Community Heat Flow Recommendations: Suitable Basal Boundary Conditions for Greenland and Antarctica in ISMIP7

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Abstract	Geothermal heat flow (GHF) influences ice-sheet thermal conditions, affecting ice flow by sliding and deformation. However, GHF distribution under polar ice-sheets remains poorly constrained, with few direct borehole-derived estimates and large discrepancies between glaciological and geophysical models caused by methodological differences and data limitations. As a result, many ice-sheet models rely on uniform GHF estimates, ensemble averages, or outdated fields that oversimplify reality. The choice of GHF product can lead to significantly different thermal conditions simulated at the ice-bed interface, which affects the projected evolution of ice-sheets under climate warming. Therefore, we conduct an expert elicitation survey to identify the most suitable GHF fields for use as basal boundary conditions in ice-sheet modelling, particularly for the Ice-Sheet Modelling Intercomparison Project for CMIP7 (ISMIP7). GHF fields generally fall into three categories: (1) outdated due to improved data availability, (2) overly simplified parameterizations, and (3) current and preferred. For GHF fields that rank highly in the survey, we discuss uncertainty, data dependency and guide their use in different applications. Finally, we recommend two Antarctic and one Greenlandic GHF field(s) for ISMIP7.

1. Introduction to Polar Geothermal Heat Flow

1.1. Context and Motivation

Geothermal heat flow (GHF) plays a vital role in ice-sheet dynamics by influencing the thermal conditions at the ice-sheet base and the englacial rheology. High GHF can cause basal melting, increasing ice flow by basal sliding (Bell et al., 1998, 2007; Fahnestock et al., 2001), while low GHF can lead to frozen basal conditions, limiting basal sliding. However, both the magnitude and also the spatial variability in GHF are important (Jordan et al., 2018; McCormack et al., 2022; Näslund et al., 2005; Pittard et al., 2016; Seroussi et al., 2017; Stål et al., 2024). Estimating GHF in Antarctica and Greenland is challenging due to sparse direct measurements (Burton-Johnson et al., 2020a; Colgan et al., 2022; Freienstein et al., 2024; Fuchs et al., 2024; Talalay et al., 2020) and complex and poorly characterized geology (Dawes, 2009; Goodge, 2018; Li & Aitken, 2024). As a result, GHF fields often rely on indirect methods based on seismic, radar, gravity, and magnetic data (Section 1.2). However, these methods face significant challenges and uncertainties resolving the lithospheric thermal structure, constraining heat production at depth, and accounting for spatial variability in crustal properties (Burton-Johnson, Dziadek, & Martin, 2020; Burton-Johnson, Dziadek, Martin, et al., 2020; Reading et al., 2022).

For ice-sheet modelling, different GHF products can lead to variations in basal temperatures of over 10°C across large areas of the Greenland Ice-Sheet (GIS), affecting the extent of thawed-bed regions, which can range from 33.5% to 60% (Zhang et al., 2024). Zhang et al. (2024) showed that the coldest GHF fields produced the highest iceberg calving because they resulted in thicker ice near tidewater fronts. At the North Greenland Ice Core Project (NGRIP) site, models estimate basal melt rates of approximately 7 mm/year when using a GHF that matches observed basal temperatures. In contrast, using a lower GHF results in negligible melt rates (<0.1 mm/year) (Greve, 2005). Karlsson et al. (2021) estimate that GHF contributes about ¼ to the basal mass balance over grounded ice, i.e., a substantial portion of the total mass balance of the ice-sheet. Llubes et al. (2006) show that a uniform increase in GHF by 20 mW/m² under the Antarctic Ice-Sheet (AIS) leads to a 6°C rise in mean basal temperature. This change tripled the basal melt rate from 6.7 km³/year to 18 km³/year. A more recent study (Raspoet & Pattyn, 2025) investigated the basal thermal conditions and meltwater production of the AIS using an ensemble ice-sheet modelling approach. Evaluating the impact of nine different GHF fields, they find that basal melting due to GHF constitutes approximately half of the total basal meltwater production across the ice-sheet, and that uncertainties in GHF have the greatest impact on the simulated ice basal temperatures and melt rates.

The Ice-Sheet Model Intercomparison Project for CMIP6 (ISMIP6), the Coupled Model

Intercomparison Project - phase 6, is a global initiative aimed at improving our understanding of ice-sheet dynamics, particularly how the AIS and GIS respond to climate change (Nowicki et al., 2016, 2020). By providing a platform for comparing and refining ice-sheet models, ISMIP6 helped produce more reliable predictions of ice-sheet behavior over the coming century and its impact on sea-level rise. These predictions are crucial for informing climate policy, especially in coastal management and adaptation efforts.
In ISMIP6 Antarctica (Seroussi et al., 2020, 2024) and Greenland (Goelzer et al., 2020), four different GHF fields were used, including outdated and uniform fields, which could significantly affect not only the model initialization but also future projections. This paper provides an assessment of GHF appropriateness for ice-sheet modelling through an online expert elicitation. We aim to provide detailed information for ice-sheet modelers and improve use of GHF in ice-sheet models like those participating in ISMIP6, reducing uncertainties and enhancing predictions of future ice dynamics and sea-level contributions in a warming climate.

1.2. Methods and Assumptions

Approaches to polar GHF (Table 1) fall into three broad categories:

1 | Forward – Uses the 1-D steady-state heat equation with geophysical inputs (crustal thickness, Curie depth, etc.). Physically grounded but highly sensitive to assumed parameters, homogeneous property simplifications, and debated Curie-depth interpretations.

2 | Data-driven/statistical – Geostatistics and machine learning infer GHF from correlations among temperature gradients, conductivity and heat production data. They capture local variability and give probabilistic uncertainty bands, yet still hinge on data coverage; ±20–30 mW/m^2 errors are common.

3 | Inverse – Combine physics and statistics, e.g. forward approach with ice-sheet-model tuning.

Across all methods, accuracy is ultimately limited by sparse, heterogeneous observations and uncertain thermal properties (Reading et al., 2022). A more detailed description can be found in the Appendix A1.

Table 1. Overview of key published continent-wide GHF models by region and method. Studies are grouped by their geographic focus and categorized by their primary approach.

Publication	Domain	Method
Hazzard & Richards (2024)	Antarctica	Seismic, forward
Haeger et al. (2022)	Antarctica	Seismic & Gravity, forward
Lösing & Ebbing (2021)	Antarctica	Multivariate
Stål et al. (2021)	Antarctica	Multivariate
Shen et al. (2020)	Antarctica	Seismic, statistical
Guimarães et al. (2020)	Antarctica	Interpolation
An et al. (2015)	Antarctica	Seismic, forward
Purucker (2013)	Antarctica	Magnetic, forward
Shapiro & Ritzwoller (2004)	Global	Seismic, statistical
Martos et al. (2017, 2018)	Antarctica + Greenland	Magnetic, forward
Fox Maule et al. (2005, 2009)	Antarctica + Greenland	Magnetic, forward
Colgan et al. (2022)	Greenland	Multivariate
Artemieva (2019)	Greenland	Thermal isostasy, forward
Greve (2019)	Greenland	Glaciological, inverse
Rezvanbehbahani et al. (2017)	Greenland	Multivariate
Lucazeau (2019)	Global	Multivariate

1.3. Current GHF Fields and Their Role in ISMIP6

1.3.1. Antarctica

A total of 12 key continent-wide GHF fields are available for Antarctica (Table 1), two of them adapted from global compilations (Shapiro & Ritzwoller, 2004; Lucazeau, 2019). The diversity in methods, data inputs, and resolution leads to notable discrepancies in inferred GHF, exceeding ±30 mW/m². The strongest disagreements prevail in (1) the West Antarctic Rift System and Thwaites–Marie Byrd Land, (2) the interior of East Antarctica, and (3) the

Transantarctic Mountains and Victoria Land volcanic province.
Among the 16 modelling groups participating in ISMIP6 (Seroussi et al., 2024), three used Shapiro & Ritzwoller (2004), three used Martos et al. (2017), and one used Fox Maule et al. (2005), despite the availability of more recent regional models. Assessments of nine ISMIP6 model outputs find West Antarctica to be predominantly thawed with widespread subglacial water, while in East Antarctica thawed zones are confined to pockets around major subglacial lake districts. From this synthesis, overall, 29 % of the AIS bed is likely frozen, 21 % likely thawed and 50 % remains uncertain (Seiner et al., 2024).

1.3.2. Greenland

There are currently eight key GHF maps available for Greenland (Table 1). Two of these are global products (Lucazeau, 2019; Shapiro & Ritzwoller, 2004). These fields are evaluated against in-situ measurements, although evaluation datasets range from <10 to >300 measurements of Greenland heat flow.
Significant disagreements exist among GHF, particularly in North Greenland. Some depict a widespread high heat-flow anomaly there (e.g., Greve, 2019), while others do not (e.g., Lucazeau, 2019). Rezvanbehbahani et al. (2017) provides products with and without this feature. Other key discrepancies include: (1) detection of the Iceland Hotspot Track in Greenland by Martos et al. (2018), (2) proximity-influenced elevated heat flow in East Greenland by Artemieva (2019), and (3) a low heat-flow anomaly linked to the North Atlantic Craton in South Greenland identified by Colgan et al. (2022).
Of the 21 Greenland submissions in ISMIP6, twelve prescribed Shapiro & Ritzwoller (2004), five prescribed Greve (2019), two prescribed GHF as a hybrid assimilation of four largely deprecated older GHF fields (Fox Maule et al., 2009; Pollack et al., 1993; Rogozhina et al., 2016; Tarasov & Peltier, 2003), and one used a spatially uniform GHF (Goelzer et al., 2020). Under these boundary conditions, the ISMIP6 ensemble suggests that ~ 40 % of GIS bed is frozen, and ~ 33 % of the ice-sheet bed is thawed or at the pressure-melting-point (MacGregor et al., 2022). The ISMIP6 ensemble disagrees on the basal thermal state beneath ~ 28 % of the ice-sheet. It is unclear what portion of this disagreement is associated with the use of differing GHF boundary conditions across ensemble members and which portion comes from other parameters and processes included by the ice flow models.

2. Expert Survey on Geothermal Heat Flow Fields in Antarctica and Greenland

We conducted an online expert survey with the aim of gathering community insights on which GHF fields are considered to be most suitable for ice-sheet modelling, specifically for

the forthcoming ISMIP7 simulations in support of IPCC AR7.
The survey was advertised widely in community forums such as Cryolist, INSTANT, and the EGU Annual Meeting. We opened the survey from March 21st till May 5th 2025 and ultimately received 32 completed entries. No survey respondents were declined on the basis of failing to fulfill the expert inclusion criterion or any other reason. Further details on the survey's content and ethical considerations can be found in the Appendix B1.

