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Potential impact of 1.5 °C and 2 °C global warming on consecutive dry and wet days over West Africa

Nana Ama Browne Klutse[1,10], Vincent O Ajayi[2], Emiola Olabode Gbobaniyi[3], Temitope S Egbebiyi[4], Kouakou Kouadio[5], Francis Nkrumah[6], Kwesi Akumenyi Quagraine[4,6], Christiana Olusegun[2], Ulrich Diasso[7], Babatunde J Abiodun[4], Kamoru Lawal[8], Grigory Nikulin[3], Christopher Lennard[4] and Alessandro Dosio[9]

1 Ghana Space Science and Technology Institute, Atomic Energy Commission, Accra, Ghana
2 Department of Meteorology and Climate Science, Federal University of Technology, Akure, Nigeria
3 Swedish Meteorological and Hydrological Institute, Norrköping, Sweden
4 Department of Environmental and Geographical Science, University of Cape Town, Cape Town, South Africa
5 Sciences des Structures de la Matière et de Technologie (SSMT), Université Félix Houphouët-Boigny, Abidjan, Côte D'Ivoire
6 Department of Physics, University of Cape Coast, Cape Coast, Ghana
7 Burkina-Faso Meteorological Agency, Ouagadougou, Burkina-Faso
8 Nigerian Meteorological Agency, Nnamdi Azikiwe International Airport, Abuja, Nigeria
9 European Commission, Joint Research Centre, Ispra, Italy
10 Author to whom any correspondence should be addressed.

E-mail: amabrowne@gmail.com

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Abstract

We examine the impact of +1.5 °C and +2 °C global warming levels above pre-industrial levels on consecutive dry days (CDD) and consecutive wet days (CWD), two key indicators for extreme precipitation and seasonal drought. This is done using climate projections from a multi-model ensemble of 25 regional climate model (RCM) simulations. The RCMs take boundary conditions from ten global climate models (GCMs) under the RCP8.5 scenario. We define CDD as the maximum number of consecutive days with rainfall amount less than 1 mm and CWD as the maximum number of consecutive days with rainfall amount more than 1 mm. The differences in model representations of the change in CDD and CWD, at 1.5 °C and 2 °C global warming, and based on the control period 1971–2000 are reported. The models agree on a noticeable response to both 1.5 °C and 2 °C warming for each index. Enhanced warming results in a reduction in mean rainfall across the region. More than 80% of ensemble members agree that CDD will increase over the Guinea Coast, in tandem with a projected decrease in CWD at both 1.5 °C and 2 °C global warming levels. These projected changes may influence already fragile ecosystems and agriculture in the region, both of which are strongly affected by mean rainfall and the length of wet and dry periods.

1. Introduction

The impacts of the changing climate ripple through the socio-economic fabric of society, affecting key sectors from water resources, human health, transportation, agriculture, to energy and tourism (Murray and Ebi 2012). These impacts include changes in extreme events such as heat waves, droughts, floods, etc coupled with the attendant risks of potential displacement of vulnerable populations, crop yield reduction or failure, food insecurity, and water scarcity. Added strain is thus placed on the lives and livelihoods of a region already plagued with underdeveloped adaptive capability. Recent studies on West Africa (e.g. Sylla *et al* 2012, Haensler *et al* 2013, Egbebiyi 2016), have demonstrated that projected increase in global greenhouse gas (GHG) concentrations will lead to increase in the frequency and intensity of extreme rainfall events.

Stemming from the Paris Agreement (Rogelj *et al* 2016), and towards reducing the risks and impact of climate change, there is a concerted effort across the international community to limit global temperature increase to 1.5 °C above pre-industrial levels and at any rate, keeping it well below 2 °C. Very few studies have quantitatively examined regional risks for West Africa at 1.5 °C global warming. Moreover, little is understood about the difference in risks between the prescribed 1.5 °C and 2 °C thresholds. While previous works abound on the gains of reduced levels of global warming, such as fewer and less intense heat extremes (e.g. (Tebaldi and Wehner 2018), research quantifying differences in climate extremes between the 1.5 °C and 2 °C global warming levels is lacking (King *et al* 2017). This is especially true for West Africa where recent studies have shown that 1.5 °C–2 °C global warming will have strong impacts on the region, owing to its low adaptive capacity (Schleussner *et al* 2016). Thus, there is need for more investigations of the potential impacts of a 1.5 °C–2 °C warmer world.

