Response to the Editor & Reviewers

Response to the Editor

Editor's comments are in blue, our reply in black.

Dear Junshun Wang and co-authors,
Thank you for your careful revisions and for engaging constructively with the reviewers' feedback. In the second round of review, both referees provided positive evaluations and acknowledged the scientific contribution and improvements made to your manuscript.

While the overall reception has been favorable, Referee #3 has raised a number of constructive comments aimed at further improving the clarity and structure of the manuscript.
I therefore invite you to submit a revised version that responds carefully to all remaining comments, particularly those from Referee #3.

Best regards,
Cheng Gong
Editor, The Cryosphere

Dear editor,
We sincerely thank you for your handling of our manuscript and for the positive assessment provided by the referees in the second round of review. We are pleased to submit the revised version of our manuscript.

We have carefully addressed all remaining comments. In particular, we have made significant efforts to further improve the clarity and structure of the manuscript to ensure the presentation meets the high standards of the journal.

Below, we provide a point-by-point response to the specific comments raised.

Sincerely,
Liyun Zhao (on behalf of all co-authors)

Response to Referee #1

Referee's comments are in blue, our reply in black, quotes in the revised manuscript in red.

Review of Wang et al. (2025) 'Quantifying Temperature-sliding Inconsistency in Thermomechanical Coupling: A Comparative Analysis of Geothermal Heat Flux Datasets at Totten Glacier'

Summary

This paper presents a new set of metrics to assess the inconsistencies between modelled basal temperatures and observed surface ice velocities in ice-sheet simulations, and applies them to evaluate the likely shortcomings of eight different geothermal-heat-flux datasets in the Totten basin in East Antarctica. The paper finds that its results in this regard agree with previous work that assessed the eight datasets using radar specularity observations to determine the presence of basal water and thus whether the ice was warm or cold, which suggests it is indeed performing well in identifying problem areas, and validates the method as a way of assessing the consistency of simulation results.

I reviewed the first version of this paper and had some relatively minor comments of a structural nature. I am pleased to see that the authors have addressed these and I think the clarity and flow of the paper are now much better. I have only a couple of small further comments related to the new material added in response to the first round of review, but, otherwise, I think the paper is ready for publication at this stage. So, minor revisions, but no more than that!

Reply: Thank you for your encouraging comments.

Page and line numbers refer to those in the clean version of the submitted manuscript.

Major Comments

• None.

Minor Comments

• Section 2.2-2.3: I know why these sections are here, having read all the reviews, but, if one hasn't, these both intrude rather awkwardly into the paper, seemingly for no reason. I think the easiest way of solving this might be to just add a sentence to the start of Section 2.2 saying something like 'We validate our work in this study by comparing our ranking of GHF datasets to the observationally constrained ranking of Huang et al. (2024). For readers not familiar with this paper, we provide here a brief summary of their method and, in the next section, clarify the distinction between their paper and the present study.' Then at least readers will understand the point of these sections and the paper will flow a bit more naturally.

Reply: Thank you for this insightful observation regarding the structure and flow of the

manuscript. We have added an introductory sentence at the beginning of Section 2.2 to explicitly state the motivation for including these sections.

In this study, we validate our method by comparing our ranking of GHF datasets to the observationally constrained ranking established by Huang et al. (2024). For readers not familiar with this paper, we provide here a brief summary of their method and, in the next section, clarify the distinction between their paper and the present study.

• Section 4.2-4.3: I might suggest swapping the order of these two sections. 4.3 follows on naturally from the discussion of possible mismatch causes in 4.1, so having the unrelated relatively technical section on sensitivity that is 4.2 in-between them feels a little odd.

Reply: Thanks for your suggestion. We agree that the interpretative discussion presented in Section 4.3 follows naturally from the analysis of potential mismatch causes in section 4.1. Section 4.2 (Sensitivity Analysis) is technically independent. We also think section 4.3 has a natural transition toward the Conclusion section, so we would like to keep section 4.3, and swap the order of the original Section 4.1 and 4.2.

Therefore, the new structure is as follows:

1. **Section 4.1:** Sensitivity of Inconsistencies to GHF Datasets (former 4.2)
2. **Section 4.2:** Causes of Inconsistencies and Sources of Uncertainty (former 4.1)
3. **Section 4.3:** Implications for Ice Sheet Dynamics

Response to Referee #3

Referee's comments are in blue, our reply in black, quotes in the revised manuscript in red.

