Responses to the community comment CC1

We would like to thank Paul-Arthur Monerie for his valuable comments and suggestions that really help to improve our manuscript. The comments are recalled in black. Our responses to each comment are written in purple.

Comment on wcd-2022-53

Paul-Arthur Monerie

Community comment on "Future changes in the mean and variability of extreme rainfall indices over the Guinea Coast and role of the Atlantic equatorial mode" by Koffi Worou et al., Weather Clim. Dynam. Discuss., https://doi.org/10.5194/wcd-2022-53-CC1, 2022

Review of "Future changes in the mean and variability of the extreme rainfall indices over the Guinea coast and role of the Atlantic equatorial mode" by Koffi Worou, Thierry Fichefet, and Hugues Goosse.

The authors assess the future evolution of precipitation characteristics (*e.g.*, extreme rainfall events) and the effects of changes in the Atlantic equatorial mode on Guinea coast precipitation variability and on rainfall indices. The topic is relevant for the scientific community and could help understanding better future changes in precipitation over West Africa.

I have several concerns that should be assessed before considering the study for publication.

- The novelty of the work is unclear. All results on changes in precipitation extremes have already been shown in the literature, and the section on the effects of the Atlantic Equatorial mode is not convincing. Please explain better what is the novelty of the study.

  Thank you for this comment. The motivation of this study is based on the fact that, over the 20th century, the Atlantic equatorial mode of variability has been the main oceanic driver of the interannual rainfall variability over the Guinea Coast, as shown in many studies (Giannini et al.,2003; Rodríguez-Fonseca et al.,2011,2015; Losada et al.,2012, Lübbecke et al.,2018; Worou et al.,2020). Other studies pointed out that this oceanic internal mode of variability could also impact extreme rainfall events over West Africa (Diatta et al,2020). An extraordinary high impact rainfall event occurs in Burkina Faso, on the 1st of September 2009, coinciding with below normal sea surface temperature (SST) conditions in the eastern equatorial Atlantic. This motivates us to study future changes in the SST variability in the eastern equatorial Atlantic and their impacts on the occurrence of extreme rainfall events over the Guinea Coast. This approach is new, because it studies a well-known couple ocean-atmosphere phenomenon, the Atlantic equatorial mode, and how future changes in this mode potentially influence changes in extremes. To our knowledge, such a specific analysis of the links between the AEM and extremes for both current and future climates has not been performed before. We will improve our motivation in the revised manuscript, accordingly.

- The introduction is too long, and its structure could be revised, with the information streamlined to provide a summary of the literature. For instance, information from Bichet and Diedhiou (2018), Odoulami and Akinsanola (2017), and Kpanou et al. (2018) is for different seasons (*g.*, AMJ, JAS), for different periods, and different metrics. Information seems also contradictory, with Odoulami and Akinsanola (2017) stating that there is a negative trend in extreme events (relative to the 95th percentile) over the Guinea coast while Kpanou et al. (2018) state that the number of such events has increased over some of the West African countries (Ivory coast, Togo, and Benin). The authors have used monthly SSTs to compute the AEM index. Please explain how monthly variabilities in SSTs could lead to changes in the variability of rainfall extremes.

We would like first to insist that we computed seasonal SST indices of the Atlantic equatorial mode (AEM) from monthly SST anomalies (linearly detrended) averaged over July, August and September (JAS). The impact of the AEM is evaluated on the seasonal rainfall characteristics.

Moreover, we did not describe the dynamics explaining the link between monthly SST variabilities and rainfall extremes in the submitted version. This will be included in the new version of the article, a few statements about the mechanism. Warm phases of the AEM during the boreal summer lead to strong low-level convergence and rising motion of humid air over the eastern equatorial Atlantic. The land-sea surface pressure gradient weakens, and limits the northward penetration of the monsoon flow toward the Sahel. Humid air is advected by the low-level circulation from the equatorial Atlantic to the coastal areas of West Africa. This provides favorable conditions for an increase in the occurrence of rainfall as well as of extreme rainfall events over the Guinea Coast. The physics behind the connection of the AEM to West Africa and the tropical regions is discussed in detail in Losada et al. (2010); Lübbecke et al.(2018) and Worou et al.(2020,2022), among others. We will modify the manuscript accordingly.

