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Climate of the Past
Discussions

Interactive comment on "Comparison of simulated and reconstructed variations in East African hydroclimate over the last millennium" *by* F. Klein et al.

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- In blue: referees' comments
- In black: our answers
- *In black italic: what we propose to add in the text*

The manuscript presents a comparative analysis of proxy records representative of hydroclimate in Eastern Africa and corresponding time series from climate simulations over the past millennium. After discussing the caveats due model spatial resolution and spatial homogeneity of precipitation this region, that authors reach the main conclusion that most of the hydroclimate variability in this region is probably caused by

internal process and that the influence of external forcing seems to be very limited, in agreement with other studies that have pointed out the importance of internal variability in hydroclimate other parts of the world. Another important conclusion is that the different models do not agree in simulating the links between hydroclimate and sea-surface-temperatures. I think the research question is important and opens up further questions, as for instance the reasons why models diverge when simulating the SST-hydroclimate link which also leads to the question of the origin of hydroclimate variability itself and its connections to global patterns of climate variations like ENSO or the Indian Ocean dipole. My general impression of the manuscript is quite positive. The manuscript is rather long and, although at some stages the study falls short of reaching robust conclusions, I think it is a worthwhile contribution and opens up some lines of research for further studies. I liked the amount of manuscript space devoted to check the spatial representativity of the hydroclimate records, the skill of the models in simulating the two different precipitation annual cycles and the teleconnections to the large-scale SSTs, although I have a comment on this last point.

I have some comments on the manuscript that the authors may want to consider. Only two of them are general enough to possibly require some major changes in the manuscript, the rest being more more specific.

- I would like to start, however, underlying that the submitted version does not appear to have been thoroughly revised by the authors. Something seems to have gone awry regarding the blank spaces to separate words, and may words throughout the manuscript appear juxtaposed, at least in the pdf copy I downloaded. This has made the reading quite uncomfortable. This impression is confirmed by the acknowledgements to Flavio (?). I believe it is appropriate to acknowledge him by his full name.

We would like to apologize for that. Something went indeed awry when compiling our manuscript with the standard LaTeX template of Climate of the Past. We have noticed that the day after the submission and have then sent a corrected version of the manuscript, but it took some time to be updated. Anyway, we should have more thoroughly checked the initially submitted manuscript and we are sorry for the inconvenience.

- My main concern is the claim that precipitation, relative to evaporation, is the main factor driving hydroclimate variability. The authors compare the standard deviation of precipitation and evaporation in the model output and reach the conclusion that the former is much larger, with a few exceptions in the Challa/Naivasha region. However, this calculation is done at interannual timescales, as far as I can judge comparing the much larger magnitude of the standard deviations shown in Figure 6 than those shown in Figure 8, which are explicitly calculated at centennial timescales. If this is correct, I think this conclusion could be premature, since at longer timescales the variability of temperature would likely grow relative to the variability of precipitation, and thus also the role of evaporation could become more important. I think this should be checked because the authors base some of the further analysis on this conclusion, and because it is a quite relevant conclusion on its own right.

Thank you for pointing this out. You are right, in the submitted manuscript the comparison between the simulated standard deviation of precipitation and evaporation is computed using annually averaged results for the last millennium (850-2005 AD; Fig. 6 of the manuscript). One could indeed expect an increasing importance of temperature and thus of evaporation when using the results averaged over longer timescales. However, this is not the case in the models (Fig. 1 of this document). Using a smoothing window of 100 years, the differences between the standard deviation of precipitation and evaporation drop by a factor of about 10, but the relative amplitudes remain approximately the same to what is shown using annual results, meaning that precipitation still dominates on evaporation.

We propose to add the following sentence at the end of Section 4.2:

Moreover, also at timescales longer than annual, rainfall has a dominant role in explaining changes in P-E, since approximately the same picture is observed when smoothing

model results with a loess filter window of 100 years (not shown).

- Another point is related to the teleconnections between precipitation and sea-surface-temperature described in section 3.3. This section directly assumes that the SST is a direct driver of precipitation, but the text does not contain a justification for this assumption. Could it be that both SSTs and precipitation are driven by the atmospheric circulation? In this region, both may be coupled being part of some coupled mode of variability, but it is also possible that the atmosphere is driving both. This possibility is related to the main conclusion of the paper that the influence of external forcing is negligible, as the atmosphere circulation would be arguably less responsive to forcing than the SST.