It has been demonstrated that downscaling global climate model (GCM) output with regional climate models (RCM) could potentially improve spatial and temporal information, especially for detailed impact assessments at the regional level (e.g. (Diallo *et al* 2012, Laprise *et al* 2013, Giorgi *et al* 2014), although RCM uncertainty can be large (e.g. (Dosio and Panitz 2016)). The Coordinated Regional Downscaling Experiment (CORDEX) has facilitated the downscaling of multiple GCMs over numerous domains including Africa (Giorgi *et al* 2009). Many studies have worked with CORDEX models over West Africa (e.g. (Nikulin *et al* 2012, Gbobaniyi *et al* 2014, Diasso and Abiodun 2017, Klutse *et al* 2015, Abiodun *et al* 2017). For example, (Egbebiyi 2016) projected an increase in the future characteristics (frequency and intensity) of extreme rainfall events over West Africa with increasing temperature under Representative Concentration Pathway (RCP)s 4.5 and 8.5 scenarios. Using CORDEX model output, Abiodun *et al* (2017) recently showed that climate change will lead to an increase in extreme rainfall events, resulting in more flooding over four coastal cities in Africa, including the megacity of Lagos in West Africa.

Using an ensemble of 25 CORDEX simulations, this present study investigates the comparative influence of 1.5 °C and 2 °C global warming on extreme rainfall characteristics in West Africa with focus on consecutive dry days (CDD) and consecutive wet days (CWD) across the region. CDD and CWD give indications of extremes in rainfall. CDD is also a useful indicator for short-term drought (Frich *et al* 2002) and drought tendencies (Orlowsky and Seneviratne 2012) as it could indicate enhanced dryness and high risk for seasonal droughts. Drought characteristics could also be combined with the CDD to consistently investigate drought occurrence (Huijgevoort *et al* 2012, Sylla *et al* 2010). Changes in CDD and CWD can lead to uneven temporal distribution of rainfall which could have a great consequence for agricultural practices (FAO *et al* 2015, Wiebe *et al* 2017, Barron *et al* 2003).

We analyze the differences between 1.5 °C and 2 °C global average temperature in order to quantify the benefits of keeping increase in the global temperature average below 2 °C. In doing this, we shall look into the model representation of CDD and CWD, examine spatial variations in their change, and also consider annual as well as seasonal (June, July, August, September–JJAS) rainfall. Lastly, we shall discuss the robustness of the simulations in terms of their agreement on the sign of the change signal and the measure of the signal strength with respect to the inter-model variability.

2. Study area

The study area covers West Africa, defined as the region between latitude 4°N–20°N and longitude 16°W–20°E. The area has some localized highlands (Cameroon Mountains, Jos Plateau, and Guinea Highlands) which influence its climate. The West African climate is essentially a monsoon system, which alternates between wet (April–October) and dry seasons (November–March) as the rainfall belt follows the migration of inter-tropical discontinuity (ITD). Rainfall is highly variable but is normally skewed to dryness across the region, and drought is a recurring phenomenon. However, floods also occur and, in some places (mostly along the Guinean Coast), this has become more recurrent.

3. Methods

We analyze an ensemble of 25 simulations from 12 RCMs driven by ten GCMs from the 5th Coupled Model Intercomparison Project (CMIP5) (see table 2S of Nikulin *et al* (2018)). We use the RCP8.5 as it comprises the largest ensemble and also may be considered as a realistic business-as-usual scenario given the current trajectory of greenhouse gases emissions.

