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Earth System
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Discussions

# *Interactive comment on* "Projected changes in crop yield mean and variability over West Africa in a world 1.5 K warmer than the pre-industrial" *by* Ben Parkes et al.

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The responses are presented as reviewer comment, our response and the modified manuscript content.

1. Information about crop models: The basic characteristics of the crop models should be given in the main text (Which models do account for CO2 fertilization? etc.). The predictors and equations of the statistical models have to be provided.

The model descriptions have been moved from the SI to the main text and a description of the linear models added. GLAM and ORCHIDEE-Crop both respond to carbon



dioxide fertilisation and ORCHIDEE-Crop has nitrogen fertiliser inputs as part of the simulated crop growth.

The linear models use a design that has been used in several previous studies Estes et al. (2013); Lobell and Burke (2010); Wang et al. (2016); Parkes et al. (2017). The models in this study use the robust linear fitting tools in MATLAB (Holland and Welsch, 1977) that are less sensitive to outliers than least squares fitting. The input data for the model have been polynomially detrended before fitting and the log of the yield was taken, this means the models produce relative changes in yield instead of absolute ones. The polynomial detrending used in the models is a two degree polynomial solved for each grid cell. The models solve the equation shown in Eqn 1 where a, b and c are constants for each grid cell and T and P are the seasonal mean temperature and total precipitation respectively. Y_it = a_i + b_i T_it + c_i P_it

2. Entire distribution of changes in crop yields: Instead of showing the heat maps of mean changes it would be much better to report the results of the individual models to illustrate the spread in the projections and allow for a risk assessment that does not only depend on ensemble mean changes but also on the range of plausible projections. For example, each individual simulation could contribute one dot to a scatter plot of present-day mean yields (x-coordinate) against relative changes in yields from present-day climate to a "1.5âŮę C world" (y-coordinate). All simulations generated by one crop model could be shown in one color. Such plots could be provided for the entire region or individual countries. I consider it particularly problematic to simply average across models accounting for CO2 fertilization effects (GLAM and ORCHIDEE-crop (I assume although it is not stated in the SI)) and others that do not (Sarra-H and the statistical models (I assume)). This could be avoided on this way.

Combined with requests from other reviewers we have built the following plots that show the map of yield and IAV changes along with scatter plots suggested above. The maize plot is shown in Figure 1 while the millet and sorghum plots have also been added to the manuscript.

The caption for figure one is "Change in maize yield and yield IAV between the historic and future climates. The top left shows the change in yield where + indicates that in three crop models the change will be positive and Âů indicates that in three crop models the change will be negative. The top right is the same as the top left except for IAV instead of yield. The units of the colour bar in the top plots is kg/ha. The bottom left shows the fractional change in yield against yield for all analysed grid cells. The bottom right shows the fractional change in yield IAV against yield for all analysed grid cells."

3. Representation of present day management in process-based models: The paper needs a more detailed discussion to what degree the process-based crop models represent present day management (fertilizer input, specification of growing seasons, representation of multi-cropping). Is there additional information about growing season or fertilizer input to evaluate the models assumptions?

Extra detail has been added in the crop models description section of the manuscript

GLAM and ORCHIDEE-Crop both respond to carbon dioxide fertilisation and ORCHIDEE-Crop has nitrogen fertiliser inputs as part of the simulated crop growth.

The planting and harvest dates for the crop models were determined using data generated as part of the Global Gridded Crop Model Intercomparison project (Elliott et al 2015). The crop models all simulate crops based on a single planting and harvest without multicropping.

4. Inter-crop model spread of projected changes: It is usually hard to really explain model differences. It may be impossible. However, any idea would be extremely valuable and should be discussed to advance the field and create a better understanding of the processes and potential deficits in their representation.

A new section describing the main differences in the models has been added.

Differences in the crop models Both GLAM and ORCHIDEE-Crop were used to simu-



late maize, SARRA-H and the generalised linear models were used to simulate maize, sorghum and millet. GLAM and ORCHIDEE-Crop both respond to carbon dioxide fertilisation and ORCHIDEE- Crop has nitrogen fertiliser inputs as part of the simulated crop growth. The crop models all simulate crops based on a single planting and harvest without multicropping. GLAM and the linear models use observational yield as an input, in both cases the input yield is detrended using a two degree polynomial before use. This detrending removes consistent trends such as management changes and technological improvements. GLAM unlike the other models was calibrated specifically for these simulations whereas ORCHIDEE-Crop and SARRA-H used pre defined parameter sets. The SARRA-H parameters were based on a study area in Burkina Faso. The process based models are time dependent and respond to the arrival of the monsoon, the linear models however only use the seasonal total precipitation. Linear models suffer with reduced accuracy outside the parameters space used to train them. In the short term linear models are not notably worse than process based models (Lobell and Asseng,2017).