We will also reduce the length of the introduction, and better structure the review of the works on the extreme rainfall events over the Guinea Coast, with focus on the boreal summer season. It is hard to compare Odoulami and Akinsanola (2017) with Kpanou et al (2018), because the former study is focused on June-September (1998-2013), while the latter is on an annual basis (1981-2015).

- Method: The authors defined an anomaly as robust when 50% of the models present a significant regression coefficient. However, this low value could be eventually obtained by chance and would not show robustness in the results. The authors should revise this threshold, using the two-thirds threshold used for the sign of the EnsMean. Data have been linearly detrended. However, it is shown that anthropogenic aerosols have strong effects on West African precipitation and have driven a part of the 1970s-1980s drought and of the precipitation recovery (*e.g.*, Herman et al., 2020, Hirasawa et al. 2020; Monerie et al. 2022). Removing a linear trend will thus not allow considering the full effect of the anthropogenic activity on West African precipitation. The authors should check the robustness of the results using other methods, such as estimating theforced response using the ensemble mean (see for instance Ting et al. 2009).

Thank you for the suggestions.

We will revise the robustness metric for the change in the regression patterns related to the AEM. We will consider the two-third threshold for the sign-agreement among the 24 models as suggested.

Our aim is not to assess the specific impact of the aerosols on the extreme rainfall trend over the Guinea Coast, which is why we remove any drift from the anomalies computed for each index. We will better motivate the detrending of the data in the method section of the revised manuscript. However, anthropogenic aerosol forcing can have a long-term impact on the climate in many regions of the world. Over the past decades, changes in the anthropogenic aerosol forcing have led to differences in the changes in sea surface temperature between the North Atlantic and the global tropics, which yielded modifications of the hydrological conditions over the Sahel (A Giannini et al., 2013). You showed (Monerie et al.,2022) that the Anthropogenic Aerosol emissions induce a negative trend in the rainfall over West Africa during 1950-1980, and a positive trend afterward. These aerosol emissions have also induced a north-to-south SST gradient trend in the tropical Atlantic, which led to a weakening of the AEM and its impact on the rainfall over the Guinea Coast. Consequently, we will mention the impact of different forcings on the West African climate, and highlight the role of aerosols in our introduction.

For the last point of the comment, we will compute a signal-to-noise ratio to compare the forced response to the internal variability. This additional diagnostic will be added to the maps of future mean changes in the extreme indices compared to the present day, following Monerie et al. (2017):

$$SNR = mean(\Delta X)/\sigma(\Delta X)$$

Where for a variable X,

- ΔX is the change for a given model,
- $mean(\Delta X)$ is the forced change signal, which is the average over the 24 GCMs, and
- $\sigma(\Delta X)$ is the intermodel spread of the changes.

- The authors argue that future changes in the variability of the Atlantic equatorial mode would have significant effects on future variability in precipitation extremes. However, the authors should that there is no relationship between the Atlantic equatorial mode and the precipitation indices over land (Figure 5). How could it then be possible that changes in the Atlantic equatorial mode could impact precipitation extremes over land? Please explain. Here I strongly disagree with the comments on lines 326-327, and 336-337, which are not supported by the results. Would averaging precipitation over the box be useful to extract a significant signal in the relationship with the Atlantic equatorial mode?

  We agree that, according to the metric that we used to check if a signal is robust or not, it seems that there is no significant point over Guinea Coast. One should bear in mind, however, that the robustness could be assessed in different ways, such as the two-third metric for instance. In the revised manuscript, we will separate models into two groups, based on the sign of their responses to the Atlantic equatorial mode. We will, however, show the average over the Guinea Coast box and we will apply the two-third sign agreement diagnostic to see if it gives clearer results.

