The Impact of Convection-Permitting Model Rainfall on the Dryland Water Balance – Reviewer Response (Review #3)

We thank the reviewer for their insightful comments and for taking the time to read the original and revised manuscript. We hope the following response will sufficiently address their comments, if not, we welcome providing additional clarification.

Main Reviewer Remark:

In this work, projections from two periods (a past one, and a future one), are used. I was expecting that the availability of these two periods would be exploited to assess the impact of the use of CP-RCM data to evaluate the evolution of hydrological indicators. However, it seems not to be the case. Actually, in most figures (except Fig 3 where all data are aggregated, and Figure 10 where we see that the past period is used), results are presented on unknown periods. This poses two issues : the first one, is that we simply don't know exactly what is shown. The second one is that, if the two periods are mixed, it involves that two different distributions of climate variables are mixed, troubling the conclusions we can draw. This issue needs to be tackled.

We thank the reviewer for this helpful comment and can address it without any major alterations to the manuscript. There appears to have been some confusion regarding the time slices used in this study. While CP4A is available for both a present-day (1997–2007) and a future (2095–2105) time slice, we only used the present-day simulation. This is already stated in the manuscript:

Section 2.2 Climate Data

"To establish whether CP4A can better capture dryland rainfall characteristics and PET dynamics (relative to P25), we compared both climate models (historical run) to the gridded Integrated Multi-satellitE Retrievals for GPM (IMERG, Huffman et al., 2012) rainfall product and an hourly potential evapotranspiration dataset (hPET, Singer et al., 2021)."

However, we agree that this needs to be made clearer. We will revise Section 2.2 to explicitly state that only the present-day (historical) simulations were used and to include the rationale for this choice.

We considered only the historical period because our analysis required direct comparison between model output (CP4A and P25) and observed rainfall and PET data. It is also worth noting that, the CP4A present-day time slice does not reproduce the actual timeseries of the climate variables between 1997-2007 – it is purely statistically consistent with historical observations. It simulates a plausible sequence of weather consistent with the observed large-scale climate of 1997-2007 but it does not reproduce the actual day-to-day or event-level sequence of observed weather over this period. CP4A realistically captures annual totals, rainfall seasonality, and the distribution of rainfall characteristics, but the precise timing, duration, spatial pattern, and intensity of individual storms do not correspond to those seen in IMERG.

We agree that exploring the future CP4A time slice to assess the evolution of hydrological indicators would be a valuable extension, but as discussed in the manuscript (Section 4.0), we have limited confidence in regional climate projections for East Africa. Including the future period would divert the focus from our central aim — understanding the influence of rainfall characteristics on hydrological partitioning. We believe that assessing future hydrological changes would be best addressed in a dedicated follow-up study. For analyses of projected rainfall changes in CP4A, we refer the reviewer to Kendon et al (2019).

We will update the manuscript accordingly.

Miscellaneous Comments:

Line 70: Is it really sensitive to PET? Because, as the authors state before, the evaporative demand is higher than the amount of water available. So, when PET increases, it might not really have an impact on actual ET, as it will rapidly be limited by the amount of available water.

- We agree with this comment that in water-limited environments hydrology is relatively insensitive to changes in PET. However, while its impact is limited compared to rainfall, PET can still exert an influence especially between rainfall events or during the rainy season. We will remove the following lines:

  "The dryland water balance is also sensitive to atmospheric evaporative demand (PET or potential evapotranspiration), both in how high PET impacts antecedent soil moisture conditions (soils quickly dry out between rainfall events) (Zhang and Shilling, 2006; Nazarieh et al., 2018; Cuthbert et al., 2019; Schoener and Stone, 2019; Schoener, 2021; Boas and Mallants, 2022) and its direct impact on agricultural yields and drought severity (Porporato et al., 2002; Lobell et al., 2011; Vicente-Serrano et al., 2018; Tugwell-Wootton et al., 2020; Kimutai et al., 2025)."

  And will update it to the following (and move it later in the introduction):

  In drylands, actual evapotranspiration (AET) is primarily constrained by soil moisture rather than atmospheric demand (i.e., water- rather than energy-limited), meaning that the direct hydrological effects of PET are typically small relative to those of precipitation (Vicente-Serrano et al., 2019). However, PET can still exert an important influence on vegetation and soil moisture dynamics, and plays a key role in land–atmosphere feedbacks (Seneviratne et al., 2010). Moreover, the strong temporal variability of rainfall means that drylands are not always water-limited—for example, during or following high-rainfall periods—when PET can shape antecedent soil moisture conditions before the next rainfall event, as soils dry rapidly between events (Zhang and Shilling, 2006; Nazarieh et al., 2018; Cuthbert et al., 2019; Schoener and Stone, 2019; Schoener, 2021; Boas and Mallants, 2022).