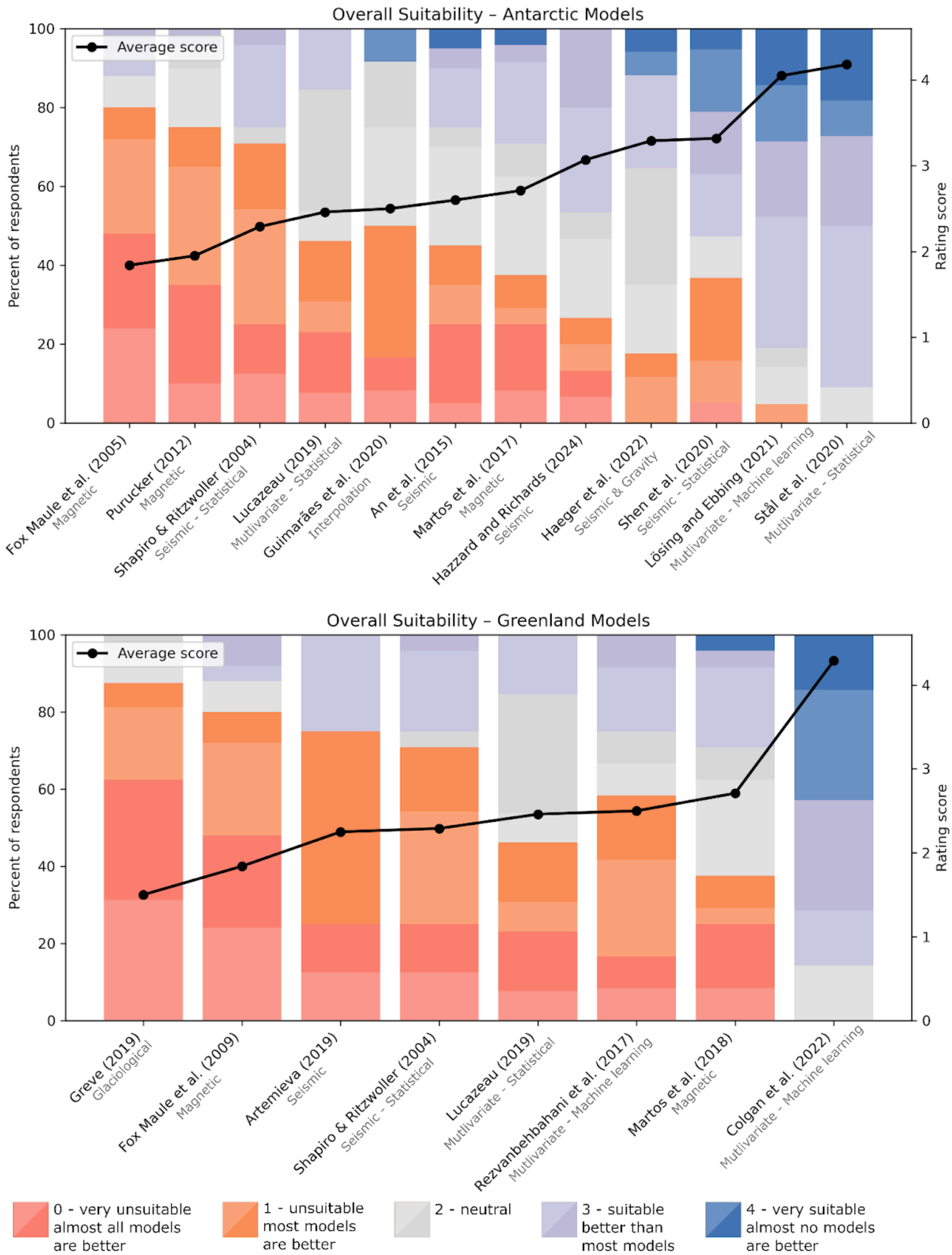
2.1. Criteria for Evaluating Heat Flow Fields

In the survey, experts were asked to evaluate each GHF field based on five criteria:
(1) the **spatial resolution**, referring to its ability to capture relevant variations at the scale of ice-sheet processes;
(2) the **method** used to generate the field;
(3) the **calibration and/or evaluation**, such as comparisons to borehole data or other ground truth;
(4) the **novelty** at the time of publication, reflecting whether new data, techniques, or insights were introduced; and
(5) the **overall suitability** for use as a basal boundary condition in ISMIP7 simulations.
Each criterion was rated on a six-point scale: no opinion on this aspect, very unsuitable (almost all models are better), unsuitable (most models are better), neutral, suitable (better than most models), and very suitable (almost no models are better). Free-form comments were also encouraged to qualify or elaborate on individual assessments.

2.2 Results of the Expert Elicitation

Figure 1 summarizes expert assessments of the overall suitability of GHF fields for use as subglacial boundary conditions. Results from the remaining criteria are shown in Appendix B2. Each model was rated by survey participants on a scale from 1 (*very unsuitable*) to 5 (*very suitable*). For Antarctica, recent fields using multivariate or statistical approaches (e.g., Lösing & Ebbing, 2021; Shen et al., 2020; Stål et al., 2021) received the highest suitability scores, while older magnetic or seismic-only fields were rated lower. For Greenland, the multivariate machine learning field by Colgan et al., 2022 received the most favorable ratings. The figure displays both the distribution of individual ratings and the average score for each model, highlighting a clear shift in expert preference toward newer, data-integrated approaches.

Fig. 1. Online expert survey results. Darker shades represent the percentage of answers from ‘Solid Earth modelers’, lighter shades represent the remaining respondents. Black circles indicate the average rating score of each GHF field with the corresponding scale shown on the right of the diagram.



In the freeform responses (Appendix B2) several experts emphasized the importance of explicitly considering both thermal conductivity and thermal gradients in future approaches, noting that many existing methods rely on proxies like seismic velocity or Curie depth. There was strong support for fields that include uncertainty estimates and for ensemble-based or weighted combinations of multiple fields to account for regional discrepancies. Many highlighted the need for high spatial resolution required by ice-sheet models, especially at the catchment scale, and warned against applying coarse continental-scale models inappropriately. While machine learning and multivariate approaches were generally seen as promising, concerns were raised about physical meaning and resolution. Respondents also stressed the importance of including oceanic shelf areas in GHF products, better crustal characterization, and integration of subglacial geological information. Finally, several experts called for broader recognition of the methodological diversity and challenges in GHF estimation, and for the ice-sheet modelling community to more actively engage with updated GHF fields rather than defaulting to outdated models.

3. Recommendations for ISMIP7

3.1. Top Recommended Field(s)

Based on natural breaks in the average suitability scores in both domains, we recommend the use of Colgan et al. (2022) for Greenland and either Stål et al. (2021) and/or Lösing & Ebbing (2021) for Antarctica. Following Colgan et al. (2022), we further recommend use of the “without NGRIP” heat flow solution for Greenland.

The most suitable fields are region-calibrated, continent-wide fields derived from multivariate approaches with robust uncertainty estimates. They rely on frameworks that integrate diverse datasets, but their predictive power depends heavily on the quality and representativeness of the region-specific training data and the resolution of underlying geophysical models. The recommendation to employ these fields for ISMIP7 marks a shift away from the (global) fields derived from forward methods that were the most popular boundary conditions used in ISMIP6.

3.2. Advances and Limitations

The Antarctic GHF field by Stål et al. (2021) resolves variations down to ~20 km, capturing some heterogeneities in crustal composition that strongly influence local ice dynamics. Despite its robustness and reproducibility, uncertainties are largest in regions with poorly constrained input data and relies on outdated seismic tomography models. The uncertainty at each grid cell is defined as the standard deviation of the ensemble of reference GHF values deemed most similar for that cell. Alternative metrics, such as information entropy, have also been calculated directly from the similarity distribution.

Similarly, Lösing & Ebbing (2021) use a machine learning approach to predict Antarctic GHF at scales of 55 km. While the method offers flexibility and incorporates diverse data types, the result is sensitive to quality and coverage of the training data and inherits uncertainties from its global calibration. Uncertainty is given as the maximum absolute difference across alternative model runs.

In Greenland, Colgan et al. (2022) compile 419 in-situ GHF measurements and apply the same method and resolution as in Lösing & Ebbing (2021). Two simulations, including and excluding the anomalously high NGRIP borehole value. The authors recommend the “without NGRIP” simulation, as NGRIP likely reflects localized subglacial hydrological processes rather than background lithospheric GHF. Uncertainties were estimated via jack-knife resampling of the measurements.

3.3. Palaeoclimatic influence

Local GHF can drift far from the steady-state values assumed in gridded GHF maps because paleoclimate still imprints the ice–bed boundary. At the DH-GAP04 borehole in West Greenland, for example, model reconstructions show that GHF has oscillated between 11 and 38 mW/m² over the last 100 kyr (Hartikainen et al., 2021), whereas the modern measurement is 28 mW/m² (Claesson Lijiedahl et al., 2016) shifts driven mainly by switches between ice-covered, cold-based and subaerial, warm-based states (Colgan et al., 2022). Similar time-lag effects operate inside thick ice: diffusion and snow-advection can delay surface-temperature signals by millennia (Calov & Hutter, 1997; Greve, 2019), so present basal gradients may still mirror past colder climates; at GRIP, the measured 61 mW/m² is ~20 % above the paleoclimatically corrected 51 mW/m² (Colgan et al., 2022; Dahl-Jensen et al., 1998). Because statistical GHF methods use point data drawn from regions with differing climate histories, they generally ignore this spatially variable palaeoclimate bias, leaving the true present-day GHF uncertain by amounts comparable to the model spread itself.

3.4. Best Practices for ISMIP Heat-Flow Boundary Condition

ISMIP6 is based on a “come as you are” approach that allows ice-sheet modellers to submit simulations performed with a range of spatial resolutions, stress balance approximations, initialization methods, physical processes, and parameterizations (Goelzer et al., 2018; Seroussi et al., 2019).

We recommend avoiding averaging different GHF fields, as their varying methodologies and strengths can be obscured in the process. Instead, we recommend using their published uncertainty bounds to drive an ensemble framework, sampling the upper and lower limits (and, ideally, the full continuous uncertainty distribution) with robust techniques such as Latin hypercube sampling (e.g., Helton & Davis, 2003) or bootstrap resampling (Davison & Hinkley, 1997). This approach captures the range of GHF realizations, with quantification of uncertainty propagation through the simulation. Statistical emulators of each GHF field can also be trained on the gridded datasets and their uncertainty layers, allowing rapid draws of new realizations without rerunning the full geophysical inversion.

For ice-flow models that employ GHF through a planar 2D ice-bed interface, and thereby do not explicitly include the effect of 3D topography on GHF, an empirically-derived topographic correction for subglacial GHF is available (Colgan et al., 2021). This correction, which can exceed a 100% enhancement of GHF in deeply-incised valleys, is also provided in the data repository associated with this article.

3.5. Fields to Avoid or Use with Caution

Many former foundational GHF products are now deprecated, due to improvements in data, prediction methods, and the number of in-situ measurements available for evaluation (Fox Maule et al., 2005, 2009; Purucker, 2013; Shapiro & Ritzwoller, 2004). Some were developed before many new seismic and magnetic data were acquired and therefore do not benefit from improved observations over the past decade.

Global fields (Davies, 2013; Gard & Hasterok, 2021; Goutorbe et al., 2011; Lucazeau, 2019; Pollack et al., 1993) lack integration of polar-specific data and are therefore less suited for ice-sheet modelling. GHF fields derived from interpolation of sparse direct GHF data offer limited value for constraining subglacial conditions.

Spectral Curie-depth mapping (Martos et al., 2017, 2018) suffer the most from poor data coverage: sparse airborne magnetics, unsuitable satellite wavelengths, and the tectonic, rather than thermal, control of anomaly wavelengths mean that Curie depths have to be considered with caution (Ebbing et al., 2009; Gard & Hasterok, 2021; Núñez Demarco et al., 2020).

3.6. Data Availability

The three recommended GHF fields (Colgan et al., 2022; Lösing & Ebbing, 2021; Stål et al., 2021) together with their uncertainties, and an additional topographically corrected version, are provided on NetCDF grids in 0.15 and 0.5 km resolution (Fahrner et al., 2025) and can be downloaded here: https://doi.org/10.5281/zenodo.1708387.

4. Future Directions and Data Needs for GHF Analysis

Advancing GHF fields requires both methodological enhancements and improved data collection. Future efforts should focus on incorporating updated datasets and refining thermal parameterization techniques, as well as providing robust uncertainty estimates.

