Greenland and Canadian Arctic ice temperature profiles

Response to Referee Comments on tc-2022-138

Anonymous Referee #1

We thank you for the time and energy that you have invested in reviewing our community paper. Below, please find responses to all comments. Your comments are in colored and italic text, and our replies are in black and plain font style.

(1) In Table 1, four measurement methods are presented. However, the digital sensor string and thermistor string are not mentioned in the text. It is better to explain more details of the two measurement methods.

In the text, 'sensor string' includes both the digital and analog variants. We have revised the text to make this more clear.

(2) In Figure 1, the drill site location in the green box is not shown in Figure 1A. It is better to show the Jakobshavn glacier.

We do not fully understand this comment. All drill sites are shown in this summary figure. Subplot 1B, with the green border, shows the upstream outer region of Jakobshavn Glacier. The location of this subplot, with boreholes therein, is indicated by the green square in Fig 1A.

(3) Line 95: Please check the ice thickness in Tuto_D-11 borehole, it looks from the Figure 2 that the ice sheet thickness is 200 ft, which is about 61 m.

A large length of the thermistor string is exposed on the ice sheet surface. From zooming into Figure 2, its text says "* 44 feet of thermocouple string was exposed on the ice beside the tube". Full resolution figure can be found at https://github.com/GEUS-Glaciology-and-Climate/greenland_ice_borehole_temperature_profiles/tree/main/boreholes/Tuto_D-11 where we add our notes, "Depth from text interpreted to mean that ice surface starts at 44 ft on cable and bottom is at 200 ft on cable. This yields an ice thickness of 156 ft or 156*0.3048 = 47.5488".

(4) In the database, it is better to presented the temperature measurement methods (e.g., type and accuracy of temperature sensors) and depth measurement methods (e.g., type and accuracy of encoder) for the readers to evaluate the uncertainty of data source.

We agree that additional metadata fields regarding uncertainty would be desirable. However, we cannot easily compile the original measurement method and its accuracy for each borehole.

Many historical products provide limited information on the temperature sensor, and none on the depth estimate method. Because we provide detailed information on the upstream (original) data sources, readers can still come up with their own uncertainty for any individual borehole if needed. We also provide guidance for assessing total measurement uncertainty, which includes all mentioned sources of uncertainty. Future versions of the database will likely have additional metadata fields added, including uncertainty, which will be populated through expert elicitation and described in a future database description article.

(5) Line 210-220: the paper of V. Zagorodnov et al. presented more detailed disturbance uncertainty of mechanical drill and some discussion can be included in the manuscript. (Zagorodnov, V., Nagornov, O., Scambos, T. A., Muto, A., Mosley-Thompson, E., Pettit, E. C., & Tyuflin, S. (2012). Borehole temperatures reveal details of 20th century warming at Bruce Plateau, Antarctic Peninsula. The Cryosphere, 6(3), 675-686.)

We now include a statement that the temperature disturbance caused by mechanical drilling with fluid-filled boreholes dissipates to the level of precision within five days, and include this citation.

(6) Section 6: Please provide more details how the author determined surface mass balance regime, the basal thermal state regime and ice dynamic regime. A table with accumulation/ ablation rate, basal temperature and strain rate is preferred.

We now more fully describe these selection criteria. More specifically, surface mass balance regime is determined by whether the borehole is located below the snow line, in the ablation area, or above snow line, in the accumulation area, in contemporary satellite imagery (Figure 1). The basal thermal state regime is based on whether the ice-bed interface is measured to be below the pressure-melting-point temperature (i.e. frozen), or not (i.e. temperate). In instances where the borehole does not each the bed, we extrapolate the basal thermal state where reasonable (i.e. FladeIsblink06 is likely frozen), or we list basal thermal state as “unknown” where the extrapolation distance seems unreasonable (i.e. CampVI_50 is unknown). Finally, ice dynamic regime is classified as high strain when the ice flow is channelized, and low strain when sites are located in sheet- or divide-flow.

In addition, some technical errors should be corrected.
(1) Line 15: “the thermal state of the sheet” should be “the thermal state of the ice sheet”.

Fixed - “ice” was included in the sentence.

(2) Line 20: “thermo-mechanical” or “thermodynamic” or “thermomechanical”? Descriptions should be consistent throughout the manuscript.

We now use “thermo-mechanical” throughout the manuscript for consistency.

(3) Line 25: Please check the sentence "borehole logging where a temperature sensor is moved up or down the borehole measuring either "continuously" as the probe moves down". Borehole logger is used only when moves down? or, it can be used when moving down or up.