Line 148: which agreements ?

- There is consistent agreement amongst convection-permitting models in being able to better represent rainfall characteristics compared to non-convection permitting models. So, our findings that CP4A can better capture rainfall characteristics (particularly in drylands) is in line with other studies that have used different CPMs in other regions.

Line 155: How does IMERG propose 30-min data if rain gauges data are daily? Does it come from the remote sensing data temporal resolution? Even if it is "the most appropriate" product in the area due to its temporal resolution, what is the quality of this product in this area?

- IMERG uses daily rain gauge data to bias-correct daily totals while keeping the temporal resolution at 30 mins. In Huffman et al., they state “that even monthly gauge analyses produce significant improvements, at least for some regions in some seasons. Recent work at CPC shows substantial improvements in the bias correction using daily gauge analysis for regions in which there is a sufficient number of gauges.” For a more detailed methodology please refer to Huffman et al (2020).
- For a review of the quality of IMERG data in Africa (including the Horn of Africa) please refer to Dezfuli et al (2017). IMERG compares well to a gauge data (where available) and other satellite-derived rainfall products, but critical for this study is that is available at hourly resolution which is critical for evaluating dryland rainfall characteristics.

Line 157: Several grammatical imperfections are present in the text, such as this sentence that misses the main sentence part, there are also sentences beginning with "But", etc.

The line in question has been altered and any sentences that begin with “But” have been altered.

Line 166: What is the quality of wind, radiation and air humidity data in these two models? Usually it is of poor quality in climate models. In addition, are these models considering evolutive aerosols? If not, radiation should not be used and should be replaced with a proxy based on temperature. See Boé J., Somot S, Corre L, Nabat P (2020) : Large discrepancies in summer climate change over Europe as projected by global and regional climate models: causes and consequences. Clim Dyn. https://doi.org/10.1007/s00382-020-05153-1

- A robust analysis of wind, radiation, and humidity data is beyond the scope of this paper; however, we feel we do not need to change our methodology as our CP4A/P25 simulations do a reasonable job of replicating hPET data and any bias in our model PET does not undermine our key finding (dryland hydrological partitioning is highly sensitive to rainfall characteristics). Nonetheless, we thank the reviewer for flagging the above publication and we acknowledge that deficiencies in model representation of these variables could impart biases into our PET simulations (for example potentially the early peak in diurnal PET cycle in both models).
- Also, if by “evolutive aerosols” the reviewer is referring to whether aerosol concentrations vary in the present-day simulations and/or if there is a change between present and future time-slice, we can confirm that CP4A uses fixed aerosols. For the future time slice, only sea-surface temperature and well-mixed greenhouse gas concentrations are altered. This decision was made to ensure clear attribution of the most fundamental climate change (Senior et al., 2020). As we did not consider the future time slice in this analysis it is not a major concern.

Line 169 : Please verify all references to Appendixes, as it should rather be here Appendix A.

- Thanks for spotting this, we have updated and doubled checked all other references to Appendices.

Line 207 : It is rather strange to compare rainfall among periods of different durations (2 to 4 months)

- These periods are defined based on what the dominant rainy seasons are in the region. Rather than computing 99th percentiles using the entire annual rainfall record, we computed the 99th percentile of wet season rainfall only. We cannot choose one rainy season for the entire region as there is variability in seasonality. In bimodal regions across the eastern drylands the dominant rainy season is either MAM or OND, whereas for the more humid Ethiopian Highlands the dominant rainy season is JJAS.

- We will also update the manuscript to clarify that it is only for the 99th percentile (extreme) rainfall that we use these seasons. All other data is analysed at an annual scale (consecutive dry days, drizzle, light vs heavy contributions).

Line 209: The numbering is right, but here it should be noted Appendix.
In addition, Appendix B should be cited before Appendix D, I suggest to reorder them.

- Thank you for spotting this, we have altered it to Appendix. We also agree that the ordering of Appendices should be altered. We have moved the rainfall and PET figures from Appendix D (Fig. 1D – Fig. 3D) to Appendix B, we have not moved the Hydrus results from this Appendix. Meaning the original Appendix B is now Appendix C, Appendix C is now Appendix D, and Appendix D has now become Appendix E. These changes are reflected in the tracked manuscript, but for clarity I will summarise each Appendix here:

  Appendix A – Provides additional detail on the method of computing PET using the Penman-Monteith equation.

  Appendix B – Mean monthly rainfall/PET and raw hourly rainfall time-series at each of our four Hydrus locations – compliments the summary statistics provided in Table 2.

