We thank the reviewer for his careful and helpful comments.

In the response, referee comments are in *italics*, our replies are in normal font, and the revised text is in light blue.

Dear authors,

I appreciated reading your paper on simulated evidence for ice over 1 Ma in the Dome A region, East Antarctica. This paper provides inputs on the search for the oldest-ice quest ; as we know multiple drilling sites are needed to resolve the puzzle: Dome C, Dome F, South Pole, ... and Dome A are potential candidates. This paper is an increment in the research even if it is not adding a lot of new knowledge since Zhao et al. (2018), the use of radar transect constraints in addition to the 1D model results to delineate promising oldest ice sites is interesting as an approach.

I would suggest the following general and major changes:

The GHF parameter, even if not used in the specific 1D model, has to be introduced and discussed, especially since it is used in Zhao et al (2018), this reference being widely used in this manuscript (e.g. figure 7).

We acknowledge the importance of this comment and have made a number of changes to the text to incorporate the specific comments on GHF from both reviewers.

From Line 66, the updated text is:

"Meanwhile, it is likely that an ice core around 600-700 ka with low age density could be extracted around Kunlun Station. In their model, GHF serves as a critical basal boundary condition that modulates the thermal regime and influences ice rheology. Since ice flow is highly sensitive to temperature-dependent viscosity, GHF significantly impacts the vertical velocity profile. To investigate the impact of GHF on ice dynamics, a series of sensitivity experiments were performed to evaluate how variations in GHF influence the modeled flow regime. Using the same methodology and the best available ice fabric, Zhao et al. (2018) found that within 400 m of Kunlun Station, 1 Ma ice could exist 200 m above the bedrock.

These models previously applied to the Dome A region, are constrained by surface velocity measurements and prescribed GHF. However, GHF is spatially variable, and surface velocity observations are sparse. The constant GHF may lead to significant uncertainty in the age of deep ice. By contrast, our approach offers three advantages: (1) the 1D steady-state model does not explicitly include parameters for GHF and surface velocity, it avoids the uncertainties inherent in their estimation; (2) It is constrained by dated IRHs, which have a stronger constraints on age-depth structure; and (3) The model has been successfully applied in multiple regions, especially at EDC and LDC where the model has been validated."

2. The use of the SMB parameter of Vostok has to be clarified, I still don't understand why you use it.

Accumulation rate in this context may have caused some confusion. The revised sentence is "…derived from accumulation history and age depth relationships from the Vostok Ice Core…". We need to account for temporal variations in accumulation rates in the Dome A region to model the depth-age relationships. For that, we used the temporal variations of accumulation at Vostok, assuming they are the same than in the Dome A region (just with a different scaling factor).

3.The comparaison with Zhao et al (2018) should be more explicit and quantified: e.g overlap maps, ...

We have revised Fig.7 and added sentences in line 229.

