Response to anonymous Referee #1

We thank the reviewer for his/her valuable and helpful comments on the manuscript. We propose to implement the following changes in a revised version.

Black = reviewer comment / blue = author's response / "*italic*" = *revised text.*

This paper presents an improved chronology for the Antarctic EPICA Dome C ice core for the time interval 0-800 kyr. The development of this chronology involved various methods, including linking to existing Greenland and Antarctic ice cores, orbital tuning with $\delta^{18}O_{atm}$, $\delta O_2/N_2$, and total air content, and employing firn modeling. One of the significant advancements is the improvement of a section around 110 ka BP, where several previous studies have pointed out that the AICC2012 chronology is too young. Additionally, the increase of new gas data ($\delta^{15}N$, $\delta^{18}O$, $\delta O_2/N_2$, TAC) has greatly improved the precision of orbital tuning and the estimation of the Lock-in depth scenario, reducing overall chronological uncertainty significantly. While assessing whether the oldest part of the AICC2023 chronology has improved from the AICC2012 chronology is challenging, it does provide a reasonable estimate with a larger age uncertainty compare to AICC2012.

The paper is clearly written and convincingly demonstrates the method, including thorough sensitivity studies. The improved chronology for the EDC core is beneficial not only for the ice core community but also for the broader paleoclimate community. Therefore, I recommend accepting this paper for publication in *Climate of the Past* after addressing the following comments.

General comments:

1) I am concerned about aligning the EDC $\delta^{18}O_{atm}$ and the precession variations older than 590 ka BP, although it seems to be a better solution than the previous one. While Extier et al. (2018) suggested that the Heinrich-like events occurring especially during deglaciations delay the response of $\delta^{18}O_{atm}$ to orbital forcing, Oyabu et al. (2022) showed that the large lags of $\delta^{18}O_{atm}$ behind 65N summer insolation (~6 kyr) are not always seen during the Heinrich-like events. For example, they showed that a large lag (>6 kyr) was found during the period of less IRD (around the penultimate glacial maximum), while the lag for HE11 during Termination II is a modest value of 4.1 kyr. Therefore, I think it would be valuable to indicate what potential errors may exist, although the authors have already given a safely large uncertainty. For example, what about applying the same approach to well-dated periods such as the last glacial period, and/or the range of time periods where $\delta^{18}O_{atm}$-$\delta^{18}O_{calcite}$ matching was conducted, with relatively small dating uncertainties on speleothems, and comparing each other? This might serve as a test to evaluate the reliability of the methodology, and the readers will be convinced of the reliability of the obtained chronology.

Author's response: Thank you for these valuable inputs.

We will indicate the potential errors that may exist for using this approach for the period 590-800 ka BP and will refer to Oyabu et al. (2022). We agree with this limitation and this is the reason why we stick with a large uncertainty for the $\delta^{18}O_{atm}$ tie points over this period (6 kyr).

We agree that such a comparison would be valuable in the Supplementary Material to support the use of the approach presented in the manuscript. Following your suggestion, we tested three methodologies to align $\delta^{18}O_{atm}$ and precession over well-dated periods when $\delta^{18}O_{atm}$- $\delta^{18}O_{calcite}$ matching was done and where we have high confidence in the chronology and we built three test chronologies:

1) The test chronology 1 is obtained by aligning $\delta^{18}O_{atm}$ to 5-kyr-delayed precession as in Bazin et al. (2013).

2) The test chronology 2 is obtained by aligning $\delta^{18}O_{atm}$ to precession as it would be expected if only precession is driving the $\delta^{18}O_{atm}$ signal through monsoon activity.
3) The test chronology 3 is obtained by aligning $\delta^{18}O_{atm}$ to precession delayed if IRD counts are superior to 10 counts/g and to precession without delay if IRD counts are inferior to 10 counts/g (i.e., the same approach used in the paper for the period 590 – 800 ka BP when the $\delta^{18}O_{atm}$-$\delta^{18}O_{calcite}$ dating uncertainty becomes larger than 6 kyr and no East Asian speleothem $\delta^{18}O_{calcite}$ records are available before 640 ka BP).

We did an additional test to obtain a chronology derived from $\delta^{18}O_{atm}$-$\delta^{18}O_{calcite}$ matching only.

Over the 100-300 ka BP period, the test chronology 3 appears to be the best compromise as it agrees well with both the AICC2023 age model and the chronology derived from $\delta^{18}O_{atm}$-$\delta^{18}O_{calcite}$ matching (Figure). This is why we believe that it can be faithfully applied to the bottom part of the EDC ice core while keeping large uncertainties in the tie points. These tests performed to justify our approach will be implemented in the Supplementary Material.

This agreement is particularly satisfying over the 120-160 ka BP time interval which is the period on which reviewer 2 wants a focus on. Over this period, Oyabu et al. (2022) identified a large peak (up to 61%) in the IRD record of McManus et al. (1999) (red plain line in panel e) and defined the associated HE 11 between 131 and 125 ka BP. Yet, if we consider the IRD record of Barker et al. (2021) used in our study because it covers the last 800 kyr (blue plain line in panel e), we observe another large peak (up to 56 counts/g) at around 150-156 ka BP. Because of this presence of IRD, to establish the test chronology 3, we tuned $\delta^{18}O_{atm}$ to the 5-kyr delayed precession over the whole period stretching from 155 to 124 ka BP (gray frame), which is larger than the duration covering only HE 11. The presence of an IRD at 150-156 ka was not noted down in Oyabu et al. (2022) but is still visible in the McManus et al. (1999) record displayed in their study (see Figure 11 of Oyabu et al., 2022). Because we have an IRD at 150-156 ka, it justifies the lag observed in our chronology as well as in Oyabu et al. (2022) between $\delta^{18}O_{atm}$ and precession.