The differences in the crop models and inputs have an influence on the results. From Figure 1 GLAM shows a greater spread of yield change with climate change than the other models whereas ORCHIDEE and SARRA-H are more consistent under climate change. The yield changes in ORCHIDEE and GLAM are also influenced by the carbon dioxide fertilisation effect and in its absence the projected yields are expected to be lower. The IAV results show greater spread in the linear models than the process based models, this is a result of the simple parameters in the linear models. The results in Figure 5 show that GLAM has a stronger negative response to precipitation loss than the other models. The temperature results for all models show a downward trend in yield with increasing temperatures. The lack of variability in the linear models is shown in Figure 4 where they consistently underestimate crop failure rates. ORCHIDEE has a smaller IAV than the other process based models which means the crop failure limit is much higher than in the other models. This results in ORCHIDEE finding a significant increase in the number of crop failures. As the ORCHIDEE IAV is closest to the observed IAV (Table 3,this indicates that GLAM and SARRA-H are likely to underestimate the number of future crop failures. For Figures 2 and 3 the country scale yields in the historic inputs can be clearly seen in the linear models as opposed to the spread of yield values in SARRA-H.

5. Comparison of return periods of crop failure: How are the return frequencies of crop failures derived? I assume that they are determined from crop-model specific samples of N = 16 climate simulations x 20 years = 320 data points. In this case it could be an artefact that the distribution of yields at 1.5âŮę C of global warming is wider (and potentially less normal) than the associated present-day sample: The 1.5âŮę C distributions simply comprises the inter-climate model spread of the simulations which is reduced in the present-day sample due to the underlying bias-correction. To avoid this artefact the change in variability would have to be estimated within each individual climate model. Averaging across the different climate models would have to be done afterwards. However, that approach would reduce the sample size to only 20 (or 30) years, probably not enough to robustly estimate crop failures in the proposed way. So it may only be possible to compare the standard deviations (or percentiles) of both 20 (30)-year samples (present-day vs 1.5âŮę C) as an alternative measure of the variability.

Every grid cell is checked for a crop failure against the crop failure limits determined by the historic simulations. The historic simulations are used instead of the observations as a sufficiently high or low bias would overwhelm the IAV and cause either zero or total crop failure. The number of crop failures is then totalled across the simulation and divided by the total number of simulations to give a crop failure fraction. The inverse of the crop failure fraction is the return time of crop failure. The following text has been added to the manuscript to clarify this.

The number of crop failures is recorded for each grid cell and the total across the domain is calculated. The total number of simulations for a crop model is the number of analysed grid cells multiplied by the number of years of simulation. The total number



of crop failures is divided by the total number of simulations to give a fractional number of crop failures, this is the crop failure rate with units of failures per grid cell per year. The inverse of the crop failure rate is the mean return time for a crop failure.

6. Assessment of adaptation methods: Figure 7 is hard interpret. I think it would be better to 1) show the effects of the on present-day distributions in one panel and 2) show the effects on the 1.5âŮę C distributions in a second panel. In each panel the 16 values of simulated yields (from the 16 climate model simulations) for one model setting could be shown in a box plot such that the first panel would include four of them (one from the default simulation and three from the alternative ones). The second panel could show the associated box plots of relative changes in yields.

Figure 7 has been rebuilt as a single boxplot with a detailed caption explaining the content. With two boxplots it was not easy to see the difference between the adaptation methods. The new plot is shown in Figure 1 and the caption is below.

Efficacy of adaptation methods for maize in GLAM. HTS is high temperature stress adapted crops, Rw H shows crops with rainwater harvesting, HTS and Rw H shows both adaptation methods in use. Each box shows the fractional yield change relative to the unadapted crop with the boxplots showing the range across the 6 member GCM-RCM ensemble. The pairs of boxes show the relative change in yield for the adaptation method in the historic climate (left) and the future climate (right).

Given the uncertain representation of the current present-day management in the crop models and the artificial turn-off of the heat stress routine in GLAM I am wondering whether the analysis could be really considered as an adaptation scenario. It may be better to frame it as a test whether the simulated yield changes are more driven by temperature stress or water scarcity. In this sense one could think about a more general indicator that measures these stresses in the process-based simulations. It would be a way to include the other models, too. It would be good to include the other models in this assessment.