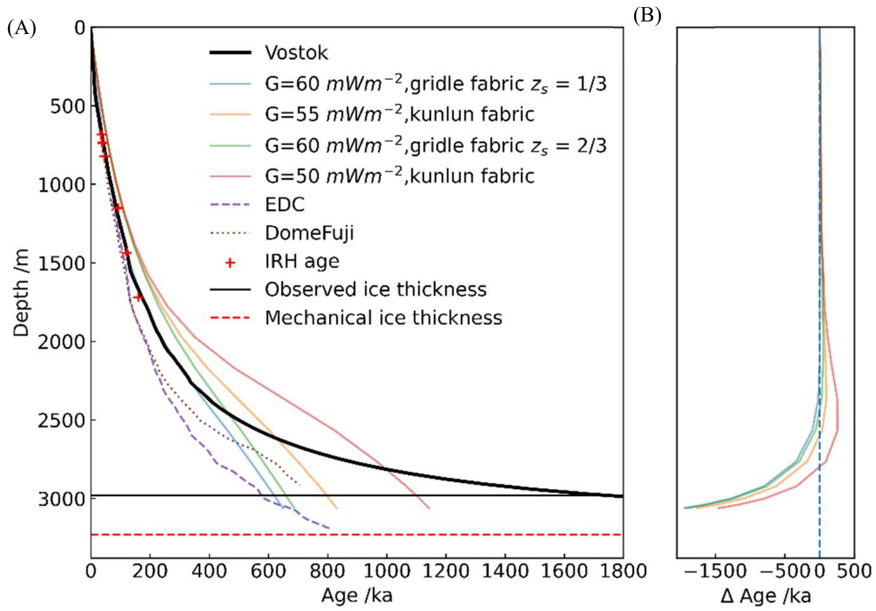

Figure 7. (A) Comparison of age-depth relationships at Kunlun Station. The primary simulation from this study (thick black curve) is validated against observed ages (red crosses). For comparison, previous model results from Zhao et al. (2018), incorporating various GHF and fabric combinations, are shown as lighter colored curves. The red dotted line denotes the mechanical ice depth. EDC and Dome Fuji denote ice core forcings. (B) Age residuals with depth.

"… exceeding the age of the curve in light blue. The residuals between the simulated ages and Zhao et al. (2018) are shown in the Fig. 7 (B). They are small in the upper part of the ice sheet. With increasing depth, the residuals first increase and then rapidly become negative. This discrepancy is likely a consequence of the different ice-dynamic frameworks. Our model defines the vertical velocity profile through a parameter p inversion, while Zhao et al. (2018) incorporate GHF boundary conditions to modulate ice rheology and temperature-dependent viscosity. These residuals highlight how sensitive ice age predictions near the bedrock can be to the underlying modeling assumptions. At the bottom of …"

4. All figures need to be revised for clarity (see attached pdf). And in particular; it would be much more interesting to zoom into the area of interest. Locations mentioned in general are too vague in the text, make sure to highlight them on figures as well.

We have increased font sizes and line weights for all figures, and added precise coordinates in the text. We have enlarged Figure 4 (A) to highlight the study areas.

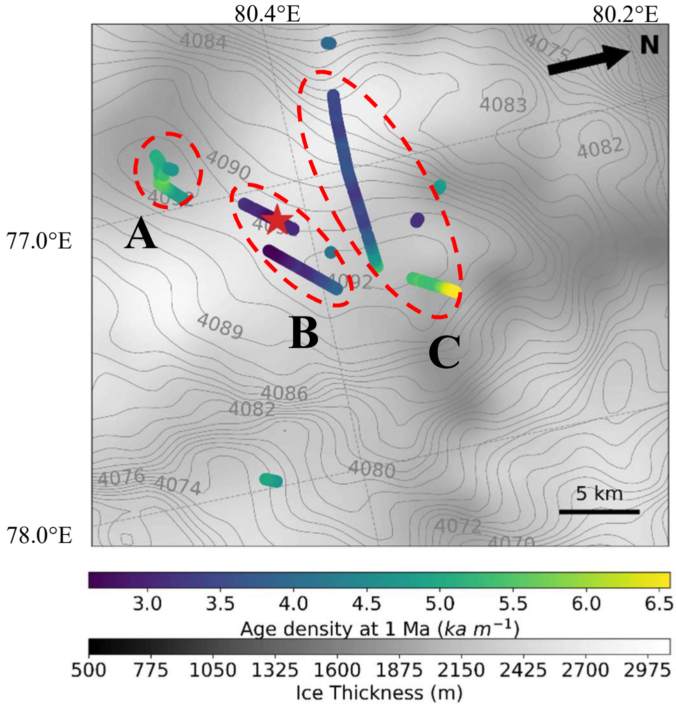

Figure. 4 (A) Age density map at 1 Ma ice age. Dashed lines indicate the optional areas for old ice drilling. Area A is 2.5 km around the point ($76.89°\ E, 80.47°\ S$). Area B is 3 km around the point ($77.12°\ E, 80.42°\ S$), Area C is 8 km around the point ($77.14°\ E, 80.37°\ S$). Kunlun station is marked by red star. The gray lines denote surface elevation contours (m).