I have deleted the word "down" so now the sentence reads: "...borehole logging where a temperature sensor is moved up or down the borehole measuring either continuously as the probe moves or is stopped to measure at every depth known as 'stop-and-go'."

(4) Line 25: "fiber-optic distributed temperature sensing", "Fiber optic distributed sensing string"? The hyphenation between fiber and optic should be consistent throughout the manuscript.

Fixed - a dash has been added so the manuscript now consistently has "fiber-optic".

(5) Figure 1: The units of Celsius should have the same format throughout the paper.

Figure 1 does not contain any temperature units. We suspect this comment perhaps refers to Figure 2, which is a reprint of a figure from the original study containing the DYE-3 temperature data with units "degC" (Gundestrup and Hansen, 1984). We cannot modify the figure that we are reprinting. Elsewhere, we have ensured we use (°C), rather than [°C], throughout.

(6) Section 4: There are two "Figure 1" in the first sentence of the section.

Fixed - the extra "Figure 1" has been removed.

(7) Line220 and 230: "hot-water-drilled borehole" or "hot-water drilled borehole"? The style should be consistent throughout the manuscript. I think it should be "hot-water drilled borehole".

Fixed - the dash was removed in line 230, now it reads "hot-water drilled" as suggested making the style consistent throughout the manuscript.

(8) Table 4: The caption of the table 4 is the same as the table 3.

Fixed - the caption has now been updated to match table 4 instead of table 3. New caption: "Overview of the number of profiles in the three regimes before and after excluding profiles not usable for the model comparison analysis."

(9) The style of the references should be consistent, for example, the first letter of each word in the title of references should be lowercase. Please carefully check your references.

The over capitalized references have now been changed, so the reference style is consistent.

Please also note the supplement to this comment:
https://tc.copernicus.org/preprints/tc-2022-138/tc-2022-138-RC1-supplement.pdf

We have addressed all comments in this response.

Brice Van Liefferinge (Referee #2)

We thank you for the time and energy that you have invested in reviewing our community paper. Below, please find responses to all comments. Your comments are in colored and italic text, and our replies are in black and plain font style.

Comment from feedback overview:
The xlsx file is for me unnecessary as the dataverse and github repository are well defined and clear. I would like to emphasize the quality of the open data sets shared with this Publication.

The .xlsx file only lists the borehole classification that we adopt for Section 6 of this manuscript (comparison with PISM temperatures). We therefore only link this classification .xlsx to this manuscript, rather than the Dataverse/GitHub, as these classifications may vary with user interpretation.

Page 1
L1: In the xlsx supplement 70 boreholes are identified but i see 79 on github and dataverse

The supplement file has now been updated to include categorization for all 85 borehole profiles.

L2: replace "profiles" with "boreholes data". If you use "profiles", it refers to the "85 ice temperature profiles" and as a result, the percentage should be 29.5%

We appreciate the potential for confusion, however, instead of using "boreholes data" we have rephrased the sentence in the following way "Profiles from only 25 boreholes (32%) were previously available in open-access data repositories". We hope this eliminates the confusion.

L3: same here, it should refer to the boreholes and not the profiles

Same here - we rephrased the sentence: "The remaining 54 borehole profiles (68%) are being made digitally available here for the first time."

L5-6: these two values must be included in the xlsx supplement.

The .xlsx file only lists the borehole classification that we adopt for this specific manuscript discussion point (Section 6; comparison with PISM temperatures). The database is not available in .xlsx format. It is only available in .csv format for both the Dataverse DOI snapshot and the GitHub living database. The two ice thickness scales are already available in both these database versions.

Page 2
L18: ice

Fixed

L36: e.g.

Fixed - e.g. is added as suggested.

L39-40: could you please provide more details: locations, depth, how many did you find,...? Too vague

We know from historical accounts that previous profiles exist but locating these data has not been straightforward. We have no constraint on the number of pre-1950 profiles.

L39: delete "may"

For the above mentioned reason we decided to keep the "may" in the sentence.

Page 4
fig1 : I don't really understand why use a satellite image as background as it is never referred to in the main document. It might be more useful to have something useful for the discussion e.g. a simpler colored background with grounding line indicated, zones of surface melt, …

We now refer to using satellite imagery to classify whether boreholes are located above or below the contemporary snow line as an indicator of whether their surface mass balance regime is accumulation or ablation.

Page 5
Your KML file is in the EPSG 4326 projection. As you use the EPSG 3413 projection for the figures, it would be good to add a Geojson or .shp file with these projections in the repository. It's a plus not a must have

Done. See https://github.com/GEUS-Glaciology-and-Climate/greenland_ice_borehole_temperature_profiles/commit/8afaa2014d2c2790fc6a4191276eb7d23a2976fa . Uploaded to GitHub for now. This has also been uploaded to dataverse, but we are waiting to publish the next Dataverse version when multiple changes associated with this review round have been accepted.