We have kept the specific adaptation results separate for GLAM as they are model specific. We have however added scatter plots of yield change (%) against precipitation change (%) and temperature change (K) to show the responses of the models. Furthermore the adaptation results have been expanded to highlight that the rainwater harvesting may be insufficiently supply water to counteract the precipitation losses in the future climate. The new figure is shown here as Figure 2 but is Figure 5 in the manuscript

The results in Figure 5 show the responses of the maize yield to changes in precipitation and temperature change for four crop models. To highlight the responses of precipitation changes between -50% and +50% the x-axis of the left figure is truncated, a full version of the figure is shown in SI Figure XXX. The maize yields in all models show an increase in yield with increasing precipitation. A negative trend is also present with increasing temperatures. The differences between the crop models can be seen in these figures. The results in ORCHIDEE-Crop show less variability than SARRA-H, GLAM or the Linear models and have a strong negative yield response for a limited temperature change. The temperature change experienced by the crops simulated in GLAM covers a larger range than the other models and the positive relationship between precipitation and yield is also shown. Water scarcity has a smaller impact on SARRA-H and the Linear models than in GLAM or ORCHIDEE and the SARRA-H results do not show a strong negative response to higher temperatures.

This result needs to be considered alongside the results in Figure 5 which show a strong negative precipitation response in GLAM, indicating that the rainwater harvesting routine, while providing some extra water does not provide enough to counteract the precipitation changes in the future simulations.

More specific comments: P2L9-P3L2: Add the level of global warming or at least the emission scenario and the timing when discussion the crop yield changes found in other studies. Do they account for the CO2 fertilization effect or not? Are projections based on the assumption of no adaptation? All the reported changes are conditional



on these assumptions and are meaningless otherwise.

The requested details have been added into the description of the existing literature.

P2L9: Crops could also be imported. Add the information to what degree the considered countries currently fulfill their demand.

Using FAO stats for 2005 in West Africa, all countries are currently net importers of cereals with Gambia and Senegal close to three times the regional average of 41 kg/person. With yield changes expected to be smaller than population changes the amount of imported food required will therefore need to increase. This has been commented on and the FAO cited in the manuscript.

To maintain current levels of food intake the crop yields in West Africa will need to increase in step with the increasing population. All countries within West Africa are currently net importers of cereals indicating that their current production is insufficient to meet demand (UN FAO)

P2L12 : Add the information which of the considered crops is C3 or C4 as the differences in CO2 fertilization effects are discussed before.

The crops are all C4 and this is now mentioned in the manuscript where we describe our work

In this paper we use four crop models simulating three crops and driven by meteorological outputs from several regional climate models. Three C4 crops have been selected for this analysis; maize, sorghum and millet.

P3L5: I am wondering whether the aim of the paper really is to “identify and quantify some of the sources of uncertainty in the West African agriculatural system as the global climate passes 1.5âŮę C”. Is it not a probabilistic projections of the impacts of 1.5âŮę C of global warming on crop yields?

We agree and this has been changed to the statement below

The aim of this paper is to produce probabilistic projections of West African crop yields as the global climate passes 1.5 K above the pre-industrial control

P3L15: Is there a trend in the reported crop yields, e.g. due to technological progress? Such a trend is probably not expected from the crop model simulations that do not account for these effects. Could that explain part of the difference between the present day simulations and observations? The technology or management induced trend in the observations would also lead to a wider distribution of the observed present-day yields and the simulated ones. How do you account for these effects?

There are a number of trends. The existing crop yields are used as inputs for two models: GLAM and the linear models. For both we detrend using a 2 degree polynomial to remove technology terms, management changes and increased mechanisation. The remaining data is expected to be primarily climate driven. This is described in the crop model section of the manuscript.

GLAM and the linear models use observational yield as an input, in both cases the input yield is detrended using a two degree polynomial before use. This detrending removes consistent trends such as management changes and technological improvements.

P5L11-13: are the differences due to different warming levels considered in these studies?

We use RCP8.5 which is the most severe of the CMIP5 warming levels, therefore it is unlikely that the scenario is less severe than the average of a meta-analysis. The earlier projected time of our results is likely the reason that the results are not as severe as they are in a meta-analysis at 2050. This has been clarified in the text.

The yield losses in GLAM and ORCHIDEE-Crop are smaller than the mean reported in the meta-analysis by Knox et al. (2012). The Knox et al. (2012) results are for crops in the 2050s and therefore our results are expected to be smaller as they are for a closer time horizon. A second meta-analysis by Challinor et al. (2014) presents results by



temperature change, our results at 1.5 K are within the range of results found in their analysis.