Summary: The paper investigates inconsistencies in ice sheet models when the basal thermal state is inferred from ice surface velocities. The authors derive six metrics with which they quantify these inconsistencies, apply their method to Totten Glacier, Antarctica, using eight geothermal heat flux models, and compare their results with radar specularity. The authors further use the discovered inconsistencies to rank the eight geothermal heat flux models in their reliability. I commence the authors for finding this novel approach and I see the added value in having an evaluation method that can be applied rapidly and with relatively little input data. However, there are inconsistencies with terminology, methodology, and clarity of the manuscript so that revisions are required.

Reply: Thank you for your encouraging comments. For the Line numbers that the referee mentioned, we assume the referee read the original version rather than the earlier version of revision we submitted. But it does not prevent us from identifying the places that need revision.

I have two major comments and a number of minor comments that are outlined below:

Major:

1. The manuscript would benefit from a clearer structure. As the paper combines a multitude of modelled and observed data, as well as several different metrics, it is hard to follow. The results section in particular is very hard to follow as it switches between GHF products, absolute and relative metrics as well as overcooling and overheating. I suggest the following:

    a. Clearly define your input datasets and metrics in the methodology section. Use different subheadings for a) Definition of Metrics B) Normalization and ranking. The section could also benefit from a table that shows all input datasets.

    b. While the maps are useful to assess the spatial distribution of different metrics, I would also add a table that shows the key differences for each metric and GHF.

    c. Structure the results section by metric with individual subheadings e.g. absolute inconsistencies, relative inconsistencies, comparison.

    d. Section 4.3. should be more on the caveats as it mostly discusses the influence of near-surface air temperatures on your results. I would change the subheading to e.g. "Impact of Input datasets", and rather than calling it an additional experiment, state that a caveat of your study is that it is influenced by the input data.

Reply: We appreciate your detailed and constructive advice on restructuring the manuscript. We have fully adopted your suggestions to enhance clarity and readability. Our specific revisions are detailed below:

a. **Methodology Structure:** Following your suggestion, we have reorganized the Methodology section and added a summary table to clearly define the input

datasets and metrics.

We introduced specific subheadings: "2.1.1 Definition of Metrics" and "2.1.2 Normalization and Ranking".
The input datasets are described in detail in Section 3.1 of the manuscript. In addition, we have added a summary table listing all input datasets. To keep the main manuscript concise, this table is provided as Table S1 in the Supplementary Material, and referenced in the methodology section.

Table S1. Summary of input datasets used in ice sheet model.

Input variables	Datset name	Reference
Surface ice velocity	MEaSUREs InSAR-Based Antarctic Ice Velocity Map, version 2	Morlighem et al. (2020)
Surface elevation, bed elevation and ice thickness	MEaSUREs BedMachine Antarctica, version 2	Rignot et al. (2017)
Surface temperature	ALBMAP v1	Le Brocq et al. (2010)
	Antarctic_T2m_reconstruction_ 2001-2018	Zhang et al. (2022)
GHF maps	—	Shen et al. (2020)
		Stål et al. (2021)
		An et al. (2015)
		Haeger et al. (2022)
		Lösing and Ebbing (2021)
		Martos et al. (2017)
		Purucker (2012)
		Shapiro and Ritzwoller (2004)
Specularity content	ICECAP basal interface specularity content	Dow et al. (2019)

b. Summary Table in Results: To complement the spatial maps, we have added a summary table (**Table 1**) in the Results section. This table highlights the key differences for each metric and GHF product, allowing for a more direct quantitative comparison.

Table 1. Summary of inconsistency metrics for different GHF maps.

GHF maps	AOC (°C km yr^{-1})	AOH (km yr^{-1})	ROC (°C)	ROH	ACI	RCI
Shen et al. (2020)	6.39	29	159	470	0.59	0.39
Stål et al. (2021)	6	31.9	144	814	0.84	0.8

An et al. (2015)	5.97	30.5	130	397	0.53	0.11
Haeger et al. (2022)	6.32	34.1	126	889	1.51	1.57
Lösing and Ebbing (2021)	6.91	34.1	290	780	1.97	1.58
Martos et al. (2017)	5.82	34.2	146	1072	1.14	1.18
Purucker (2012)	5.89	30.6	115	375	0.5	0
Shapiro and Ritzwoller (2004)	5.65	31.8	138	417	0.54	0.19

c. **Structure of Results section:** We have restructured the Results section to align with the specific metrics. The section is now organized under the following subheadings: "3.3.1 Overcooling Inconsistency on Frozen Beds" and "3.3.2 Overheating Inconsistency on Thawed Beds".
d. **Framing of Section 4.3:** We agree that the discussion on near-surface air temperatures serves more as a caveat regarding input data sensitivity than a standalone experiment. We retitled this section as "Impact of Input Datasets".