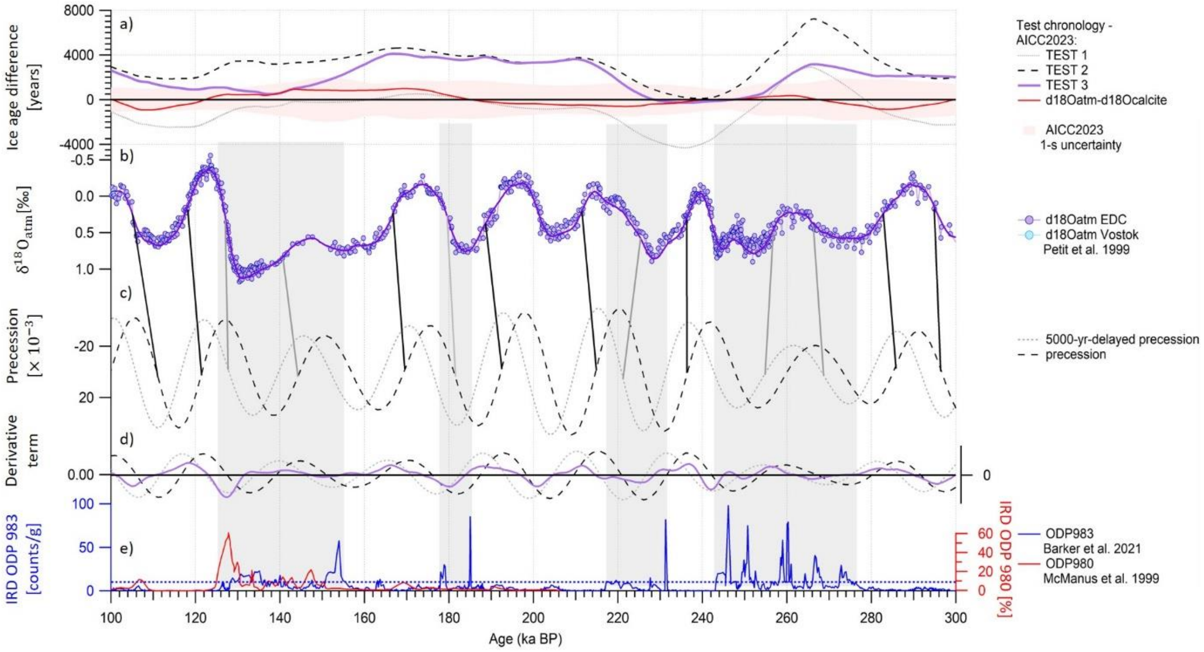

Figure. EDC ice age difference between test chronology and AICC2023 between 300 and 100 ka BP. a) EDC ice age difference between AICC2023 and 4 tests chronologies: (i) test chronology 1 (grey dotted line), (ii) test chronology 2 (black dashed line), (iii) test chronology 3 (purple plain line) and (iv) test chronology derived using only $\delta^{18}O_{atm}$-$\delta^{18}O_{calcite}$ matching (red plain line). AICC2023 ice age 1σ uncertainty is shown by the red area. b) $\delta^{18}O_{atm}$ data from EDC (purple circles) and Vostok (blue circles). c) Precession delayed by 5 kyr (grey dotted line) and not delayed (black dashed line) (Laskar et al. 2004). d) Derivative term of precession (black dashed line), delayed precession (grey dotted line) and of the compiled $\delta^{18}O_{atm}$ record (purple plain line). e) IRD (blue by Barker et al. 2021; red by McManus et al. 1999). The gray squares indicate periods where IRD counts are superior to the 10 counts/g threshold shown by the blue dotted horizontal line.

Regarding the gas age for the last 60 kyr, there are some age reversals in the AICC2012 chronology. I believe that the AICC2023 chronology has improved as the tie points have been updated and there have been significant progress on the construction of prior LIDs, but please make sure whether the AICC2023 chronology addressed and resolved the issue.

Author's response: The AICC2023 chronology resolved this issue. We believe this was due to the too important variability of the analyzed LID scenario that is transferred to the Δdepth, itself driven by the high uncertainty associated with background LID. To address this problem, we revised the background LID scenario using new data of $\delta^{15}N$ and reduced its relative uncertainty to 10-20 % (where it was evolving between 20 and 70% in the AICC2012 chronology). Here the less variable LID scenario results in less gas age inversion. It can be seen in the figure below where EDC gas age augmentation rate is plotted as a function of the age for AICC2012 (black) and AICC2023 (blue).