Recommendations:

1. **Integrate diverse datasets**: Combine geophysical and geological data to create more comprehensive products.
2. **Couple statistical and physical models**: Link empirical/statistical GHF estimates with solid Earth models, enabling improved geological plausibility.
3. **Enhance spatial resolution**: Develop fields that better capture local variability, particularly in regions with complex geology and high ice-sheet sensitivity to GHF variations. Report on differences between inherent spatial variability and resolution.
4. **Use topographic correction** (e.g. Colgan et al., 2021)
5. **Focus on Uncertainty**: Include robust quantification and clear reporting of uncertainties to enable better interpretation.
6. **Extend beyond coastal boundaries to include the continental shelf:** Seamlessly carry heat flow fields across the grounding line into the near-shore ocean and shelf, capturing the land-ocean transition that controls grounding-zone melt and ice-shelf buttressing.

5. Conclusion

GHF exerts a strong control on the basal thermal state and dynamics of polar ice-sheets. Our review of existing continent-wide GHF fields highlights a transition in the community toward data-integrated and probabilistic frameworks. While early forward approaches laid foundational work, they often lack the resolution or uncertainty quantification needed for modern ice-sheet applications. Through expert elicitation, we find strong support for using multivariate methods that combine geological and geophysical information, such as those by Stål et al. (2021), Lösing & Ebbing (2021), and Colgan et al. (2022). These outperform earlier fields in their ability to represent local heterogeneity, include uncertainty estimates, and align with observed basal conditions.

Finally, continued progress in heat flow predictions depends on both methodological advances and new data (Burton-Johnson, Dziadek, Martin, et al., 2020). Remote sensing techniques, particularly microwave radiometry, show great potential for indirectly constraining basal temperatures at scale (Yardim et al., 2022). Moving forward, coupling machine learning and physical models, integrating data across disciplines, and enhancing spatial resolution will be critical to improve GHF fields.

In preparation for ISMIP7, we provide three recommended GHF fields on standard grids along with uncertainty products and optional topographic corrections (see Section 3.6). We strongly recommend that future efforts move away from outdated or interpolated GHF maps and adopt data-driven fields that reflect the current state of knowledge.

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	AGB - Project administration; Validation; Resources; Investigation (survey governance) TZ - Investigation; Interpretation; Writing – original draft HS - Investigation; Interpretation; Writing – original draft FSM - Investigation; Interpretation; Writing – original draft DF - Data curation; Visualization SHS - Interpretation; Writing – original draft
Competing interests	The authors declare no competing interests.

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Appendix A

A1 GHF Methods Overview

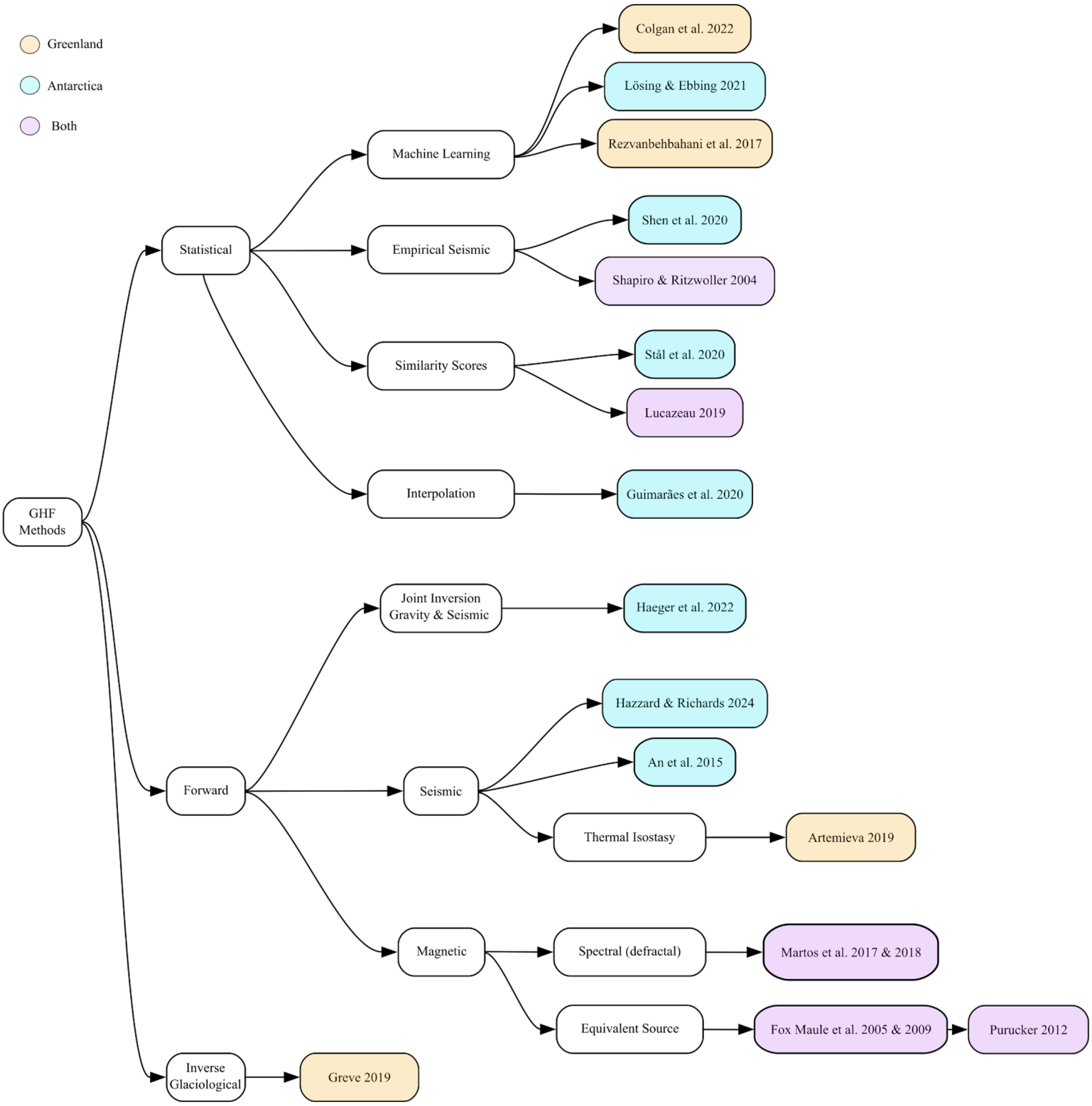
Various approaches have been applied to estimate GHF in polar regions (Table 1, Fig. A1); in the following, we outline the assumptions and methodologies underlying these approaches.

Forward methods of GHF usually use the 1D-steady-state heat equation to derive the thermal field based on isotherms and interfaces estimated from geophysical data (An et al., 2015; Artemieva, 2019; Fox Maule et al., 2005, 2009; Haeger et al., 2022; Martos et al., 2017, 2018; Purucker, 2013). This includes estimates on crustal thickness, radiogenic heat production, thermal conductivities, and mantle heat contributions. While forward methods can offer physically grounded estimates, they are sensitive to parameter assumptions and data limitations. In particular, Curie isotherm depth estimates are controversial. While the base of magnetic sources is often interpreted as the Curie depth, it may reflect the geometry of the crystalline crust rather than the thermal structure (Pappa & Ebbing, 2021). Additionally, many forward methods assume homogeneous thermal properties over broad regions, neglecting localized variations caused by differing rock types or structural complexities. Furthermore, the vertical distribution of heat production is often estimated using depth-decay functions or layered approximations, assuming uniform values. For regional-scale analysis, this approach underestimates local anomalies due to geological heterogeneity.

Some of these assumptions can be circumvented by using geostatistical techniques, similarity functions, or machine learning (e.g., Colgan et al., 2022; Lösing & Ebbing, 2021; Lucazeau, 2019; Rezvanbehbahani et al., 2017; Shapiro & Ritzwoller, 2004; Shen et al., 2020; Stål et al., 2021). These approaches reduce reliance on rigid structural or thermal property assumptions, offering a probabilistic framework that better represents uncertainty. By leveraging correlations between temperature gradients, thermal conductivity, heat production, and geophysical observations, these methods can capture enhanced spatial variability. However, despite their flexibility, the accuracy and reliability remain tightly coupled to the quality, density, and representativeness of the input data. Probabilistic methods (e.g., Bayesian) can provide credible intervals that reflect the confidence in each estimate. In many regions, uncertainty bounds on GHF can exceed ±20–30 mW/m² (Stål et al., 2021). Reliable bounds represent not only measurement or methodological errors, but also uncertainty in underlying physical parameters.

Hazzard & Richards (2024) integrate elements of both forward method and statistical techniques, combining physical constraints with probabilistic adjustments to refine GHF estimates. Greve (2019) scales the GHF field by Pollack et al. (1993) and tweaks it with an ice-sheet model to fit basal-temperature observations from five ice cores. Guimarães et al. (2020) interpolate IHFC (International Heat Flow Commission) data, estimates of magmatic heat in volcanic regions, and inferred basal temperatures in subglacial lakes, filling gaps with clast-derived proxy GHF by Goodge (2018) and references therein.

Fig. A1. Taxonomy of published GHF products used for polar ice-sheet studies. Box colours denote geographic coverage: yellow = Greenland, turquoise = Antarctica, mauve = both ice-sheets. The scheme illustrates both the methodological diversity and the spatial imbalance of available GHF models.



Appendix B

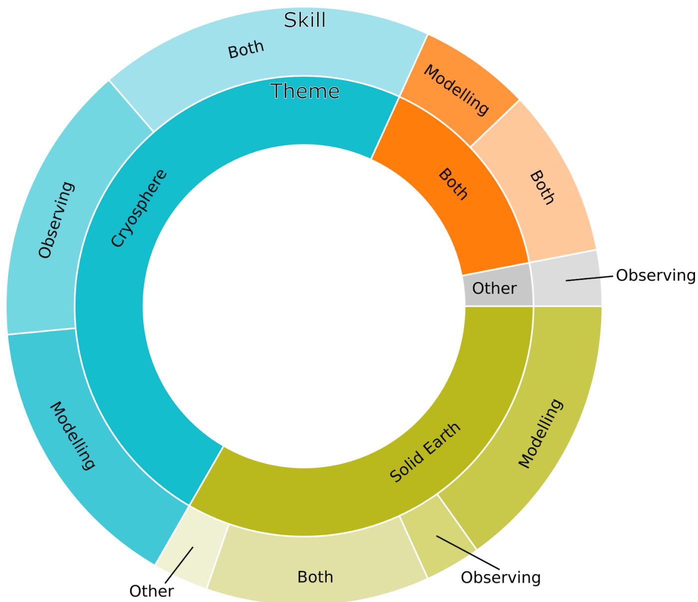
B1 Survey

Expert Panel Selection and Participant Demographics

The expert inclusion criterion for participation in this survey was defined as providing proof of either: (1) peer-reviewed first-author experience with geothermal heat flow in poorly understood environments, and/or (2) peer-reviewed co-author experience with geothermal heat flow in Greenland or Antarctica. We identified 86 candidate experts from both the heat flow and ice-sheet communities, who were invited to complete the survey.

Participants were asked to indicate their thematic background (*Cryosphere*, *Solid Earth*, *Both*, or *Other*) and their skills background (*Modelling*, *Observing*, *Both*, or *Other*), with an option to specify details if selecting "Other". Figure B1_1 shows the composition of participants based on background and skill. Nearly half (16) work primarily on the Cryosphere, one-third (11) on Solid Earth, and a smaller group (5) span both Cryosphere and Solid Earth, with a single respondent falling into an “Other” category. When it comes to skills, 12 participants identified as Modellers, 7 as Observers, and 13 as proficient in both Modelling and Observing, while again one person chose “Other”. At the end of the survey, respondents could choose whether their responses should be attributed (with their name listed in the publication) or remain pseudonymized.