We term the average global warming level above some baseline period (of e.g. 1.5, 2, 3, 4 degrees) as global warming levels (GWLs). The methodologies used to determine GWLs, the timing of when these levels are reached, and a quantification of the robustness of regional change signals at these warming levels are presented in Nikulin *et al* (2018) of this focus collection. We summarize these methodologies very briefly here and refer the reader to Nikulin *et al* (2018) for details.

Although different definitions of GWLs exist in the literature, all generally start with some pre-industrial (PI) baseline and use an averaged window period e.g. 15, 20 or 30 years to compute departure from the baseline and arrive at GWL of interest. We take 1861–1890 to define the pre-industrial (PI) period as it is available across all CMIP5 historical simulations. The timing of the relevant GWL, for each downscaled GCM, is defined as the first time the 30 year moving average (center year) of global temperature is above 1.5 °C or 2 °C compared to pre-industrial. The corresponding 30 year period is then extracted from the corresponding RCM simulations for analysis using 1971–2000 as a control (CTL) period.

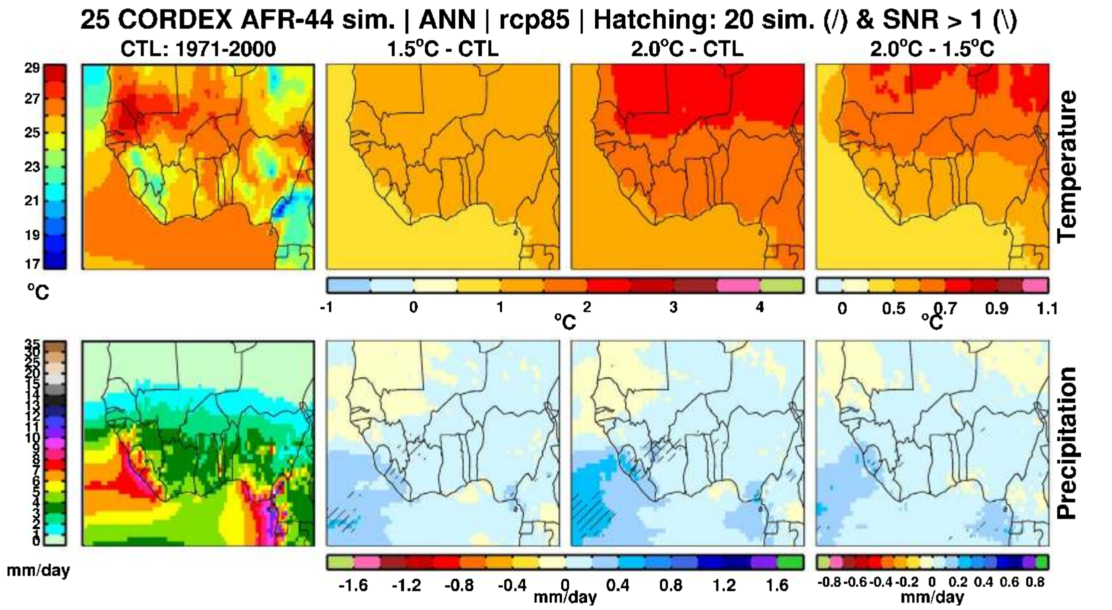

Figure 1. The CORDEX Africa ensemble average annual mean temperature and precipitation for 1971–2000 (CTL, left column), the projected changes at the 1.5 °C and 2 °C GWLs with respect to 1971–2000 (middle columns) and difference between the changes at 2 °C and 1.5 °C GWLs (right column). Areas where at least 80% of the simulations (20 of 25) agree on the sign of the change are marked by positively sloped hatching. Areas where the signal to noise ratio is equal or more than 1 are marked by negatively sloped hatching. For temperature all grid boxes satisfy the two criteria (the agreement and signal to noise ratio) and the hatching is not shown. Note that colour scales for the 2 °C–1.5 °C plots are different from the 1.5 °C–CTL and 2 °C–CTL ones.

