We thank the reviewers for their time and valuable suggestions to improve the manuscript. Here below, we respond to each individual comment and propose modifications to the manuscript to accommodate the concerns raised. The following convention is used in this document to illustrate the text modifications in the original manuscript: modified text. Additionally, we mention new changes that we implemented in the revised manuscript.

1 Anonymous Referee 1

1.1 Anonymous Referee 1 Comment

The paper aims at understanding concurrent climate extremes over the eastern parts of Africa using three different emission scenarios. The results show that, concurrent climate extremes are likely to increase with high magnitude over the Nile and Congo basin that are currently the wet regions over East Africa. Heat waves are wildfires are likely to dominate the region by the end of the 21st century as projected by all the emission scenarios.

The paper is coherent, the methods deployed are relevant and the paper conceptualization is well thought of.

Hence, I recommend the paper to be accepted for publication in EGU with minor correction.

Minor Correction.

The authors should enhance labelling of Lat and Lon in all the spatial maps since they are not currently clear.

Response: We thank you the reviewer for their feedback. We have revised the labelling of the Latitudes and Longitudes in all the spatial maps (Fig 2, 3, 5, A1-A4, B1-B4, and D1-D4) by changing the font color of the labels from grey to black and increasing their font size, to ensure that they are clear.

2 Anonymous Referee 2

This paper analysed the frequency and spatial extent of 15 types of concurrent extreme events in East Africa, highlighted the concurrent extremes will become the norm in the future. However. It remains some issues to be discussed before it is considered for publication.

2.1 Anonymous Referee 2 Comment 1

The pair of concurrent extreme events defined in this paper represent two extreme events occurred within the same location in the same year, no matter if it occurred once or several times. The physics meaning of this definition is unclear. Usually the concurrent extreme events are defined based on daily data, i.e., a pair of extreme events occurring on the same day. The definition in this paper seems to be too crude to obtain physically-meaningful knowledge.

Response: We thank the reviewer for this comment. There are three distinct motivations for our methodological choice to consider annual time steps in this study. The first concerns data availability: the available dataset from ISIMIP 2b only provides annual occurrences of the six categories of climate extreme events (as mentioned in one of the caveats in lines 79-80 of the manuscript). Unfortunately, no multi-hazard future data is available at daily resolution. Due to this limitation of the dataset, we define concurrent events as two events occurring in the same location, during the same time step (here being the same year). A second reason is that some of the climate extremes we consider play out over longer time scales: for example, droughts may last several months to even years, wildfires may rage an entire summer season, and crop failures may result from extreme conditions during the entire growing season. A third motivation is that the impacts of compound extremes may be larger than those for individual events even in the case where the concurrence is not on a daily timescale. These are sometimes termed temporally compounding extremes (e.g. Zscheischler et al., 2020), although for simplicity we opted not to make this terminological distinction in our study. For example, vegetation impacts of drought events can be aggravated by droughts in consecutive growing seasons (e.g. Bastos et al., 2021). Similarly, societal vulnerability to floods is modulated by the occurrence of successive flood episodes (Chacowry et al., 2018). We therefore argue that there is some relevance to considering concurrent extremes on yearly timescales.

We nonetheless agree that being able to discriminate the timescale of concurrence of the extreme events we study would allow a more nuanced analysis, as illustrated in lines 23-30. Similarly, we agree with the values of knowing whether a given extreme has occurred once or several times in a given year. We updated the original manuscript to clarify these messages throughout the revised text in Sect. 2 lines 78-87, as follows:

