We thank referee #2 for helpful comments.

General comments

The authors present a thorough analysis of ice samples collected in a blue ice area in Northern Victoria Land, East Antarctica. With complementary methods, both in the field, and in the laboratory, the chronostratigraphy of the ice is analyzed. By comparing the results to existing ice core records, a convincing proof of the estimated age of the ice and the gas entrapped in the ice is provided. Together with radar observations, the analyses from a three-dimensional image of age isochrones, which also allows an estimation of the age of ice near the bedrock. Given the importance of Antarctic blue ice areas in the recent developments in the search for the oldest ice, where 2.7-million-year-old ice has been recovered from a blue ice area in the Transantarctic mountains, the manuscript is very relevant for future paleoclimatic studies, and it can help in defining field work practices of sample collection and motivating site selection for shallow ice cores from blue ice areas.

The authors place their manuscript into context through a short literature review, after which the methods are described with clear subheadings. The results and discussion do justify the conclusions that are drawn, after which the paper is shortly wrapped up in a conclusion.

I do think the implications of the analyses are underexposed and need to be further elaborated without reducing the technical details. These technical details are generally clearly described and seem to ensure reproducible research, although the editor must know that I do not have the required laboratory experience/background to criticize this well. I have noted my suggestions below.

Specific comments per section

Abstract: clear and concise

Line 1: I do think the first line provides a circular argument

- We do not understand the comment.

Line 26: BIAs

- Line 31: We changed "BIA" to "BIAs".

1 Introduction: In general, the introduction gives all necessary background for reading the paper. However, I think the structure is a bit confusing, with paragraphs that do not follow each other in a logical order. Moreover, the last paragraph that introduces the study is too concise and does not clearly bring forward the goal of the research. Proposed solution: I would suggest to merge the paragraph starting on line 77 to the other paragraph on blue ice areas, starting on line 47.

- Line 62: We moved the paragraph right after the paragraph that the reviewer suggested.

Moreover, the approaches in the study (now outlined in the last paragraph), could be merged into the paragraphs starting from line 56 and from line 65 and/or the last paragraph can be more elaborate.

- Line 107: We more elaborated the last paragraph as follows:
  - "Our study focuses on the chronostratigraphy of ice in Larsen BIA, Antarctica, which may facilitate future research in this region. We describe the ice flow and structure of an ice body using dust bands and ground penetration radar (GPR) surveys, and then assessed the alterations of the measured stable water isotopes, greenhouse gases (CH_4, CO_2), and gas isotopes ($\delta^{15}N$-N_2, $\delta^{18}O_{atm}$). To constrain the unknown gas and ice ages, $\delta^{18}O_{atm}$, CH_4, and $\delta^{18}O_{ice}$ were correlated with existing ice core records. We also independently confirmed the ages using the radiometric ^{81}Kr dating method. Finally, using the $\delta^{15}N$-N_2, and the Δage (ice age-gas age difference) results, we present the record of surface temperature and accumulation rate. In contrast to the previous studies, which used the Herron-Longway model (Herron and Langway, 1980; Baggenstos et al., 2018; Menking et al., 2019; Yan et al., 2021), we applied a recently developed analytical framework to estimate past surface temperature and accumulation rates (Buizert, 2021)."

Line 42: I think it is important to mention that the flow is redirected. Normally, the ice flows under gravitational forces towards the margins of the continent. Moreover, it is not the bedrock itself that causes the ice to flow upwards, but it is the bedrock geometry (which in some sense is equal to the mentioned basal topographic obstacles). Also, in many cases these obstacles are exposed above the ice (nunataks).

- Line 46: We added that the ice flow is redirected and removed "bedrock" from the sentence.
  - "Once ice is deposited, ice flows to the margin of the ice sheet, where it is exposed on the surface since the basal topographic obstacles cause deep glacial flow upward. Moreover, surface snow is ablated by katabatic winds and/or sublimation (Bintanja, 1999; Sinisalo and Moore, 2010)."

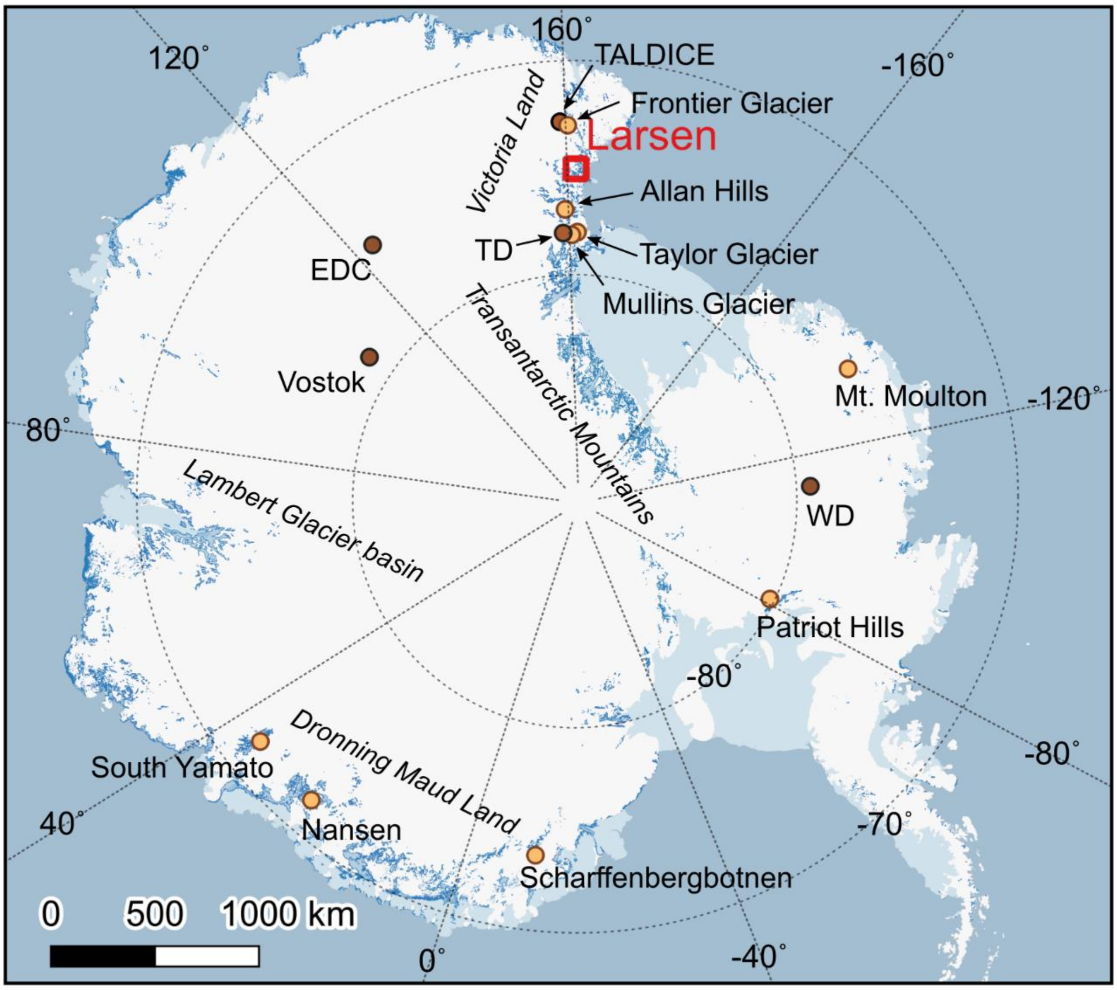
Line 52: instead of blue ice, specify that you mean samples taken from blue ice areas. This remark also applies to the rest of the paper.

