

Reply to Pete D. Akers (Referee) regarding cp-2022-62

"Synchronizing ice-core and U/Th time scales in the Last Glacial Maximum using Hulu Cave 14C and new 10Be measurements from Greenland and Antarctica" by Giulia Sinnl et al., *Clim. Past Discuss.*, <https://doi.org/10.5194/cp-2022-62-RC2>, 2023

We thank the referee Pete D. Akers for the feedback. We have marked our responses to each comment in blue.

>>General comments

>>In this paper, the authors examine the chronologies in three sets of paleo records over the Last Glacial Maximum: Greenland ice cores, a West Antarctic ice core, and Hulu Cave speleothems. To examine the synchronicity of the existing chronologies for each record set, the authors use cosmogenic nuclides as the comparative proxy under the assumption that changes in these nuclide fluxes are globally synchronous and avoid the impacts of local climate that can cause issues when matching other environmental proxies like stable isotopes of oxygen and carbon. They use these comparison to estimate that over a century offset exists between the Greenland and Antarctic chronologies, and both ice core records are offset from the speleothem record by 200 additional years. I found this paper to be very well written and organized. Their approach of linking 10Be with 14C data is well-thought out and impressive in its level of detail dedicated to modelling and cross-examining between records. The paper overall is fairly heavy on methods and technical speak, but such a focus is likely necessary due to the nature of this study, and I applaud the authors for providing very detailed information on all parts of this work. In particular, there is very good supportive data in the captions (e.g., supporting citations, clear descriptions of figure color/symbols), which I often find lacking in papers under review. That said, some captions are very lengthy, and while I think the supportive information is good, some considerations could be made for making the information in the captions more succinct. Similarly, I'd suggest examining if any of the deep technical details could be streamlined without sacrificing important context, which I think would help the paper prove more approachable to a broader audience. However, I think this manuscript still manages to have a clear narrative structure and is one of the better manuscripts that I've reviewed in terms of presenting clear results and conclusions while still providing deep technical detail. My specific comments are minor. Some of the modelling aspects of the paper are outside my scientific expertise, but the described approaches and discussion of the results are all logical to me and supported by ample evidence. Some additional focus could possibly be made toward considering in more detail the impact these new chronologies should have on paleoclimate reconstructions, or how the ice core community should respond to the findings of century-scale offsets in chronologies. Such additional information are not required edits from me, but offered here as consideration to the authors if they wish to elaborate more. There are many acronyms/abbreviations in the paper. To improve readability, I suggest eliminating the ones that are only used once or twice, which I list in the technical corrections. Throughout the paper, uncertainties in age corrections and estimates are usually given as 1 SD, but a 95% confidence interval would likely be more informative and representative. As of now, the offsets between the different chronology sets are sometimes within the 95% confidence window. I think the magnitude of difference and consistency of difference is large enough to believe you are observing true offsets, but you might want to target this point more with a

dedicated response to avoid the appearance that you used 1 SD values to make the results look more differentiated from each other.

Some restructuring of the introduction would probably make the paper more effective. It takes quite a while before you point out what your paper is doing, and what problem currently exists that you are attempting to solve. So we read about LGM events like stadials and HEs, but without the context for why we need to know this. Likewise, there is a lot of discussion about the specifics of the three different chronologies without the reader's context for why this information will be important later. Being more explicit about the currently known or expected issues in record synchronicity early on and repeatedly linking the background information to these issues and your study approaches will make for a tighter, more effective introduction.

Reply: Thank you for your positive feedback of the overall contents and structure of the manuscript. We will restructure the introduction to be more informative and improve its readability. We will also reflect on the broader impact of our research for the paleoclimate community, as you suggest. We will shorten the captions where necessary and avoid redundant acronyms. As for the uncertainty issue, we have dedicated some discussion about how to possibly reduce them, and we will convert to 95% intervals throughout.

>>Specific comments

>>65: I'm slightly unclear in what this sentence is meaning by "correspondence". The first part makes it clear that HS-1 is only part of GS 2.1, but "a correspondence with the late GS-3" could be taken either as 1) HS-2 is similar to HS-1 in that it only covers part of GS-3 (the late part) or 2) unlike HS-1, HS-2 coincides with the entirety of the late GS-3 unit. A rewording will help the point you are intending to make be clear.

Reply: We meant it as in 1), i.e. we observe a similarity between the two HSs. We will clarify this.

>>83: The objective is determining if the accepted chronologies at three sites actually align when compared with a globally synchronous marker, right? "Comparison of three time scales in the LGM" is vague and doesn't really capture the point of your work.