You are right. Although the association between tropical Indian and Pacific Ocean SSTs and East African rainfall has been emphasized in numerous studies (see references in the introduction), only a few of them really focus on understanding the underlying mechanisms. Here, we observe that SSTs and precipitation are correlated. However, based on available climate model experiments we cannot say whether both variables are part of a coupled mode of variability, are dynamically linked independently of a mode, or are just correlated without any dynamical link. Answering this question would probably require additional simulations with sensitivity experiments, which is outside the scope of this study.

Nevertheless, it is instructive to test if models are able to reproduce observed correlations, whatever the cause of those correlations. We propose to explain that more explicitly in Section 3.3 of the revised version of the manuscript:

In addition to evaluation of the mean state, it is important to assess the ability of climate models to represent the observed regional patterns in the inter-annual variability of East African rainfall. Although it is not our goal here to study the mechanisms responsible for this simulated variability, it is illustrated by calculating the correlation between East African precipitation and tropical SSTs, which are considered a direct *driver of precipitation over East Africa (e.g. Goddard and Graham, 1999; Ummenhofer et al., 2009).*

We will also clearly state in Section 3.3 that these correlations do not necessarily imply dynamical links.

Particular points:

- The 1000-year time series representing hydroclimate variation in the Lake Challa region in Tierney et al. (2013) is the first principal component of composite variation in three moisture-balance proxies, namely a presumed indicator of catchment [precipitation]. It would be useful to quote the variance explained by this leading PC. Is it clearly over 30%, which would be the expected value if the three series were uncorrelated?

PC1 accounts for 40% of the variance in the 3 data time series, as mentioned in the supplementary materials of Tierney et al. (2013). This information will be added in Section 2.2 (Proxy-based hydroclimate reconstructions).

- pattern during an El Niase of ENSO. typo

This will be corrected.

- the series has been linearly standardized so that the maximum of the absolute values equals 1. This standardization is not really robust, as it depends on one single value: the maximum element in the series. The amplitude of the standardized series may therefore depend on an outlier.

Here, the outliers do not have an important impact on the amplitude of the standardized series since the raw time series are annually averaged and filtered before being standardized. We limited the amplitude of the time series between -1 and 1 mainly for aesthetic reasons. If we standardize by dividing the time series by their standard deviation instead of their maximum, the resulting figure is qualitatively the same (Fig. 2 of this document). We propose thus to keep the figure as in the submitted manuscript.

- I really had to wrestle to understand Figure 9. First, I could not see the individual simulations of the CESM ensemble in panel upper row centre, apparently drawn with different shades of grey according to their distance to the median. I do not think it is necessary to show the distance to the median (what is the reason ?), and it quite messes up the figure. What would be the distance criterion anyway?

We wanted to show the information contained in all 10 ensemble members of CESM1 while having a clear picture. Showing all individual members makes the figure quite noisy (Fig. 3 a of this document), so our compromise was to draw the median of these ensemble members together with the range (Fig. 3 b of this document). The different shades of grey correspond to the number of ensemble members included between the median and the edges of the shades: for a given year, the furthest ensemble member (corresponding to the range) is thus drawn in the lightest grey, the second furthest in a bit darker grey, etc. We are sorry you could not discern between the different shades of grey and will make sure that the distinction between them is adequate in the revised version of this figure.

Second, I did not understand the blue shading. It apparently shows the 2$\times$ standard deviation derived boundaries from a control run, added to the median simulation (?). But it seems that the blue shading is not simply the median line with (constant) 2$\times$sigma boundaries added. The blue-shaded area has a time evolution that is different to that of the median simulation.

The blue shading is indeed 2 $\times$ standard deviation computed from the pre-industrial control runs, but around zero, as mentioned in the caption. The shading is thus drawn between -2 $\times$ standard deviation to +2 $\times$ standard deviation. It is not added to the median simulation. These values are constant through time.

Third, if the blue-shading indicates the standard deviation from control simulations, it is much smaller than the standard deviation from the forced simulation, so why is the line indicating the latter dashed?

If you refer to the results from CESM1 in the Masoko/Malawi region, the standard deviation of the control run is indeed smaller than the standard deviation of the forced simulation (which is not the case for Challa/Naivasha). It has to be noted that in the case of CESM1, the standard deviation of the forced run shown is the mean of the standard deviation of each ensemble member, and not of the standard deviation of the median which would have prevented any valuable comparison with the standard deviation of the single control run.