2. At various times in the manuscript, the authors label datasets and values as unrealistic, gold standard or otherwise. These labels are unscientific and should be removed (see more detailed comments below for occurrences that I have spotted).

Reply: We agree with you that terms such as "unrealistic", "gold standard", and similar labels imply subjective judgement and are therefore not appropriate in a scientific context. Following your comment, we carefully reviewed the entire manuscript and replaced these subjective labels with more objective and precise terms.

We have revised the relevant sentence in **Section 4.2** (Line 495 – 499) to: While full-Stokes is generally considered as an ice sheet model with the most complete physical processes to date, the use of an isotropic rheology may not be valid in some parts of the ice sheet, such as near ice divides or at the margin of an ice stream where the history of past ice deformation creates anisotropic crystal fabric that affects the present-day mechanical properties.

In addition, we have removed all instances of "unrealistic" from the manuscript and rewritten the corresponding sentences to be more objective.

Example 1:

Original: Assuming the inconsistencies are mainly due to **unrealistic** GHF datasets, we use the inconsistencies to assess the reliability of those GHF datasets.

Revised: Assuming the inconsistencies are mainly due to quality issues of GHF datasets, we use the inconsistencies to assess the reliability of those GHF datasets.

Example 2:

Original: An overheating inconsistency in the eastern Totten Glacier with all GHFs suggesting overestimation of ice temperature due, in this case, to an **unrealistically** warm surface temperature.

Revised: An overheating inconsistency in the eastern Totten Glacier with all GHFs

suggesting overestimation of ice temperature due, in this case, to **a warm bias** in the surface temperature.

Minor:

Throughout the manuscript the authors switch between surface velocity and surface speed. For consistency, it should be one or the other.

Reply: To ensure consistency, we use "surface velocity" throughout the revision. In equations or comparisons involving only scalar values, we use the term "velocity magnitude".

Line 85: Insert “the” before basal friction coefficient.

Reply: We have added it.

Line 125 – 132: This paragraph could go into the introduction as you define inconsistencies there. I would, however, remove the sentence in Lines 92-94 and rephrase the sentence in Lines 125 – 126 to the following: “*For this study we define inconsistencies as differences between modelled frozen bed and modelled basal sliding (which is tuned to match the observed fast surface velocity during the inversion), and between modelled warm bed and observed slow surface velocity. The inconsistencies originate from multiple causes, including uncertainties in GHF, surface ice temperature, ice sheet geometry, bed topography, surface velocity, ice density and incomplete ice flow mechanics.”*

Reply: We appreciate your suggestion to define the "inconsistencies" earlier in the Introduction. Following your suggestion, we have removed the sentence “which we refer to as inconsistencies in this study” (Lines 92-94) in the Introduction, rephrased the sentences in Lines 125-132 as below, and moved them to the Introduction: “For this study, we define the inconsistencies as differences between a sliding inversion and the temperature/rheology field used as an input to that inversion. More specifically, the inconsistencies are between modelled basal sliding (which is tuned to match the observed fast surface velocity during the inversion) and modelled frozen bed, and between observed slow surface velocity (which is most likely indicative of a non-slip basal condition) and modelled thawed bed. The inconsistencies originate from multiple causes, including uncertainties in GHF, surface ice temperature, ice sheet geometry, bed topography, surface velocity, ice density and incomplete ice flow mechanics.”

Lines 155 – 156: This sentence is unnecessary. Consider removing.

Reply: We have removed it.