Fig. B1_1. Chart illustrating the composition of survey respondents by thematic and skills background. The inner ring shows the four thematic categories: Solid Earth, Cryosphere, Both, and Other, while the outer ring breaks each theme down into respondents whose primary skill background is Modelling, Observing, Both, or Other. Segment size is proportional to the number of participants in each category.



We acknowledge that in conducting our expert elicitation, there is a large overlap between the experts organizing the survey and the experts responding to the survey. This is perhaps inherent when conducting a highly specialized expert elicitation. Our survey team made every attempt to ensure that the survey feedback was collected in a fair and transparent fashion. This included consulting the survey structure and protocol with a survey expert from outside the heat flow and ice-sheet communities. This arm's length expert served as data controller responsible for pseudonymizing data and evaluating expert inclusion criterion. GDPR (General Data Protection Regulation) compliance was approved via the University of Copenhagen using the SurveyXact software platform.

Informed Consent and Data Protection

Prior to participating in the survey, all respondents were presented with an informed consent statement outlining the scope and handling of personal data. By providing consent, participants agreed to the collection, storage, and processing of their personal information (including name, email, and survey responses) for the purpose of this research. The survey was administered via SurveyXact, and all data were securely stored on a server maintained by the University of Copenhagen.

Participants were informed that the survey results will be published in aggregated form in a peer-reviewed journal article. At the end of the survey, participants were given the option to have their responses either attributed (with their name listed among contributing experts) or pseudonymized. While full anonymization is not feasible due to the need to assess inclusion criteria, all data were initially handled by a researcher who is independent of the geothermal heat flow and ice-sheet modelling communities, thereby ensuring impartial data management prior to transfer to the core research team.

Participation in the survey was restricted to individuals aged 18 years or older and was entirely voluntary. Participants could withdraw at any time prior to submission by simply closing their browser window. Rights under the General Data Protection Regulation (GDPR) were fully respected, as outlined in the University of Copenhagen's privacy policy: https://informationssikkerhed.ku.dk/english/protection-of-information-privacy/privacy-policy/.

Withdrawal of consent is effective from the time of request and does not affect the legality of data processing conducted prior to withdrawal.

Data controller is University of Copenhagen, CVR no. 29979812. The research project is co-headed by Anne Gravsholt Busck, Professor at University of Copenhagen (Øster Voldgade 10, DK-1350 Copenhagen K), who can be contacted by email agb@ign.ku.dk or phone +45 3532 2564.

Survey Setup

The survey elicited structured expert judgment on published GHF fields and their suitability as basal boundary conditions for ice-sheet simulations. Sixteen models, presented in chronological order (beginning with the oldest), were evaluated using a common rubric and optional free-text rationale to capture context-specific strengths and limitations. This design balances comparability (standardized information across publications) with nuance (expert commentary), producing both quantitative suitability scores and qualitative insights to guide model selection.

Fig. B1_2. Example page from the heat flow expert survey, showing model #1 by Shapiro & Ritzwoller (2004). Participants are presented with the citation, links to datasets, information on domain, resolution, and a short summary of the method. Primary heat flow results from the publication are shown. Additional subfigures were greyed out to standardize the information presented across all models. Participants are asked to assess each model and optionally provide feedback.

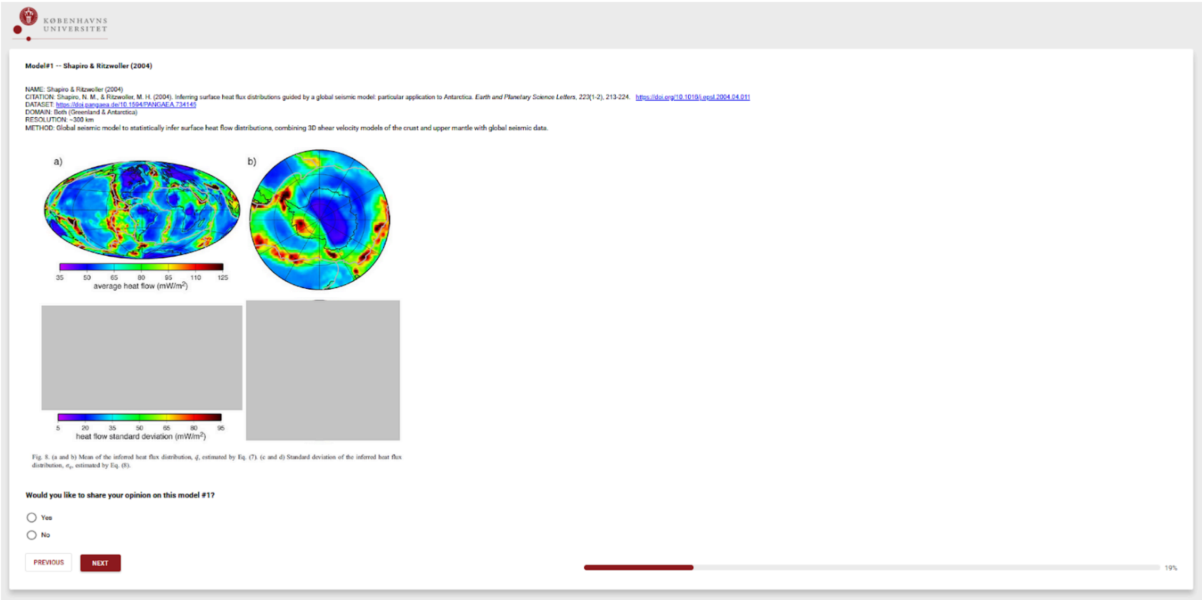
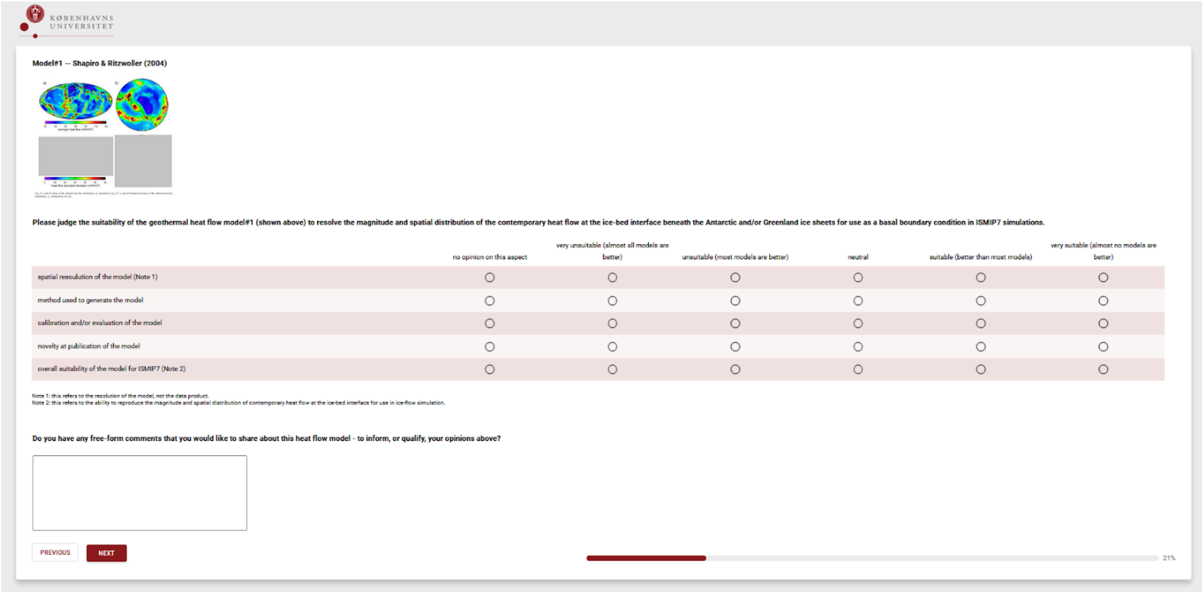


Fig. B1_3. Expert evaluation interface for geothermal heat flow model #1 Shapiro & Ritzwoller (2004) within the structured heat flow model survey. Participants are asked to assess the model's suitability as a basal boundary condition for ice-sheet simulations (e.g., ISMIP7), based on criteria such as spatial resolution, method, calibration, novelty, and overall applicability. An optional comment box is provided to elaborate on or qualify their responses.



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Model#1 -- Shapiro & Ritzwoller (2004)

Please judge the suitability of the geothermal heat flow model#1 (shown above) to resolve the magnitude and spatial distribution of the contemporary heat flow at the ice-bed interface beneath the Antarctic and/or Greenland ice sheets for use as a basal boundary condition in ISMIP7 simulations.

	no opinion on this aspect	very unsuitable (almost all models are better)	unsuitable (most models are better)	neutral	suitable (better than most models)	very suitable (almost no models are better)
spatial resoulution of the model (Note 1)	○	○	○	○	○	○
method used to generate the model	○	○	○	○	○	○
calibration and/or evaluation of the model	○	○	○	○	○	○
novelty at publication of the model	○	○	○	○	○	○
overall suitability of the model for ISMIP7 (Note 2)	○	○	○	○	○	○

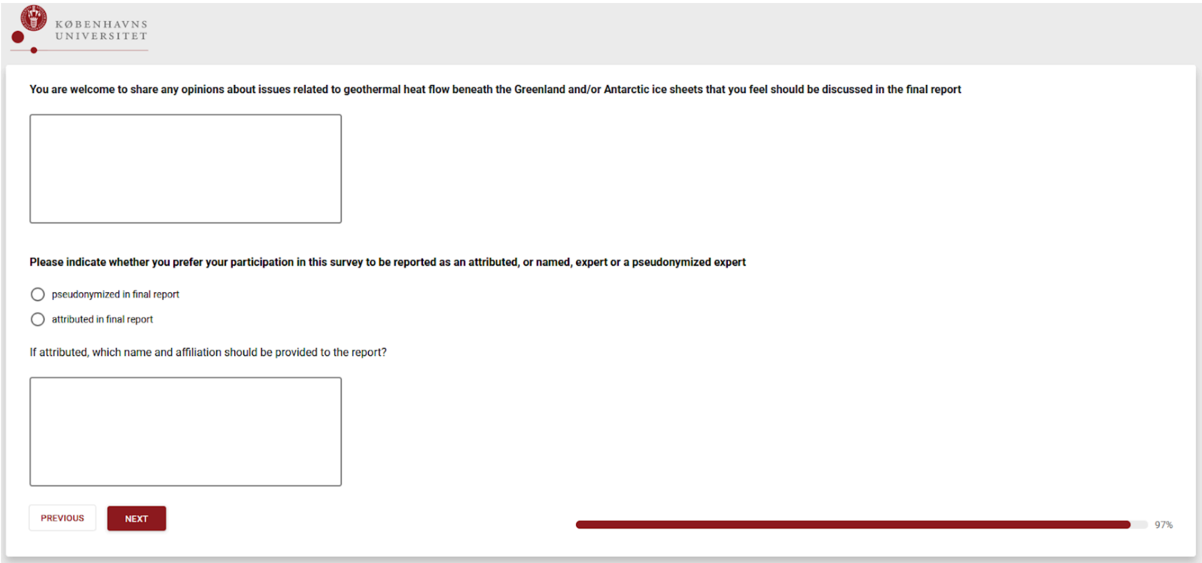
Note 1: this refers to the resolution of the model, not the data product.
Note 2: this refers to the ability to reproduce the magnitude and spatial distribution of contemporary heat flow at the ice-bed interface for use in ice-flow simulation.

