Author's Response to the Review Comments

We appreciate the time and effort by the Editor and the reviewer in assessing our manuscript and the thoughtful and valuable suggestions offered. We are pleased that our reviewer advises now only "minor" revisions, but we have still taken every suggestion seriously and responded in full as described below. We hope that our paper amendments are to the satisfaction of the reviewer and that the manuscript can be considered for publication in GMD.

In the following reply, the black italic text is the reviewer's requests, the black indented text is our responses and the blue text in quotes are revised text in the manuscript.

1. Response to Comments from Editor:

Are the links and DOI to code & data up-to-date? Is it easy enough for someone to reproduce your results and build upon your work? etc.

[Response] Thank you for reminding us of this. We have uploaded the latest code to GitHub. In addition, we also uploaded the driving data so that it is publicly available, with all links shown in the README file in GitHub. Finally, we use the GitHub-to-Zenodo integration and updated the related DOI in the manuscript. With these data and code, readers can reproduce our results in full following the instructions provided.

2. Response to Comments from Reviewer #1:

Section 5.1: The higher error in MAP for both PREMU and the linear regression seems to occur in Australia and West Africa (or more across the Sahel) which surround arid areas. It may also be that these areas have low relative changes in precipitation and hence prediction with principal components based on gridded Tair becomes more tough. This could be easily checked by the significance in their coefficient values obtained for Equation 2.

[Response] Thank you for this suggestion. We agree that the higher error in changes of MAP for PREMU and the linear regression occurs in the arid areas (Fig. 4**b, d, f**). Following the reviewer's suggestion, we have checked the significance of the correlation between the precipitation from GSWP3 and the estimation from PREMU (as given by Eq.2) during the period 1901-1950 for each month (Figs. R1-R2). We find that there is almost no difference in significance level in the correlation between these arid areas and other regions. However, notable is that the coefficient of variation of precipitation (shown as the ratio of the standard deviation to the mean) is much greater in arid areas (e.g., Australia and Sahel; Fig. R3-4 below). Hence these two factors together imply that the regression models in these regions still fit well variations as well as trends - yet for arid regions we can expect both PREMU and linear regression to show larger absolute errors in MAP.

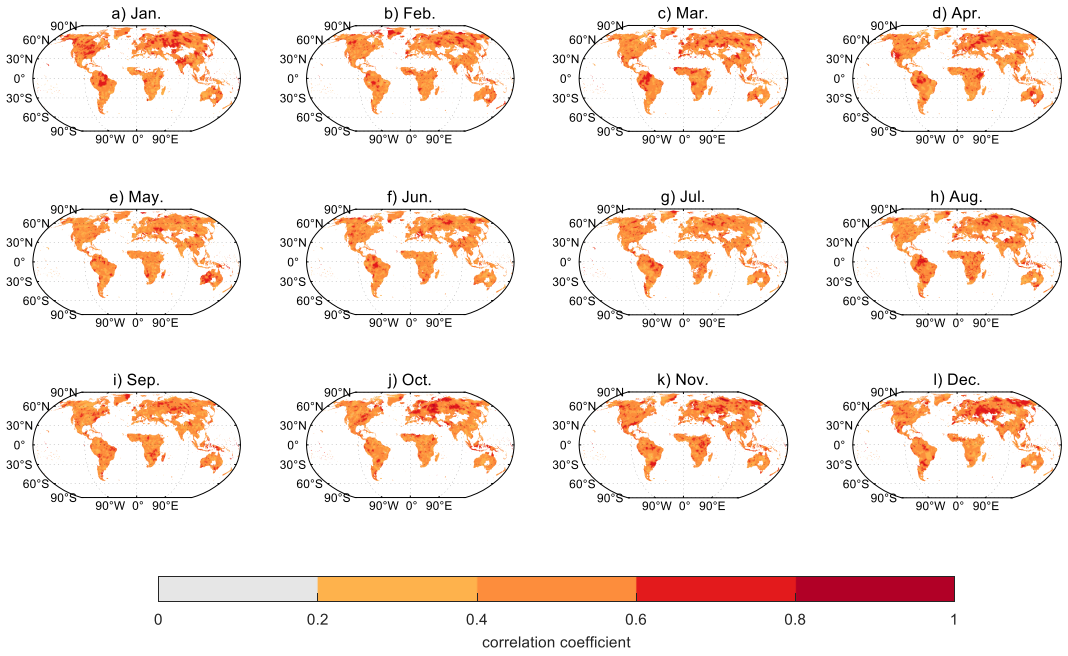

Figure R1 The correlation coefficients between precipitation from the GSWP3 dataset and estimates from PREMU. Statistic is calculated for each month (a-l respectively), and for the period 1901-1950.