  It is highlighted in the conclusion that "extreme rainfall anomalies related to one standard deviation of the AEM under the present-day conditions are barely significant over the Guinea coast". Please note that those anomalies are not significant, not barely significant.
  We will modify our statement according to the different modifications that are planned in the revised manuscript.

  In the abstract, it is stated that "the decreased variability of the AEM in a warmer climate leads to a reduced magnitude of the rainfall extreme response associated with AEM". (i) This will be more about a weaker effect of the AEM than because of a reduced variability of the AEM, because the AEM index is standardized, and Figure 8 shows reduced effects of the AEM for one standard deviation.

  Thank you for the comment, we will modify out text in the revised version, accordingly.

  (ii) It is argued in the introduction that the EAM effect on rainfall is stationary. This is here contradictory to the comments of the authors, please comment. The authors show the change in the regression patterns of the JAS extreme rainfall indices associated with the standardizedJAS AEM SST index (Figure 8). It would be best to also know if the regression coefficient is significant over the 2080-2099 period (*i.e.*, as for figure 5 but for the period 2080-2099). This would help understand the results of the authors.

  We will improve our text to clarify the apparent contradiction that you mention. We are discussing the stationary relationship between the AEM index and the Guinea Coast rainfall (GCR) over the last century. By stationarity, we mean no change in the significant positive correlation between the AEM index and the GCR index over the observation period. We propose to add a figure in the revised manuscript, showing a moving correlation between the AEM and the GCR indices (with a window length of 30 years), from 1995 to 2099 in the GCMs. This will help to see how the overall relationship between the AEM and Guinea Coast rainfall may change with time.

We will also show the long-term future (2080-2099) regression maps of the extreme indices onto the standardized AEM index.

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Hirasawa, H., Kushner, P. J., Sigmond, M., Fyfe, J., & Deser, C. (2020). Anthropogenic

Aerosols Dominate Forced Multidecadal Sahel Precipitation Change through Distinct Atmospheric and Oceanic Drivers, Journal of Climate, 33(23), 10187-10204. Retrieved Nov 4, 2022, from https://journals.ametsoc.org/view/journals/clim/33/23/jcliD190829.xml

Additional comments

Lines 33-35 are about future changes in heavy precipitation trends, but the following part of the paragraph (lines 35-39) is about the total wet day rainfall and rx5day. There is therefore no rationale for the "for instance" of line 36. Lines 38-39: What "could be" mean here in terms of confidence?

Lines 33-35 are about the changes in the heavy precipitation over West Africa during the last decades (and not future changes). The next sentence follows thus logically but we will modify the text in the revised version to make this clearer. Moreover, we believe that a proper detection and attribution study would be needed to allow a strong statement that attributes a flooding event as a consequence of an extreme rainfall event. It could also result from compounding events. As this has not been done in the cited article, we believe that Dike et al. (2020) prefer to use "could be". We will add a few words in our revised version to highlight this point.

Lines 40-47: What the authors are trying to demonstrate is not clear. Is there a spatial inhomogeneity in changes in rainfall indices, or is it about the complexity of changes in precipitation characteristics, that will be rainfall indices-dependent? Please rephrase the text to show the main point of the paragraph more clearly.

In the revised manuscript, this section will be rewritten, with a focus on a few extreme indices common in the literature. The complexity of this paragraph is in part due to different indices computed from different data sources, different periods, and different seasons. That did not help to synthetize easily the main information. In the revised manuscript, the text will be restructured to clarify our demonstration. It is clear that there is a spatial inhomogeneity in the trend of observed extreme indices. The different indices however help to understand the character of the rainfall, but studies over different periods and seasons can lead to different conclusions.

Line 48: Is this information obtained from observations?

This information is from observations (CHIRPS data and rain gauges). We will add this comment to the revised manuscript.

Lines 61-69: Do the authors note a relationship between bias in the different rainfall indices and bias in seasonal mean precipitation?

We did not look at the links between bias in the indices and the mean precipitation. We will provide this information in our revised manuscript. Thank you for this suggestion.