Do you have any free-form comments that you would like to share about this heat flow model - to inform, or qualify, your opinions above?

PREVIOUS NEXT

21%

Fig. B1_4. Final section of the heat flow expert survey, inviting participants to provide open-ended comments on geothermal heat flow beneath Greenland and/or Antarctica. Experts can choose whether their responses are attributed or pseudonymized in the final report, with an optional field to specify name and affiliation if attribution is preferred.



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You are welcome to share any opinions about issues related to geothermal heat flow beneath the Greenland and/or Antarctic ice sheets that you feel should be discussed in the final report

Please indicate whether you prefer your participation in this survey to be reported as an attributed, or named, expert or a pseudonymized expert

○ pseudonymized in final report
○ attributed in final report

If attributed, which name and affiliation should be provided to the report?

PREVIOUS NEXT

97%

B2 Survey Results

This appendix summarizes the expert survey that guided our GHF recommendation for ISMIP-7 (Section 3). Respondents rated each candidate model against a set of diagnostic criteria: Method, Calibration/Evaluation, spatial resolution and variability, novelty at time of publication, and overall suitability for integration with ice-sheet models, using the five-point suitability scale described in the legend below. “No opinion” or blank responses were excluded from the averaging.

For every criterion we convert the qualitative choices (“very unsuitable” … “very suitable”) to equally spaced numerical scores (1 … 5). For each publication, we report: the average score, the (possibly multi-valued) mode, the mode count, the number of valid responses N, and the modal share (mode count/N) (Tables B2_1 – B2_5).

Figs. B2_1–B2_5 visualize the response distributions as 100%-stacked bars for each publication, ordered left-to-right by the combined share of favourable ratings (4 + 5), with “No opinion” or blank responses shown for transparency. The plots highlight the range of community support and uncertainty attached to each candidate GHF field.

Figs. B2_6–B2_21 show individual publication ratings by criterion, with 100%-stacked bars for each rating bin stratified by respondent background (theme and skill). Bars sum up to 100% within each criterion for that publication, allowing to see where views diverge between Cryosphere vs Solid Earth and Modellers vs Observers.

Legend Key

NA - No answer
NO - "no opinion on this aspect",
1 - "very unsuitable (almost all models are better)"
2 - "unsuitable (most models are better)"
3 - "neutral"
4 - ”suitable (better than most models)"
5 - "very suitable (almost no models are better)"

Table B2_1. Statistical results from the expert survey on ‘The method used to generate the GHF field’. Responses were mapped to numeric scores. N = number of answers.

Publication	**Avg. Score**	**Mode**	**Mode Count**	**N**	**Share**
Shapiro & Ritzwoller (2004)	3.27	4	11	22	0.5
Fox Maule et al. (2005, 2009)	2.62	3	7	24	0.29
Purucker (2012)	2.41	3, 1	6	17	0.35
An et al. (2015)	3.26	3	8	19	0.42
Rezvanbehbahani et al. (2017)	3.33	4	6	12	0.5
Martos et al. (2017, 2018)	2.65	3	9	23	0.39
Artemieva (2019)	2.75	3	3	8	0.38
Greve (2019)	2.12	2	6	16	0.38
Lucazeau (2019)	3.71	4	8	14	0.57
Guimarães et al. (2020)	2.92	3	5	12	0.42
Shen et al. (2020)	3.67	4	11	18	0.61
Stål et al. (2020)	4.13	4	16	23	0.7
Lösing and Ebbing (2021)	4.1	4	9	21	0.43
Colgan et al. (2022)	4.33	5	3	6	0.5
Haeger et al. (2022)	3.56	3	7	16	0.44
Hazzard and Richards (2024)	3.64	4	9	14	0.64

Table B2_2. Statistical results from the expert survey on ‘The calibration and/or evaluation of the GHF field’. Responses were mapped to numeric scores. N = number of answers.

Publication	**Avg. Score**	**Mode**	**Mode Count**	**N**	**Share**
Shapiro & Ritzwoller (2004)	3.17	3	11	23	0.48
Fox Maule et al. (2005, 2009)	2.58	2, 3	7	24	0.29
Purucker (2012)	2.59	3	8	17	0.47
An et al. (2015)	3.18	3	9	17	0.53
Rezvanbehbahani et al. (2017)	3	3, 4	4	11	0.36
Martos et al. (2017, 2018)	2.74	3	11	23	0.48
Artemieva (2019)	2.75	3	4	8	0.5
Greve (2019)	2.2	2, 3	6	15	0.4

Lucazeau (2019)	3.54	3	6	13	0.46
Guimarães et al. (2020)	3.33	3	6	12	0.5
Shen et al. (2020)	3.5	3, 4	7	18	0.39
Stål et al. (2020)	4.04	4	12	23	0.52
Lösing and Ebbing (2021)	3.71	4	12	21	0.57
Colgan et al. (2022)	4.5	5, 4	3	6	0.5
Haeger et al. (2022)	3.27	3	9	15	0.6
Hazzard and Richards (2024)	3.17	4	6	12	0.5

Table B2_3. Statistical results from the expert survey on ‘The spatial resolution/variability of the GHF field’. Responses were mapped to numeric scores. N = number of answers.

Publication	Avg. Score	Mode	Mode Count	N	Share
Shapiro & Ritzwoller (2004)	1.96	2	11	23	0.48
Fox Maule et al. (2005, 2009)	2.27	3	9	26	0.35
Purucker (2012)	2.26	2	9	19	0.47
An et al. (2015)	2.7	3	7	20	0.35
Rezvanbehbahani et al. (2017)	2.67	3	5	12	0.42
Martos et al. (2017, 2018)	3.44	4	11	25	0.44
Artemieva (2019)	2.25	2	4	8	0.5
Greve (2019)	2.31	1	6	16	0.38
Lucazeau (2019)	3	2	6	14	0.43
Guimarães et al. (2020)	2.67	2	5	12	0.42
Shen et al. (2020)	3.16	3	8	19	0.42
Stål et al. (2020)	4.39	4	12	23	0.52
Lösing and Ebbing (2021)	3.9	4	14	21	0.67
Colgan et al. (2022)	4.43	4	4	7	0.57
Haeger et al. (2022)	2.94	3	7	17	0.41
Hazzard and Richards (2024)	2.93	2	6	15	0.4

Table B2_4. Statistical results from the expert survey on ‘The novelty at time of publication of the GHF field’. Responses were mapped to numeric scores. N = number of answers.

Publication	Avg. Score	Mode	Mode Count	N	Share
Shapiro & Ritzwoller (2004)	4.17	5	10	23	0.43
Fox Maule et al. (2005, 2009)	3.73	4	16	26	0.62
Purucker (2012)	2.88	3	7	17	0.41
An et al. (2015)	3.22	3	7	18	0.39
Rezvanbehbahani et al. (2017)	4.25	4, 5	5	12	0.42
Martos et al. (2017, 2018)	3.36	3	10	25	0.4
Artemieva (2019)	3	2, 4	3	8	0.38
Greve (2019)	2.62	2	6	16	0.38
Lucazeau (2019)	3.69	3	6	13	0.46
Guimarães et al. (2020)	3	3, 4, 2	4	12	0.33
Shen et al. (2020)	3.26	3	13	19	0.68
Stål et al. (2020)	4.04	4	12	24	0.5
Lösing and Ebbing (2021)	4.05	4	13	22	0.59
Colgan et al. (2022)	3.86	3	3	7	0.43
Haeger et al. (2022)	3.59	3	8	17	0.47
Hazzard and Richards (2024)	3.77	4	8	13	0.62

Table B2_5. Statistical results from the expert survey on ‘The overall suitability of the GHF field’. Responses were mapped to numeric scores. N = number of answers.

Publication	Avg. Score	Mode	Mode Count	N	Share
Shapiro & Ritzwoller (2004)	2.29	2	11	24	0.46
Fox Maule et al. (2005, 2009)	1.84	1	12	25	0.48
Purucker (2012)	1.95	2	8	20	0.4
An et al. (2015)	2.6	3	6	20	0.3
Rezvanbehbahani et al. (2017)	2.5	2	5	12	0.42
Martos et al. (2017, 2018)	2.71	3	8	24	0.33
Artemieva (2019)	2.25	2	4	8	0.5
Greve (2019)	1.5	1	10	16	0.62

Lucazeau (2019)	2.46	3	5	13	0.38
Guimarães et al. (2020)	2.5	3	5	12	0.42
Shen et al. (2020)	3.32	4, 2	6	19	0.32
Stål et al. (2020)	4.18	4	14	22	0.64
Lösing and Ebbing (2021)	4.05	4	11	21	0.52
Colgan et al. (2022)	4.29	5, 4	3	7	0.43
Haeger et al. (2022)	3.29	3	8	17	0.47
Hazzard and Richards (2024)	3.07	4	7	15	0.47

Fig. B2_1. Result of expert survey rating of the ‘method’ of published GHF products for ISMIP-7. Each stacked bar represents one publication and sums to 100 % of respondents (N = 32). See legend key for response options. Publications are ordered from left to right by the combined share of favourable ratings (4 + 5).

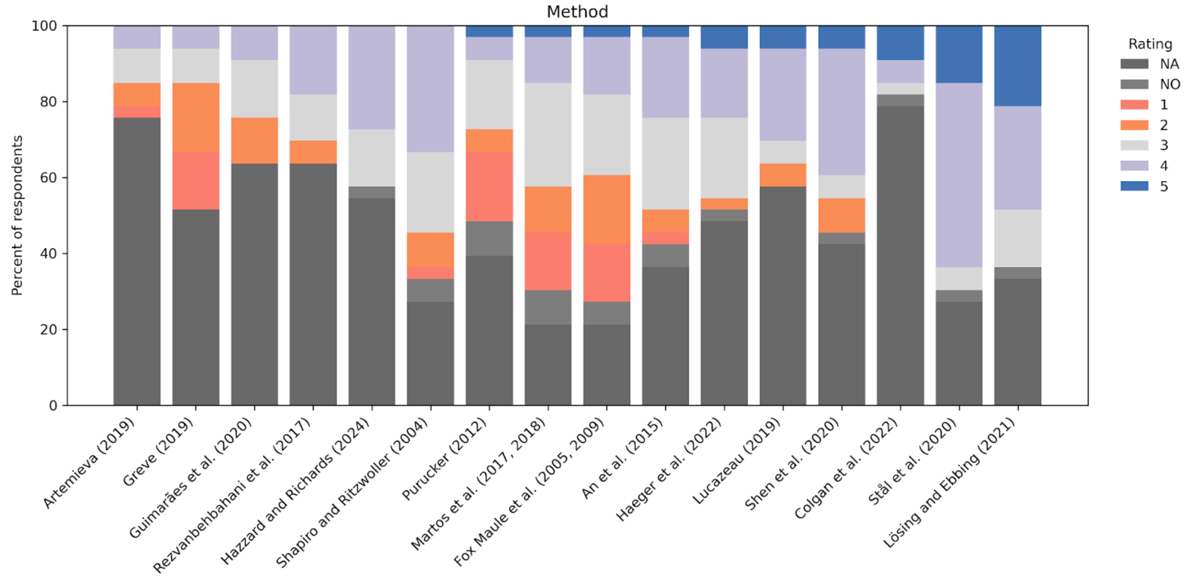


Fig. B2_2. Result of expert survey rating of the ‘calibration and/or evaluation’ of published GHF products for ISMIP-7. Each stacked bar represents one publication and sums to 100 % of respondents (N = 32). See legend key for response options. Publications are ordered from left to right by the combined share of favourable ratings (4 + 5).