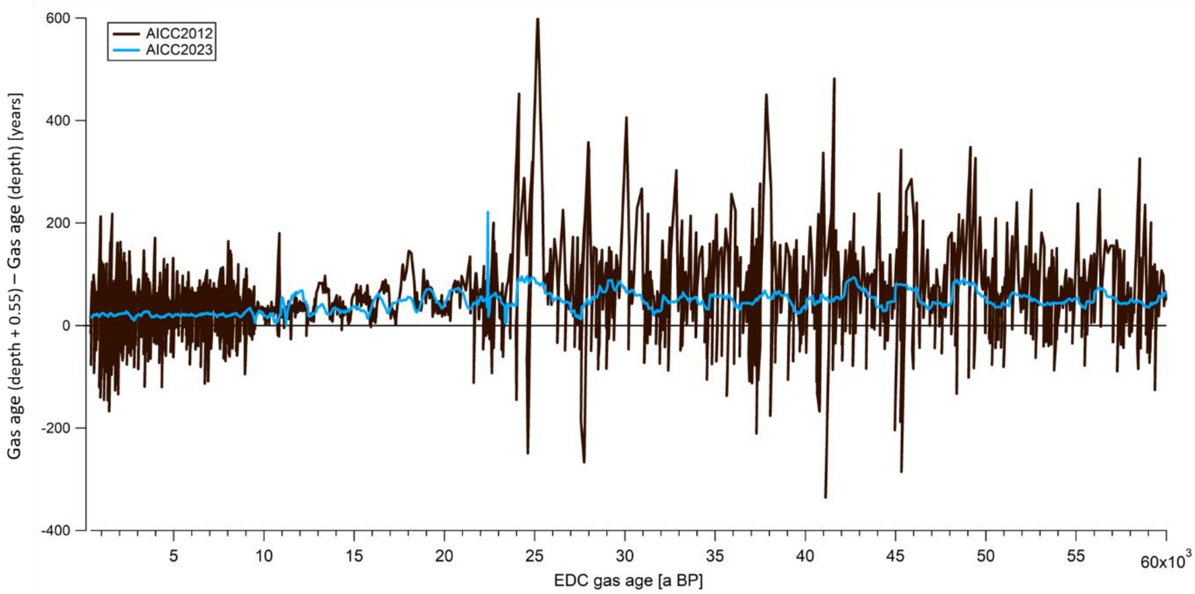

Figure. Gas age augmentation rate in AICC2012 (black) and AICC2023 (blue). The augmentation rate is defined as: gas age (depth + 0.55) – gas age (depth).

Specific comments:

- The authors probably have already prepared the dataset, and please indicate data availability. New ages and their uncertainties, age markers used in this study including both updated and old ones, posterior of accumulation rate, thinning function and LID, and gas data should be included.

Author's response: A folder including new ages and their uncertainties, age markers used in this study including both updated and old ones, posterior of accumulation rate, thinning function and LID, and gas data is currently reviewed by the PANGAEA repository. The link will be added into the paper:

https://doi.pangaea.de/10.1594/PANGAEA.961017.

In addition, the input and output files of the AICC2023 Paleochrono run include all these parameters and are available on GitHub. The link will be included in a Code Availability section in the paper.

- In Paleochrono, the assignment of uncertainties to the prior scenarios (accumulation rate, thinning function and LID) has a significant impact on the final estimation of age uncertainties. Please indicate what uncertainties the authors assigned.

Author's response: The current manuscript presents the uncertainty obtained when preserving the background uncertainties assigned by Bazin et al. (2013) (black plain line in Figure). However, we agree that although there is no objective way to assign specific prior uncertainties, the values chosen by Bazin et al. (2013) seem unrealistic (i.e. 80% of uncertainty for the LID during some glacial periods at EDC whereas firn modelling and δ^{15}N agree within a 20%-margin at most).

That is why we believe the prior uncertainties should be reduced in AICC2023 and propose the following major changes (blue plain line in Figure):

- The LID relative uncertainty is reduced to values oscillating between 10 and 20% at most, excluding values reaching 80% used in AICC2012. The reason for this modification is that in 2012, the mismatch between firn model outputs and δ^{15}N-inferred LID was not understood. In the meantime, much progresses have been made, confirming that the δ^{15}N-inferred LID was correct and firn models or their forcing have been adapted (Parrenin et al., 2012; Breant et al., 2017; Buizert et al., 2021).
- The thinning relative uncertainty is evolving linearly, rather than exponentially as it was done in AICC2012. The linear uncertainty allows to have a significant uncertainty at intermediate depth levels while with the exponential shape, the uncertainty was essentially located at lower depth levels, which was not realistic.
- The accumulation relative uncertainty is decreased to 20%, as opposed to 60% used in AICC2012. This choice is motivated by the study of Parrenin et al. (2007) who counted event duration in EDC and DF ice cores and found out an offset of 20% on average.

We performed several sensitivity tests to assess how the choice of uncertainty affects the age and error. In the figures below, you will find the EDC ice age difference between AICC2012 and the different test chronologies and associated errors (corresponding to different prior uncertainties for thinning, LID and accumulation described in the Table). The first figure shows the whole 800 ka BP while the second focuses on the most recent 160 ka BP. Following your comment, we will add a section presenting the sensitivity tests in the Supplementary Material.