P5L14: How is the IAV calculated? See potentially associated problems mentioned in the general comment above. Differences in the variability of observed and simulated crop yields could also be induced by the technological progress affecting the observational data but not represented in the observations or differences in the variability of the climate forcing compared to the observed weather fluctuations. To what degree does the bias-correction the adjust the variability of the simulated climate to the variability of the observed climate?

The IAV is the standard deviation of the crop yields, averaged over the domain. The observed crop yields have been detrended to remove non-climate signals as described in the crop modelling section. The multisegement approach of the bias correction will adjust the simulated variability to closely match the observed variability and in doing so removes a number of 'drizzle' events from the record and increases the intensity of wetter events to match the observations.

The multisegement approach of the bias correction will adjust the simulated variability to closely match the observed variability and in doing so removes a number of 'drizzle' events from the record and increases the intensity of wetter events to match the observations.

P6: There should be some more detailed information about the representation of high temperature effects within GLAM.

This information is now in the main manuscript

The high temperature stress at flowering routine was enabled, if the maximum daily temperature is above 37 C the yield is reduced, above 45 C the yield is set to zero (Challinor et al 2005,2015). To test the importance of high temperature stress during flowering, this routine is disabled.

Section 1 of the SI What does it mean that “GLAM used the maize yield data as an input” (SI)? Is the model calibrated to reproduce reported yields in the historical period when forced by observational climate data?

This is correct and has been clarified in the updated manuscript.

GLAM and the linear models use observational yield as an input, in both cases the input yield is detrended using a two degree polynomial before use. This detrending removes consistent trends such as management changes and technological improvements.

Minor issues: P2L4: “or” instead of “of” P2L9: “need to increase” instead of “need increase” P2L19: change “predicted” to “projected” as the results are conditional on the emission scenario. P3L9: “Two adaptation methods. . .” instead of “The use of two adaptation options. . .” P3L18: Would be good to directly name it RCP8.5 P4L26: “With increases” instead to “with to increases” P6L9: “simulation for the historical period” instead of “Simulations in for the historical period” P6L16: Change “predicted” to “projected” P6L32: Delete “agree” Caption of Figure 1: I do not understand the sentence “Sarra-H indicates the model simulating the 90 day variant of maize.”

These corrections have been made, with the exception of the figure captions which have been replaced by new figures and captions.

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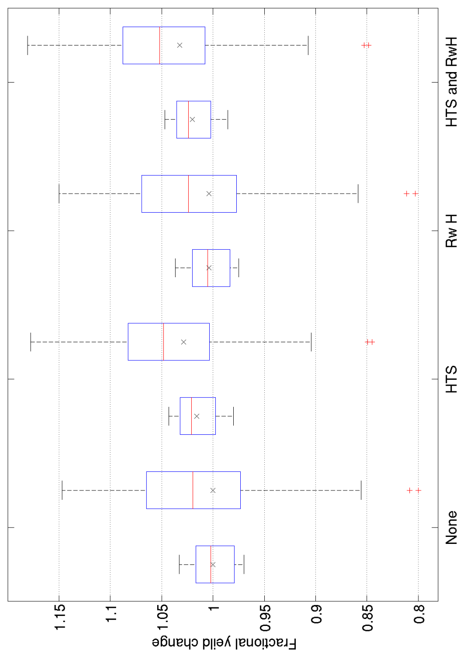


**Fig. 1.**

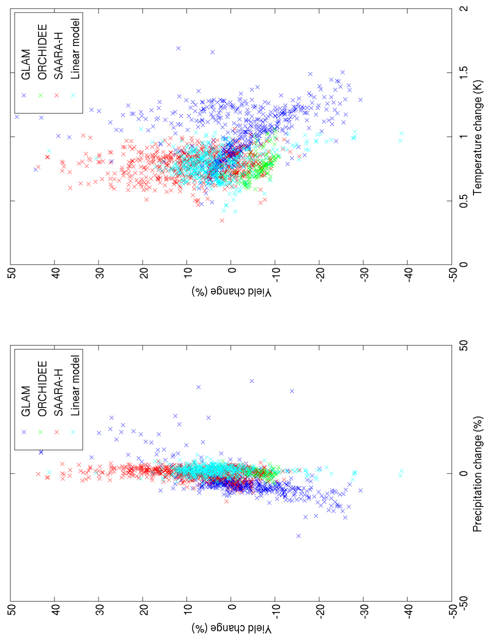
GLAM
ORCHIDEE
SAARA-H
Linear model
Temperature change (K)
Yield change (%)
GLAM
ORCHIDEE
SAARA-H
Linear model
Precipitation change (%)
Yield change (%)

**Fig. 2.**