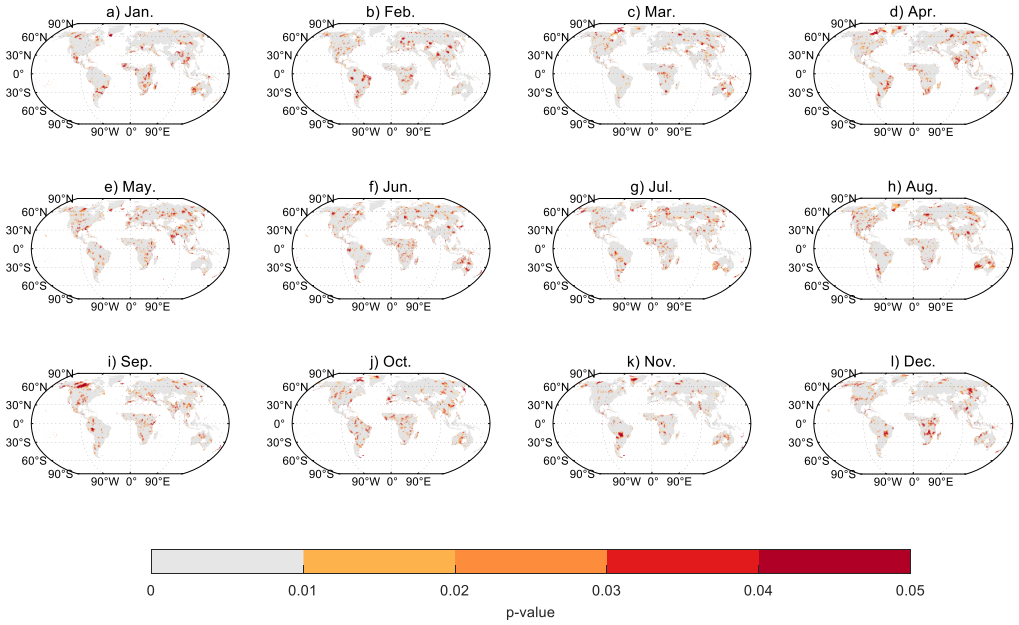

Figure R2 The significance of correlation between precipitation from the GSWP3 dataset and estimates from PREMU. Statistic is calculated for each month (a-l respectively), and for the period 1901-1950.