5. The discussion should include a comparison with other oldest ice sites where we already have studies, data, and in particular Dome C, Dome F.

We have added a new section beginning at line 250.

"5.3 The oldest ice : Comparison with previous studies

Dome A, Dome C and Dome Fuji are regarded as potential regions in Antarctica where very old ice may be preserved (Van Liefferinge and Pattyn et al., 2013). Observations indicate that the EDC ice core contains ice as old as ~800 ka, while the deepest ice recovered at Dome Fuji reaches ~720 ka (Wang et al., 2023). Numerical simulations in the Dome C region, particularly at LDC, suggest that maximum ice ages at 20 kyr m^{-1} reach up to ~1500 ka under frozen basal conditions, with a time-averaged accumulation rate of ~19 mm yr^{-1} ice equivalent (Chung et al., 2023). Similarly, modeling studies at Dome Fuji indicate that the maximum ice ages could reach ~1350 ka despite basal melting, with a time-averaged accumulation rate of ~22 mm yr^{-1} (Wang et al., 2023).

Our simulations suggest a maximum ice age of ~1737 ka at Kunlun station. Although slight basal melting (0.14 ± 0.119 mm yr^{-1}) is predicted, the melt rate is very small. The time-averaged accumulation rate (~27 mm yr^{-1}) is similar to those reported for Dome C and Dome Fuji. In addition, the modeled age–depth profile in Fig. 7(A) shows a stronger age gradient near the bed than those observed in the EDC and Dome Fuji ice cores, which may favor the preservation of older ice."

I attach a detailed point-by-point review of the paper.

Best,

Brice Van Liefferinge

-Line 19, remove comma

Done.

-Line 22, I recommend the use of "resolution" everywhere to be consistent with your co-authors' papers such as: https://tc.copernicus.org/articles/17/3461/2023/

We have now made the wording more consistent with previous work.

In Line 23, we have rephrased to "…the maximum age density of 20 kyr m^{-1} required for paleoclimate reconstruction."

In Line 66, we have rephrased to "Meanwhile, it is likely that an ice core around 600-700 ka with low age density could be extracted around Kunlun Station"

-Line 42-43, Please add a link between the two sentences, as the link is not clear

We have added a sentence in the middle. The corrected sentence is "…1.2 million years old (Chung et al., 2023). It has also been suggested that there is a 200 m thick layer with different ice dynamic characteristics as the base of LDC, though comprehensive analysis of the LDC ice core is not yet available. Analysis of ….".

-Line 51, Please provide the full name (North Patch)

The revised sentence is "…old ice location, The North Patch (NP), …"

-Line 52, You mentioned 1D models (plurial) in Line 50; here only one, please state which ones were used.

The revised sentence is "Wang et al.(2023) used the same model as Chung et al. (2023)…".

-Line 59, surface

We have added it.

-Line 60, please quantify the SMB

The revised sentence is "…and an extremely low surface mass balance of 25mm yr^{-1} ice equivalent."

-Line 62, also the SMB, see later comment

We agree that the word "small" was somewhat vague. We have revised this to "not excessively thick". Because too thick ice may lead to temperate basal conditions.

-Line 69, The community decided to use "geothermal heat flow (GHF): White Paper Antarctic Geothermal Heat Flow: Future research directions https://nora.nerc.ac.uk/id/eprint/527967/

In Line 62, we changed "heat flux" to "geothermal heat flow (GHF)" as this is it's first appearance.

In Line 69, we have changed "geothermal flux" to "GHF".

-Line 70, please add references

Done. The revised sentence is "…and surface velocity observations are sparse (Yang et al., 2014; Schroeder et al., 2014)".