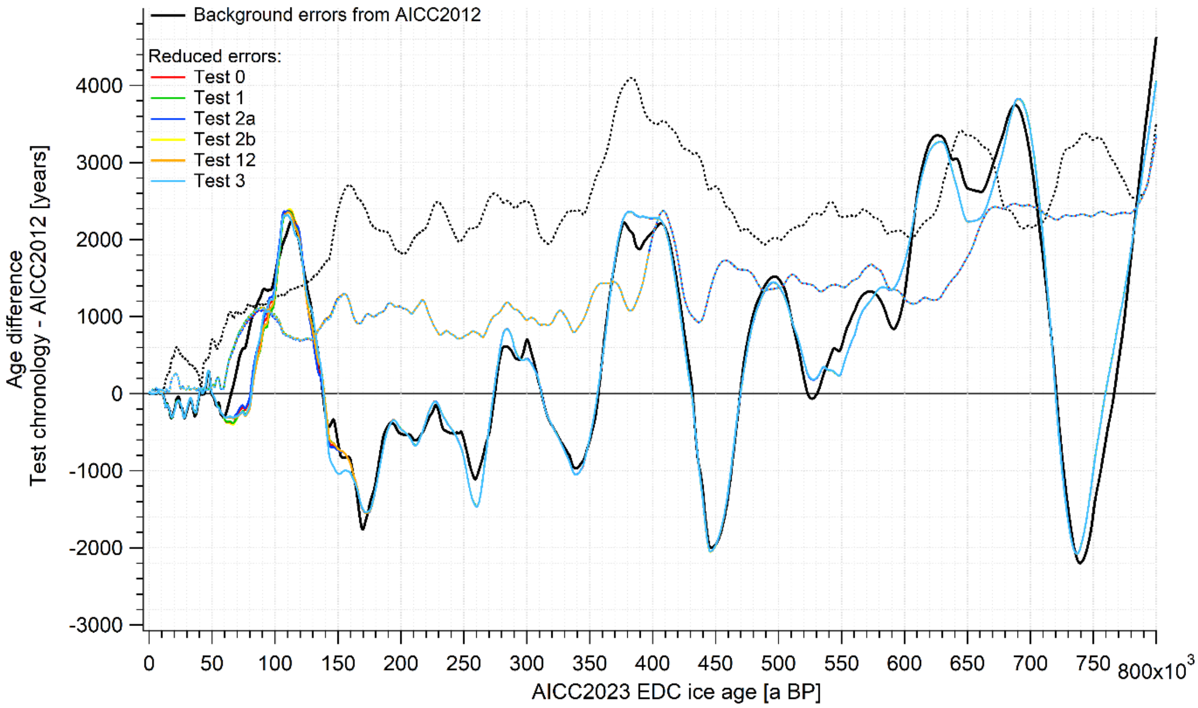

Figure. EDC ice age difference between each test chronology and AICC2012 timescale between 800 and 0 ka BP. The different test chronologies have been obtained by keeping the same age constraints and background scenarios as in AICC2023 but varying the background errors.

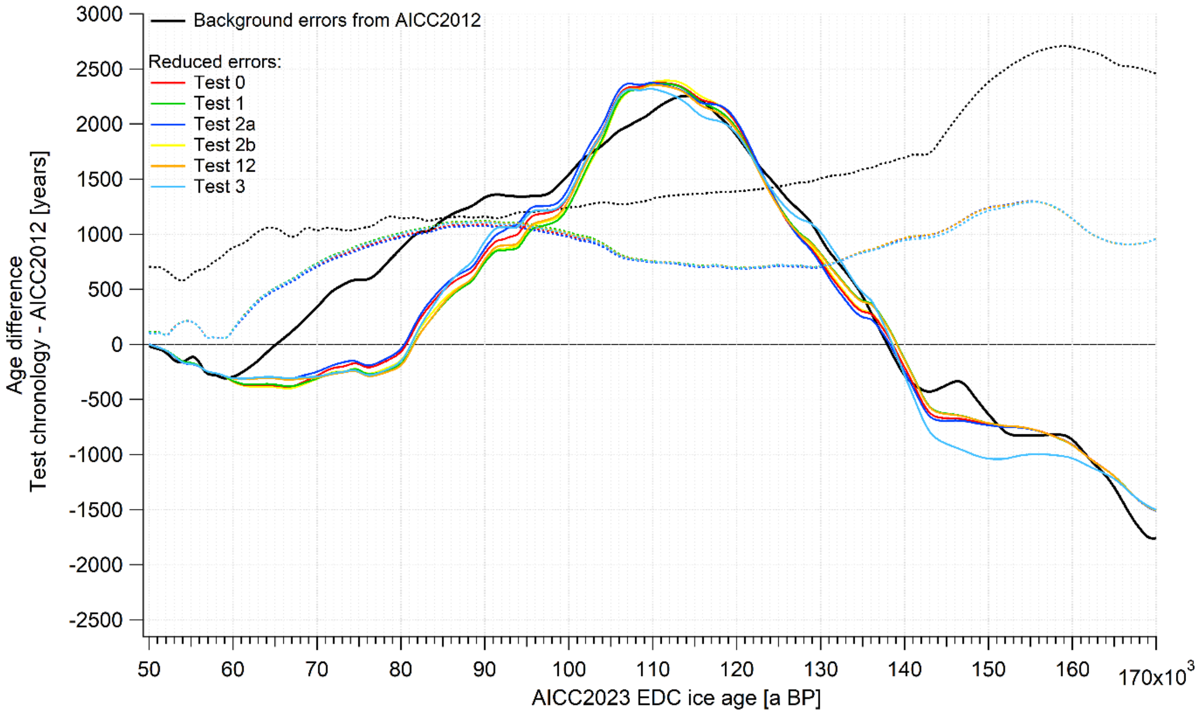

Figure. EDC ice age difference between each test chronology and AICC2012 timescale between 170 and 50 ka BP.

Table. The different prior relative uncertainties tested for thinning, LID and accumulation.