Reply: Thank you for your point, we have clarified the statement about our objectives.

>> 589: This is probably my biggest comment here, in that all the age offset "fault" is taken to lie with the ice cores. I think that this is reasonable, since the layer counting of ice cores has known issues, but it would still be good to elaborate a little more on what the UTh uncertainties might represent. How much older would the "too old" estimates be, as cited by Corrick? Do any estimates exist for this time period? This might get more into the mechanics of U-Th dating, thorium corrections, U-Th half life estimates, etc, than warranted by your study, but any additional clarification and constraint you can give on this point will make your argument stronger toward the ice core re-dating conclusion.

Reply: Thank you for this comment. The layer identification issues pose a clear challenge to the accuracy of ice core time scales. We are not aware of estimates in the LGM period showing Hulu being dated too old, but Corrick et al. (2020) do mention a possible issue of sub-optimal

sample positioning of U/Th and/or $\delta^{18}\text{O}$. If one uses the argument of $\delta^{18}\text{O}$ synchronicity across Asian speleothems, considering all caveats because of climate effects, then one can observe a spread of the HE-2 onset between Hulu and the Cherrapunji speleothem (Dong et al., 2022) of about 100 years, where the Hulu record shows the oldest onset of HE2. This could indicate that dating issues in Hulu are in fact present (given that Cherrapunji was very carefully counted over the LGM using annual lamina). If Hulu was 100 years too old in the LGM, then the offset to GICC05 and WDC would obviously be smaller. However, there is no radionuclide data for the Cherrapunji speleothem, so our methodology remains strongly dependent on the Hulu ^{14}C record. We have presented these arguments in the revised manuscript.

>>626: MCE was defined back at line 98 but hasn't been used until now. I had forgotten what this acronym stood for and had to look it up again. It would probably be good to redefine it again here (or around 700 when it is used a lot again) for the reader.

Reply: We will redefine MCE here.

>>Technical corrections

Reply: All technical corrections have been considered and accepted. Thank you for your detailed review.

>>60: Probably worth spelling out Heinrich events here, since it starts the sentences and HEs is only used in this way once here.

>>70: "it has been suggested that during HS-1, the empirical" – removing a comma will make the sentence read better

>>76: Check this sentence for phrasing. I think the first comma needs to go after GS-3, but the sentence does not make full sense at the moment. It is also rather long and run-on.

>>80: Similarly to HEs, I would spell out Heinrich stadials here to aid the reader already seeing lots of abbreviations, and also HSs is only used once here.

>>88: Just a consideration that you could term this ^{14}C calcite to be consistent with the other stalagmite proxies.

>>168: The only "previously reported" radionuclide tie point? Or is this the only excursion that can function as a tie point according to some parameter?

>>179: Table should be capitalized. Also Fig. and Table throughout manuscript.

>>187: Period after "Table 1". Also in all other captions for figures and tables as well. May be caught in proofing.

>>Table 1: Geographic coordinates need degrees symbols. All sites should have same level of significant decimal digits (see WDC longitude).

>>192: Timescale here is one word whereas earlier it is written as two words (time scale). Consistency needed (or use "chronology" term instead).

>>Figure 1: Be aware that overlapping symbols in red and green (Fig 1e) may cause accessibility issues for colorblind readers. Check with a colorblind filter to make sure figure color schemes are accessible.

>>Figure 2: The image is fuzzy compared to Figure 1, so just make sure there is a high quality version for final submission.

>>241: "here, the box-diffusion..."

>>264: GCRs not GCR's. Also, consider just spelling this out since it is the only use of this abbreviation in the manuscript.

>>246: The comma after 14C seems oddly placed for phrasing in this sentence.

>>Figure 6: No y axis marks for d, but some superfluous yellow ones at right. Check y-axes labels and numbers for overlap (e.g., a+b, c+d).

>>Figure 8: I appreciate the dedication to information in these captions. This caption, however, is very wordy and could use some of the methods text in it to be greatly summarized or moved into the main text or supplement.

Kind regards,
Giulia Sinnl et al.

References:

Corrick, E. C., Drysdale, R. N., Hellstrom, J. C., Capron, E., Rasmussen, S. O., Zhang, X., ... & Wolff, E. (2020). Synchronous timing of abrupt climate changes during the last glacial period. *Science*, 369(6506), 963-969.

Dong, X., Kathayat, G., Rasmussen, S. O., Svensson, A., Severinghaus, J. P., Li, H., ... & Cheng, H. (2022). Coupled atmosphere-ice-ocean dynamics during Heinrich Stadial 2. *Nature communications*, 13(1), 1-14.