Many methodologies exist for determining the robustness of a climate change signal (e.g. Collins *et al* 2013). For our study, we consider a climate change signal robust if the following two conditions are met:

a. more than 80% of model simulations agree on the sign of the change.
b. the signal to noise ratio, i.e. the ratio of the mean to the standard deviation of the ensemble of climate change signals, is equal to or larger than one.

The former considers model agreement and the latter is a measure of the strength of the climate change signal (with respect to the inter-model variability in that signal). We use both conditions in defining robustness because the former may be fulfilled even in the case of a very small, close to zero change.

To assess the response of extreme rainfall characteristics to the 1.5 °C and 2 °C GWLs, we examine two indices of importance to the region from the Expert Team on Climate Change Detection and Indices (ETCCDI), namely: the maximum number of consecutive days with rainfall amount less than 1 mm (CDD) and the maximum number of consecutive days with rainfall amount more than 1 mm (CWD).

The annual (ANN) mean precipitation, seasonal mean precipitation, and mean temperature are also analyzed to assess the regional response to global temperature increase. CDD analysis is applied to JJAS in order to assess both dry and wet spells within the rainfall season, which is very important to agricultural practices in the region. New *et al* (2006) clarified that CDD analysis applied to annual rainfall datasets can be used to detect lengthening or otherwise, of the dry season.

4. Results and discussion

Increased global warming at the 1.5 °C threshold could have a considerable impact on rainfall characteristics over West Africa. While projected changes in precipitation are, and remain marginal under each GWL, changes in temperature are big across the region (figure 1). At the 1.5 °C GWL, temperature increase is rather homogeneous (between 1 °C and 1.5 °C) across the region. However, at the 2 °C GWL, temperature increase varies widely across different climatic zones, from 1 °C to 2 °C in the Savannah to between 2 °C and 2.5 °C in the Gulf of Guinea. More than 80% of the simulations agree to the sign and amplitude of the change signal at both GWL. The models suggest that West Africa has experienced a 1.5 °C warming since 2004 and this is projected to continue through 2049, increasing to 2 °C warming from around 2012 through 2066, (Nikulin *et al* 2018) with the northern part of the region having higher temperatures than expected in the control. This agrees with Vizy and Cook (2012) who projected an increase in both minimum and maximum temperatures over the Sahel. The 2 °C GWL brings an additional regional warming of 0.4 °C to 0.8 °C compared to the 1.5 °C GWL. The difference of the GWLs indicate a spatial north-south temperature gradient which may result in modulating the dynamics of rainfall formation and distribution over West Africa.