Lines 197 – 199: This sentence can be incorporated into the next one e.g. *“We obtain three absolute inconsistencies (AOH, AOC, ACI) and three relative inconsistencies (ROH, ROC, RCI), with which we can comprehensively analyze …”*

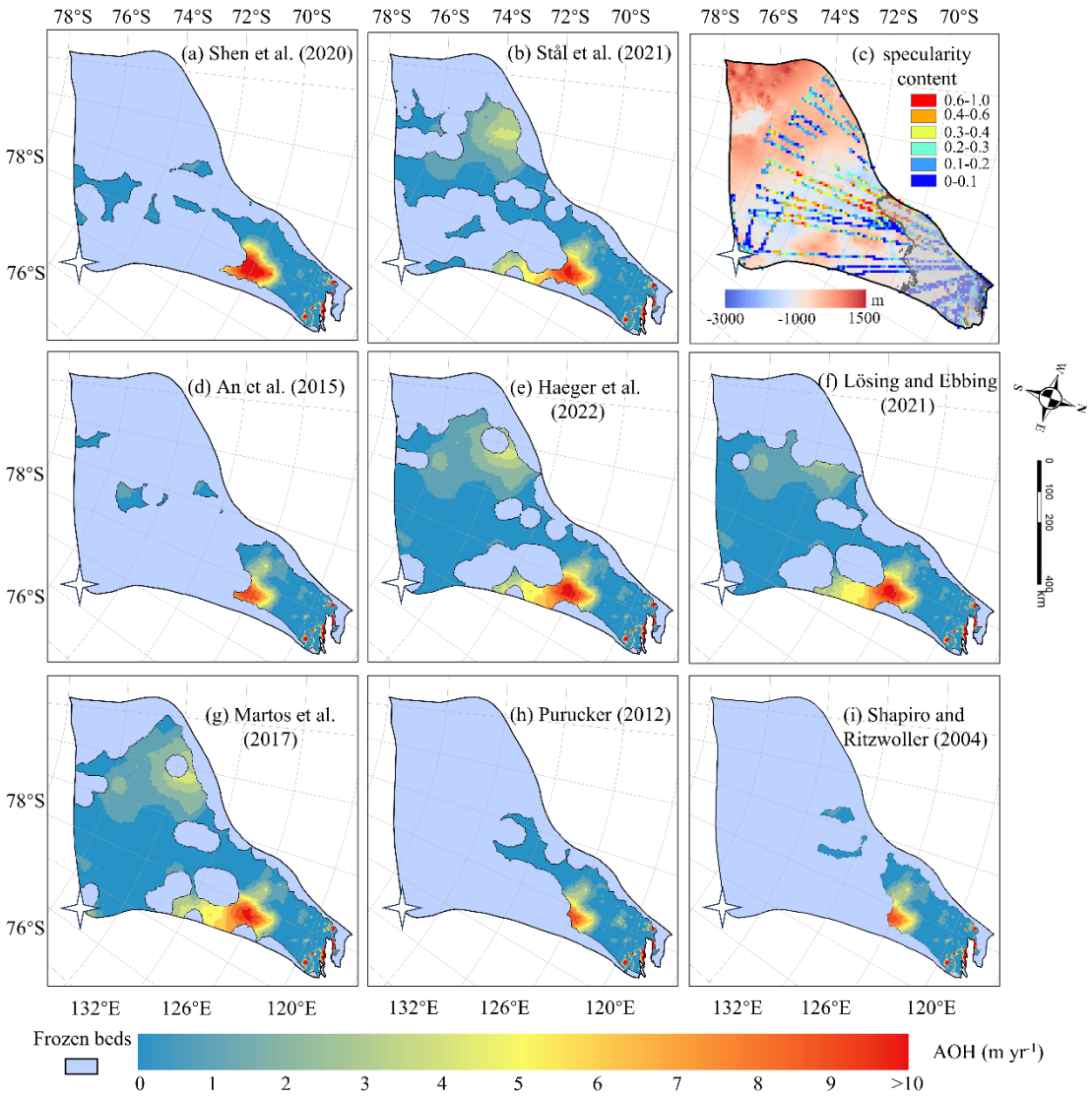
Reply: We have revised the manuscript and incorporated this sentence into the following one, as you suggested.

“Therefore, we obtain three absolute inconsistencies (AOH, AOC, ACI) and three

relative inconsistencies (ROH, ROC, RCI), with which we can comprehensively analyze the temperature-sliding inconsistency in the inversion results of ice sheet model."

Line 230: It is not quite clear from the map where 71°S is as the map only shows 76°S and 78°S. The map should either show the coordinates referred to in the text or the area should be highlighted somehow.

Reply: To address this, we have revised all figures containing maps in the manuscript. We have added clear coordinate labels (latitude and longitude) to the axes of these figures to ensuring that locations such as 71°S are easily identifiable. An example of the updated figures is provided below.