> The dataset we use comes with a number of caveats. A minor caveat is that it does not contain crop failure projections under RCP8.5. More importantly, the data represents the occurrence of an extreme event category as a single event within a grid cell per year, no matter if it occurred once or several times within the same location in the same year. Finally, an extreme event such as a wildfire, river flood or tropical cyclone can only partly cover a given grid cell, whereas other extreme events (heatwaves, droughts and crop failures) are assigned by default to the entire grid cell. Thus, for the former three extremes, we consider that a grid cell is entirely affected when more than 0.5% of the 0.5°x0.5° grid cell area is simulated to be affected by the extreme event. Whilst these are limitations of the dataset, we have three distinct motivations to use it throughout our analysis: (i) the dataset is amongst the most detailed and complete of its kind, and provides information on the

occurrence of extreme events within the study region over a very long time period (from 1861 until 2099); (ii) some of the climate extremes we consider play out over longer time scales, for example droughts may last several months to even years, wildfires may rage an entire summer season, and crop failures may result from extreme conditions during the entire growing season; (iii) the impacts of compound extremes may be larger than those for individual events even in the case where the concurrence is not on a daily timescale. These are sometimes termed temporally compounding extremes (e.g., Zscheischler et al. 2020b). For example, vegetation impacts of drought events can be aggravated by droughts in consecutive growing seasons (e.g., Bastos et al. 2021). Similarly, societal vulnerability to floods is modulated by the occurrence of successive flood episodes (Chacowry et al., 2018). We therefore use it as the backbone for this study.

2.2 Anonymous Referee 2 Comment 2

> From fig.1, among the 15 pairs of extremes, all the concurrent extremes including heatwaves show the strongest increase. It this related to the apparent global warming trend? And all the future years will become extreme years of heatwaves?

Response: Yes, the increases shown in Fig.1 are due to the global warming trend. However, while our analysis shows that frequency of heatwaves will increase drastically, not all future years are projected as extreme heatwave years for every location (grid) in East Africa, even under the high warming scenarios (***Illustration 1***). As reported by many studies, the frequency and magnitude of heatwaves is projected to increase in many regions of the world as a result of global warming (e.g., Russo et al. 2014, 2015, Thiery et al. 2021, IPCC 2021). This is generally confirmed in our analysis over East Africa (Table 2), whereby the mean percentage area affected by heatwaves is projected to increase by the end of the century under all the three future climate scenarios, with larger increases in the warmer scenarios. Furthermore, the increase in probability and spatial extent of concurrent extremes including heatwaves (in the pairs) is projected to increase, with increases in heatwaves identified as a main driver of these events. This is illustrated in lines 290-297 of the revised manuscript. While we indeed find that the change in heatwave occurrence provides a strong contribution to the change in occurrence of concurrent extremes, this is far from our only result/conclusion. Indeed, we also highlight river floods and wildfires as a pair of extremes whose concurrence will increase sharply (Fig. 5), and we analyse other pairs of concurrent extremes not involving heatwaves (Appendix D). We have added the following text in the method (Sect. 3.3 Line 125-127) to clarify that the changes in the concurrent extreme occurrence are projected as a result of global warming.:

Considering that the processed impact model simulations account only for climate-induced changes in the extremes (as defined by Lange et al. (2020)), and not for other changes such as land-use, here we only analyse the climate change-driven effects on concurrent extremes. At a given location, from a statistical perspective, the probability of concurrent extreme events can be affected by the effect of climate change on: (i) the probability of the individual extreme events and/or (ii) the dependence between the events (Bevacqua et al., 2020; Zscheischler et al., 2020b). To gain insights into the drivers of the changes, we compute the change in the probability of concurrent extreme events when assuming: (i) changes in the probability of extreme events in one variable only; and (ii) changes in the coupling between the variables only (Bevacqua et al., 2020).