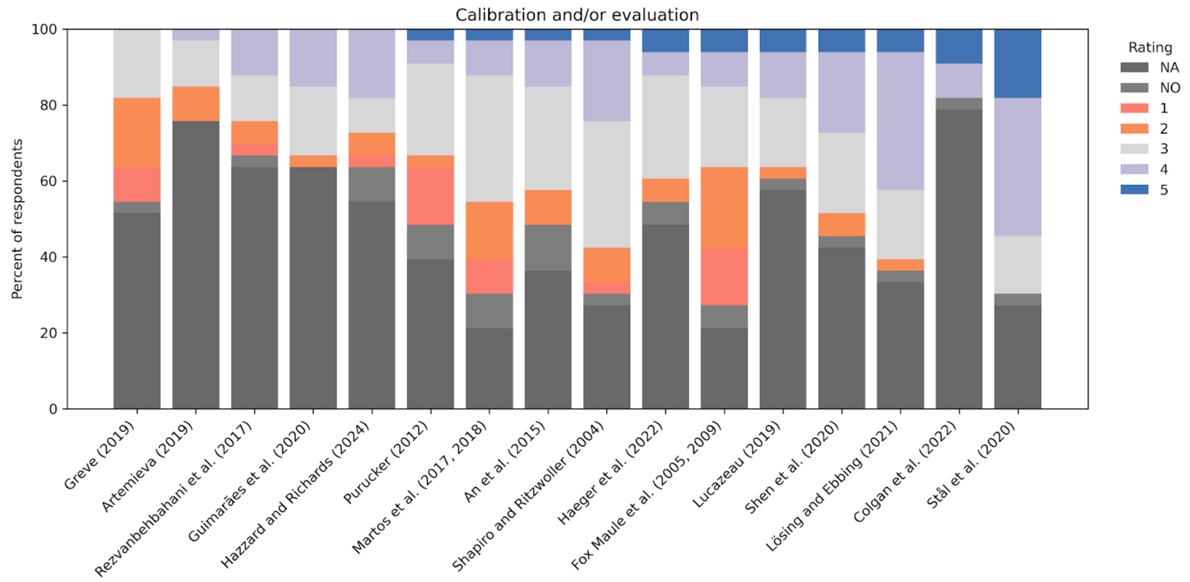


Fig. B2_3. Result of expert survey rating of the 'spatial resolution/variability' of published GHF products for ISMIP-7. Each stacked bar represents one publication and sums to 100 % of respondents (N = 32). See legend key for response options. Publications are ordered from left to right by the combined share of favourable ratings (4 + 5).

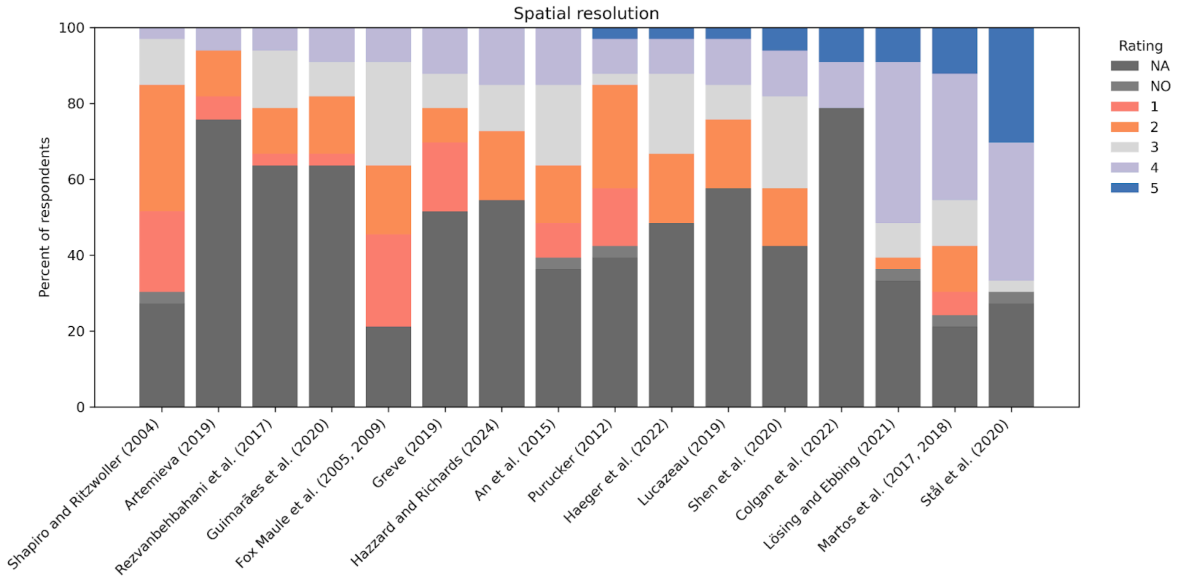


Fig. B2_4. Result of expert survey rating of the 'novelty at time of publication' of published GHF products for ISMIP-7. Each stacked bar represents one publication and sums to 100 % of respondents (N = 32). See legend key for response options. Publications are ordered from left to right by the combined share of favourable ratings (4 + 5).

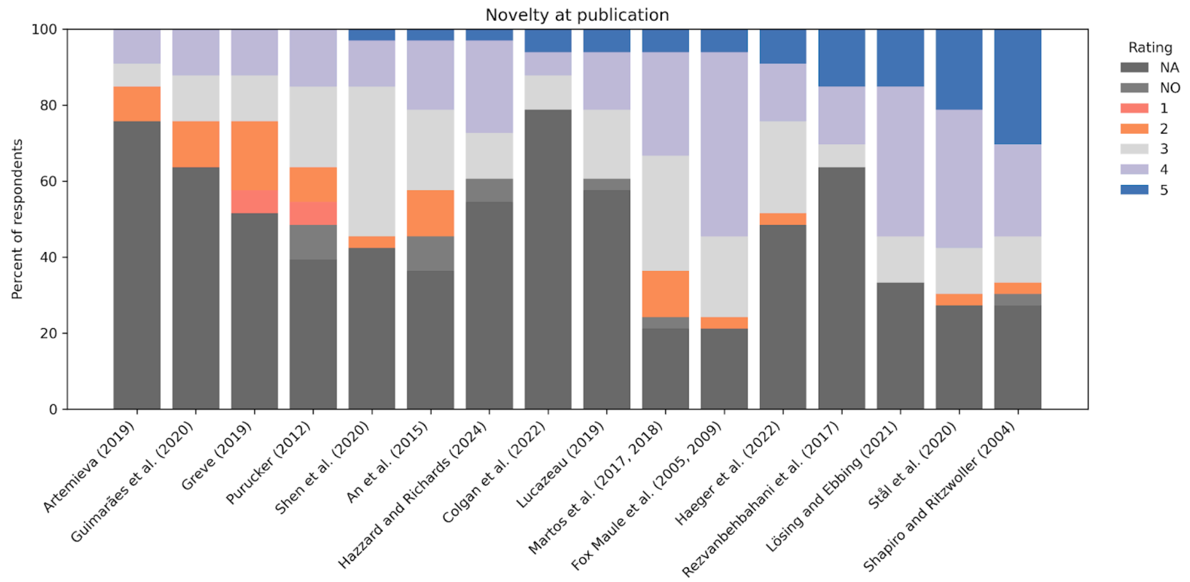
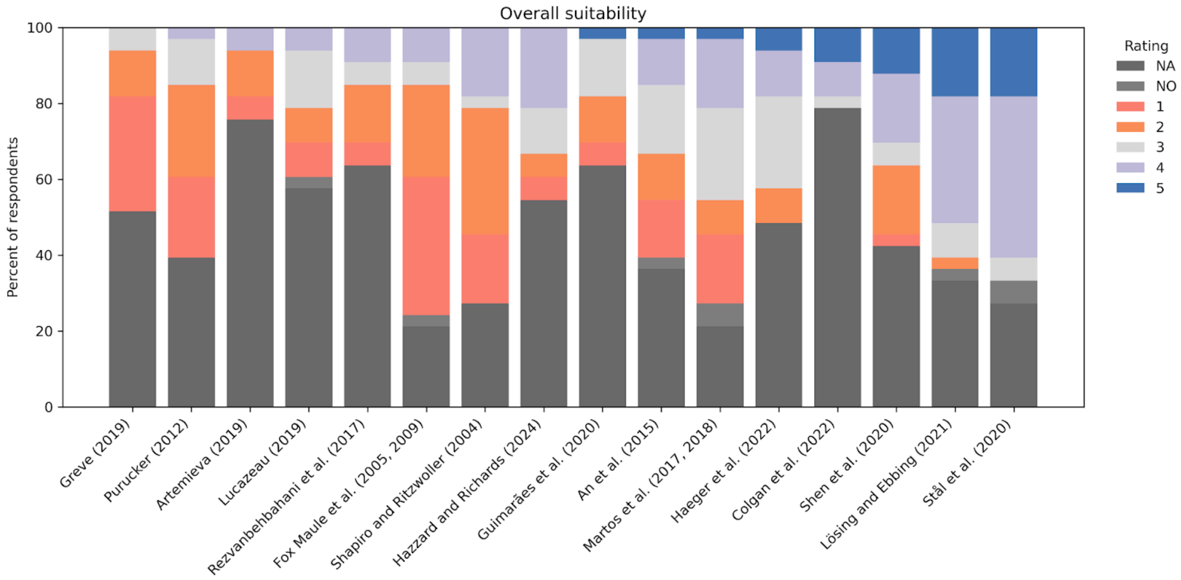


Fig. B2_5. Result of expert survey rating of the ‘overall suitability’ of published GHF products for ISMIP-7. Each stacked bar represents one publication and sums to 100 % of respondents (N = 32). See legend key for response options. Publications are ordered from left to right by the combined share of favourable ratings (4 + 5).