-Line 72, It is not clear why the uncertainty will be lower because the model is well established, what is the link between the two ? The GHF, SMB,surface velocities, ... constraints are different from site to site

We have rewritten these sentences as this also caused confusion for Reviewer 1. We are comparing the GHF representation in the Zhao et al. (2018) with that of IsoInv1D and have changed the text accordingly. The new text may be seen in answer to the first major comment on GHF.

-Line 73, remove the "f"/ add a space/ please be consistent in the terms you use: 1D steady-state model or Isoinv1D model like in the abstract

Done. We have used 1D-steady-state model.

-Line 74, please add Parrenin and other (2006,2017).

We have changed "Chung et al.(2023)" to "Chung et al.(2023) and Parrenin et al. (2006, 2017)"

-Line 94, please check the font of all subscript text of the document

Done.

-Line 101, First mentioned by Fujita and others; 2000: A summary of the complex dielectric permittivity of ice in the megahertz range and its application for radar sounding of polar ice

sheets, in Physics of Ice Core Records

You can also cite: Cavitte and others; 2016: https://www.cambridge.org/core/journals/journal-of-glaciology/article/deep-radiostratigraphy-of-the-east-antarctic-plateau-connecting-the-dome-c-and-vostok-ice-core-sites/1B82F2326F81986302EA370860086017 . This paper is clearly relevant for your study.

The revised reference is "…0.168-0.1695 m/ns in ice sheet (Fujita et al., 2000; Cavitte et al., 2016)."

-Line 107, The map needs improvements for clarity:

1) add more lat and lon coordinates

2) the legend is meaningless (blue and dark blue ?)

3): use same terminology as in the text and the figure caption: C21DA, C21KL

4) in the "mini" map it should say Kunlun (or Dome A) and not Vostok

5) is the bedrock elevation or the ice-thickness the important parameter you should be showing here?

We have corrected the issues raised in points (1)-(4). For point (5), we have included the ice thickness in the map.

-Line 119, Missing a dot

Done.

***-Line 125**, It is a big assumption that should be discussed in term of uncertainties, ...*

Reviewer 1 also raised the point about using Vostok accumulation variations. We now also use the forcings from the EDC and DF ice cores to test the sensitivity of our results to this forcing. Please see our response to Reviewer 1 for further details.

~~Accumulation rate in this context may have caused some confusion. The revised sentence is "…derived from accumulation history and age depth relationships from the Vostok Ice Core…" We now also use the forcings from the EDC and DF ice cores to test the sensitivity of our results to this forcing.~~

-Line 155, Please rewrite, I don't understand the distances mentioned !

The revised sentence is "Simulated ice ages near the bed are relatively older at distances of 4 km, 13 km, and 44 km from the C21 KL endpoint, which is located near the center of C21DA. These sites correspond to regions with low basal melt rates."

-Line 159, The most important parameter is the Misfit and not the the absolute age error value. Please correct and describe in more detail.

The revised sentence is "…are shown in Table 1. We define the misfit as the normalized residual, which is the ratio of the absolute age error to the observed age error of the IRH. The calculated misfit values for IRH1 to IRH6 are 0.08, 1.85, 2.85, 4.03, 0.77, 1.58. The misfit for IRH3 exceeds 3. The largest…".

-Line 160, Please avoid subjective words like "much, very, ...". ==> "less than 7.21%"

Done.

-Line 165, Please add locations on top and put axes / color bar, ... in bold or more readable (also for the other figures). The labelling is too small to read.

Done.

-Line 168, Use "basal conditions"? basal melting is not an ice state

Done. We have used "Basal conditions".

-Line 175, It is difficult to read the figure: use thicker lines. Plotting ice thickness is more relevant than bed elevation with regards to your text discussion.

We have used thicker lines and ice thickness in the map.

-Line 181, On the figure you plot bed elevation, so it is hard to follow. I suggest you plot ice thickness data on the figures.

We will add ice thickness data as the background, as shown in the following figure.

