parameterization to boundary layer in the RCMs. However, the uncertainty associated with the projected changes in RCD is higher than that of ROD.

As projected changes in ROD are stronger than those in RCD, the pattern of changes in length of rainy season (LRS) mirrors that of ROD (figure 4). So a decrease in LRS is projected over most areas in West Africa. The maximum decrease (about 6 days) is

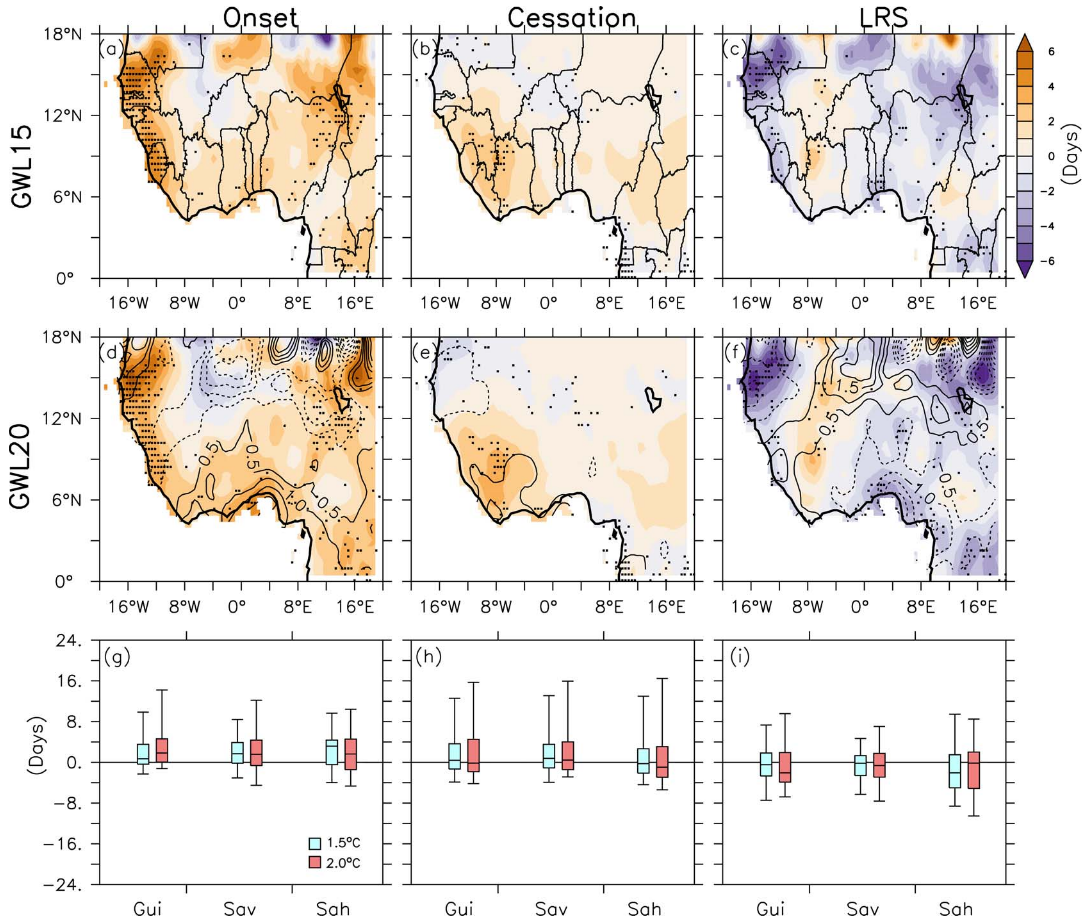

Figure 5. Same as figure 4, except for RCP8.5 scenario.

located over the western and eastern part of Sahel zone. The delay in rainfall onset over the western Sahel is in agreement with some previous studies that used CORDEX models (e.g. Mariotti *et al* 2014, Diallo *et al* 2016). These studies did not only suggest a projected delay in onset of the rains over the said area, shortening of the rainy season over this part of the Sahel was also projected to occur. While Mariotti *et al* (2014) associated the precipitation decrease with a weakening of the 6–9 day regime of the African Easterly Waves (AEWs) activity, Diallo *et al* 2016 attributed the cause as mostly associated with the large warming, probably a result of lower evaporative cooling and cloudiness found in that region. Despite the delay in ROD over the western part of Guinea zone, an increase in LRS is projected over this area because of the delay in RCD. This suggests a forward shift in the rainy season of this area. Nevertheless, the response of LRS changes to the increase in warming level varies over the region. For instance, figure 4(*f*) shows that while the additional warming (i.e. from GWL15 to GW20) intensifies the LRS decreases over Sahel (by up 3 days) and strengthens the LRS increases over the western part of Guinea and Savanna (by about 2 days), it reduces the magnitude of LRS decreases over the eastern part of Guinea and Savana. There is uncertainty in the projected changes in average LRS over the zones because of the disagreement among the simulations regarding the direction of the LRS changes (±6 days over Guinea and Savanna and ±8 days over Sahel). The level of this uncertainty increases with the warming level (figure 4(*i*)). Nonetheless, for both GWL15 and GW20, more than 50% of the simulations agree on a decrease in mean LRS over each of the zones. Hence the level of uncertainty in LRS projection is lower than that of RCD but higher than that of ROD.