Individual Ratings

Fig. B2_6. Expert ratings for the Shapiro & Ritzwoller (2004) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

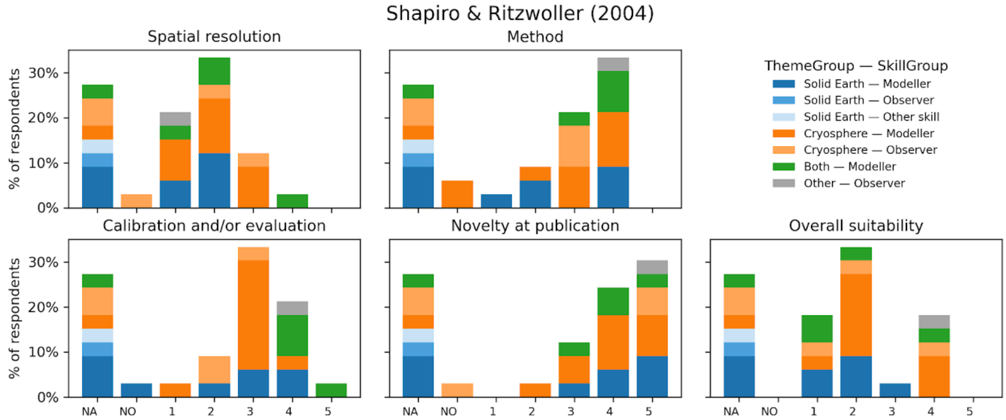


Fig. B2_7. Expert ratings for the Fox Maule et al. (2005, 2009) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

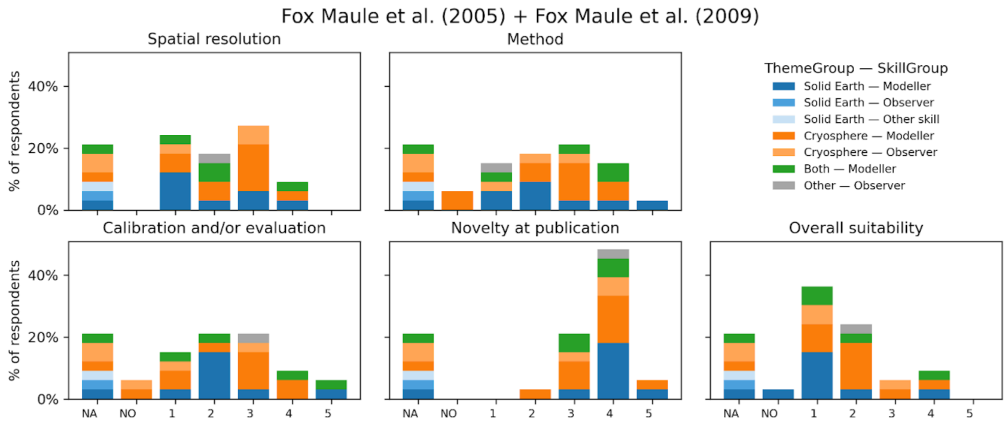


Fig. B2_8. Expert ratings for the Purucker et al. (2012) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

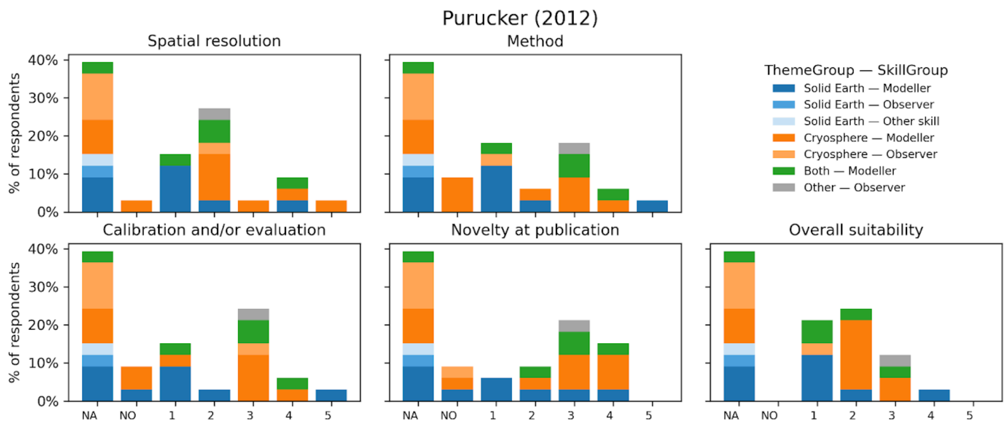


Fig. B2_9. Expert ratings for the An et al. (2015) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

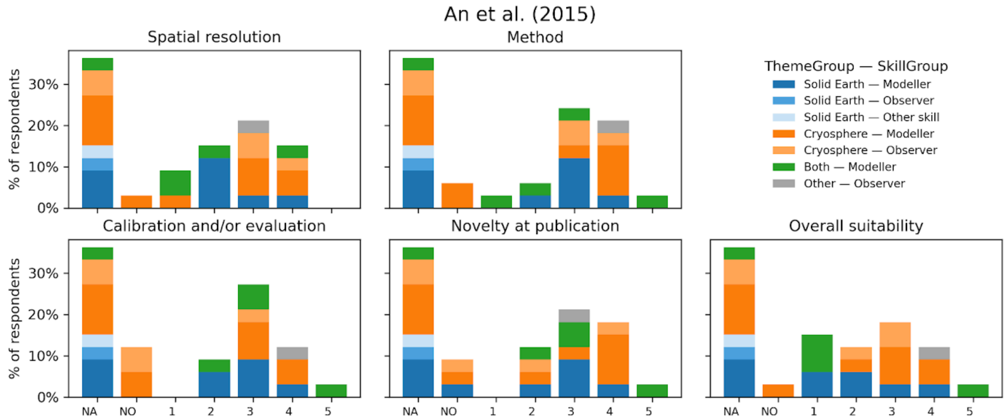


Fig. B2_10. Expert ratings for the Martos et al. (2017, 2018) GHF products by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

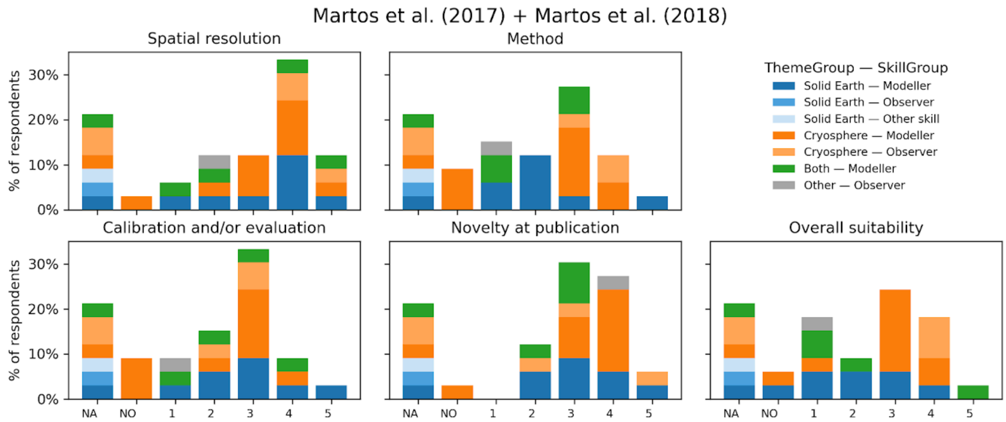


Fig. B2_11. Expert ratings for the Rezvanbehbahani et al. (2017) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

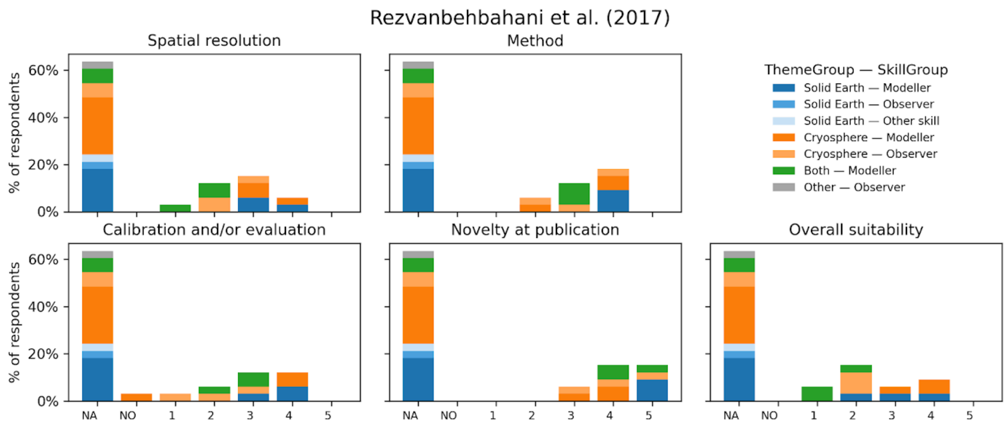


Fig. B2_12. Expert ratings for the Artemieva (2019) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

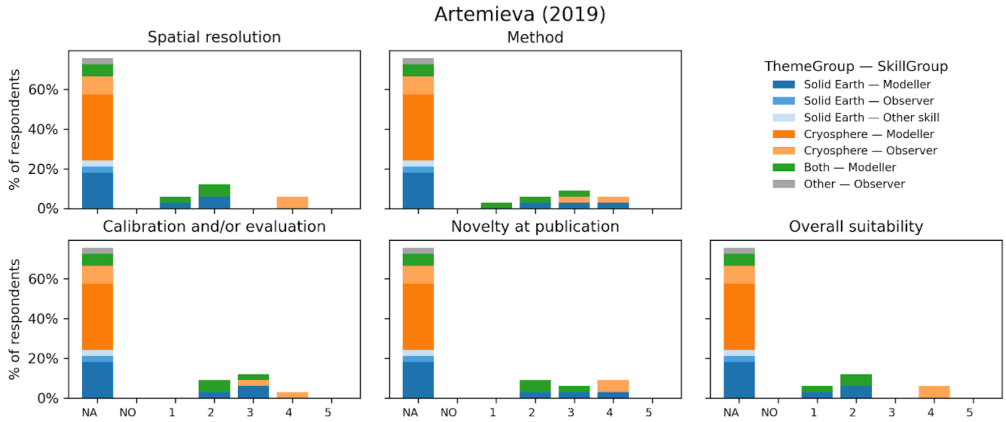


Fig. B2_13. Expert ratings for the Greve (2019) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

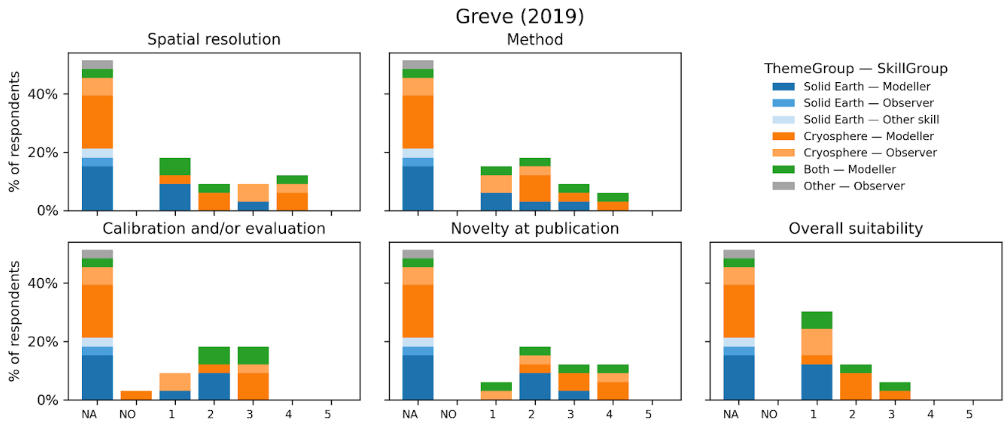


Fig. B2_14. Expert ratings for the Lucazeau et al. (2019) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

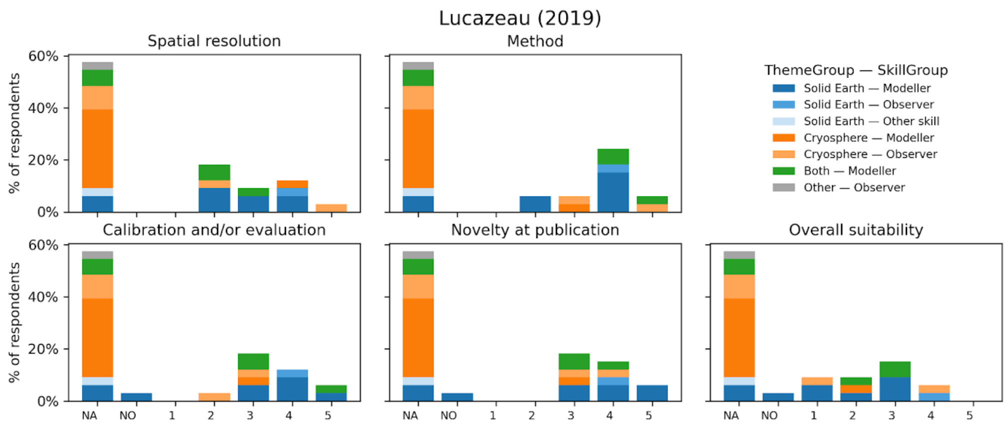


Fig. B2_15. Expert ratings for the Guimarães et al. (2020) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