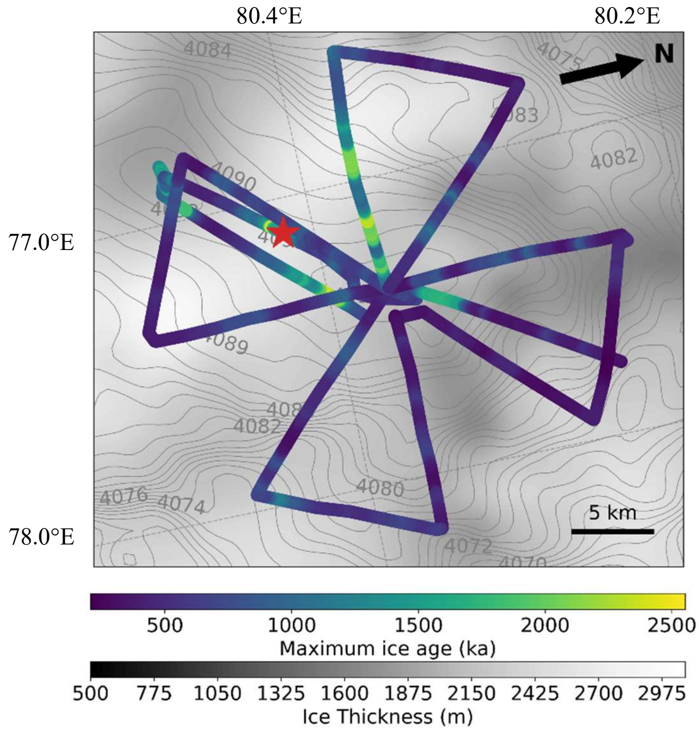

Figure 3. (A) Maximum simulated ice age. The background color denotes ice thickness, and the gray lines denotes surface elevation contours (m). Kunlun station is marked by red star.

-Line 185, please change "corresponding" to "indicates" an age density ... You cannot compare apples and pears, please check in the main document each time the word

The revised sentence is "…with an age density of 2.5 kyr m^{-1}".

-Line 189, remove

Done.

-Line 195, see comments on previous figures

Done.

-Line 202, see previous comments

Done.

-Line 203, Standard deviation

Done.

-Line 210, The accumulation rates values should be compared and discussed with the ones mentioned earlier (Vostok, Dome C, LDC)

The revised sentence is "…the center of the survey line. The simulated accumulation rate in the Dome C region ranges from 17 to 21 mm yr^{-1} ice equivalent, while it is 19 mm yr^{-1} at LDC (Chung et al., 2023). At Vostok Station, the average accumulation rate is 14 mm yr^{-1} (Salamatin et al., 2004). Overall, the accumulation rates differ only slightly and are of the same order of magnitude. …".

-Line 216, 1) Emphasize your results. As is, it is difficult to read

2) The importance of the GHF should be discussed in more details in the introduction so that the comparison with Zhao (2018) is buildling on that knowledge

(choice of GHF values, importance of the parameters, ...).

For point 1), We have emphasized our result in the figure and the caption. The revised sentence is "Figure 7. (A) Comparison of age-depth relationships at Kunlun Station. The primary simulation from this study (thick black curve) is validated against observed ages (red crosses). For comparison, previous model results from Zhao et al. (2018), incorporating various GHF and fabric combinations, are shown as lighter colored curves. The red dotted line denotes the mechanical ice depth. EDC and Dome Fuji denote ice core forcings. (B) Age residuals with depth."

For point 2), We have added further description in line 67 in the preprint, as shown in the answer to the first major comment of this review. The revised sentence is "In their model, GHF serves as a critical basal boundary condition that modulates the thermal regime and influences ice rheology. Since ice flow is highly sensitive to temperature-dependent viscosity, GHF significantly impacts the vertical velocity profile. To investigate the impact of GHF on ice dynamics, a series of sensitivity experiments were performed to evaluate how variations in GHF influence the modeled flow regime. …".