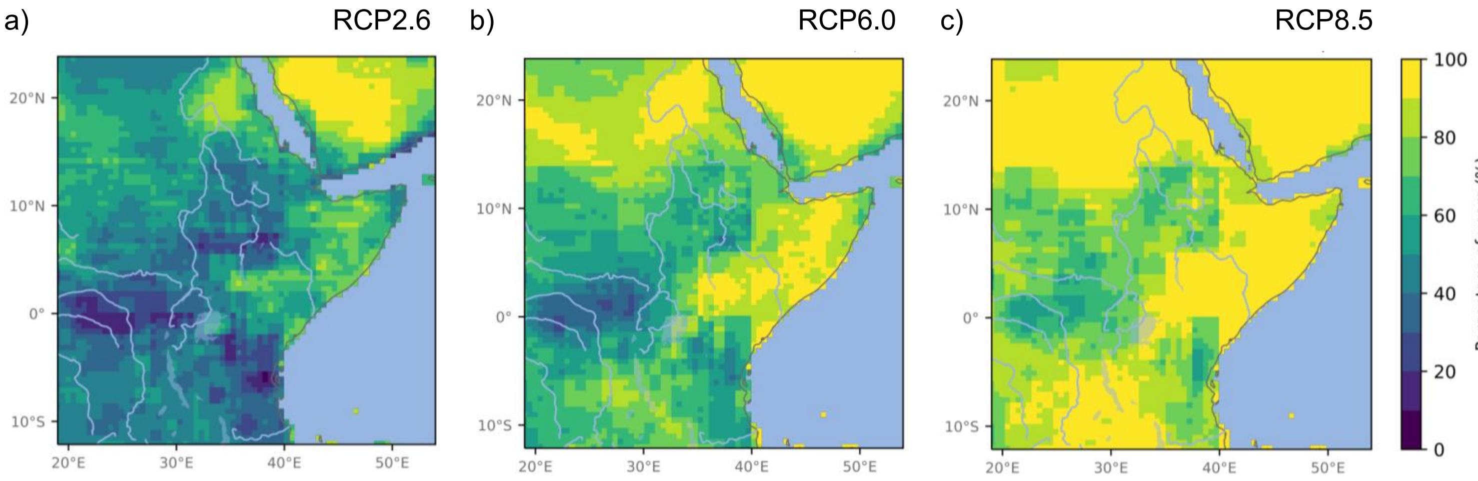

Illustration 1: Average percentage of years projected with occurrence of heatwaves by the end of the century (2050-2099) under RCP2.6 [a], RCP6.0 [b] and RCP8.5 [c] scenarios. The average percentage of years with occurrence of heatwaves represents the multi-model ensemble mean across all available GCMs (considering one heatwave definition: HWMId99).

2.3 Anonymous Referee 2 Comment 3

> The method used in this paper to search drivers of concurrent extremes seems to be too shallow. So, the results look very obvious, i.e., the global warming is the most important driver. The paper lacks an analysis of the dynamic process that cause to concurrent extreme events

Response: Considering that the six extreme events considered each have different meteorological and physical drivers, and that we utilise extreme event data from processed impact model simulations, diving into the meteorological and physical drivers of the concurrent extreme events presents near-insurmountable challenges. We nonetheless believe that our analysis investigating the changes in the probability of occurrence of concurrent events under future climate scenarios in comparison to early-industrial conditions. This is because: (i) The models only account for climate-induced changes in the hazards and not changes due to land-use change (e.g., deforestation fires) (Lange et al., 2020). Therefore, we can only look at climate change/global warming as the driver of the changes in extreme event occurrence, and in turn the changes in concurrent extremes. (ii) We, furthermore, go deeper in our analysis by splitting the change in concurrent extreme event occurrence into: changes in only one variable per pair, and the changes in the (coupling) dependence between extreme events in a pair, as illustrated in Section 3.3. This provides a good basis to formulate some physical hypotheses on the drivers of the changes in concurrent extreme events as illustrated in Sect. 5.3.

