We thank referee #1 for helpful comments.

Lee et al establishes the chronology of a blue ice field at the Larsen Glacier in north Victoria Land, East Antarctica by cross-correlating properties recorded in the ice (and the enclosed air). Further aided by absolute radiometric ^{81}Kr dating, the authors report the discovery of a horizontally continuous ice section spanning from the early Holocene through the Last Glacial Maximum, with the age gets progressively older downstream. It is therefore concluded that Larsen Glacier could serve as a paleoclimate archive to study the transition from the Last Glacial Maximum to the Holocene. While the study subject of this manuscript (blue ice) is clearly part of the cryosphere, hence making the manuscript within the scope and aim of the journal The Cryosphere, the manuscript would benefit from more in-depth discussion on the glaciological or climatic implications of the discovery of stratigraphically continuous blue ice at the Larsen Glacier: what does it mean for the local ice dynamics, East Antarctic Ice Sheet, or paleoclimate (given the authors argue this blue ice field could be utilized to study climate changes across the Last Deglaciation)?

- In this manuscript, we described the stratigraphy and established the unknown ice and gas ages for the Larsen blue ice. Our chronostratigraphic study for the outcropped ice will serve as a groundwork for future study on Larsen Glacier. Well-constrained chronology for the outcropped ice will enable studies that have been difficult by the limits of availability of large ice samples.
- We added a reconstruction of past accumulation rate and surface temperature in section 3.7. In addition, we also added a description of the greenhouse gas alteration at the very shallow depth in BIAs with comparing the gas alteration with other BIAs in section 3.3. For the ice age and gas age uncertainties, we added section 3.6.

It must be acknowledged that a continuous blue ice section is exciting and rewarding for all the field and lab work that was done, but LGM (or Termination I) isn't a particularly understudied interval. A large number of deep ice cores from Greenland and Antarctica have provided a detailed record of atmospheric composition and local to regional climate.

- Lots of studies were published in terms of the LGM and the last glacial termination. However, the associated climatic processes remain unclear partly because of the limited size of ice samples, especially for isotopic analysis of greenhouse gas and trace elements. Huge volume of ice sample is allowed from BIAs given that the chronology of the ice is well-constrained.

A blue ice field in Taylor Glacier in the Dry Valleys, less than 500 km away from the Larsen Glacier, provides a near continuous surface ice record already providing large-volume samples for various novel geochemical analyses. Therefore one has to wonder what new information blue ice field in Larsen Glacier could bring about.

- Distance between Larsen Glacier and Taylor Glacier is about 330 km and we think this is not a small distance. In addition, when considering the original snow deposition sites, the spatial difference between the Larsen and Taylor glacier might be larger. Further study in Larsen BIA will give ice flow information of the Northern Victoria Land, while Taylor Glacier will give information about the Southern Victoria Land. Using the ice samples from Taylor Glacier, Allan Hills, and Larsen Glacier together, may also give information about climate conditions in the past as well as the growth and/or retreat of Ross Ice Shelf during the last deglaciation. In addition, we may get benefits from various sites because the ice quality for paleoclimate study depends on glaciological conditions.

- We added description of the gas alteration at the very shallow depth in BIAs and compared it with other BIAs (Elephant Moraine, Allan Hills, Taylor Glacier) in section 3.3.

A few questions that may be worthy of consideration: Can you trace the original deposition site by GPR and dust bands? Or if you already know where the ice was deposited, could you estimate the velocity of ice motion? In terms of climate, presumably you could infer annual layer thickness from GPR and that should provide information about past accumulation rates and ice thinning function. If so, what does it mean for the local climate and ice dynamics?

- To trace the original deposition site, we should operate an ice flow modeling and conduct further GPR surveys. For study in this aspect, the work in our manuscript will give fundamental information.
- Estimation for past accumulation rates and surface temperature can be derived from using Δage (ice age and gas age difference), and $\delta^{15}N$-N_2. We added the estimated values in section 3.7.

Since both hydrogen and oxygen isotopes in water have been measured, could you calculate the deuterium excess and what does that tell us about the hydrological changes in north Victoria Land on glacial-interglacial timescales?