- Line 17: Changed "blue ice" to "blue ice area."
- Line 53: Changed "blue ice" to "BIAs".
- Line 58: We changed "blue ice" to "ice samples taken from BIAs (hereafter referred to as blue ice)".
- Line 59: Changed "blue ice" to "BIAs".

Figure 1: Specify that orange dots represent "a selection" or "examples", as not all BIA where the chronology has been studied seem to be included (e.g., Zekollari et al. 2019)

- Zekollari, S. Goderis, V. Debaille, M. van Ginneken, J. Gattacceca, A. J. Timothy Jull, J. T. M. Lenaerts, A. Yamaguchi, P. Huybrechts, P. Claeys, Unravelling the high-altitude Nansen blue ice field meteorite trap (East Antarctica) and implications for regional palaeo-conditions. Geochim. Cosmochim. Acta. **248**, 289–310 (2019).

- We added Nansen BIA and Taylor Dome (TD) to the figure 1.



2 Study area and methods: In general, well-structured and clearly described.

Line 97: (Fig. 2a)

➢ Line 119: We changed "Fig. 2" to "Fig. 2a".

Line 97-99: A low mean annual temperature does not guaranty the absence of melt in a blue ice area. We need to know either the standard deviation of this annual temperature, or a maximum/high percentile of the observations.

➢ Line 120: There was a typo. We changed "-27.2 °C" to "−24.4 ± 11.7 °C".

Line 104: Using Quantarctica needs to be acknowledged by also citing the entire dataset and the corresponding paper

Matsuoka, K., Skoglund, A., & Roth, G. (2018). Quantarctica [Data set]. Norwegian Polar Institute. https://doi.org/10.21334/npolar.2018.8516e961

Matsuoka, A. Skoglund, G. Roth, J. De Pomereu, H. Griffiths, R. Headland, B. Herried, K. Katsumata, A. Le, K. Licht, F. Morgan, P. D. Neff, C. Ritz, M. Scheinert, T. Tamura, A. Van De Putte, M. Van Den Broeke, A. Von Deschwanden, Quantarctica, an integrated mapping environment for

Antarctica, the Southern Ocean, and sub-Antarctic islands. Environ. Model. Softw. 140, 105015 (2021).

- Line 126: We added "Matsuoka et al., 2018; Matsuoka et al., 2021".

Line 104-105: it is remarkable that the stratigraphy is disturbed upstream. Why does this not have implications on the stratigraphy downstream? What is the cause of the disturbances? Is there a temporal component to this? These questions should be addressed in the results and discussion section.

- Generally, many BIAs have a complicate stratigraphy because of the complicate ice flow and basal topography, as we explained in the introduction section. According to the GPR survey and the dust bands, we confirmed that the stratigraphy of the downstream part is not disturbed. However, it is hard to specify why the upstream part is disturbed but the downstream part is not disturbed. We need ice flow modeling studies and clearer GPR profile.

Line 110-113: can be more concise and clearer, something like: reprojected perpendicular to a line parallel to the ice flow direction.

- Line 134: We rephrased the sentence.
  - "An imaginary line parallel to the ice flow direction was used to define the horizontal distance, while a perpendicular line from each sampling location to the line parallel to the ice flow direction was projected to identify the intersection point. Each intersection point was then used to measure the horizontal distance from the most upstream sampling site (Fig. S1)."

Figure 2: mention that dust bands are observed in the field and how they are measured (GPS tracks?)

- Line 139: We added "observed in the blue ice field. The line marks are derived from what appeared on Google Earth.".