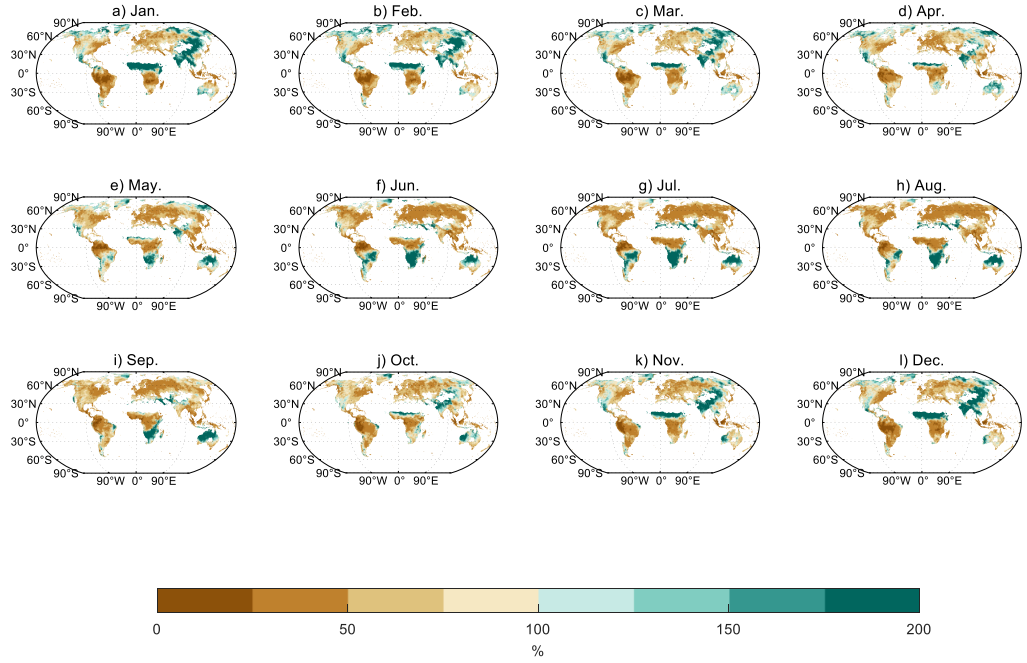

Figure R3 The ratio of the standard deviation in precipitation to the mean of precipitation, using the GSWP3 dataset. Statistic is calculated for each month (a-l respectively), and for the period 1901-1950.

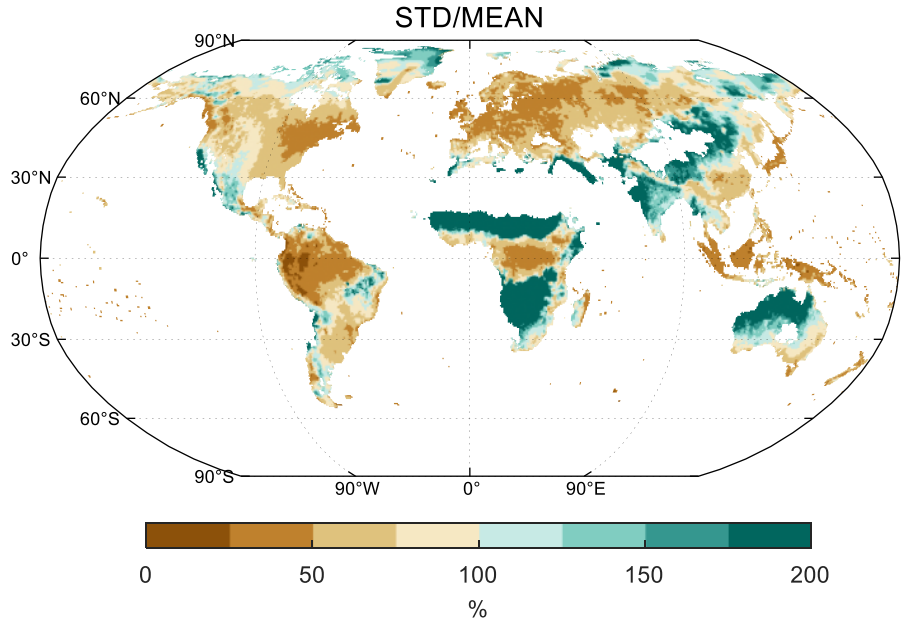

Figure R4 The average ratio (across all months) of the standard deviation to the mean of the GSWP3-based values presented in Fig. R3.

Editorial Comments:

(1) R4.2 "Thus, Lower complexity models (LCMs) are designed as the common approaches to improve computational efficiency in climate change research ***by focussing*** *on the most impact relevant variables".*

[Response] We have revised the wording, following the reviewer's suggestion.

(2) R4.4 The emulators developed by Beusch and Mckinnon are a bit different, consider restructuring to e.g.
"Joint temperature and precipitation emulation by considering anthropogenic GHG forcing and large-scale modes of Sea Surface Temperature (SST) variability has proven possible (Mckinon and Deser 2018; Mckinon and Deser 2021). More recently, a spatially resolved emulator (MESMER) solely requiring GMT e.g. by coupling to the emission-driven LCM (MAGICC), to then generate annual temperature fields, has been developed (Beusch et al. 2021)".

[Response] Thank you. The paper has been revised, using the suggested wording.