Line 71 and Line 72: "anthropogenic emission of greenhouse gases", and "the shared socioeconomic pathway scenarios". Please name the scenarios

Line 71: This is a general context statement, and we believe that there is no need to go too much into details as the different studies use different experimental designs. For instance, Rind et al. (1989); Mearns et al. (1995) used a doubling CO_2 simulation. Hegerl et al. (2015) and Diedhiou et al. (2018) discussed RCP2.6,RCP4.5,RCP6.0,RCP8.5 projections. Akinsanola et al. (2020) evaluated the

RCP4.5 and RCP4.8 scenarios. Van der Wiel et al. (2021) perform specific simulations (present-day, 2°C, 3°C, and outputs from CMIP5 RCP8.5 GCMs simulations). However, for specific results that we mentioned, we provide information about the scenarios.

For line 72, Li et al, 2021, we will add the SSP scenarios used (1-2.6, 2-4.5, 3-7.0, 5-8.5) in the revised manuscript.

Line 74: The sentence is about RX1day and RX5day while the previous sentences are about extreme events. Please be clearer.

The previous sentence that you mention talks about "extreme rainfall events" in general. These events can be characterized in terms of frequency, duration and intensity. The index RX1day describes the maximum rainfall quantity in one day (so an intensity). The RX5day describes the maximum of 5 consecutive days of rainfall, which is a measure of duration and intensity. We will modify the sentence in the revised manuscript to lake this point clearer.

Line 77: "RCM-CMIP5" Please define and explain.

We will modify this expression: "Regional climate models (RCM)" forced with outputs from CMIP5 models". Thank you for the comment.

Lines 75-79: Are the results also model-dependent?

There are noticeable differences between GCMs projections and those from RCMs, in terms of rainfall characteristics. Moreover, within the RCMs simulations, there is still a spread in the magnitude of the changes, and even in the sign of the changes depending on the variable of interest. This can be seen in Figure 8 of Akinsanola and Zhou (2019). In our revised manuscript, we will show box-whisker plots for different diagnostics, which will give an idea of the model dependency of the changes.

Line 80: Does "These simulations" refer to Akinsanola and Zhou (2019)? Please be more specific.

Yes, we will clarify this point by referring to Akinsanola and Zhou (2019) at the beginning of the paragraph. Thank you for the remark.

Line 89: both enhanced.

Thank you for the remark, we will take it into account.

Lines 94-96: The increase in air moisture following Clausius Clapeyron explains a part of the seasonal mean increase in water vapor. I am puzzled about how the increase in water vapor, following Clausius Clapeyron could lead to a change in precipitation variability. Do the authors mean that it would be due to a change in variability of the temperature (SSTs) that would lead to different changes in air moisture?

This is an interesting point. Unfortunately, the authors did not provide more information. They computed a change in the rainfall variability due to the enhanced water vapor content of the atmosphere in the future . As the obtained change in variability exceeds the simulated change in the rainfall variability, and as they expect a decrease in the contribution of the dynamics, they conclude that the increase in the variability is due to thermodynamic changes. Because of this lack of information , we propose to keep in Lines 94-96 .

Line 103: Please replace "More" with ", where"

The corrections will be applied, and the dot will be removed. Thank you

Line 107: "warming and cooling", is that following a north/south dipole? Please be more specific.

No, we were not talking about a dipole. Rather, we were referring to the different positive and negative phases of the AEM, which are characterized by positive and negative SST anomalies in the eastern equatorial Atlantic, respectively. We will modify the statement accordingly.

Lines 113-114 could be shortened, removing "The first mode…indicates a strong", and removing ", and", in line 115.

We will shorten the statement as suggested. Thank you

Line 115: Is it the "total variability" in Guinea coast rainfall? What is the time scale considered for the variability? (*e.g.*, daily, interannual?).

This is not the variability over the Guinea Coast, but the covariability between West African rainfall anomalies and the tropical Atlantic SST anomalies. This covariability between the Guinea Coast rainfall and the eastern equatorial Atlantic SST is dominant on the interannual timescale. We will add the information to the new text.

Line 116: Is it about the wind convergence?

Yes, this is about a low-level wind convergence. We will add "wind" in the revised text.