  Appendix C – Soil hydraulic and Feddes' parameters used for all Hydrus runs, including for results not shown in the main body of text.

  Appendix D – Figures that compliment Section 3.1 & Section 3.2 (rainfall and PET results).

  Appendix E – Additional results from Hydrus simulations – includes more detailed analysis of the default results (those primarily discussed in the main body of text) as well as additional low/high hydraulic conductivity/Feddes' parameter runs.

Line 214: Doesn't it seriously smooth the precipitation patterns?

- Regridding does smooth/dampen precipitation intensity, but if we are to compare climate model rainfall (in terms of characteristics) fairly we need to use a common grid. Else it would be challenging to discern whether differences in rainfall intensity (for example between CP4A and P25) are due to model physics or simply the grid resolution of model output. As peak rainfall intensity is always likely to be higher if outputted on a smaller grid as it is averaged over a smaller spatial area. So, it is important to note that if we compared CP4A and P25 at their native grids (4.5 km vs 25 km) the differences in rainfall intensity would be even more pronounced.

Line 220: Did you use LAI from climate models? Is this LAI evolving (due to increased CO2 for instance)?

- LAI data was taken from Vermote (2019). It is a NOAA remote sensing product that captures the temporal evolution of LAI in the region. Please refer to Vermote (2019) for more details on the methodology.

  The source is stated in the manuscript:

  "To calculate transpiration Hydrus needs land cover (Table 2) and leaf area index (LAI) data, which were taken from iSDA (as of 2019) and the National Centers for Environmental Information AVHRR LAI dataset (Vemote, 2019) respectively."

Table 2: It is common practice, especially in hydrology, to bias correct climate projections. Here, it would have had even more sense, as the rationale of the study is that hydrology of drylands is impacted by the distribution of rainfall rather than the total amount, so having the same average amount would have allowed a fair comparison. I do see that the P/PET ratio is higher with P25, but the message could be altered.

- We agree that this would have been a potential option to ensure any hydrological differences only reflected differences in the rainfall distribution, but we feel that our choice to not bias-correct but select locations where P25 simulates higher rainfall (and higher P/PET ratio) is equally robust. As this means our findings that forcing Hydrus with CP4A rainfall results in higher soil moisture, transpiration, and bottom drainage is despite total rainfall being lower in CP4A compared to P25. So, we can confidently say that these higher values of the above variables are not simply driven by higher rainfall totals, but rather reflect how rainfall is delivered (light/frequent vs heavy/infrequent).

Line 315: « This mean » -> « This means »

- Updated

Line 319: does that mean that LAI is fixed for all years? Is it also the case for the future?

- LAI is time-evolving and reflects crop/vegetation growth from 1997 to 2007, see Vermote (2019) for more details. We did not consider the future CP4A time-slice.

Line 390: « IN » -> « in »

- Updated

Line 391: this is not very precise: for the IQR bounds? For the mean?

- These values refer to the median 99th percentiles, the manuscript will be updated to reflect this and a reference to see Table 3 for the IQR.

Figure 5: I agree that heavy rainfall is more frequent in CPA4 than in P25. However, as it is based on the 95th percentile of IMERG, shouldn't it be ideally 5% in CPA4? Here it seems that the percentage is too high.

- The 95th percentile of IMERG rainfall is used to define a 'heavy' rainfall threshold at every grid cell across our domain. It is not based on the 95th percentile of annual rainfall totals. This means that while 'heavy' rainfall events will be infrequent, they can contribute far more than just 5% of the annual rainfall totals. This is particularly true in drylands, where a large proportion of rainfall falls during very intense but short-lived events.

Figure 7: The periods that are studied are missing on most figures

- All results refer to analysis from 1997-2007, where it is appropriate to include the periods in the x-axis (time-series) we have done so. We have updated the manuscript in section 2.1 to make this clear.

References: Several DOIs are missing, Leterne et al. Is listed as a discussion paper whereas it has been accepted 13 years ago. Same goes for Quichimbo, accepted 4 years ago.

- Will update the references listed above and ensure all DOIs are listed where available.

References (not cited in original manuscript).

Dezfuli, A.K., Ichoku, C.M., Huffman, G.J., Mohr, K.I., Selker, J.S., van de Giesen, N., Hochreutener, R. and Annor, F.O., 2017. Validation of IMERG precipitation in Africa. *Journal of Hydrometeorology*, *18*(10), pp.2817-2825.

Senior, C., Finney, D., Owiti, Z., Rowell, D., Marsham, J., Jackson, L., Berthou, S., Kendon, E., Misiani, H. (2020). Technical guidelines for using CP4-Africa simulations data. Future Climate for Africa. https://doi.org/10.5281/zenodo.4316466.