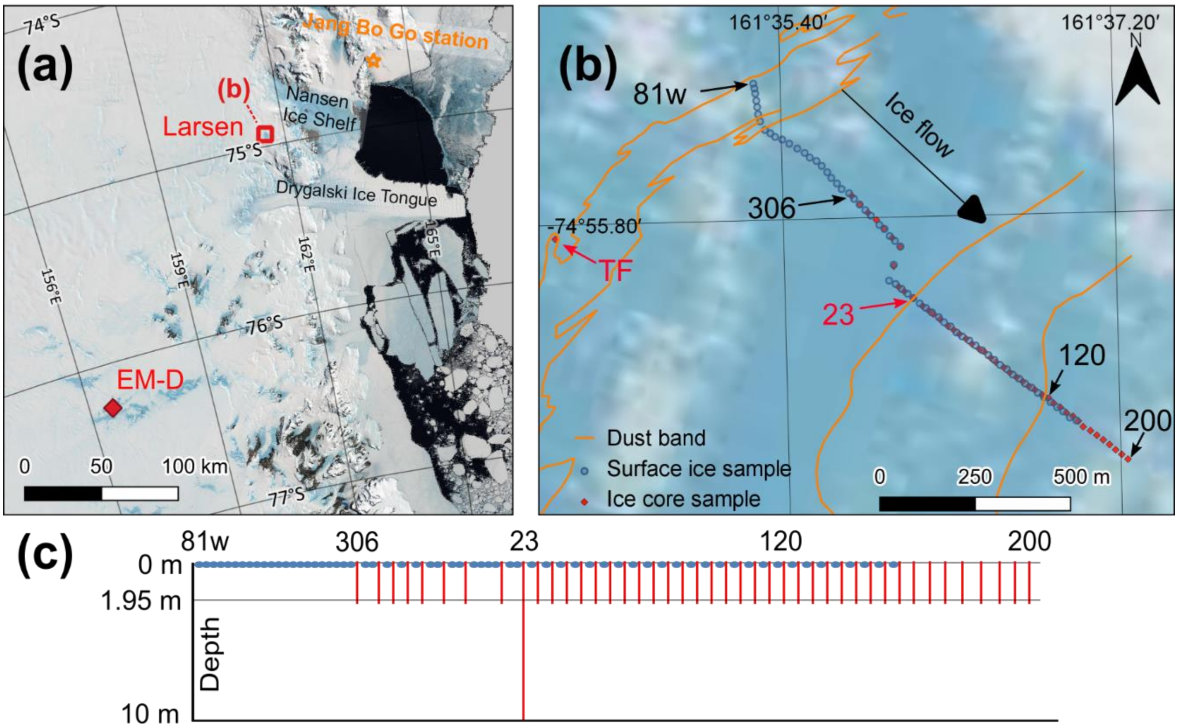


Figure 2. Location of the Larsen BIA and sample collection. (a) Location of Larsen BIA, EM-D core, and Jang Bo Go station. **(b)** Magnified map of Larsen BIA including sample locations. Orange lines represent dust bands observed in the blue ice field. The line marks are derived from what appeared on Google Earth. Blue dots represent locations of surface ice samples. Red diamonds are locations of shallow ice cores. Six representative names are shown, red letters for ~10 m long cores (TF and #23), black letters for 2 m long cores (#306, #120, and #200) and surface ice (81w). Z- and S-folds are recognized by the dust bands at upstream ices. The total transect of the ice sample is approximately 1.4 km. **(c)** Schematized cross-section of the transect. Satellite photo of Antarctica is from the QGIS Quantarctica package (Bindschadler et al., 2008).

Line 135: change "interval" to "spacing"?

- Line 159: We changed "interval" to "spacing".

Line 136: specify that these are vertical intervals (also in line 146).

- Line 160: We added "vertical".
- Line 171: We added "vertical".

Line 154: an average offset should be one number, not a range.

- Line 179: Daily average offset is not constant. It changes every day. Hence, we provided the range of the daily average offset. We added "which is in the range of 2–20 ppb".

Line 182: in this section I miss the description of the $\delta Ar/N_2$ analyses that are mentioned in the abstract and published in the supplementary materials.

- Line 210: We added ", and $\delta Ar/N_2$".
- Line 240: We added "Gravity-corrected $\delta Ar/N_{2,gravcorr}$ ($\delta Ar/N_{2,gravcorr} = \delta O_2/N_2 - 12 \times \delta^{15}N$) is listed in Table S1 and Table S2 but was not used in this study.".

Line 228: please briefly specify here why you use the TALDICE ice core in your research.

- Line 261: We added "When constraining the ice age of Larsen ice, the TALDICE record was selected to synchronize Larsen $\delta^{18}O_{ice}$ due to its proximity to the upstream direction of the Larsen BIA.".

3 Results and discussion: In general, the emphasis of this section seems to be more on the results than on the discussion. To make the manuscript more accessible for a wide readership and to do justice to the analyses performed by the authors, most paragraphs would need some additional sentences that discuss (the implications) of the data.

Line 243: This line should be at the end of the subsection 3.1, as now first the authors explain the stratigraphic profile, then discuss the basal topography and then return to discussing the stratigraphic profile. Also, in Figure 3b, the ice thickness varies between 200 and 320 meter (not 400). Lastly, it would be nice to have a qualitative statement that the ice thickness decreases along the flow and how this relates to the exposure of glacial ice (as mentioned in the introduction).

- Line 281: We moved the sentence to the last part.
- Line 282: We changed "400 m" to "380 m".
- Line 282: We changed "Fig. 3b" to "Fig. 3a, b".
- Line 284: We added a statement about the ice thickness.

- “The ice thickness decreases as ice flows with increasing bedrock elevation, which is a favourable condition for the ice to be outcropped.”

- The modified paragraph is as follows:
  - “In the GPR survey, we identified ice layers (or isochrones) in the transect parallel to the ice flow direction (Fig. 3). The dips of the ice layers range from 1° to 6° with a decreasing trend from the upstream to the downstream direction. The ice layers of the radargram were not clearly visible at a depth of < 10 m because of the direct wave signal. We did not observe any stratigraphic folding structure in the ice layers that made age inversion along the ice flow direction in the mid- to downstream areas (from ice cores #23 to #200). Therefore, we expect monotonic and continuous age changes along the ice-flow direction. However, as shown in the dust bands with S- and Z-folds in the upstream area (Fig. 2b), the upstream stratigraphy might be repeated on a scale of tens of meters (from 81w to ice core #23). In addition, the subsurface ice layer in the upstream area (0–800 m from the most upstream side) was not well recognized from the GPR profile (Fig. 3c). It is possible that the noise caused by crevasses, cavities, or cracks could obscure the signals. In addition, accurate data acquisition might have been hindered by antenna tremors or low battery power at severely cold temperatures. The basal topography is well defined from the GPR data; we observed an ice thickness variation of 200–380 m (Fig. 3a, b). The results of the bedrock elevation and ice thickness (Fig. 3a) were obtained using a kriging method, which is a method of interpolation that provides unbiased prediction at unsampled areas (Oliver and Webster, 1990). The ice thickness decreases as ice flows with increasing bedrock elevation, which is a favourable condition for ice to be outcropped.”