Line 124: "variability of the AEM". Is it the daily variability? Please be more specific throughout the text.

All our analysis is focused on the interannual timescale. We will put this information at the beginning of this paragraph. Thank you for the remark.

Lines 205-215: The authors could add sentences to explain briefly why the authors are using these metrics.

We will give more motivation to the choices of the metrics.

Lines 225-230: Are the changes in rainfall indices following the changes in seasonal mean precipitation (sign and pattern)?

We will provide in the supplementary material some figures showing a scatter plot of the changes in the mean precipitation and the changes in the rainfall indices. We will say a few words in the main revised manuscript about the outcomes.

Line 225: "simulated by climate models". The authors are not showing the results for each model individually in Figure 1. Please change it to "shown by the CMIP6 ensemble mean".

We will correct the sentence. Thank you.

Line 230: "observations". Shown where?

This was shown on Figure A1.g of the submitted manuscript. This will be specified in the revised manuscript.

Lines 236-246: Are these results model-dependent?

We will provide in the revised manuscript the results at a model level. We will also comment on the model dependency of the results.

Figure 1: It would be helpful to have the observation with contours.

In the revised manuscript, we will show in color the multimodel ensemble median and in contours the ensemble median of the 6 rainfall observation datasets. Thank you for the suggestion.

Lines 261: There are plenty of references on the change in seasonal mean precipitation over West Africa and over the Sahel. Please acknowledge the literature.

We will acknowledge the literature as mentioned. Thank you.

Lines 272-273: Is the change in RX1day consistent with the shortening of the rainy season over the western Sahel?

The change in the frequency of wet days is consistent with the shortening of the rainy season over the western Sahel (Fig. 3I of the submitted manuscript). The RX1day just tells us about the maximum intensity of a daily rainfall event, which is increasing over all the regions of West Africa (Fig. 3h of the submitted manuscript). We did not aim to discuss the Sahel in our study, but we will say a few words about these changes in the revised manuscript and also acknowledge the literature.

Figure 3: The pattern of R10mm is very similar to the pattern of PRCPTOT (Figure 3). The authors could comment on the possible strong role of R10mm in the total change in precipitation. Does R10mm provide a similar result for the number of rainy days?

The best way to make this link is to evaluate the contribution of the R10mm events (defined as days when more than 10mm of rainfall occurs) to the total rainfall. We do not compute this index, and we won't do it, as we have to reduce the number of indices in our article and ??? will not be included. This choice has been motivated by the suggestions of the two anonymous reviewers. Still, this would be a nice approach.

Line 285: What is the timescale used for computing the standard deviation here?

The standard deviation is simply computed over the 20 years period (with one value per year), without removing any trend or any frequency from the raw indices. We will add this information to the new version of the manuscript.

Lines 311-312: As for the precipitation indices, result sensitive to how the forced response was removed? (*e.g.*, a linear trend here)

We didn't test different ways to remove the trend, but in our previous work (Worou et al., 2022), we tested the impact of a linear trend compared to a quadratic trend on the AEM variability. Similar results were obtained in both cases. This has not been done here to avoid to simplify the discussion.

Line 314: "total wet-day precipitation index" does not show significant differences over land in Figure 5.

Much of the robust responses to the AEM are over the equatorial Atlantic, and we have few areas over land which show a robust response in the "total wet day precipitation index". In the revised manuscript, we will apply only the two-third sign agreement metric, and we will see it the results will be clearer.

Line 364: "weakened variability". What is the considered time scale?

We are considering the interannual timescale. We will add this information to the revised manuscript.

Line 375-377: Are differences between periods significant? How would this be consistent with Figure 5 which shows no robust effects of the tropical Equatorial mode on precipitation extreme over land?

The significance between different periods depends on the metrics used. In Figure 8 of the submitted manuscript, we do not penalize models which show "no robust signal aver land" in the historical simulation. The results show some robust differences for some indices. Moreover, In the revised manuscript, we will consider only the sign of the changes and a two-third agreement, as you suggested (corresponding to Figure 8, submitted manuscript).

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