In the revised manuscript, we improved the communication of the method that we use to identify the drivers of changes in the concurrent extreme occurrences by adding the following text in the methods section (Sect. 3.3, Line 125-127) to clarify this point:

> Considering that the processed impact model simulations account only for climate-induced changes in the extremes (as defined by Lange et al. (2020)), and not for other changes such as land-use, here we only analyse the climate change-driven effects on concurrent extremes. At a given location, from a statistical perspective, the probability of concurrent extreme events can be affected by the effect of climate change on: (i) the probability of the individual extreme events and/or (ii) the dependence between the events (Bevacqua et al., 2020; Zscheischler et al., 2020b). To gain insights into the drivers of the changes, we compute the change in the probability of concurrent extreme events when assuming: (i) changes in the probability of extreme events in one variable only; and (ii) changes in the coupling between the variables only (Bevacqua et al., 2020).

Furthermore, in the discussions (Sect 5.3, Line 290-304), we added the following text to illustrate possible dynamical causes of change in river floods.

According to Niang et al. (2014) & Seneviratne et al. (2021), the East African region is also projected to experience increased intense precipitation by the end of the century (with high confidence) under RCP8.5 scenario. This could be linked to projected changes in large-scale modes of variability, such as the Indian Ocean Dipole and the El Niño-Southern Oscillation, which influence precipitation across East Africa and are already showing change under present-day conditions relative to the pre-industrial period (medium confidence, Seneviratne et al., 2021). In addition to large-scale teleconnections, projected changes in mesoscale circulation and local land-atmosphere feedbacks may further affect future precipitation patterns in the region (Souverijns et al., 2016).

3 Other changes to the original manuscript

3.1 Table 1

Here we edited the reference of the extreme event definitions (within the column headings) as follows:

> Definition in Lange et al. (2020)

3.2 Text in Section 1

We added one missing word in line 45 as shown below:

> This indicates the need for a detailed analysis of compound extremes in East Africa, that will allow for a better understanding of the possible dependencies between extreme events, their recurrence, and the effect of different future emission scenarios on their frequency. This is not only important for disaster risk management, but it is also key for climate change adaption planning by the government authorities in the region.

3.3 Text in Section 3.3

We edited the text describing the interpretation of Equation 7 as follows:

> Eq. 7 should be interpreted carefully when changes in P(x) and/or P(y) are large. In fact, as a caveat of 6 the fact that we deal with binary variables, by construction, when positive changes in P(x) and/or P(y) are large, the estimated future dependency tends to be small (i.e., D(x,y)future ≃ 1) despite the continuous variables from which the binary variable X and Y possibly being coupled. This, in turn, affects the estimated P Rchange in D. However, we also note that under such potentially very large changes in P(x) and/or P(y), such changes control the actual change in the probability of concurrent extremes, and dependency changes become irrelevant (Bevacqua et al., 2022). In the case of very large negative changes in P(x) and/or P(y), the denominator in Eq. 7 would be very small, and thus it is not obvious to get a small future dependency. For a thorough assessment of the changes in the dependencies, continuous rather than binary variables X and Y (Bevacqua et al., 2020), as well as larger sample sizes (Bevacqua et al., 2023), would be required.

3.4 Updated reference in Section 5.4

We updated the previous ‘In-press’ reference on line 321 in the original manuscript with the reference for the recently published paper as follows:

> Further research into concurrent extremes in East Africa could also expand the methodology taken in this study to consider more than two extreme events occurring in the same location and year, and thus carry out a more complete multivariate 320 analysis. Additionally, we recommend the implementation of other metrics, such as propensity (Rosenbaum and Rubin,

1983) and co-occurrence ratio (Kornhuber and Messori, 2023), to further understand the occurrence of concurrent extremes in East Africa. Lastly, we recommend the application of our methods to other regions to illustrate how climate change may modulate concurrent extremes in different parts of the globe.

4 Added References to the manuscript

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Chacowry, A., McEwen, L. J., & Lynch, K. (2018). Recovery and resilience of communities in flood risk zones in a small island developing state: A case study from a suburban settlement of Port Louis, Mauritius. International Journal of Disaster Risk Reduction, 28, 826-838, https://doi.org/https://doi.org/10.1016/j.ijdrr.2018.03.019, 2018.

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