Why did you apply a cubic spline interpolation? Why not simply use a simple piecewise linear interpolation ? The effects of thermodynamical parameters (mainly surface temp, geothermal heat flow, ice velocity, ...) on the ice temperature vary with depth and so a cubic spline is not necessarily the best fit for all depths. Could you explain why you used a cubic spline everywhere ?

We opted for cubic spline because there are some records with large depth distance between measurements and a curved line appeared to fit the data better. We provide easy access to both the raw data (see `data.csv` file in each folder in https://github.com/GEUS-Glaciology-and-Climate/greenland_ice_borehole_temperature_profiles/tree/main/boreholes) and our code so users can access raw data if they need to reprocess it differently.

L78: cross out "format" behind "KML"

Fixed

L78: insert "format" in front of "KML"

Fixed

L85: insert "t"

Fixed

Page 7
I understand that it is complex to show all the drill site temperature data in one figure but at this scale it is difficult to see which data set is which. In itself, the figure is interesting to show the overall variations in the temperature data but not useful to show specific data sets. Maybe using differing linestyles would help separating out data sets visually. Another solution would be to make a bigger figure as supplementary material.

We have tried many different visualization approaches pre-submission within our author team including some of the points suggested here, but all seemed to have shortcomings. So we are receptive to specific editorial feedback. To accommodate the comment, the figure has been made larger but is currently still included in the main text.

Page 10
You should mention how deep you find the coldest temperature (surface, near the surface). It could give the false impression that the whole profile is quite cold which is only true in the upper part of the profile and does not reflect the processes occurring near the bed

I have added the following "halfway down the profile at normalized depth 0.48." So the full sentence now reads: "The inland profiles also exhibit the coldest temperatures, with temperatures reaching a minimum of around -32°C halfway down the profile at normalized depth 0.48"

Page 13
Table 3: Could you please define what "negligible" is. For some, 0.01 °C is also negligible (e.g. modelers). In other words, what is your defined limit ?

We now state “negligible (<0.01 °C)” in the table caption to constrain the adjective for readers.

Section 6: This paragraph is interesting and shows the importance of providing good constraints for models. You should add a table listing the key parameters used in the model (even-though it is not a paper on PISM) and explain how well they are constrained.

Instead of making a table we added the following (at the end of section 6): “In this modeled run key parameters influencing the modeled temperatures are the enthalpy, which requires understanding of the liquid water fraction in the ice column and its evolution in time, the geothermal heat flow which also have the potential to affect the presence of water in a given location, and the surface boundary conditions i.e. accumulation rate, which control vertical temperature advection, and ice surface temperatures. These parameters are all very difficult to constrain, however, this is especially the case for the enthalpy and the geothermal heat flow parameter. “

Page 14
L250: You should mention that GHF is underestimated in some locations, see the paper of : Rezvanbehbahani, S., Stearns, L. A., Kadivar, A., Walker, J. D., and van der Veen C. J. (2017). Predicting the geothermal heat flux in Greenland: A machine learning approach. Geophysical Research Letters, 44, 12,271–12,279. https://doi.org/10.1002/2017GL075661

We now acknowledge that there is a diversity of opinion regarding the magnitude and spatial distribution of geothermal heat flow beneath the ice sheet, and that modeled ice temperatures are likely influenced by choice geothermal heat flow map. We cite Rezvanbehbahani et al. (2017) and Colgan et al. (2022), which provide end members.

L259: The constraint at the bed (GHF) has a key influence on the thermal state. Could you please develop in one or two sentences the conditions used in the model at the bed?

Yes - We have added the following sentence “The geothermal heat flow map by Shapiro and Ritzwoller (2004), variable in space but not time, was used as a basal thermal boundary condition.”

Page 15
Table 4: the caption is not related to the table. Same as table 3 !!

The caption has now been updated to match table 4 instead of table 3. New caption: “Overview of the number of profiles in the three regimes before and after excluding profiles not usable for the model comparison analysis.”

Page 17
L302: The community has decided to use flow and not flux anymore see : https://tc.copernicus.org/articles/14/3843/2020/ and the associated white paper. Please change flux to flow in the whole manuscript.

The term “flux” has now been changed to “flow” in the four instances where it occurred in the text.

L306: Please also mention the paper of Rezvanbehbahani, S., et al, 2017 see above

We have now cited this paper.

Page 21
L441: the link is not valid

Fixed, the link is now valid.