Line 245: are these crevasses, cavities, or cracks observed during the measurement campaign?

- Cracks were observed at the surface but crevasses or cavities were not. However, we cannot exclude the existence of crevasses or cavities in the subsurface. So, we are suggesting the possibility of those factors.

Figure 3: From Figure S1, it does not appear that the GPR has been performed as a grid of flight lines, are the results presented in panel a obtained by interpolation? Moreover, in the text there is no reference/analysis of the data shown in panel a, so I would suggest to either move the panel to supplementary materials or discuss it in the main text.

- Line 282: We added “The results of the bedrock elevation and ice thickness (Fig. 3a) were obtained using a kriging method, which is a method of interpolation that provides unbiased prediction at unsampled areas (Oliver and Webster, 1990).”.

Line 277: Reconsider combining section 3.3 and 3.4 and renaming it: “analysis of gas entrapped in the ice”.

- Line 324: We combined section 3.3 and 3.4 and renamed it as “Analysis of gas entrapped in the ice”.

Line 252-271: clear and nice balance between results and discussion of results.

Line 259: Please mention the references to the other published ice core records.

- Line 298: We added "(Petit et al., 1999; EPICA Community Members, 2004; Stenni et al., 2011)".

Line 265: why do you conduct a linear interpolation? To have measurements at equal horizontal/vertical spacing?

- In order to be most objective, we did a linear interpolation. As our data sets are not a continuous measurement, directly pinpointing the data point is subjective.

Line 279: What do you mean by altered? In Figure A1 only large fluctuations can be observed. Proof for altering comes only when discussing the comparison of the results from NIPR to SNU. This textual discussion would be greatly supported by plotting them in a (separate?) figure.

- Line 327: The sentence is modified as follows:
    - "The measurement results of the CH_4 and CO_2 concentrations for the vertical cores are presented in Fig. A1. The shallow ice cores (#306, #120, #201) show that greenhouse gases are significantly altered for the top 2 m, showing out-of-range values of the range of natural greenhouse gas concentrations during the last 800 ka BP: 340–800 ppb for CH_4 and 180–300 ppm for CO_2."

Line 295: Refer to Figure 4.

- Line 352: We added "(Fig. 4b)".

Line 303: Reconsider combining section 3.5 and 3.6 and adding a little introduction that explains your approach of first identifying the glacial termination, then matching the measured isotope and gas concentration profiles with existing (dated) ice cores, and then confirming your findings with the ^{81}Kr dating.

- Synchronizing Larsen to existing ice core record and identification of the glacial termination is a different subject, so providing a separate section of it will be more proper.

Line 319: … > 1.95 m (Fig. A2); the offset….

- Line 377: We moved "(Fig. A2)" to the suggested place.

Line 319: It is not clear why the offset may also come from age difference.

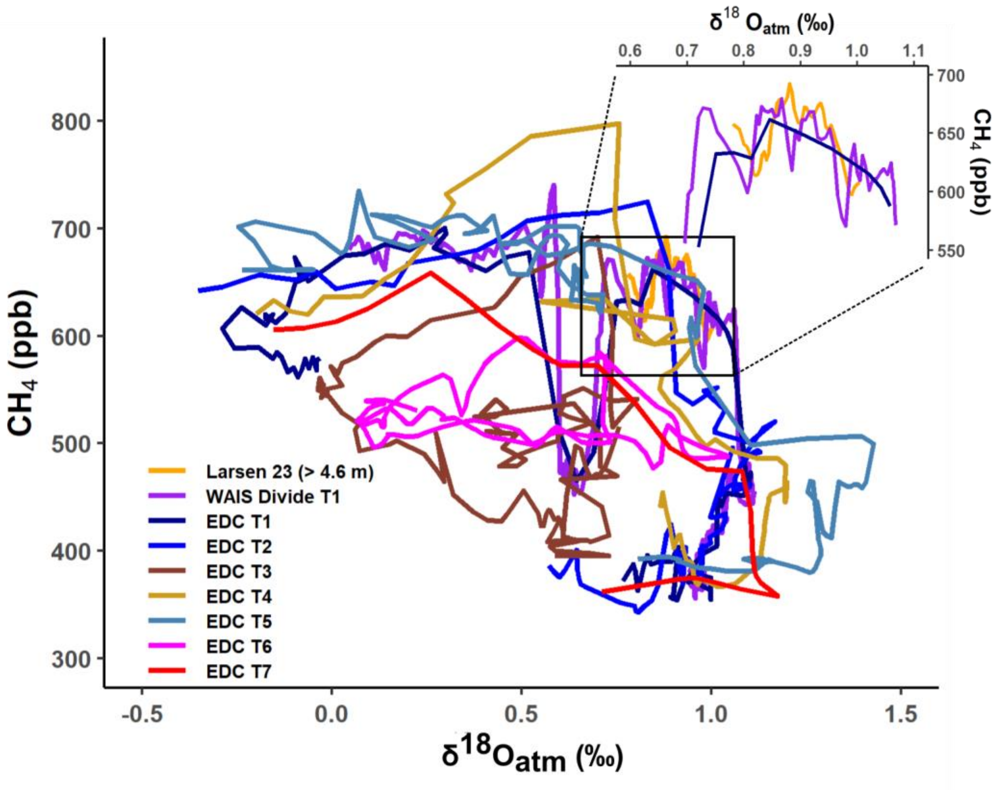
- Line 377: We added "because some $\delta^{18}O_{atm}$ record is estimated by linear interpolation due to the lack of $\delta^{18}O_{atm}$ record corresponding to the CH_4 of core #23".

Line 321: The statement about that it is altered naturally and/or contaminated is rather speculative. It is also in disagreement with section 3.3. In my opinion, this observation is very interesting and deserves further research (could be mentioned as limitation/recommendation).

- Line 380: We deleted "Probably, it is altered naturally and/or contaminated, even at depths of 4.6–10 m (Fig. A3, Fig. A4)".
- Line 381: We added "CO_2 concentration warrants further investigations.".