- Line 284: We added "Deuterium-excess ($d = \delta^2H_{ice} - 8 \times \delta^{18}O_{ice}$) shows a wide range (5.40 to −3.89 ‰, Table S5) from the entire near-surface ice samples. The negative d-excess likely indicates that isotopic fractionation is attributed to the sublimation of ice in the accumulation zone (Hu et al., 2021). Negative d-excess values were also observed in the Allan Hills BIA (Hu et al., 2021). Meanwhile, sublimation can deplete ^{16}O and ^{1}H in ice and make the isotopic ratios ($\delta^{18}O_{ice}$ and δ^2H_{ice}) enriched. Thus, the wide range and negative value of d-excess results indicate that stable water isotopes are not proper proxies for the changes in temperature and vapour sources."

This is not to say that these are the only questions that must be answered here. The bottom line is that as a reader of The Cryosphere I am hoping to see what new scientific discovery is being made. It might be an abrupt change in accumulation rates, or a different local precipitation regime. The current manuscript feels to me more like a detailed progress report without firm conclusion on what new is being presented. Of course it could be argued that the discovery of a potentially useful paleoclimate archive itself is an achievement, but back to my earlier points, the Last Glacial Maximum is already an intensively studied interval.

- Taking the advantage of BIA (using huge amount of ice) is essential to discover new insights for the last deglaciation. Therefore, well-constrained chronology for the outcropped ice will enable studies that have been difficult by the limits of availability of large ice samples.

- To find very old ice (> 1 Ma BP), BIAs are the major targets recently. However, well-constrained chronostratigraphic study of BIAs is scarce. Thus, the manuscript here is not just a detailed progress report but a fundamental work and a pioneer of BIA study. The manuscript highly contributes to the ice core society for finding very old ice in BIAs.
- We added a comparison of depths of the un-altered gas between BIAs in section 3.3.
- We added the estimated value of past accumulation rate and surface temperature and the interpretation of it in section 3.7.

Finally, before proceeding to detailed comments, I feel a bit confused why the manuscript does not present the absolute dating results first. ^{81}Kr is a well-established absolute dating method for glacial ice and underground water. Unless the authors are worried about contamination of modern air (a hypothesis that was later rejected based on undetectable ^{85}Kr), the results of absolute dating (high accuracy, low precision) should come before the cross-dating efforts that have a high level of precision. In doing so you could easily narrow the range of age search to the last glacial cycle and therefore shorten a considerable portion of the current discussion (in particular 3.5) that might be devoted to more glaciological-focused discussion.

- We used the ^{81}Kr dating method later in the manuscript, serving as an independent age constraint and strengthening the age constraint established by correlations with existing ice core record. Even though the modern air contamination could be rejected, the use of ^{81}Kr isotopes for accurate age constraint could be limited because of the age uncertainty originating from inaccurate calibration, estimation of the Kr half-life, and the production rate of Kr through the past.

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Specific comments:

Line 18: the claim of a "simple stratigraphy of ice" seems to contradict the description that the ice upstream has age repetitions (i.e. is folded). Perhaps you could rephrase it into something like "Here we report a surface transect of ice that has a simple horizontal stratigraphy." This would exclusively correspond to the downstream section described in the current manuscript.

- Line18: We rephrased the sentence.
  - "Here, we report a surface transect of ice with an undisturbed horizontal stratigraphy from the Larsen BIA, Antarctica, making the area valuable for paleoclimate studies."

Line 32: please add Lüthi et al (2008) Nature and Bereiter et al (2015) GRL to the citation.

- Line 36: We added "Lüthi et al., 2008; Bereiter et al., 2015".

Line 49: it is necessary to point out that the current longest continuous ice core record stops at 800,000 years.

- Line 54: We added "(to date, the longest continuous ice core record covers the last 800 ka BP)".

Line 60: this sentence is equivocal. Does "globally well-mixed" also apply to glaciological records? Based on the nature of stable water isotopes I don't the authors imply that the glaciological records are also globally mixed (in fact, they are not). Please (1) consider splitting the gas age and ice age synchronization methods and (2) point out that the age of the gas is different from the age of the ice at the same depth.