Updated Figure 6. Spatial distribution of *AOH* in thawed-bedded regions with **(a-b, d-i)** corresponding to the GHFs **(a–h)** in Fig. 2. The blue region indicates frozen-bedded areas. **(c)** Locations of specularity content, same as Fig. 4c. The white star represents Dome C.

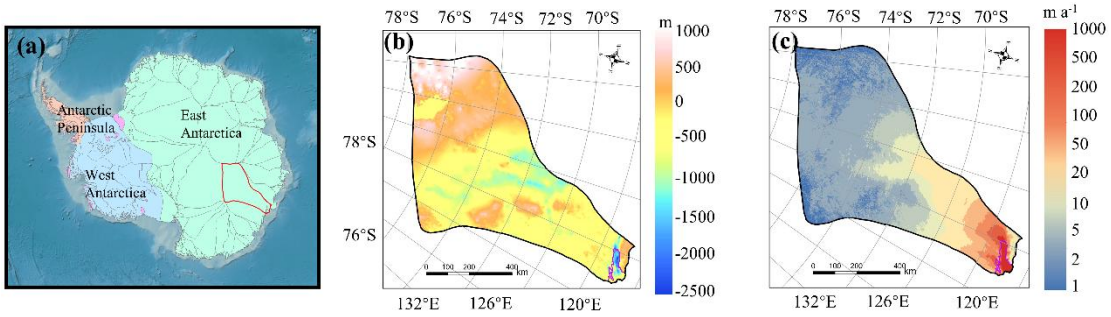
Line 234: Being colder than what? I assume than the other GHF products. Consider adding *"... than the other four GHF products."*.

Reply: Thank you for identifying this ambiguity. We have added the suggested phrase to clarify the comparison.

"All 8 GHF datasets produce low basal ice temperatures in the inland southwest, with Purucker et al. (2012), Shapiro and Ritzwoller (2004), Shen et al. (2020) and Lösing and Ebbing (2021) being colder than the other four GHF products."

Line 240: The canyon is not really apparent in Figure 1b - Consider adding an outline.

Reply: Thank you for pointing this out. We agree that the canyon was not sufficiently clear in the original version of Figure 1b. We considered adding an outline (contours) to highlight the canyon; however, we found that this resulted in visual clutter and compromised the overall readability of the map. Instead, we have optimized the color scale (colormap) to enhance the contrast in this specific range. Consequently, the subglacial canyon is now clearly visible in the revised figure.



Updated Figure 1. (a) Geographic location of Totten Glacier (red outline) in Antarctica; **(b)** bed elevation of Totten Glacier, the purple curve represents the grounding line; **(c)** observed surface velocity.

Lines 244 – 245: This should go further up in the methods section where you define AOH and AOC.

Reply: We assume the referee means this sentence: "We calculate the absolute inconsistencies, AOH, in the warm bed, and AOC in the cold bed." Hence, we guess the referee read the original version rather than the earlier version of revision we submitted. The sentence in Line 244-245 of the original version is Line 320-321 in the earlier revision. We removed this sentence. We also reorganized the method section according to another referee's comments. So we do not need this sentence in the revision.

Lines 246 – 247: Again, it is not clear where the area referred to in the text is located as the coordinates in the map do not correspond.

Reply: Thank you for pointing this out. To improve clarity, we have added coordinate labels directly to the map, which now clearly indicate the location of the area referred to in the text.

Line 254 – 256: This sentence refers to ice flow and references Figure 3, which does

not show ice flow. I would suggest referring to Figure S2 for ice velocity and Figure 3 at the end of the sentence.
Reply: We added a citation to Figure S2.

Line 261 – 263: I would expect the spatial distribution of the two metrics to be different as they are derived differently. Consider removing the sentence as I think it is not providing any additional information. If it stays in the manuscript, it should be absolute "overheating" inconsistencies in Line 262.
Reply: We have removed this sentence.