Figure 7: Consider omitting T3, T5 and T6, and check the color scheme for color blinds.

- We changed the color of EDC T2 to blue from dark green.
- We want to show $\delta^{18}O_{atm}$- CH_4 trend also indicates T1. Thus, we did not omit T3, T5, and T6.



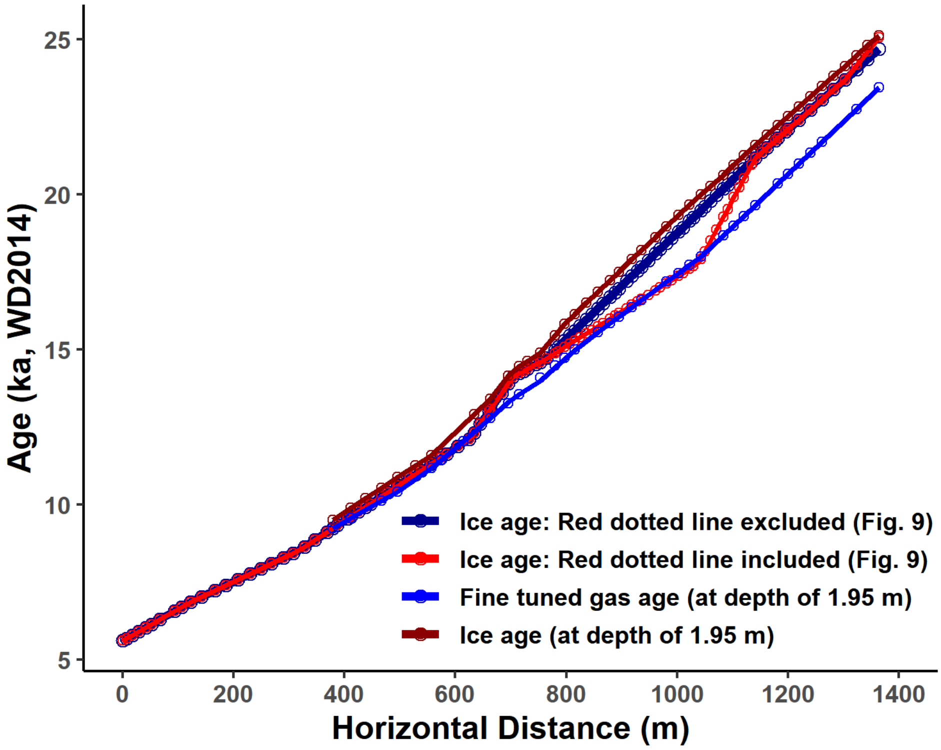
Line 342: (Fig 8d)

- Line 401: We changed "Fig. 8c" to "Fig. 8d".

Line 345-355: Did you consider an automated method such as dynamic time wrapping? Also, it would be nice to discuss already in this paragraph the relation between the corrections made to match the horizontal distance to the age and the observed dip angles (as in line 380-384).

- We did not consider an automated method. We will add a new section of age uncertainty (see below).
- We added the horizontal distance and age relationship of the fine-tuned gas age and 1.95 m depth ice age in figure A7.

- Line 417: We added "The age/distance relationship was reasonable (Fig. A7), showing no abrupt change, as supported by the gradual change in the ice layer dip (Fig. 3c).".



Line 371: I do not understand how biases in the $\delta^{18}O_{ice}$ record are avoided by interpolating the original record.

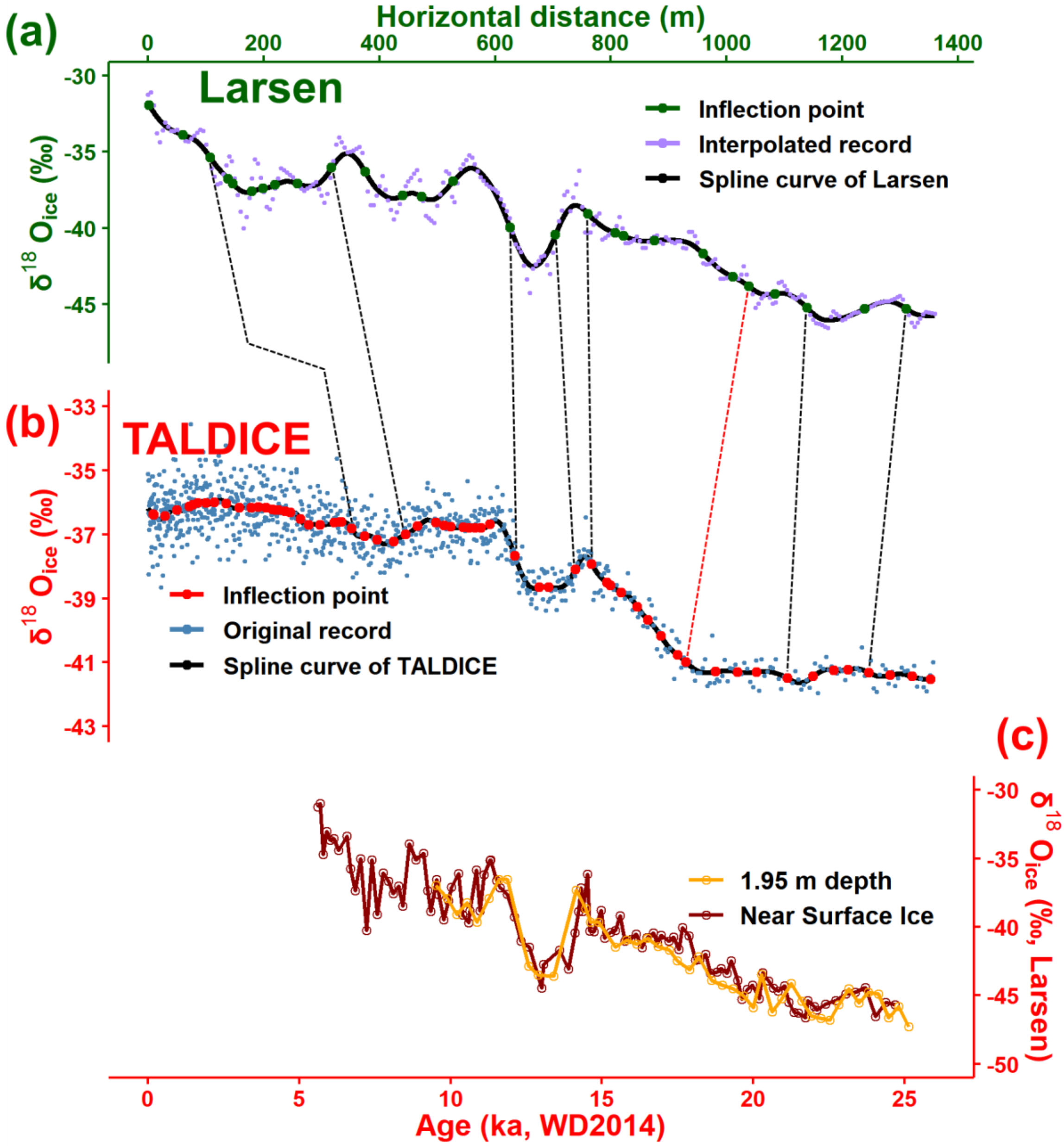
- Line 431: We added "spline curve of the".