- Line 76: We split the words related to dating methods for gas and ice ages. The relevant text is reworded as follows:
  - One effective method for dating the gas age is to correlate globally well-mixed atmospheric gas records (e.g., CH_4, CO_2, $\delta^{18}O_{atm}$) with existing well-dated ice core records (Spaulding et al., 2013; Baggenstos et al., 2017; Menking et al., 2019; Yan et al., 2021). Other methods include the use of stable Ar isotopes (Higgins et al., 2015; Yau et al., 2015; Yan et al., 2019) or radioactive ^{81}Kr (Loosli&Oeschger 1969; Buizert et al., 2014; Tian et al., 2019; Crotti et al., 2021), both of which provide independent and absolute age constraints. However, the use of Ar and Kr isotopes have certain limitation for accurate age constraint. The age uncertainty of Ar dating is ±180 ka or 11 % of the age; the uncertainty is originated from the regression line Bender et al. (2008) used. In addition, the ages can be corrupted by the injection of radiogenic ^{40}Ar from the continental crust (Bender et al., 2010). The age uncertainty of ^{81}Kr dating ranges between 5–20 % of the age depending on the sample age and sample size (Jiang et al., 2020). It also has a systematic age uncertainty of ~5 % due to the uncertainty in the ^{81}Kr half-life. For dating ice ages, glaciochemical records (e.g., nss-Ca^{2+}, $\delta^{18}O_{ice}$, $\delta^{2}H_{ice}$) can be used for correlation with existing well-dated ice core records (Baggenstos et al., 2018; Menking et al., 2019). 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).

Line 61 & 81: please add Yan et al (2021) Clim. Past to the citation.

- Line 66: We added "Yan et al., 2021".
- Line 78: We added "Yan et al., 2021".
- Line 91: We added "; Yan et al., 2021".

Line 62: if absolute dating methods are effective, readers without sufficient knowledge on their limits may why bother correlating gas-phase and ice-phase properties? It may be better to introduce absolute dating methods first, then acknowledge their uncertainties, and finally introduce a more precise way of age synchronization.

- Line 78: We removed "effective".
- Line 80: We added the limintations of Ar and Kr dating.
  - "However, the use of Ar and Kr isotopes have certain limitation for accurate age constraint. The age uncertainty of Ar dating is ±180 ka or 11 % of the age; the uncertainty is originated from the regression line Bender et al. (2008) used. In addition, the ages can be corrupted by the injection of radiogenic ^{40}Ar from the continental crust (Bender et al., 2010)".

Line 85: please specify which "area" you are referring to (north Victoria Land?).

- Line 70: We changed "area" to "BIAs in Northern Victoria Land.".

Fig 1: Is there a particular reason for the current orientation of the Antarctic continent?

- In Figure 3, north is directed to the top and the directions of ice flow and GPR results are presented in the same way. To keep a consistent orientation in the figures, we flipped the Antarctic continent in Figure 1. We think the opposite orientation in Figure 1 may make the readers confused. However, if the editor and the reviewers strongly suggest to change the orientation, we will do that in the revised manuscript.
- Line 104: We added "To keep a consistent orientation with the GPR profile in Fig. 3, we flipped the classical map of Antarctica (East Antarctica to the left-hand side)".

Line 154: could you please evaluate the potential of in situ methane production in ice cores with high dust concentrations (Lee et al 2020 GCA)?

- We have not measured concentration of ion species such as Na^{+} or Ca^{2+} so we are not able to discuss excess CH_4 with high dust concentrations in this manuscript.

Line 157: please specify what 2nd gas extraction means. Does it imply the refrozen meltwater is melted once again?

- Line 182: We added "(refrozen meltwater was melted and refrozen once again)".

Line 169: please specify the temperature of the water trap.

- Line 195: We added "(approximately −80 °C)".

Line 189: what does "unclear ice" mean? It is not a common word to describe ice cores. Please elaborate.

- Line 217: We changed "removed some unclear ice surface" to "shaved away some blurry ice surface".

Line 240: could you define the origin to which downstream and upstream are referenced against?

- Line 276: We added "(from ice cores #23 to #200)".

➢ Line 278: We added "(from 81w to ice core #23)".

Line 261: the possibility of large variations in temperature and vapor sources is an interesting one. Perhaps you could quickly test them using deuterium excess data.

➢ Line 302: We added "Deuterium-excess ($d = \delta^2H_{ice} - 8 \times \delta^{18}O_{ice}$) shows a wide range (5.40 to −3.89 ‰, Table S5) from the entire near-surface ice samples. The negative d-excess likely indicates that isotopic fractionation is attributed to the sublimation of ice in the accumulation zone (Hu et al., 2021). Negative d-excess values were also observed in the Allan Hills BIA (Hu et al., 2021). Meanwhile, sublimation can deplete ^{16}O and ^{1}H in ice and make the isotopic ratios ($\delta^{18}O_{ice}$ and δ^2H_{ice}) enriched. Thus, the wide range and negative value of d-excess results indicate that stable water isotopes are not proper proxies for the changes in temperature and vapour sources.".