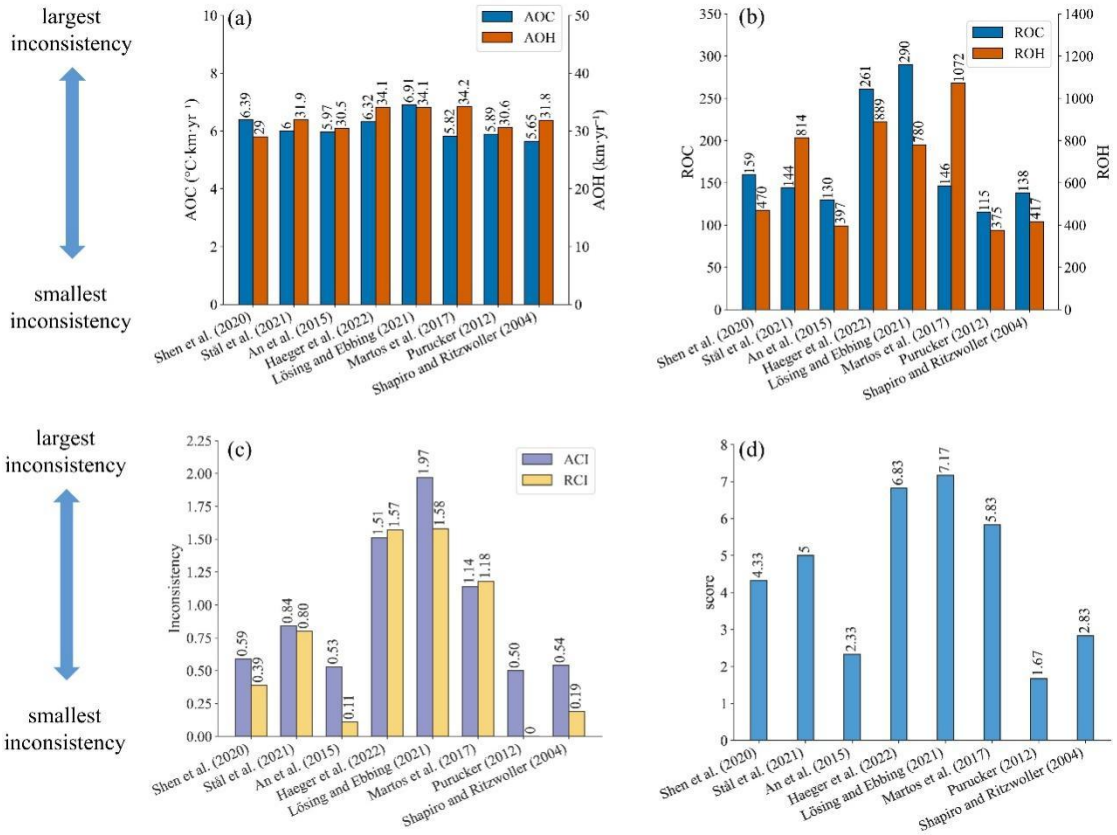
Line 263: Mention how to find Dome C in the figure (e.g. Dome C (Blue Star, Figure 4).
Reply: We have added the text to help readers locate Dome C in the figure.
The largest value of ROC across most GHF occurs at Dome C (white star in Figure 5), where the observed surface ice velocity magnitudeis close to zero (Fig. 1c).

Figures 4 – 6: Keep the wording consistent. Where the color scale is logarithmic, say that instead of "non-linear". Consider changing the color for the Dome C marker – It is very hard to see. Also, if Dome C is marked in all figures, it should also be referred to in the figure caption.
Reply: Thank you for these helpful suggestions. We have ensured consistent wording across Figures 4–6 and now explicitly describe the color scale as logarithmic where applicable. The color of the Dome C marker has been changed to white to improve visibility. Dome C is marked in all figures, and referred to in the figure captions.

Lines 282 – 284: Repetition from Lines 216 – 218. Consider removing.
Reply: We have removed the sentence.

Line 287: Again, the coordinates are meaningless if the map doesn't reflect them.
Reply: Thank you for pointing this out. We have added coordinate labels to the map, which now clearly indicate the location of the area referred to in the text.

Figure 7 a,b: Not the best colors for colorblindness. Consider changing (check here)
Reply: We have redrawn the figure using a colorblind-safe palette (specifically, a distinct blue and vermilion pair adapted from the Okabe-Ito palette) to ensure distinct contrast for all readers.



Updated Figure 8. Six inconsistency indicators and the final ranking of 8 GHF datasets. **(a)** the absolute overcooling and overheating inconsistencies, AOC and AOH; **(b)** the relative overcooling and overheating inconsistencies, ROC and ROH; **(c)** the absolute and relative combined inconsistencies, ACI and RCI; **(d)** the average of ranking scores from 1 to 8 using the six inconsistency indicators. The value of inconsistencies and scores are labeled at the top of the bars.