The red line, which represents the mean of 2× standard deviation of each forced run of CESM1 around zero, is dashed because it is significantly different from the same diagnostic computed from the control run, according to a F-test (5% level).

My impression is that this caption is not quite right. Maybe the blue shading indicates the within-ensemble standard deviation from the CESM ensemble (and so it is time-evolving as well) and not the standard deviation from a control run (constant). I think I see the point that the authors are trying to make in this panel. Perhaps the authors may want to consider just showing one or two simulations from the CESM ensemble if what they wish is to convey the amplitude of variations as compared to the other models. Showing the median is misleading (compared to other models), and showing the within-ensemble standard deviation (if this is what the blue-shading indicates) does not alleviate the problem.

Given the above information, we don't think that the caption is wrong, but we propose to modify it to be more explicit:

Figure 9: *Simulated time series of P-E over the Challa/Naivasha and Masoko/Malawi regions throughout the last millennium (850-2005). Results are mean annual values smoothed using a loess filter with a window of 100 years, and are presented as anomalies with respect to the entire period. The horizontal red lines are displaced on both sides of the zero line at two times standard deviation of the smoothed time series. The horizontal blue lines also represent 2 standard deviations on both sides of zero*

but based on the time series from pre-industrial control simulations. The horizontal lines are dashed if the variance of the simulation with time-varying forcing (black line) is significantly different (F-test, considering a 5% level) from the variance of the simulation with fixed forcing; if not, it is solid. For the CESM1 model, the black curve is the median of the ten ensemble members, while the range is shown in grey shading. Within the grey area, the ranges excluding the furthest ensemble members above and below the median, the furthest two ensemble members above and below the median and the furthest four ensemble members above and below the median are drawn using increasingly darker shades of grey.

Also, to make the figure clearer, we propose to replace the blue-shaded area by two horizontal blue lines only, and to change the colour of the horizontal black lines to red, as in the Fig. 4 of this document.

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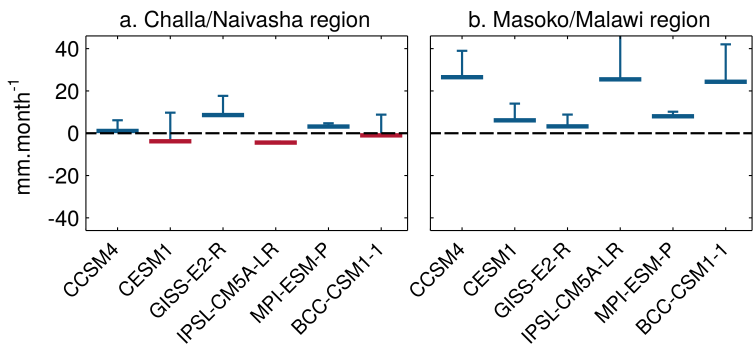


Figure 1 – Mean annual precipitation minus mean annual evaporation (horizontal bars), and standard deviation of annual precipitation minus the standard deviation of annual evaporation (vertical bars) using smoothed results with a window of 100 years. The period considered is the entire last millennium (850-2005). The differences between the standard deviation of precipitation and evaporation (vertical bars) are multiplied by 10.

Fig. 1.