Line 289: why aren't $d^{15}N\text{-}N_2$ and $d^{18}O\text{-}O_2$ expected not to be altered substantially? The intrusion of modern air might not be a problem, but there could be gas loss from the ice and hence fractionation.

➢ Line 346: We changed the sentence.

  ➢ "As $\delta^{15}N\text{-}N_2$ and $\delta^{18}O_{atm}$ were measured at very shallow depths (~1.95 m), we compared the horizontal results with the vertical distribution of the ice core #23.".

Line 300: the depth at which $d^{15}N\text{-}N_2$ and $d^{18}O\text{-}O_2$ no longer vary appears to be different at different sites. In Allan Hills BIA gas composition is stabilized below 7 to 10 m (Spaulding et al 2013, Quaternary Res). Can you comment on this variability?

➢ Line 339: We added "Table 2. Depth of unaltered greenhouse gas composition and mean annual temperature of BIAs.".

Table 2. Depth of unaltered greenhouse gas compositions and mean annual temperature of BIAs.

Site	Depth of unaltered greenhouse gas composition (m)	Mean annual temperature (°C)	Reference for depth of unaltered air	Reference for mean annual temperature
Elephant Moraine Texas Bowl	> 10*	-30.3	This study (Fig. A1)	KOPRI AWS (76.27° S, 156.71° E)
Allan Hills	> 7–10	-31†	Spaulding et al. (2013)	Delisle and Sievers (1991)
Larsen Glacier	> 4.6	-24.4	This study (Fig. A1)	Antarctic Meteo-Climatological Observatory
Taylor Glacier	> 4	-18‡	Baggenstos et al. (2017)	United States Antarctic Program
Pakitsoq	> 0.3	-5.4¶	Petrenko et al. (2006)	Climate-data.org

*Depth of unaltered greenhouse gas compositions from Elephant Moraine Texas Bowl remains uncertain due to the lack of data at depth of > 10 m. Mean annual temperature of Elephant Moraine: provided by KOPRI's automatic weather station (AWS) record of year 2020 and 2021. †Allan Hills: not provided by an AWS but by stable water isotopes. ‡Taylor Glacier: assumed to be comparable with the mean annual temperature of nearby McMurdo station (~100 km away). ¶Pakitsoq: assumed to be comparable with the mean annual temperature of the nearby town of Ilulissat (~ 40 km away).

- Line 357: We added "In contrast, $\delta^{15}N$-N_2 and $\delta^{18}O_{atm}$ values in the Allan Hills are stabilized below 7–10 m (Spaulding et al., 2013).".

Line 303: it seems that this section could be simplified given your ^{81}Kr dating results.

- We used the ^{81}Kr dating method later in the manuscript, serving as an independent age constraint and strengthening the age constraint established by synchronization. Even though the modern air contamination could be rejected, the use of ^{81}Kr isotopes for accurate age constraint is limited because of the age uncertainty originating from inaccurate calibration, estimation of the Kr half-life, and the production rate of Kr through the past.

Line 374-375: the origin of ice age-gas age difference should be introduced in the earlier section.

- We moved the statement to line 86. It was also more elaborated.
  - 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).

Line 385: the maximum delta-age at 17.5 ka is another interesting observation that could have important paleoclimate implications (Buizert et al 2021, Science).

- We estimated the past accumulation rate and temperature with the delta-age and $\delta^{15}N$-N_2 (see the new section 3.7 below).

Line 403 & 414: it would be worthwhile to calculate the temporal resolution of the Larsen BIA samples, especially in the horizontal dimension (easy to do given Fig A7). How does that compare to, for example, the Talos Dome ice core record nearby?

- Line 457: We added temporal resolution for the Larsen BIA.
  - The established horizontal ice chronology shows that temporal resolution 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 405: the word "chemical" usually refers to ions in ice cores.

- Line 572: We changed "chemical result" to "analytical data".

Line 406: again please provide a clear reference point against which downstream and upstream are defined.

➢ Line 573: We added "(from ice cores #23 to #200)".

Line 412: can you provide more proof to back the claim of "high-precision ages"? It would be helpful if errors associated with cross-correlating different properties could be presented, like what Menking et al (2019) Clim. Past did.