(3) R4.5 "Precipitation has high spatio-temporal variability and is affected by atmospheric dynamics ***and*** *inter-annual modes of variability (Li et al., 2021; Tsanis and Tapoglou, 2019), making* ***represention of it*** *with traditional LCM approaches difficult. Thus, only two LCMs (IMOGEN and OSCAR) have tried to emulate precipitation****, but***

with poor skill *(Zelazowski et al., 2018; Gasser et al., 2017). IMOGEN emulates the gridded precipitation based on the regression relationship (by month and location) between gridded precipitation and global land average temperature (Zelazowski et al., 2018). OSCAR constructs the emulator by establishing* ***a*** *relationship between global average precipitation and global average temperature and radiative forcing,* ***from which a pattern-scaling method is used to deduce the gridded precipitation*** *(Gasser et al., 2017). Nevertheless, the gridded precipitation estimated by the simple linear method is not* ***fully*** *reliable* ***in either*** *IMOGEN* ***or*** *OSCAR; the gridded precipitation predicted by IMOGEN ~~only~~ explains less than 20% of variance of seasonal precipitation in most regions (Zelazowski et al., 2018) and OSCAR cannot capture…".*

[Response] Again, thank you for providing a suggested reword, that we have adopted in our paper.

(4) L204: Refer to ONeill (https://doi.org/10.5194/gmd-9-3461-2016) when referencing SSP 5-8.5, consider also rephrasing :
due to it representing the most extreme changes in Tair amongst SSPs.

[Response] Thank you. This reference has been added and, and the related text revised as: "For the estimates of future change, we used precipitation and Tair from SSP5-8.5 scenario of greenhouse gas increases to calibrate the ESM-specific emulator. We selected this scenario due to it representing the most extreme changes in Tair amongst SSPs. (O'Neill et al., 2016).".

(5) L209 and L318: Set out in ~~the~~ Table

[Response] It has been revised.

(6) L214: Do you have examples of the "limited area application", it is not too important but a reference here may help give an idea about what improvements your study's approach brings.

[Response] This reference has been added (Rahaman et al., 2019): "However, unlike many limited-area applications that derive a single timeseries (to multiply each PCA; Rahaman et al., 2019)".

(7) L215: and hence ~~why~~ … has a k dependency

[Response] It has been revised.

(8) L312: ~~and~~ where

[Response] It has been revised.

(9) L315: Do you mean?:
we constructed 315 the regression relationship between GLAP and the 10 individual principal components ~~individually~~ separately.

[Response] Thank you. Yes, we do mean that, and the paper has been revised accordingly.

(10) Section 3.2.2 seems to be more of a "Generating emulations using PREMU" than "Validation". Section 3.3 seems to capture validation quite well so maybe consider renaming?

[Response] Thanks for the suggestion. We have renamed Section 3.2.2 as "Generating emulations using PREMU" and Section 3.3 as "Validation".

(11) L320-L323: Based on the principal component coefficients extracted using these calibration datasets, we then estimated the $T_{e,m}^{PCA}(y,i)$ *using Equation 1, for 1951-2016 using Tair from GSWP3 and for 2015-2100 using Tair from each ESM independently under the other three SSPs ~~weighted by ⋯ Eq. 1.~~*

[Response] It has been revised.

(11) L403: The percentage error at each grid ***point***

[Response] It has been revised, as suggested.

(11) L459: A key requirement of ***PREMU*** *is that it⋯*

[Response] It has been revised.

(11) L485: West Africa

[Response] Thank you. This geographical description has been corrected throughout the text.

(11) L486: which ***is*** *discussed*

[Response] It has been revised.

(11) L591: considering restructuring the sentence "⋯, that are account for in ESM simulations, ⋯" seems to be floating without any subject

[Response] Thanks. After consideration, we decided to delete this and revised as: "We speculate that this may be caused by the most drastic land use changes associated with that former SSP scenario, resulting in a slower increase in precipitation under SSP3-7.0 (Riahi et al., 2017).".

(11) L607: the SSP5-8.5 scenario and SSP1-2.6 scenario. Though with a different order of PCA coefficients (Fig. S19-S20), this suggests⋯

[Response] It has been revised, as suggested.

(11) L623: . There are some studies that predict ~~that the variability of precipitation will increase in a warmer world~~ an increased variability in precipitation under a warmer world (Zhang et al., 2021; Song et al., 2018),

[Response] Thanks. It has been revised.

(11) L635: Throughout this study, we used ~~Here, we used throughout~~ the three-month average temperature…

[Response] It has been revised.

*(11) L650: This may **be** due to…*

[Response] It has been revised.