-Line 228, strongly

Done.

-Line 233, at / Neem, GRIP?

We changed "from" to "at". The revised sentence is "…while in Greenland Ice-core Project (GRIP), this value is 200 m."

-Line 245, As mentioned earlier, you should detail the implication of GHF. What do you mean by relatively low, what are the mean, min, max values at Dome A from different data sets, ...

We analyzed a rectangular region centered at Dome A with a maximum dimension of approximately 80 km. The [mean, min, max] GHF values calculated for this area are: [53.2, 52.5, 54.1] mW m^{-2} (Lösing et al., 2020); [55.3, 47.1, 58.6] mW m^{-2} (Liu et al., 2025); [59.1, 52.8, 62.4] mW m^{-2} (Stål et al., 2021). The revised paragraphs are

"However, greater ice thickness does not necessarily imply increased basal melting. The thermal state of the ice sheet base depends on the competition between geothermal heating and the downward advection of surface cold. In the East Antarctic interior plateau, where surface mean temperatures can drop below -50°C, the downward transfer of cold can effectively counteract or even exceed the effects of geothermal heating and pressure melting. A prime example is Dome A, where GHF is relatively low compared to the West Antarctic average (Burton-Johnson et al.,2020). Based on different datasets, GHF at Dome A is estimated to range from 47.1 to 62.4 mW m^{-2} (Liu et al.,2025; Lösing et al., 2020; Stål et al., 2021), a level of thermal input low enough to allow the ice sheet base to remain frozen despite its significant thickness. This may explain why our simulation along the C21KL transect (Fig. 2) did not exhibit the expected trend of higher basal melt rates with increasing ice thickness.

Unlike Full-Stokes models that forward-calculate velocity from explicit GHF, our approach infers the vertical velocity shape parameter p and mechanical ice thickness directly from observations. Thus, while GHF is not an explicit input, its physical impact on the basal thermal state is implicitly encapsulated in the optimized p and H_m, which acts as a data-constrained proxy for the effective geothermal forcing. Specifically, by optimizing p and H_m, we effectively control whether the basal vertical velocity is zero (frozen bed) or positive (melting), a mechanism that is functionally equivalent to the role of GHF in determining the basal thermal regime."

-Line 260, Please provide numbers

The revised sentence is "…radar accuracy. The age uncertainty we calculated for the deepest isochrone (IRH6) is 5.8 ka, surpassing the 1.5 ka estimated by Wang et al. (2016) and leading to an age uncertainty exceeding 200 ka at the bedrock of Kunlun Station."

-Line 276, isochrone

Done.

-Line 294, adapted from Parrenin, 2006

The revised sentence is"We used the 1D pseudo-steady-state model adapted from Parrenin et al. (2006, 2017)…".

-Line 296, Here and in section 4 it is clear but I still don't understand why you mention the use of Vostok SMB (line 125 section 3), please clarify !

Reviewer 1 also raised the point about using Vostok accumulation variations. We now also use the forcings from the EDC and DF ice cores to test the sensitivity of our results to this forcing. Please see our response to Reviewer 1 for further details.

-Line 298, Maybe here and in the main text, you should provide precise locations ! e.g 2 km

around the point x lat y lon, otherwise we get lost

Three areas (A, B and C) are investigated and highlighted in Fig. 4 (A). Area A is 2.5 km around the point ($76.89° E, 80.47° S$), Area B is 3 km around the point ($77.12° E, 80.42° S$), Area C is 8 km around the point ($77.14° E, 80.37° S$).

-Line 300, A map with ice thickness is more than welcome for ease of comprehension or as suggested put the ice thickness instead of bed elevation as your background map!

Done.

Reference

Burton-Johnson, A., Dziadek, R., and Martin, C.: Review article: Geothermal heat flow in Antarctica: current and future directions, The Cryosphere, 14, 3843–3873, https://doi.org/10.5194/tc-14-3843-2020, 2020.

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