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Comment on cp-2022-62

Anonymous Referee #1

Referee comment on "Synchronizing ice-core and U²³⁵/²³⁸Th timescales 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-RC1>, 2022

In this study, new ¹⁰Be NorthGRIP and WAIS Divide ice core measurements were compared to Hulu cave ¹⁴C measurements to constrain the age scales of these records through the Last Glacial Maximum (LGM). This exercise is important for improving the understanding centennial-scale climatic events in the LGM. Radionuclide particle production changes as a result of solar activity variability. Once changes in its transport to and deposition at ice core sites are accounted for, radionuclide particle variability in proxy records is therefore independent from changes in climate. It is beneficial to use radionuclide particle records to constrain proxy age scales due to this independence. In this study, a time period characteristically similar to the Maunder Minimum identified in the LGM ¹⁰Be records was used to synchronize the Greenland (GICC05) and Antarctic (WD2014) ice core ages scales. Using this analysis, an ~125-year difference between the age scales prior to synchronization was determined. A wiggle-matching algorithm was also used to synchronize the ice core age scales to the Hulu Cave age scale. The offsets between the Hulu Cave age scale and the GICC05 and WD2014 age scales were ~375 years and ~225 years, respectively.

This study is important to publish because highly temporally resolved paleoclimate datasets can only be compared to other archives if the age scales of the datasets are accurate. An improvement in the accuracy of proxy age scales therefore leads to better understanding of the timing and progression of climate events and therefore a better understanding of the climate system.

Major comments:

The introduction needs to be revised. The introduction is a long description of several well-known past climate events without giving the readers any context for why they are being

presented with this information. Is there something about these climate events that is unresolved that is addressed in this study? It is a nice literature review, but why is it given?

Along the same lines, in the introduction, the authors state that the "objective" of the study is a "comparison of three timescales." This isn't really an objective. The comparison is really the approach used to address the objective, which I believe is to improve the accuracy of the timing of climate events in the LGM, which is necessary to understand (eventually) the mechanisms behind them.

The age scale development of the three proxies is then nicely summarized in the introduction, but again, the readers are not given any information about how the current study fits into any of it until ~line 155. It would be very helpful if the authors explained the flaws in the previous dating methods much earlier. Otherwise, the reader does not know why they are being given the summary. It needs to be made very clear that the benefit of using radionuclide records is that their variability is independent from (at least in the case of flux) climatic events. Therefore, the circular nature of dating proxies using climate events and then, in turn, interpreting the timing of those events, is avoided.

The uncertainties in the age scale offsets are rather large given the small magnitude of the offsets. In the conclusion, it would be helpful if the authors could suggest ways in which these uncertainties could be reduced in future studies.

The focus of this study is the LGM, but as the authors state that the age scales were not stretched in this study. How would the age scales before and after the LGM be affected by the offsets suggested here? Are offsets of a few hundred years too small to make much of a difference?

The conclusion made in this study is that age scale corrections need to be made to the ice core records, and that the problem is the result of annual-layer-undercounting. Why does the problem lie with the ice cores? Is the age scale of the Hulu Cave record that much more certain?

Minor comments:

Line 60: This sentence is confusing: "During this time, a phase of massive discharge of icebergs from the Laurentide ice sheet was inferred from the ice-rafted debris content of North Atlantic marine sediments, defining the occurrence of the Heinrich Event 2 (HE-2;

Bard et al., 2000; Peck et al., 2006).” You mean that HS2 happened at the same time as the LGM, right? Simplify this sentence.

Lines 63-66: “The term Heinrich Stadial (HS) is often used to indicate the period affected by the HE. The duration of HS-1, for example, is limited to the 14.5-17.5 ka b2k interval within GS-2.1 (Broecker and Barker, 2007), while for HS-2, a correspondence with the late 65 GS-3 is often argued for, based on speleothem water isotope records (e.g. Li et al., 2021)”. It would be very useful if the timing of each Heinrich Stadial and each Greenland Stadial referenced was defined and easily referenced. Maybe a table could be added?

Even though it is commonly used, please add a sentence defining the IntCal20 curve.

Line 100: “and GICC05 was extended to these ice cores.” This is odd phrasing. I’m not sure what this means.

Why was before 2000 (b2k) used instead of the conventional, before 1950?

Lines 117-119: “The authors duly excluded the GI-2–AIM-2 pair from their lead-lag analysis, firstly because the GISP2 CH₄ record did not support synchronicity with the GI-2 temperature increase, and, secondly, because the older HE-4 and HE-5 were similarly associated with higher CH₄ levels.” What is meant by “because the older HE-4 and HE-5 were similarly associated with higher CH₄ levels?” Does this mean that GI2 and the HE’s can’t be distinguished, and that the HE’s are associated with stadials?