Line 374: This statement is not clear and can be elaborated.

- We moved the statement to line 86. It is also more elaborated as follows:
  - "Notably, the ice is older than the gas at the corresponding depth because the gas is isolated and stops mixing with the atmospheric air when the firn completely transforms into ice (Schwander and Stauffer, 1984)."

Figure 9: Panel d does not show much more detail and could be omitted.

- We removed panel (d).



- Line 467: We removed "(d) $\delta^{18}O_{ice}$ record of TALDICE shown in more detail (Stenni et al., 2010, Bazin et al., 2013c)."

Line: 398-403: This paragraph sounds more like a part of the conclusion.

- Line 453: We removed the paragraph.

Line 398: The first sentence undersells the results. It can be a valuable (but obvious) recommendation but needs an explanation of why we would need more precise ages. Moreover, it is not in line with the statement on Line 412.

- Line 453: We removed the paragraph.

Line 401: please specify which atmospheric greenhouse gas can be measured at what depth (very relevant for other field work missions).

- This is written in line 577–578.

Line 401-403: nice and clear statement.

4 Conclusion: The conclusion section can be more elaborate. I suggest including the last paragraph of the previous section (line 398-403). Moreover, an estimation of the horizontal relationship between distance and age (i.e., xxx year/horizontal m), would be informative for other studies at blue ice areas.

- We think the paragraph should be in the chronology section.
- Line 457: We added temporal resolution for the Larsen BIA.
    - "The established horizontal ice chronology shows that temporal resolutions of 10 yr m^{-1} and 17 yr m^{-1} are available for the Holocene (5.6–12 ka BP) and for the last deglaciation (12–24.6 ka BP), respectively, at the surface ice from Larsen BIA. These estimated resolutions are higher than those of the deep ice core TALDICE covering this time interval (~18 yr m^{-1}) (Masson-Delmotte et al., 2011)."

Line 409-410: would be nice to guide the reader along the blue ice area and explain why the observations reveal a very typical glacial termination (as for instance Line 304-305, and the mention of the Antarctic Cold Reversal). Moreover, the Δage along the flowline (Figure A6) can be included in this explanation.

- Line 579: We added "(the Larsen $\delta^{18}O_{atm}$ shows both negative and > 1.0 value)".

Line 414: not only on blue ice areas in the Northern Victoria Land. The comprehensiveness makes it a valuable study for BIAs across the Antarctic continent.

- Line 584: We changed "blue ice in the Northern Victoria Land." to "on BIAs across the Antarctic continent.".

Appendices: clear and concise.

Figure A3, A4: Consider omitting T3, T5 and T6.

- We wanted to show that CO_2-CH_4 and CO_2-$\delta^{18}O_{atm}$, also indicate Termination 1. Hence, should be included.

➢ We added new sections.

3.6 Age uncertainty

3.6.1 Gas age uncertainty

There are two types of uncertainty to consider: (1) the relative Larsen gas age uncertainties to the WAIS Divide (WD) gas age, and (2) the absolute WD gas age uncertainty itself. To assess the relative Larsen gas age uncertainty to WD gas age, we applied a Monte Carlo simulation running the model 10000 times. The model is described in detail in the following paragraph.

First, to assign relative Larsen gas age uncertainties of the points that were pin-pointed to WD (pink and purple dots in Fig. 8a, b), analytical uncertainty should be defined. The analytical uncertainty of $\delta^{18}O_{atm}$ from Larsen is assumed to be ±0.05 ‰, as discussed in Sect. 3.3.2. The analytical uncertainty of $\delta^{18}O_{atm}$ from WD was ±0.006 ‰ (Severinghaus et al., 2015). Because the analytical uncertainty of $\delta^{18}O_{atm}$ from WD is about one order of magnitude lower than Larsen's uncertainty, we assume the total analytical uncertainty to be ±0.05 ‰. Then, the gas age for the pink dots (Fig. 8a, b) was assigned 10,000 times using a Monte Carlo simulation considering the analytical uncertainty. The standard deviation of the assigned ages were used for the relative gas age uncertainty.

The relative Larsen gas age uncertainty estimation process for the older tie-points (purple dots in Fig. 8a, b) is more complicated. We repeatedly produced the spline curve 10000 times using the Monte Carlo approach and found the location (horizontal distance) of the local maximum and local minima. The simulation results were rejected when there was no or only one local minimum. This Monte Carlo result and its uncertainties were used to detect outliers (> 2σ). The process was iterated until no outliers were detected. Using the location (horizontal distance) uncertainty of the local maximum and local minima, we then estimated the relative Larsen gas age uncertainty to WD gas age using the Monte Carlo simulation.

