Response Letter

Dear Editor and Reviewers,

Thank you again for your time and effort for evaluating and improving our manuscript. Following the reviewers' suggestion, we have made necessary changes and point-by-point answers.

Best,
Hu Yang on behalf of all coauthors.

Anonymous referee #1

In my view the revised version of the manuscript has significantly improved, and the authors have adequately handled most of the revision requests. I have only a few, very minor issues that should be tackled before acceptance:

A: Thank you for your encouragement and valuable time.

- L8 (abstract): include "synthesis of (geological records)" (similar to what is written later on in the introduction.

A：Modified.

- I am not fully satisfied with the response to my comment to the statement in the new L245ff. As I have written in my previous review, this statement is not entirely true. In tropical settings, speleothem growth is often biased towards the winter season due to temperature related ventilation (e.g., Sekhon et al., 2021, Vieten et al., 2016, Voarintsoa et al., 2021, ...). BUT (and I think that is what the authors mean) - the d18O of the speleothems is usually a precipitation weighted-annual average, which is then biased towards the rainy season (which is often the summer). But this has not necessarily to do with the season of deposition, because usually, the drip water is a mix of rainwater over several months to years. This is important because the non-expert reader may misunderstand this statement as is, so please clarify this, e.g. by writing "Tropical speleothem d18O records typically reflect an amount-(or infiltration) weighted annual mean precipitation d18O, and are therefore typically biased towards the rainy season."

A：Thank you for your clarification and accurate words. We have replaced the sentences as suggested.

Line 253-254: "*Tropical speleothem δ18O records typically reflect an amount-(or infiltration) weighted annual mean precipitation δ18O, and are therefore typically biased towards the rainy season.*"

- In L317ff the authors briefly mention a potential impact of their result on the practice of astronomical tuning. I suggest to add 1-2 more sentences, that explain how significant this is, e.g., explicitly name a constellation, when and where such tuning may be significantly wrong, and by how much chronologies may be "off". This could include also a suggestion how astronomical tuning could be improved.

A: As suggested, we have extended our discussion on the astronomical tuning and provide solution for improving the tuning.

Line 324-331: *"Astronomical tuning is widely used to establish the chronology of paleo proxies. By doing this, the phasing of proxies is artificially synchronized. However, our results indicate that the astronomically driven climate changes can naturally follow diverse rhythms. This questions the reliability of the astronomical tuning strategy. For example, absolutely dated proxies indicate an asynchronous onset and termination of Greening Sahara at different latitudes (Kuper and Kropelin, 2006; H.ly et al., 2014; Shanahan et al., 2015). Synchronizing the ages of proxies from different regions may lead to biases of a few millennia and introduce difficulties in understanding their dynamics. Based on our model simulations (Fig. 6), we suggest that astronomical tuning should target the insolation 1-2 months before the local rainy season, at least for precipitation-related proxies in low-latitudes."*

References

Sekhon, N., Novello, V. F., Cruz, F. W., Wortham, B. E., Ribeiro, T. G., & Breecker, D. O. (2021). Diurnal to seasonal ventilation in Brazilian caves. Global and Planetary Change, 197, 103378.

Vieten, R., Winter, A., Warken, S. F., Schröder-Ritzrau, A., Miller, T. E., & Scholz, D. (2016). Seasonal temperature variations controlling cave ventilation processes in Cueva Larga, Puerto Rico. International Journal of Speleology, 45(3), 7.

Voarintsoa, N. R. G., Ratovonanahary, A. L. A. J., Rakotovao, A. Z., & Bouillon, S. (2021). Understanding the linkage between regional climatology and cave geochemical parameters to calibrate speleothem proxies in Madagascar. Science of the Total Environment, 784, 147181.

Anonymous referee #2

I thank the authors for the comprehensive revision including the implementation of the fixed angle calendar. I only have a few minor clarification comments remaining. Otherwise, this is a nice study with a novel view on the interpretation of how precession alters tropical rainfall seasonality, and deserves to be published.

A: Thank you for your encouraging words and time.

1) Lines 140-147. The description of the EOF needs sufficient detail so that it can be reproducible. Specifically: what latitudes are you applying the EOF; and are you accounting for area weighting in the calculation? I assume that the first mode strongly dominates (as shown by the variance explained) so you don't need to worry about the robustness of EOF1.

A: As suggested, we have included the area (40S-40N) where the EOF analysis was applied. Area weighting is not applied.

Line 145-151: *"The Empirical Orthogonal Functions (EOF) analysis (Hannachi et al., 2007) is used to identify the spatial and temporal characteristics of terrestrial precipitation at low latitudes. EOF analysis is widely applied in Earth science. It is generally used to simplify a spatial-temporal data set by converting it into spatial patterns of variability and temporal evolution of these patterns. For the idealised Earth system experiment without tilted Earth rotation axis, we applied EOF analysis on the climatology monthly convective precipitation over land between 40oS-40oN (Fig. 4). For the 24 simulations recovering a precessional cycle, we applied EOF analysis on the individual monthly convective precipitation over land. For example, December precipitation in the 24 simulations is selected and applied a EOF analysis to generate Fig. 5a. Area weighting is not applied in the calculation."*

2) Figure 5 and associated caption. I have a few suggestions for improvement:

i) The pink dot is hard to see, please use a different color/shape?

A: As suggested, we have replaced the pink dot to red arrow to better illustrate the location and timing of the perihelion.

ii) Also, what is the area taken in the averaging of the solar radiation and temperature for the curves in the left hand panels? Please specify in the caption.

A: We have selected the region show on the map, i.e., 40S-40N to calculate the temperature and solar radiation. The corresponding information is added in the new caption.

iii) For the caption: 'climatological precipitation' not 'climatology precipitation'

A: Corrected.

iv) Also, when you say "the plotted solar radiation is for an earlier month', do you mean one month before, or are you picking the best month that fits with the other curves? If the latter, how would you justify it give that the delay in the precipitation response from the insolation is a physical process that should be more or less the same regardless of the month

A: The plotted solar radiation is from one month before, not artificially selected. For example, for the subpanel of February precipitation, the insolation in January is plotted; for the panel of August precipitation, the solar radiation in July is plotted. There is logical reason for this. As

the solar radiation at one month early will determine the temperature and precipitation in the next month.