Test	Sites	LID	Thinning	Accumulation
Test 0	EDC	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	EDML	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	From AICC2012 (between 0.2 and 0.8)

	VK	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	TALDICE	0.2	From AICC2012 (exponential from 0 to 2.4)	0.2
	NGRIP	0.2	Linear from 0 to 0.5	0.2
Test 1	EDC	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	EDML	0.1 (data) or 0.2 (no data)	Linear from 0 to 1	From AICC2012 (between 0.2 and 0.8)
	VK	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	TALDICE	0.2	From AICC2012 (exponential from 0 to 2.4)	0.2
	NGRIP	0.2	Linear from 0 to 0.5	0.2
Test 2a	EDC	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	EDML	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	VK	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	TALDICE	0.2	From AICC2012 (exponential from 0 to 2.4)	0.2
	NGRIP	0.2	Linear from 0 to 0.5	0.2
Test 12	EDC	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	EDML	0.1 (data) or 0.2 (no data)	Linear from 0 to 1	0.2
	VK	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	TALDICE	0.2	From AICC2012 (exponential from 0 to 2.4)	0.2
	NGRIP	0.2	Linear from 0 to 0.5	0.2
Test 2b	EDC	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	EDML	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	VK	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	TALDICE	0.2	From AICC2012 (exponential from 0 to 2.4)	0.2
	NGRIP	0.2	Linear from 0 to 0.5	0.2
Test 3	EDC	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	0.2
	EDML	0.1 (data) or 0.2 (no data)	Linear from 0 to 1	0.2
	VK	0.1 (data) or 0.2 (no data)	Linear from 0 to 0.5	Linear from 0.2 to 0.7
	TALDICE	0.2	Linear from 0 to 1	0.2
	NGRIP	0.2	Linear from 0 to 0.5	0.2

- I suggest showing not only the posterior LID but also the posterior of the accumulation rate and thinning function, either in the main text or supplement.

Author's response: We agree and this will be added to the supplement.

- Figure colors: Grey squares in Fig. 4, 7, 8, 9,10, 12, and S4 are too light in color to see.

Author's response: The changes will be made.

Lines 23-24: The use of three orbital markers does not necessarily reduce uncertainties.

Author's response: We agree to delete the reason (2) and suggest to add this sentence at the end of Line 28: *"For the first time, three orbital tools are used simultaneously. Hence, it is possible to observe that they are consistent with each other and with the other age markers over most of the last 800 kyr (70%). This, in turn, augments our confidence in the new AICC2023 chronology."*

Line 29: Is the uncertainty 1 sigma or 2 sigma?

Author's response: It is 1 sigma, we will precise in the new version.

Line 54: EDC -> EPICA Dome C (because it first appears here in the main text).

Author's response: It will be changed.

Line 59: I would specify the boundary conditions.

Author's response: We suggest to specify: *"poorly known parameters including boundary conditions such as bedrock topography, geothermal properties or subglacial sliding."*

Line 72: Need reference(s) for 81Kr dating.

Author's response: We suggest to add the following reference:

Jiang, W., Hu, S-M., Lu, Z-T., Ritterbusch, F., Yang, G-M.: Latest development of radiokrypton dating – A tool to find and study paleogroundwater, Quat. Int., 547, 166-171, https://doi.org/10.1016/j.quaint.2019.04.025, 2020.

Lines 99-100: Oyabu et al. (2022) also used $\delta O_2/N_2$ for the Dome Fuji core over the last 207 kyr and they estimated uncertainties as about 250 to 600 years.

Author's response: This will be added in the references.

Line 115: Change to "air is trapped in enclosed bubbles and diffusivity becomes effectively zero". The gas diffuses through the ice matrix (e.g., Salamatin et al., 2001, DOI:10.1016/S0022-0248(00)01002-2), so the original description might possibly be misleading.

Author's response: The change will be made.

Line 145: Same as line 29.

Author's response: We will change to *"AICC2012 1σ uncertainty"*.

Lines 146-147: "(i) discrepancy between $\delta^{18}O_{atm}$, $\delta O_2/N_2$ and TAC series and their orbital target". Difficult to understand what the authors meant. Do the authors mention about the inherent dissimilarity in curve shape?

Author's response: We suggest to clarify: *"(i) some inherent dissimilarities between $\delta^{18}O_{atm}, \delta O_2/N_2$ and TAC series and their curve-shaped orbital target"*

Line 188: Does the synchronization dating method mean orbital tuning in this context?

Author's response: Yes. It also refers to the method consisting in aligning $\delta^{18}\mathrm{O}_{\mathrm{atm}}$ to $\delta^{18}\mathrm{O}_{\mathrm{calcite}}$. Hence the phrasing "orbital tuning" is not used.

Line 189: It seems that Δdepth constraints were not included in this study. Although Δdepth may have a small effect on reducing the age uncertainties, it should be important for constraining the ice-gas relationship. It is possible to make Δdepth constraints using δD and CH_4 by assuming a bipolar seesaw relationship, and I think it may help to improve dating accuracy.

Author's response: Many thanks for this interesting comment. We would prefer avoiding to assume a systematic bipolar seesaw relationship when building the chronology through alignment of δD maximum and CH_4 abrupt increase. The first reason is that this matching does not always hold (δD maximum at EDML is reached several centuries before the abrupt CH_4 peak, Landais et al. 2015; Buizert et al., 2018). However, we agree that our new chronology with more precise LID determination thanks to the new $\delta^{15}N$ data can help testing the bipolar seesaw relationship between δD and CH_4 over the last 800 kyr. This is beyond the scope of this study focused on the chronology.

Lines 200-204: I read the sentences as the authors did not use age intervals but used dated horizons for the last 60 kyr, and I would refer to Fig. S8 here.

Author's response: I would not refer to Fig. S8 here as this figure shows the CH_4 matching and not the ties between AICC2023 and GICC05 mentioned in this paragraph.