The absolute WD gas age uncertainty itself should also be considered (Sigl et al., 2019). Because the relative Larsen gas age uncertainty to WD gas age and the absolute WD gas age uncertainty are independent, the total Larsen gas age uncertainty can be calculated using Eq. (4):

$$\sigma_{total} = \sqrt{\sigma_{abs.}^2 + \sigma_{rel.}^2} \quad (4)$$

The uncertainties are presented in Table 3. The gas age uncertainty between the tie-points was determined by linear interpolation, and the uncertainty located outside the last tie-point was linearly extrapolated using the uncertainty/age relationship of 18–22 ka BP.

Table 3. Result of gas age uncertainties. $\sigma_{rel.}$, $\sigma_{abs.}$, and σ_{total} represent relative Larsen gas age uncertainty to WD gas age, absolute WD gas age uncertainty, and total uncertainty of Larsen gas age, respectively.

Gas age (ka)	$\sigma_{rel.}$ (ka)	$\sigma_{abs.}$ (ka)	σ_{total} (ka)
9.24	0.324	0.055	0.329

10.74	0.130	0.062	0.144
13.02	0.274	0.117	0.298
15.17	0.084	0.158	0.179
18.05	0.194	0.214	0.289
22.04	0.254	0.257	0.361

3.6.2 Ice age uncertainty

Similar to the Larsen gas age uncertainty, the Larsen ice age uncertainty consists of (1) the relative Larsen ice age uncertainty to TALDICE ice age, and (2) the absolute TALDICE ice age uncertainty itself. The total analytical uncertainty of $\delta^{18}O_{ice}$ is assumed to be ±0.6 ‰, the same as the $\delta^{18}O_{ice}$ uncertainty of Larsen ice (Sect. 3.2) because the analytical uncertainty of $\delta^{18}O_{ice}$ for TALDICE (±0.07 ‰) is negligible (Stenni et al., 2011). The method to constrain the relative Larsen ice age uncertainty to the TALDICE ice age is similar to the case of estimating the gas age uncertainty of the older tie-points (purple dots in Fig. 8a, b). In contrast, in this case, we found the location (horizontal distance) of the inflection points, not the local maxima or minima. The relative uncertainty can also be derived from when choosing the tie-points in TALDICE. In addition, the ice age uncertainty for a depth of 1.95 m should be larger than the uncertainty we provide because it was estimated using the average dip of the ice layer (Appendix C). Therefore, the relative Larsen ice age uncertainty provided here is a lower limit.

The absolute TALDICE ice age uncertainty itself should also be considered, where the uncertainty is calculated by quadratically combining the absolute WD ice age uncertainty and the volcanic synchronization uncertainty. Then, quadratically combing the absolute TALDICE ice age uncertainty and the relative Larsen ice age uncertainty to the TALDICE ice age (Eq. (4)) provides the total Larsen ice age uncertainty (Table 4). The ice age uncertainty between the tie-points was determined by linear interpolation, and the uncertainty located outside the last tie-point was linearly extrapolated using the uncertainty/age relationship of 18–23.8 ka BP.

Table 4. Result of ice age uncertainties. $\sigma_{rel.}$, $\sigma_{abs.}$, and σ_{total} represent relative Larsen ice age uncertainty to TALDICE ice age, absolute TALDICE ice age uncertainty, and total uncertainty of Larsen ice age, respectively.

Ice age (ka)	$\sigma_{rel.}$ (ka)	$\sigma_{abs.}$ (ka)	σ_{total} (ka)
6.73	0.023	0.030	0.038
8.51	0.014	0.040	0.043
12.12	0.044	0.084	0.095
14.12	0.023	0.135	0.137
14.67	0.041	0.147	0.152
21.14	0.053	0.211	0.218

23.83	0.060	0.238	0.246

3.6.3 Δage uncertainty

To estimate the Larsen Δage uncertainty, the relative Larsen gas age uncertainty and relative Larsen ice age uncertainty should be on the same ice core. Here, we used the relative Larsen gas age and ice age uncertainties to the WD gas age and ice age, respectively. We assumed that the Larsen Δage uncertainty consists of (1) the relative Larsen gas age uncertainty to WD gas age, (2) the relative Larsen ice age uncertainty to WD ice age, and (3) the Δage uncertainty of WD. Quadratically combining these three components provides the total Larsen Δage uncertainty, similar to Eq. (4). The relative Larsen ice age uncertainty to TALDICE ice age and the relative TALDICE ice age uncertainty to WD ice age were quadratically combined to estimate the relative Larsen ice age uncertainty to WD ice age. Volcanic synchronization uncertainty is used for the relative TALDICE ice age uncertainty to the WD ice age. The Larsen Δage uncertainty is presented in Table S8.

3.7 Estimation of past surface temperature and accumulation rate

As discussed in Sect. 3.2, $\delta^{18}O_{ice}$ and $\delta^{2}H_{ice}$ might have been enriched during the sublimation of ice. Therefore, it is inadequate to use stable water isotopes to estimate past surface temperatures. Instead, the analytical framework developed by Buizert (2021) allows us to estimate the past surface temperature using the $\delta^{15}N\text{-}N_2$ and Δage. The methods for estimating the surface temperature and accumulation rate are described in detail in the Supplement (Text S1). The results are presented in Table S9 and Fig. 10. The accumulation rates in TALDICE, EDC, Taylor Dome, and Taylor Glacier are also shown for comparison (Veres et al., 2013; Baggenstos et al., 2018). The youngest three reconstructed values of Larsen BIA were rejected (red line in Fig. 10) due to the large relative uncertainty in Δage (including the possibility of negative Δage), and the implied 10.5 °C increase in just ~1,200 years. This might be due to a low bias in the reconstructed ice age, which leads to a lower Δage. Hence, the ice age in this part should be more strongly constrained by using dust concentrations in a future study.