Lines 345 – 347: Repetition from Lines 125 – 132. Consider removing.

Reply: We have removed this sentence.

Line 349: “check” sounds a bit informal. Maybe use “assess”.

Reply: We have replaced the word “check” with more appropriate scientific terms such as “assess” or “evaluate” throughout the manuscript.

Lines 361 – 362: This is a very strong statement, and I don’t think you can say that unless you have a product that captures GHF correctly or a citation to back it up. Consider removing or at least toning it down.

Reply: We agree with your assessment. Since ground truth GHF data is unavailable, claiming that none of the products captured the "true" GHF is indeed too definitive. We have toned it down, and rephrase this sentence

“This could be because none of the input GHF fields correctly captured the true GHF, but it could also indicate problems with other model inputs.”

to

"This could be related to uncertainties or limitations in the input GHF fields, but it may also indicate sensitivities to other model inputs."

Lines 367 –368: In contrast to what - Not quite clear why this sentence follows the section on uncertainty metrics. Maybe it was supposed to go after Line 365. Also, it should be "in contrast" not "by".
Reply: We change this sentence to
"While the cooler surface temperatures during the glacial period exerted a cooling effect on ice sheet temperature, lower surface accumulation rates over the same period induced a warming effect."

Line 376: Considered "gold standard" by who? Either add a citation or refrain from using ratings.
Reply: We have removed the term "gold standard" throughout the manuscript. We change it to
"While full-Stokes is generally considered as an ice sheet model with the most complete physical processes to date, ..."

Line 395: Insert "is" between "impact" and "beyond".
Reply: Done.

Line 405: Remove "we know for sure".
Reply: Done. We change this sentence to "This makes methodological sense, as sliding is generally expected to occur where the bed is thawed."

Figure 8 – caption: Change "thick black curves" to "black lines".
Reply: We have revised this.

Line 480: Remove "the" before "dynamic ice loss".
Reply: Done.

Lines 481 – 482: Rephrase. Currently, the sentence doesn't make any sense.
Reply: We have rephrased the sentence to improve grammatical correctness and clarity regarding physical implications.
"Similarly, underrepresentation of thawed bed conditions will lead to an underestimation of ice discharge and, consequently, an underestimation of ice sheet's response to climate warming."

Lines 482 – 483: This sentence needs a citation.
Reply: We have added two references as below:
"The basal thermal regime critically influences the stability of grounding lines and the behavior of ice streams (Dawson et al., 2022; Robel et al., 2014)."

Line 494: Change "under climate change" to "under future climate change scenarios".

Reply: Done.

Line 501: Change “checking” to “assessing”.
Reply: Done.

Line 507: This is the first time you talk about englacial temperature. I assume you mean basal temperature.
Reply: We changed “englacial” to “basal”.

Line 509: Which simulation results? Add a citation or refer to a specific simulation.
Reply: We modified this sentence as “We apply this method to evaluate the steady-state simulation results of Totten Glacier presented by Huang et al. (2024), which were derived using a 3D full-Stokes model with 8 different GHF datasets.”

Line 511: Again, this is a strong assumption unless you know what is realistic. Maybe use "due to differences in".
Reply: We agree. We have removed the word “unrealistic”. We change it to “Assuming the inconsistencies are mainly due to the quality issues of GHF datasets, ...”

Lines 518 – 519: See comments above on coordinates.
Reply: We have added coordinate labels to the map figure, which now clearly indicates the location of the area referred to in the text.

Line 519: Find a different word unless you can prove that is not realistic.
Reply: We have replaced this “unrealistically warm surface ice temperature” with “a warm bias in the prescribed surface ice temperature”.

Line 520: Remove “there”.
Reply: We have removed it.

Supplementary material
Figure S1 – caption: Add abbreviation for pressure melting point. It is otherwise not clear what PMP in the legend stands for.
Reply: We have added “The abbreviation PMP stands for pressure melting point.”

Figure S4: The labels should include the year of the publication as is present in all other figures (e.g. Purucker (2012) – Lösing and Ebbing (2021))
Reply: We have updated the labels in Figure S4 to include the year of publication.

As you are citing in the figure captions, you should add a reference list.
Reply: We have added a reference list in Supplementary material.