The following comments are also relevant to Section 3.4. In Fig. S8, tie points for the CH_4 concentrations are placed up to ~115 ka BP. Did the authors utilize tie points as dated horizons for time periods younger than 60 ka BP and as stratigraphic links between the NGRIP core and other Antarctic cores before 60 ka BP? In the AICC2012 chronology, Veres et al. (2013) employed absolute tie points placed at one-meter intervals to closely fit the AICC2012 chronology to GICC05 over the last 60 kyr. Did the authors apply the same approach for the AICC2023 chronology? Also, where does 122 kyr (lines 162 and 594) come from?

Author's response: As Veres et al. (2013), we closely aligned NGRIP to the GICC05 age scale through absolute tie points placed at one-meter intervals over the last 60 kyr. In addition, over the 0-122 ka BP period, we used the CH_4 tie points as gas-gas stratigraphic links between NGRIP and the four Antarctic ice cores. As a result, only the age models of the four Antarctic ice cores are slightly modified so that they are better aligned with GICC05 (see Figure S8).

The 122 kyr refers to the oldest CH_4 tie point identified by Baumgartner et al. (2014) at 121.9 ka BP which was not appearing on Fig. S8. This will be modified in the revised version, see updated Fig. S8 below.

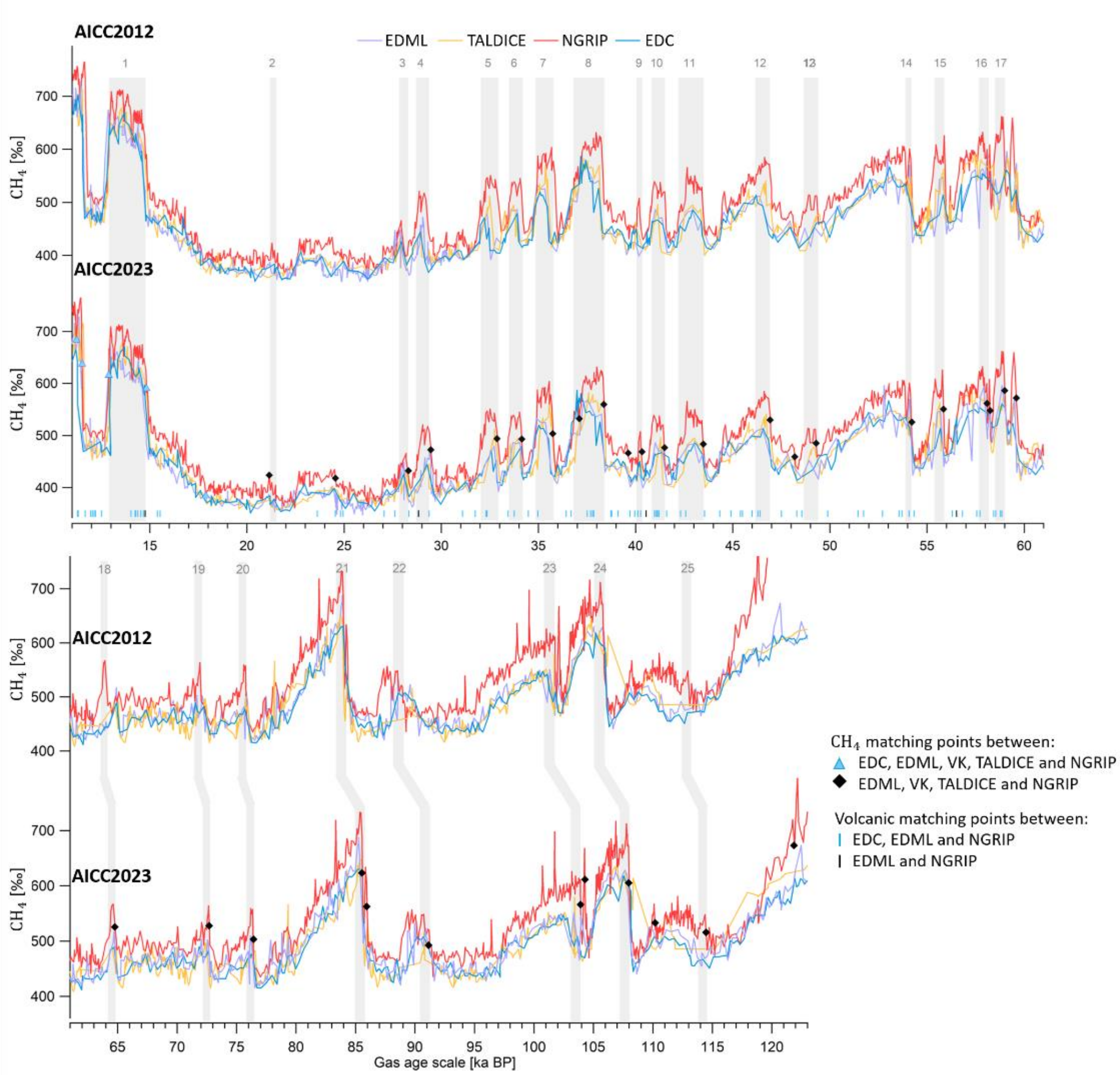

Figure S8. CH_4 records from Antarctic and Greenland sites over the last 122 kyr. CH_4 from EDML, TALDICE, NGRIP and EDC ice cores on the AICC2012 gas timescale (top panel). CH_4 from EDML, TALDICE, NGRIP and EDC ice cores on the AICC2023 gas timescale (bottom panel). Stratigraphic links between CH_4 series from EDC, EDML, Vostok, TALDICE and NGRIP ice cores (blue triangles and black squares, Baumgartner et al., 2014) and between volcanic sulfate patterns from EDC, EDML and NGRIP ice cores (vertical bars, Svensson et al., 2020) are used to constrain AICC2023 over the last 120 kyr. Abrupt D-O events are shown by grey rectangles and numbered from the youngest to the oldest (1-25) (Barbante et al., 2006).