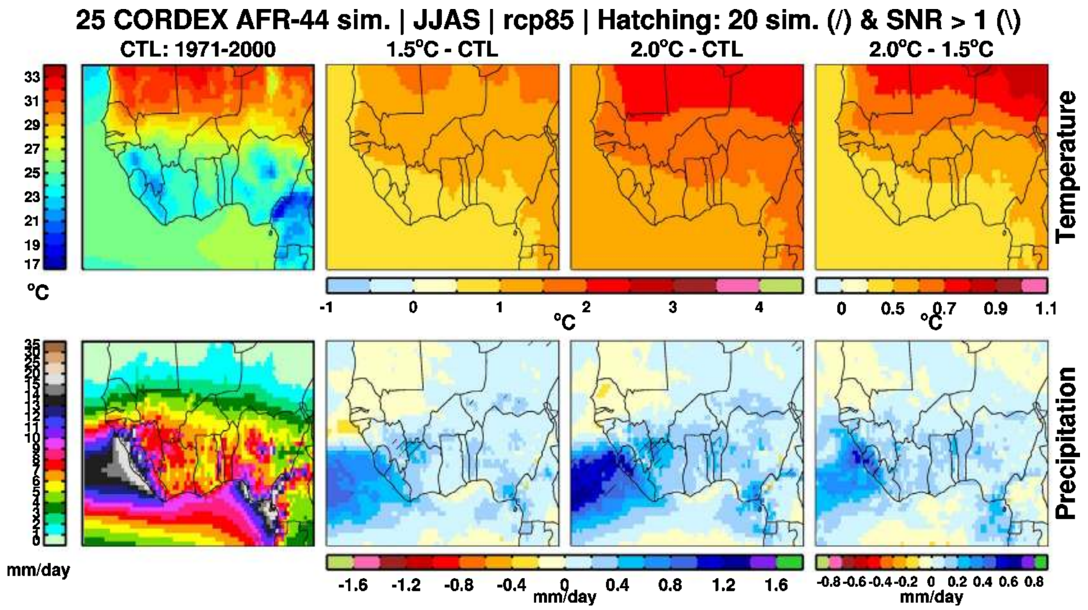

Figure 2. Same as in figure 1 but for JJAS.

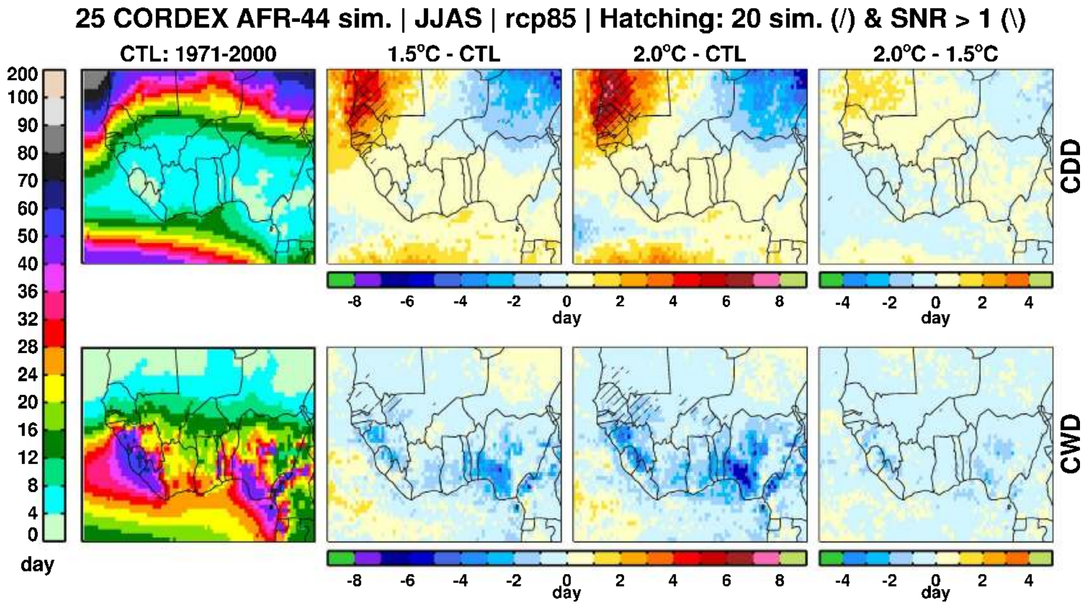

Figure 3. Same as in figure 2 but for CDD (upper panel), and CWD (lower panel).

On the seasonal scale, temperature increase occurs with an enhanced warming of more than 1 °C at 1.5 °C GWL and up to 3 °C at 2 °C GWL in the northernmost parts (figure 2). In the southern part of the region, temperature increase is below 1 °C for 1.5 °C GWL and between 1 °C and 1.5 °C increase for warming reaching 2 °C threshold. The difference in projected changes between both GWL is about 0.5 °C at the south and up to 1 °C at the north.

Enhanced warming leads to an increase in mean seasonal rainfall in most parts of the region except for the northwest which is dryer. At least 20 models agree to a wetter climate at the southwestern part under an enhanced warming regime. Specifically, seasonal rainfall averages increase by about 0.6 mm day^{-1} in parts of the Guinea Coast. Other parts of the region receive an increase of about 0.2 mm day^{-1}, up to 0.4 mm day^{-1} in a few isolated areas.