➢ We added "Section 3.6 Age uncertainty". In this section we discussed the gas age, ice age, and Δage (ice age – gas age) uncertainties. See below.

References:

Bereiter, B., Eggleston, S., Schmitt, J., Nehrbassâ€• Ahles, C., Stocker, T.F., Fischer, H., Kipfstuhl, S. and Chappellaz, J., 2015. Revision of the EPICA Dome C CO2 record from 800 to 600 kyr before present. Geophysical Research Letters, 42(2), 542-549.

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Lüthi, D., Le Floch, M., Bereiter, B., Blunier, T., Barnola, J.M., Siegenthaler, U., Raynaud, D., Jouzel, J., Fischer, H., Kawamura, K. and Stocker, T.F., 2008. High-resolution carbon dioxide concentration record 650,000–800,000 years before present. Nature, 453(7193), 379-382.

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Spaulding, N.E., Higgins, J.A., Kurbatov, A.V., Bender, M.L., Arcone, S.A., Campbell, S., Dunbar, N.W., Chimiak, L.M., Introne, D.S. and Mayewski, P.A., 2013. Climate archives from 90 to 250 ka in horizontal and vertical ice cores from the Allan Hills Blue Ice Area, Antarctica. Quaternary Research, 80(3), 562-574.

Yan, Y., Spaulding, N.E., Bender, M.L., Brook, E.J., Higgins, J.A., Kurbatov, A.V., and Mayewski, P.A., 2021. Enhanced Moisture Delivery into Victoria Land, East Antarctica During the Early Last Interglacial: Implications for West Antarctic Ice Sheet Stability, Climate of the Past, 17(5), 1841–1855.

➢ 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 $\delta^{15}N$-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.

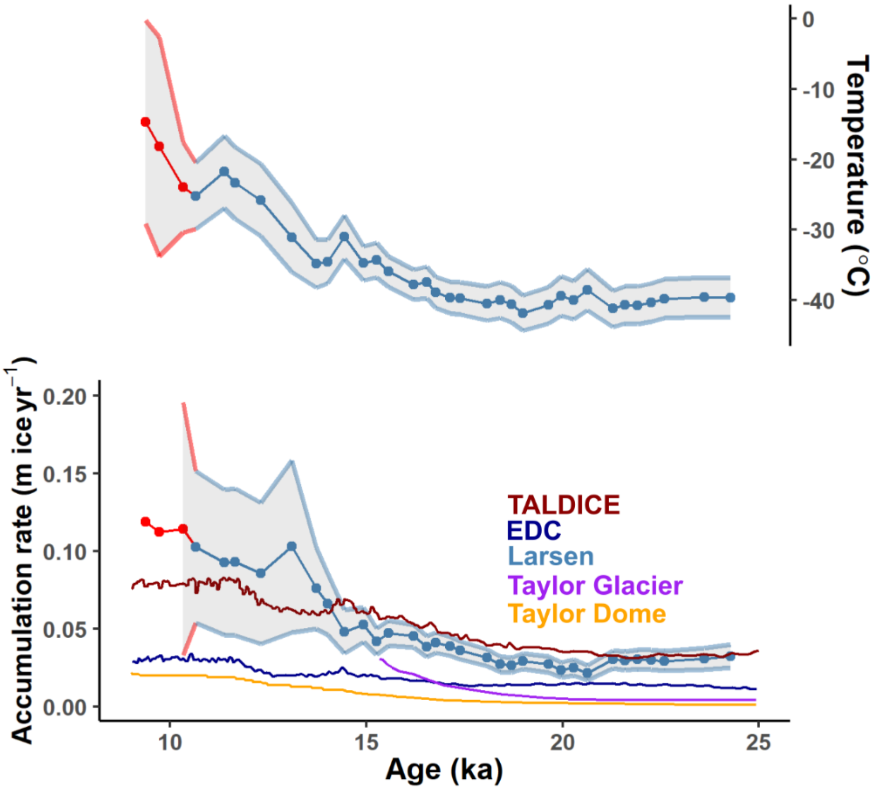

Figure 10. Reconstructed surface temperature and accumulation rate. Accumulation rates of TALDICE, EDC are from Veres et al. (2013). Accumulation rates of Taylor Dome, and Taylor Glacier are from Baggenstos et al. (2018). The first three reconstructed values of Larsen blue ice are rejected (red line)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