Lines 128-130: This needs to be more prominent: “Resolving some time-scale issues, which we will delineate shortly, will clarify the distinctive timing factors of the global climate around HE-2, compared to the ‘conventional’ bipolar seesaw scenario.”

Lines 31-33: This point should also be more prominent: “Traces of volcanic eruptions and cosmogenic radionuclides provide synchronization tools that do not rely on the precise identification of climatic match-points and on the assumption of their synchronicity.”

It is hard to see the effect of the ¹⁰Be flux calculation when the concentration and flux aren’t plotted together.

Lines 241-243: “A carbon-cycle model (here the box-diffusion model by Siegenthaler, 1983) is necessary to derive the atmospheric $\Delta^{14}\text{C}$ signal, i.e. the decay and fractionation-

corrected ratio of $^{14}\text{C}/^{12}\text{C}$ relative to a standard (Stuiver & Pollach, 1977), from the measured ice-core ^{10}Be ." Please clarify what is meant by "from the measured ice core ^{10}Be ." How was the ^{10}Be used in the model?

Lines 258-260: "The strength of the geomagnetic field directly affects both the ^{10}Be and ^{14}C production rates. Although each radionuclide may be affected differently (Masarik & Beer, 2009), most studies do not find any significant difference in production rates (e.g. Kovaltsov et al., 2012; Herbst et al. 2017)."... I thought that the geomagnetic field did affect production rates? Please clarify this sentence.

Lines 256-258: "To compare the measured and the modelled $\Delta^{14}\text{C}$, in this study we will make use of linear detrending, as this largely removes the systematic offsets associated with the unknown carbon cycle history and inventories." Were both datasets detrended? Please clarify what was done to detrend the data and which datasets were used.

What is the orange in Fig. 5?

Line 505-506: "The stack is shown in fig. S1, with uncertainty bands derived from the standard deviation of the 1000 simulated fluxes." Is there a reason the stack isn't shown in the main manuscript? Is it not particularly relevant?

Lines 516-518: "The G2B event: a relatively abrupt increase of 30 ‰ in the modelled $\Delta^{14}\text{C}$ from ^{10}Be , reaching its maximum at 21,725 years b2k (GICC05 ages), about 100 years after the maximum is reached in ^{10}Be fluxes." This is a bit confusing because this event is called the "G2B" event, but then it is stated that happens 100 years after the ^{10}Be . Please explain. Also, if the timing were the same as the ^{10}Be event, wouldn't you expect this, considering that the ^{10}Be data are an input that is used to produce the modelled $\Delta^{14}\text{C}$ data?

Table 3 is very helpful!

Lines 654-656: "We cannot provide an Antarctic comparison in this context, as the WD2014 chronology does not currently apply to other ice cores, hence an updated Antarctic synchronization across AIM-2 would be required." I don't quite understand this. Isn't WD2014 applied to the South Pole Ice core (SPICE) and to Skytrain (paper recently submitted to CP)?

Technical changes:

Line 50: change "being debated" to "under debate"

Line 52: add comma after "cold period"

Line 54: "was established to have lasted until"...change to something like "suggest that the LGM lasted until..."

Line 56: "since it coincides with the age limits of our new Greenland 10Be dataset"...what does this mean?

Line 108: Define $\delta^{18}O_{ice}$

Figure 1 caption: The second "d" should be "e"

Sections 2.1 and 2.2: references to the 10Be methods???

Line 323: "quantify the impact of 10Be measurements uncertainty" change to "quantify the impact of 10Be measurement uncertainty"

Line 275 vs. line 390: 21.7 ka event in one line and 22.7 ka event in another. Are these different events?

Line 451: "some eruptions are better visible in the"...change to "more visible"

Line 461-462: "and we obtained a timescale correction, which we apply in the following to the GRIP data." This is confusing. Please simplify this sentence.

Line 560: "Measured Hulu Cave used for synchronization" You should add that this is $\Delta^{14}C$.

Line 672: change "As much as the GICC05 layers are concerned," to "As far as the GICC05 layers are concerned"

Line 677: change "Acknowledging the 125-years offset" to "Acknowledging the 125-year offset"

Line 677-678: change "the 375 years offset between GICC05" to "the 375-year offset between GICC05"

Lines 746-747: "However, the onset of the Greenlandic dust peak moved to be roughly synchronous with the signal in the Hulu speleothem that has been linked to the HS-2 onset." Turn this into a sentence.