Lines 224-225 and line 40 of Supplementary Material: The $\delta O_2/N_2$ obtained from ice stored at -50 ˚C appears much less affected by the gas loss than those obtained from ice stored at -20 ˚C. However, I do not agree that the new data is not affected by the gas loss, because it can be clearly seen that there is offset between the values of Extier et al. (2018) and the new data (e.g., 190 – 260 ka BP in Fig. S1). This discrepancy suggests that the new data was affected by the gas loss. The 3-5 mm surface removal probably does not completely remove the ice affected by the gas loss as shown by Oyabu et al. (2021) (https://doi.org/10.5194/tc-15-5529-2021). While the offset may not affect dating in terms of peak positions (need to check), the absolute value is still important if this data is to be used to reconstruct atmospheric oxygen concentration (e.g., Stolper et al., 2016, doi/10.1126/science.aaf5445; Extier et al., 2018). In such a case, it would be risky to state that no gas loss correction is necessary. I suggest to the authors mention about the $\delta O_2/N_2$ data that the new data is slightly affected by the gas loss, although peak positions are not affected.

Author's response: The authors agree and we will follow the suggestion given here.

Line 227: The reported pooled standard deviation for $\delta O_2/N$ appears to be small by one order of magnitude (Extier et al. (2018) reported it as 0.37‰).

Author's response: The correction will be made. One zero has been added by mistake.

Line 268: Need reference(s).

Author's response: We will implement Herron and Langway 1980; Alley 1987; Arthern et al., 2010, Ligtenberg et al., 2011 and Kuipers Munneke et al., 2015.

Line 270: Move "Capron et al. (2013)" to the end of the sentence.

Author's response: This will be done.

Figure 1: I would suggest placing minor ticks between major ticks for the age scale (like fig. 9). Figure 1 and Figure 2 have duplicate items, and it would be sufficient to use only Figure 2.

Author's response: We agree to keep only Fig. 2 with additional minor ticks for the age scale.

Line 302 Chapter title: This chapter mostly describes what age constraints and background LID scenarios were used. It may be better to change the chapter title (e.g., 3 Age constraints and background scenarios).

Author's response: The change will be made.

Lines 373-375: I would suggest having a little more explanation of how the 3 kyr was derived.

Author's response: We will add at Line 375: *"They examined three $\delta O_2/N_2$ records from Vostok, Dome Fuji and EDC ice cores over MIS 5 and detected some site-specific $\delta O_2/N_2$ variations. This observation, along with the presence of a 100 kyr periodicity in the $\delta O_2/N_2$ record and the difficulty of identifying $\delta O_2/N_2$ mid-slopes and maxima, led them to recommend the use of a 3 kyr uncertainty."*

Figure 2, line 380: Change to "Extrema in the compiled filtered $\delta O_2/N_2$ dataset (blue plain line in panel a) are identified and…." . (b) in the figure should be shown a little lower (next to the insolation curve); it appears to point to the compiled $\delta O_2/N_2$.

Author's response: The panels will be modified to a) $\delta O_2/N_2$, b) compiled and filtered $\delta O_2/N_2$, c) orbital target, d) time derivative.

Line 418: "All extrema are not…" should be "Not all extrema are…".

Figure 3, line 435: What is the bottom line? Maybe the "bottom" should be "horizontal."

Lines 469-470 and Figure 5: There are several cases where the vertical lines in the figure appear to point to the slope instead of the extrema of the temporal derivative. In addition, the type and number of lines connecting (b)-(c) and (d)-(e) do not match in several places—for example, around 160 ka BP and 370 ka BP.

Author's response: This will be corrected.

Line 482: I would suggest briefly explaining the source of uncertainty for 1.1 – 7.4 kyr.

Author's response: We suggest to add that: *"the age constraints are attached to an uncertainty varying between 1.1 and 7.4 kyr which is the sum of the uncertainties of the speleothems ^{230}Th dating, the $\delta^{18}O_{atm}$ response to orbital forcing (1 kyr) and the $\delta^{18}O_{atm}$-$\delta^{18}O_{calcite}$ matching (0.5 kyr)."*

Figure 5, line 484: Need a reference for the Chinese $\delta^{18}O_{calcite}$.

Author's response: The reference will be added.

Figure 5, lines 486-487: Reconsider the descriptions. For example, "Tie points represented by blue vertical bars are determined by Extier et al. (2018) and those by black vertical bars are determined by this study. Both are used in the AICC2023 chronology."

Author's response: The changes will be made.

Line 491: Did the author decide to use the $\delta^{18}O_{atm}$ orbital markers after 590 ka BP rather than after 640 ka BP because the age uncertainties of the speleothem become large?

Author's response: Yes, this will be specified in the manuscript.

Line 499: Delete the period after Bazin et al. (2013).

Author's response: The change will be made.