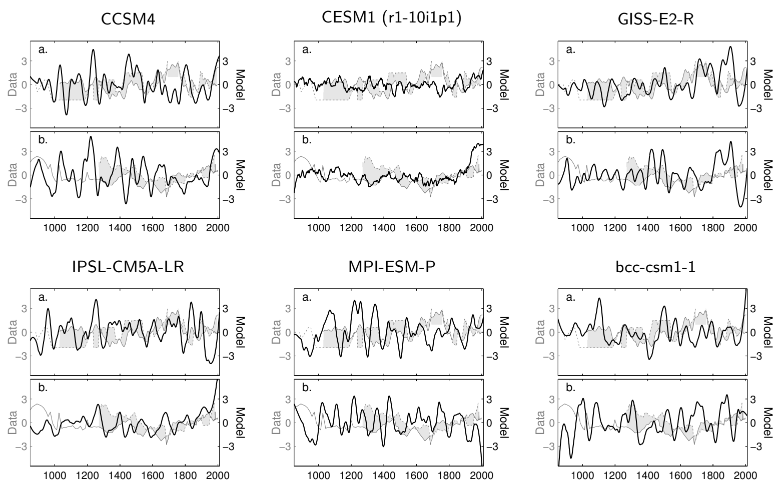
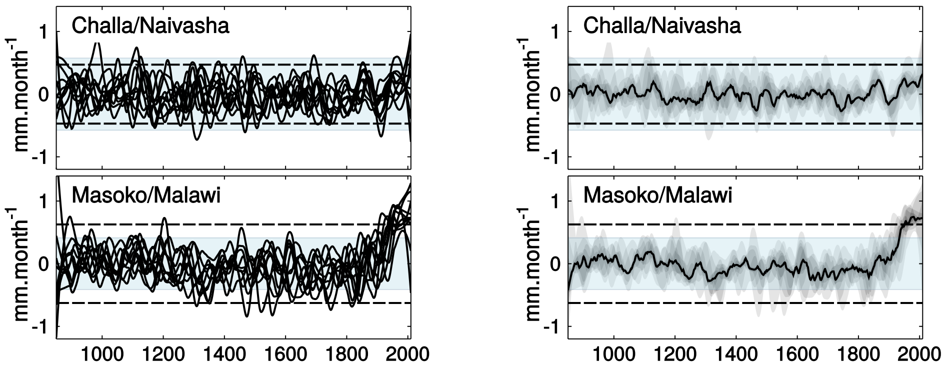


Figure 2 – Comparison between last-millennium time series of the reconstructions (in grey) and of P-E simulated by six GCMs (in black) averaged over the Challa/Naivasha region (a), with the Naivasha record shown as dashed line and the Challa record as solid line; and over the Masoko/Malawi region (b), with the Malawi record shown as dashed line and the Masoko record as solid line. In both regions, the area between the two records is shaded in light grey. Both proxy-based and simulated time series are presented as anomalies with respect to the whole period, and are standardized by being divided by their standard deviation. Ordinate axes are oriented such that wetter (drier) conditions point upwards (downwards). Model time series are annual mean values filtered using a loess method with a window of 100 years. For the CESM1 model, the black curve is the median of the ten ensemble members previously standardized and smoothed.

Fig. 2.



(a) 10 ensemble members of CESM1 separated.

(b) Median of the 10 ensemble members and range.

Figure 3

Fig. 3.

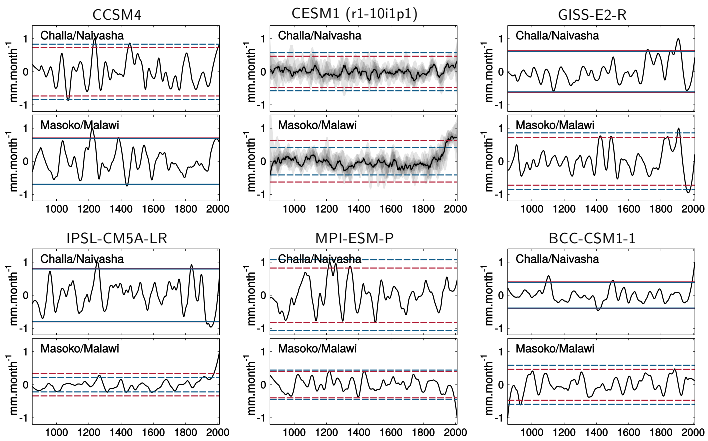


Figure 4 – Simulated time series of P-E over the Challa/Naivasha and Masoko/Malawi regions throughout the last millennium (850-2005). Results are mean annual values smoothed using a loess filter with a window of 100 years, and are presented as anomalies with respect to the entire period. The horizontal red lines are displaced on both sides of the zero line at two times standard deviation of the smoothed time series. The horizontal blue lines also represent 2 standard deviations on both sides of zero but based on the time series from pre-industrial control simulations. The horizontal lines are dashed if the variance of the simulation with time-varying forcing (black line) is significantly different (F-test, considering a 5% level) from the variance of the simulation with fixed forcing; if not, it is solid. For the CESM1 model, the black curve is the median of the ten ensemble members, while the range is shown in grey shading. Within the grey area, the ranges excluding the furthest ensemble members above and below the median, the furthest two ensemble members above and below the median and the furthest four ensemble members above and below the median are drawn using increasingly darker shades of grey.

Fig. 4.