3.2.2. RCP8.5 projection

There are some notable differences between the RCP8.5 and RCP4.5 projections (compare figures 4 and 5). For example, in contrast to RCP4.5 projection, RCP8.5 projection features early RODs (up to 2 days) over the central Savanna and Sahel, and indicates that further warming may make it even earlier. This suggests that the increased GHG forcing (i.e. RCP8.5) may encourage early start of rains over these areas. Furthermore, over most parts of West Africa (except for the western part), the period of delay in RCD is shorter in RCP8.5 scenario than RCP4.5. Also, with GWL15, the magnitude of the decrease in LRS over most part of West Africa is smaller in RCP8.5 projection. The strongest disagreement among the models occurs in the projection of LRS over the Savanna (under GWL15) and Sahel (under GWL20) under RCP8.5 scenario.

While the level of uncertainties in the projected changes in RCD and LRS under RCP8.5 scenario is the same with that of RCP4.5, the level of uncertainties in ROD projection is lower under RCP4.5 than RCP8.5.

The differences between the impacts of GWL15 and GWL20 also differs (in magnitude and direction) under RCP8.5 and RCP4.5 scenarios. For example, the RCP4.5 projection indicates that the increase in global warming level (from GWL15 to GWL20) enhances ROD delay (up to 2 days) over the entire West Africa, but the RCP8.5 projection suggests that the increase enhances the delay (by about 1 day) only over the Guinea zone and fosters early ROD over the Sahel zone. In addition, while RCP4.5 projects a further delay in RCD (up to 2 days) over most parts of West Africa following the warmer climate, RCP8.5 limits the delay (about 1 day) in the south-western part of Guinea zone. Hence, with RCP8.5, the additional warming (i.e. from GWL15 to GWL20) generally encourages decrease LRS over the Guinea zone and an increase LRS over the Sahel zone; but, with RCP4.5, the reverse is the case. The discrepancy between the RCP8.5 and RCP4.5 projections may be attributed to a number of factors. First, it may be that feedback mechanisms in the climate system enhances the different perturbation in the parameters in different directions. A delay in RCD in a year may trigger an early ROD in the following year if the soil is still moist before the ROD, and vise-versa. Secondly, it could also be that the different warming rate in the two scenarios induces different magnitude of inter-annual variability of the parameters. Lastly, it may be due to varied differences in the simulations, especially given magnitudes of the changes and uncertainty in the projections.

However, both RCP4.5 and RCP8.5 scenarios feature a delay in RODs over the western and eastern Sahel, a delay in RCD over the western part of the Guinea coast, and a shorter LRS over the western and eastern Sahel also features in RCP8.5 scenario. And, in most cases, the level of uncertainty associated with projected changes over each zone for both scenarios is comparable. Some of the outcomes from this study agree with some previous studies in West Africa (e.g. Diffenbaugh and Giorgi 2012, Ibrahim *et al* 2014, Sylla *et al* 2016). For instance, Ibrahim *et al* (2014) and Sylla *et al* (2016) have reported a shortening of the Sahel rainy season over the region. Unlike these studies, the present study quantifies the uncertainty with the projection and focus on impacts of GWLs. The results further show that in addition to the impacts on rainfall amount over West Africa (Sarr 2012), climate change may alter the onset of rainfall and length of raining season over West Africa. The above results suggest that farmers may need to modify their crop management and planting practices to accommodate the projected changes in onset and length of the rainy to reduce crop failures and climate risks associated with the projections.

4. Conclusion

As part of efforts to understand the future impacts of global warming (at 1.5 °C and 2 °C above pre-industrial levels) on the regional climate over West Africa, the present study has examined the potential impacts on ROD, RCD and LRS over the region. The multi-model multi-ensemble high resolution simulations from CORDEX were utilized for the study. The capability of the models to simulate these parameters (i.e. ROD, RCD and LRS) was evaluated by comparing the historical simulations with two observations, before analyzing the model projections for the two GWLs under RCP4.5 and RCP8.5 scenarios. The results of our study can be summarized as follows:

- The RCM ensemble gives a realistic simulation of RODs, RCDs and LRS in historical climate and captures all the essential features in the observed field. Over each climatic zone, the RCM spread encloses the observed values.
- For both GWL15 and GWL20 under the two scenarios (RCP4.5 and RCP8.5) the RCM ensemble projects a delayed ROD and shorter LRS over the western and eastern Sahel, and a shorter LRS over the western part of the Guinea coast.
- There are uncertainties in the projections over each climatic zone, but the uncertainty associated with ROD and LRS is lower than that of RCD. In general, the level of uncertainties is comparable across the zones, GWLs and climate forcing scenarios.
- In some cases, the increase in global warming from 1.5 °C–2.0 °C produces different impacts under the two scenarios. It enhances late ROD over the entire West Africa under the RCP4.5 but fosters early ROD over the Sahel zone under the RCP8.5. It encourages decrease LRS over the Guinea zone and an increase in LRS over the Sahel zone; but produces opposite results under RCP8.5.

To improve the robustness of these results and make them more relevant for policymakers, the study can be improved in several ways. For example, the magnitude of the projected changes in mean ROD, RCD and LRS are small. This may be because of the long-term averaging; the magnitude of the projected inter-annual variability could be larger. However, information on impacts of the warming on the interannual variability of the parameters would be more useful to the farmers and stakeholders who take decisions based on year-to-year variation in these parameters. Furthermore, this study only had access to 19 simulations. Increasing the number of the simulations will improve the spread of the model results and the level of uncertainty associated with the results. Lack of relevant upper level data for all the simulations used in the study hinders the analysis of dynamic changes associated with the results. It is recommended that CORDEX Phase 2 should archive upper-level variables for all the participating RCMs for future studies. However, the present study has shown West African rainfall onset, cessation and the length of the rainy season are sensitive to the ongoing global warming. The study also identified the hot-spot of future changes in these parameters under the 1.5 °C and 2 °C warming levels, but cautioned that the changes may not be linear to the warming levels nor to the climate forcing scenarios. The results may help minimize the climate risk on agriculture and food security in West Africa.

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