Lines 508-512 and Section 4.2.3: The Matsuyama-Brunhes geomagnetic reversal has recently been dated with high precision from detailed studies of the Chiba composite section (e.g., Haneda et al., 2020; Suganuma et al., 2020), and ^{10}Be data has also been published (Simon et al., 2019). International Union of Geological Sciences ratified the Chiba composite section as the Global Boundary Stratotype Section and Point for the Chibanian stage and middle Pleistocene subseries of the quaternary system. In addition, the age of the M-B boundary in Lake Sulmona has been suggested to be affected by remagnetization (Evans and Muxworthy, 2018). Therefore, I recommend referring to the age from the Chiba composite section. The authors possibly be able to increase the accuracy of the chronology by including ^{10}Be matching as an absolute dated horizon (I am not a ^{10}Be expert, and it is difficult for me to suggest an appropriate matching method between the ice core and the Chiba composite section) or to verify the final chronology with better precision with the age from the Chiba composite section.

Author's response: We agree that the Chiba composite section also provides high-resolution ^{10}Be record, as the Sulmona basin lacustrine succession (Giaccio et al., in prep.), the Montalbano Jonico marine section (Simon et al. 2017) and the EDC ice core do. Although, the ^{10}Be flux records of Sulmona and EDC show a similar pattern and the same asymmetrical shape (i.e., slow increase followed by an abrupt ^{10}Be peak termination), the sharp termination is less obvious in the Montalbano Jonico and Chiba records. In addition, Chiba and Montalbano Jonico records are shallow marine deposits, hence expression of paleoclimatic proxies can be amplified and/or hampered by fluvial input (Nomade et al., 2019). Finally, substantial adjustments, up to 10.2±5.5 kyr (i.e., exceeding the related uncertainty) are required to fit the millennial scale variability of the Chiba record within the Sulmona radioisotopic-based chronology. Giaccio et al. point out that, despite these relatively large temporal offsets for the Chiba record, the Sulmona-based age model is more linear and describes a simpler, and likely more realistic, history of sediments accumulation. Therefore, we would like to rather use the Sulmona succession to compare with AICC2023. However, we suggest to mention the existence of the Chiba record and to specify why we only consider the Sulmona succession in the manuscript.

We agree that using ^{10}Be tie points might help constrain the ice core chronology over MIS 19, though we also believe that the age models of Chiba and Sulmona also are highly questionnable between 770 and 750ka. We support the need for further work towards the synchronization of such paleoclimatic archives, but this is beyond the scope of this study.

Section 3.3 and Figure S4: I am curious to see how well the Bréant model reproduced the $\delta^{15}N$ based LID. It is difficult to see a similarity from Fig. 7(b) and 7(c), and I would like to see a figure that both LIDs are plotted on the same panel (either in the main text or supplement).

Author's response: We agree that such figure could be useful in Supplement. It could fit within an additional section focusing on background scenario and uncertainties at the five sites. Please find below the Fig. 7 modified so that modeled LID with and without considering dust (respectively orange and red plain lines) are superimposed to $\delta^{15}N$ (markers).

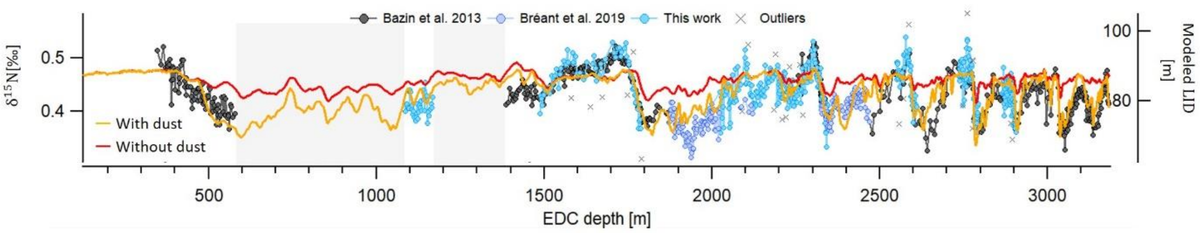

Figure. Modeled LID and $\delta^{15}N$ data over the 0-3200 m depth interval.

Figure 7, line 535: The data of Bréant et al (2019) is not mentioned.

Author's response: The reference will be added.

Section3.4: I recommend uploading the file containing all tie points used in this study, together with the chronology and its uncertainty, to a data repository.

Author's response: The file containing the chronologies and their uncertainties at the five sites is under review in the PANGAEA repository. We agree to add a file containing the tie points. All the files will be uploaded to Zenodo as well and available on GitHub.

Figure 8: Grey squares, vertical and horizontal ticks and MIS numbers are too light in color to see.

Line 673: Insert "and" between $\delta O_2/N_2$ and $\delta^{18}O_{atm}$.

Author's response: The changes will be made.

Figure 9: Is the uncertainty shown in the figure 1σ? I suggest adding a figure of gas age similar to Fig 9.

Author's response: Yes, it will be mentioned in the caption. Such a figure would be quite similar to Fig. 9, hence we suggest to add it in the Supplement.

Figure 10, line 699~: References for the CH_4 and δD data are necessary.

Author's response: The references will be added.

Lines 749-750: I agree that a smaller sample size generally increases the noise in data. In addition, I suspect that the EDC samples were slightly affected by gas loss, producing some scatters.

Author's response: Yes.

Figure 12: The $\delta O_2/N_2$ data from Oyabu et al. (2022) is extended to 207 kyr BP. The gray rectangle in the figure is drawn slightly younger from MIS5e.

Figure S4: Modify the label of panel (b) (Backgroun“d”).

Figure S8: Hard to distinguish between blue and black markers for the volcanic matching points. Also, see the comments for lines 200-204.

Author's response: The changes will be made.