During the last deglaciation, the surface temperature increased by approximately 15 ± 5 °C (from 24.3 ka BP to 10.6 ka BP), which is greater than those for any other ice core sites including nearby Taylor Dome where a recent reconstruction suggests 7.1 ± 2 °C of deglacial warming (Buizert et al., 2021). However, the interpretation should be cautious because of the large uncertainty. The large magnitude of the reconstructed temperature change is a consequence of Δage, which is around 300 % larger during the Last Glacial Maximum (LGM) than during the Holocene in our reconstruction. By comparison, most Antarctic sites show only a 60 % to 120 % Δage increase (Buizert et al., 2021). While the Larsen BIA is currently close to the open ocean, during the LGM, the Antarctic ice sheet reached the continental shelf break covering the entire Ross Sea Embayment (Conway et al., 1999). Climate models identified strong cooling over the Ross sea sector, reflecting the increased elevation and albedo of the extended ice sheet (Buizert et al., 2021). We suggest that this enhanced cooling may have affected the deposition site of Larsen BIA. We note that the past ice sheet thickness at Larsen and the upstream distance travelled since deposition are poorly constrained; both of these should impact the magnitude of the reconstructed temperature change. The temporal isotope slope (α_T = 0.58 ‰ K^{-1}) is lower than that for any other ice core site (Buizert et al., 2021) and smaller than the spatial regression slope of around 0.8 ‰ K^{-1} (Masson-Delmotte 2008). However, the temporal isotope slope we reconstructed is likely to be a lower bound because the sublimation might have enriched the $\delta^{18}O_{ice}$ of the glacial (downstream) part of Larsen BIA. The reconstructed surface temperature change of 15 ± 5 °C assumes that the selected tie points are correct.

However, if the $\delta^{18}O_{ice}$ features used for the matching are not climatic in origin but rather reflect local effects (such as sublimation intensity, and accumulation controls by surface slope), then our tie points would be incorrect. Future measurements of ice chemistry and dust loading may improve our Δage estimates, which will allow a refined estimate of past glacial cooling.

From 24.3 ka BP to 10.6 ka BP, the accumulation rate increased a factor of 3 ± 2 (from 0.033 ± 0.01 to 0.103 ± 0.05 m ice yr^{-1}). The accumulation rate at TALDICE and EDC began to decrease transiently around 14.5 ka BP following the Antarctic Cold Reversal (ACR), while the reconstructed accumulation rates at the deposition site of Larsen BIA and Taylor Dome keep increasing across the ACR. We acknowledge that the accumulation rate of the deposition site of Larsen ice younger than 14 ka BP remains poorly constrained because of the large uncertainty, but is highly constrained for the older part (> 14 ka BP). The accumulation rate at the deposition site of Larsen ice is lower than that of TALDICE during 14–21 ka BP and exceeds the accumulation rate of TALDICE after 14 ka BP. The Ross Ice Shelf (RIS) retreated during the last deglaciation (Ship et al., 1999; Yokoyama et al., 2016), and as the RIS retreats, the storm track migrates to the Southern Victoria Land from the northern part and increases precipitation to the site (Morse et al., 1998; Aarons et al., 2016; Yan et al., 2021). Therefore, we speculate that the storm track affects the original deposition site of the Larsen BIA more than the Talos Dome after 14 ka BP. This interpretation may help studies for reconstructing past atmospheric circulation associated with the retreat of RIS. Likewise, a strong accumulation increase across the last deglaciation was seen at the coastal Law Dome site in the Indian Ocean sector (Van Ommen et al., 2004), also attributed to increases in storm-derived precipitation. However, spatial difference of the original deposition site of the upstream and downstream Larsen ice is not constrained; this must be known for better interpretation of the accumulation rate.

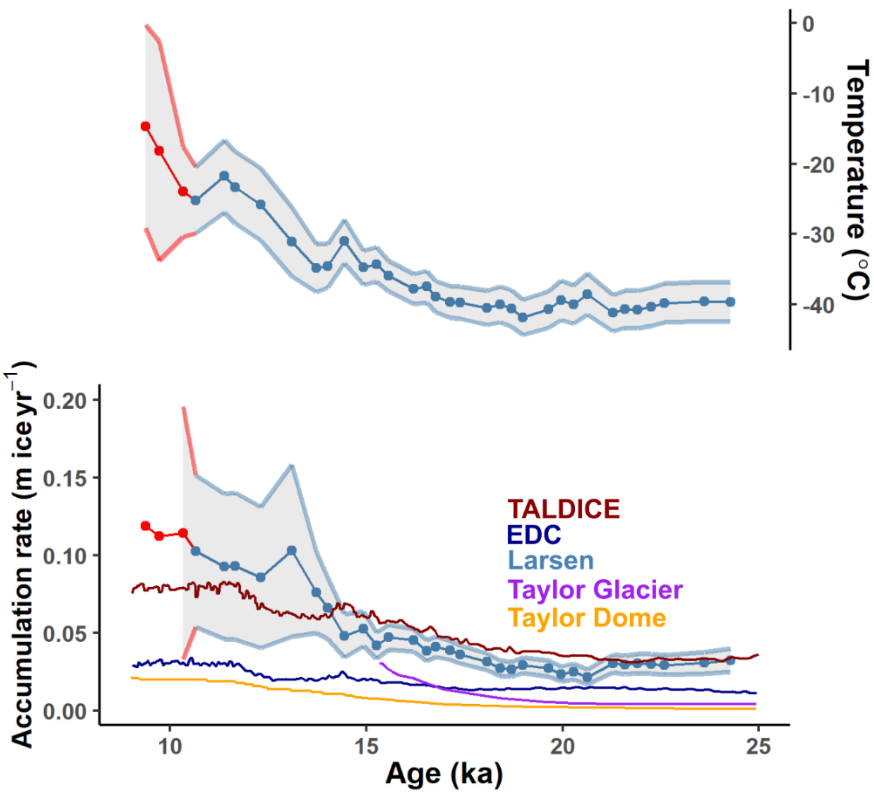


Figure 10. Reconstructed surface temperature and accumulation rate. Accumulation rates of TALDICE, EDC are from Veres et al. (2013). Accumulation rates of Taylor Dome, and Taylor Glacier are from Baggenstos et al. (2018). The first three reconstructed values of Larsen blue ice are rejected (red line) due to the large uncertainty in the Δage that translates into the possibility of negative accumulation rates and an unexpected 10.5 ℃ increase in ~1200 years.