The CDD distribution in the control period is maximum in the northern belt of West Africa and decreases southward, while CWD follows a reversed pattern (figure 3), similar to the zonal distribution of rainfall (figure 2). CDD (of up to 70 d) is higher in the Sahel than the Guinean Coast by a factor of almost ten. The coastal parts of Nigeria, northern parts of Liberia, and Sierra Leone have CDD of up to 4 d. At the 1.5 °C GWL, CDD in the Guinean Coast increases by up to 2–3 d in most areas like Togo, Benin, Côte d'Ivoire, Sierra

Leone, Liberia and Southern Nigeria. An increase of about 5–7 d is projected for parts of Mali, Mauritania and Senegal. Reduction in CDD is however projected in most parts of Niger and the northernmost part of Nigeria. The CDD distribution at the 2 °C is similar to that of 1.5 °C GWL because unlike temperature, there is a higher latency in the response of rainfall enhance warming as seen in figure 2. This however agrees with the result of Sultan and Gaetani (2016) who reported a decrease in number of dry days over central Africa in spring and over eastern Sahel in summer. The difference in CDD patterns between 1.5 °C and 2 °C GWL is marginal.

At both enhanced warming levels, there is a CWD reduction of up to 4 d, especially in the Guinea Coast (figure 3, lower panel). However, minor differences of up to 3 d exist between the two GWLs in the coastal regions. Only minor changes exist in CWD across the northern parts of West Africa. This, however, is contrary to the results of Vizy and Cook (2012) which projected increases in the northern parts of the region. The high level of model agreement is noteworthy. Over 80% of ensemble members agree on both the CDD and CWD signals. The projected changes in the region also demonstrate a low signal-to-noise ratio, thereby attributing the difference to change and not just inter-annual variability.

5. Conclusion

This study assessed the potential impact of a 1.5 °C and 2 °C global warming levels on consecutive dry/wet days over West Africa from the RCP 8.5 climate scenario. We used an ensemble of 25 regional simulations forced by a total of ten GCMs, with a control period of 1971–2000. Our results indicate a consistent change signal in temperature and rainfall over many areas of West Africa. It is important to note that an increase of 0.5 °C increase in the global average leads to an enhance warming of up to 1 °C in some part of the region.

In areas of increased simulated drying, drought persistence (CDD) increases, while the CWD decreases. For example, CDD is projected to increase, particularly in the northern part of the region while CWD is projected to decrease with over 80% model agreement in each case. The projected increase in CDD which is an indicator for increase in dry spells may have implications for West Africa where rain-fed agriculture is dominant. The projected increase in consecutive dry days may adversely influence future crop yield thereby increasing the risk of food insecurity in the region.

Finally, the difference of impacts between 1.5 °C and 2 °C warming on the projected changes of CDD and CWD is not much, implying that either we meet the threshold of 1.5 °C or 2 °C we are going to face similar seasonal impacts.

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ORCID iDs

Nana Ama Browne Klutse https://orcid.org/0000-0001-5156-2765
Vincent O Ajayi https://orcid.org/0000-0002-9662-5683
Emiola Olabode Gbobaniyi https://orcid.org/0000-0002-0214-0010
Kouakou Kouadio https://orcid.org/0000-0003-0255-1757
Francis Nkrumah https://orcid.org/0000-0002-4723-8062
Kwesi Akumenyi Quagraine https://orcid.org/0000-0002-7887-6040
Christiana Olusegun https://orcid.org/0000-0001-7208-0095
Ulrich Diasso https://orcid.org/0000-0002-7461-7295
Kamoru Lawal https://orcid.org/0000-0002-8198-8844
Grigory Nikulin https://orcid.org/0000-0002-4226-8713
Christopher Lennard https://orcid.org/0000-0001-6085-0320
Alessandro Dosio https://orcid.org/0000-0002-6365-9473

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