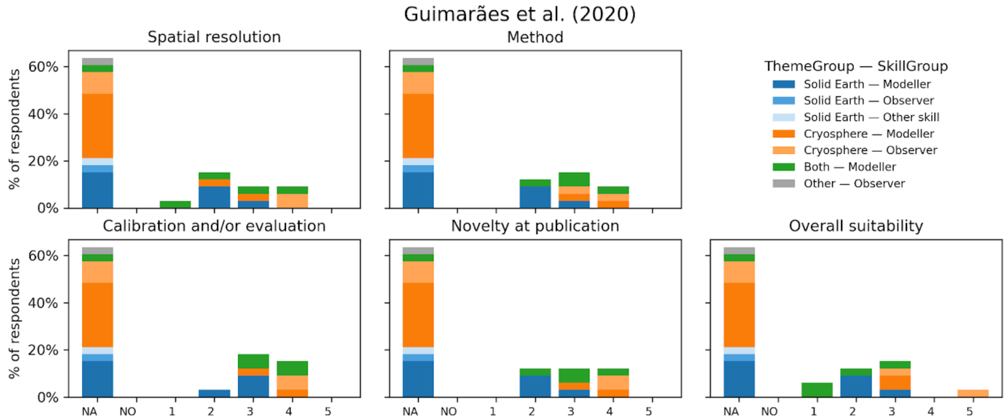


Fig. B2_16. Expert ratings for the Shen et al. (2020) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

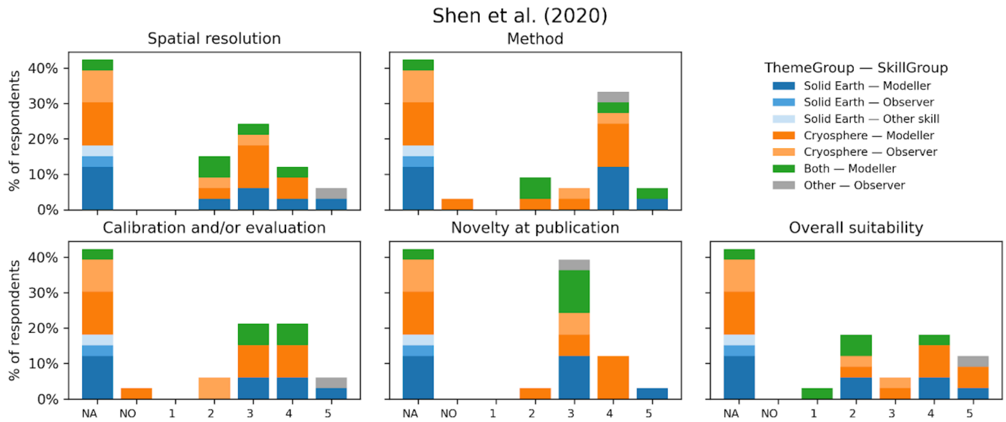


Fig. B2_17. Expert ratings for the Stål et al. (2021) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

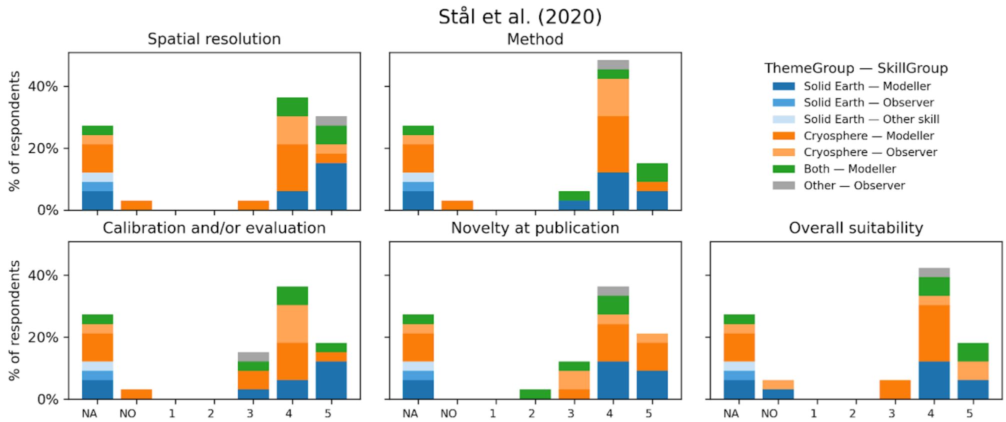


Fig. B2_18. Expert ratings for the Lösing et al. (2021) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

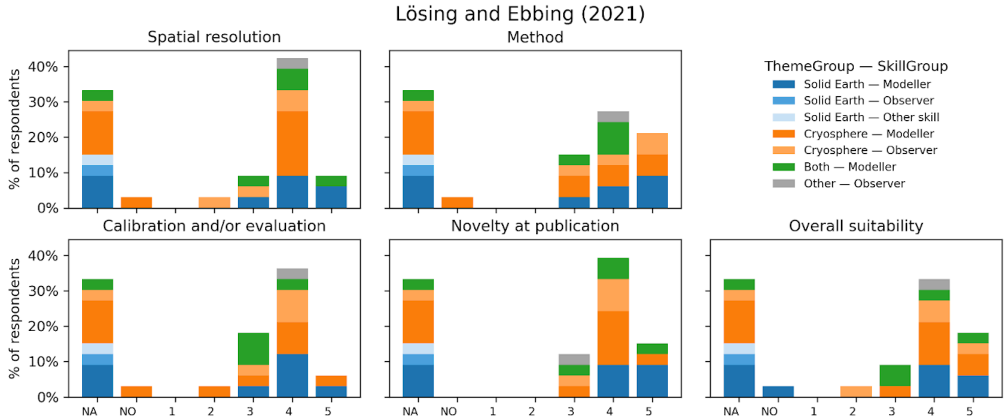


Fig. B2_19. Expert ratings for the Colgan et al. (2022) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

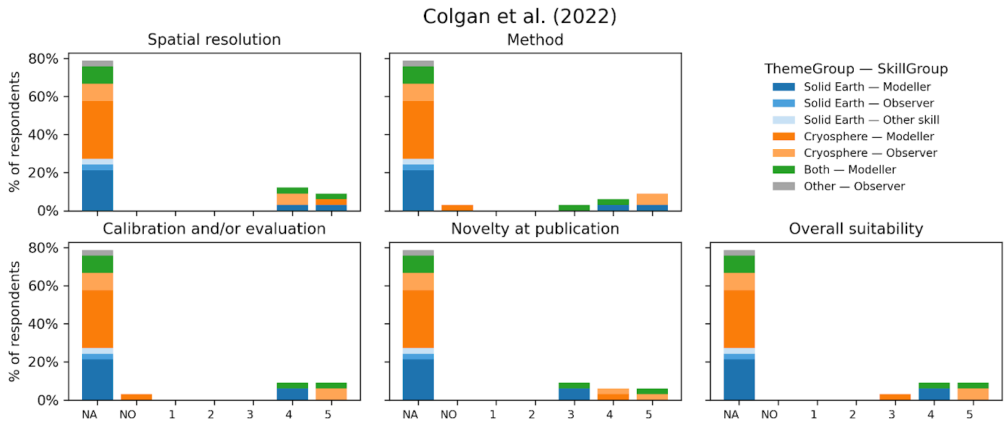


Fig. B2_20. Expert ratings for the Haeger et al. (2022) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).

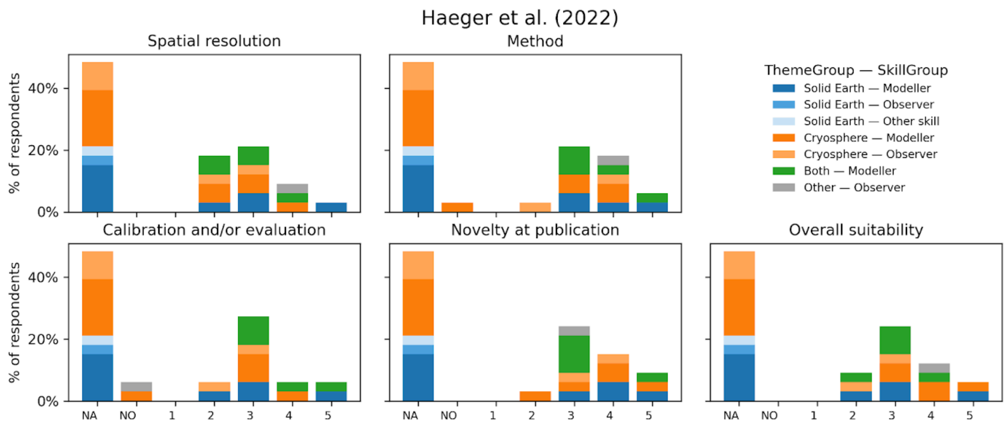
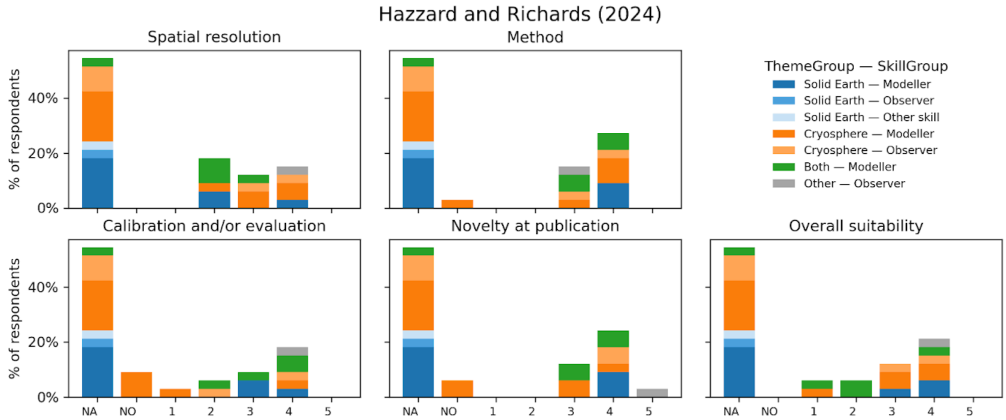


Fig. B2_21. Expert ratings for the Hazzard and Richards et al. (2024) GHF product by criterion. For each panel, stacked bars show the percentage of respondents (N = 32), with colors indicating respondent background (theme and skill group).



Freeform Comments from the Survey

General Comments:

-*Proxies such as seismic velocity, Curie depth, gravity etc are inherently tied to temperature, whereas the dominant contribution to uncertainty in heat flow determinations is almost always thermal conductivity. More reliable mapping methods should explicitly consider both thermal conductivity and thermal gradient.* *(Solid Earth, Observing)*

-"Speaking as someone with decades of paleo ice sheet modelling experience/expertise, I would offer the following:

1) Only consider GHF models that have detailed/explicit/meaningful uncertainty estimates. After picking the 3 mostly defensible candidates for each region, examine to what extent uncertainty ranges are mutually consistent. Ask the relevant authors to jointly discuss regions with significant inconsistencies.

2) Verify that all these models are actually for the ice/bed boundary. I've wondered how much this ambiguity might go toward explaining some of the large discrepancies between different models.

3) If possible, for those of us doing paleo spinup with coupled bedthermal models, assemble a deeper (in the 3-6 km depth range) bedthermal model/inference for use as a boundary condition.

4) For each ice sheet, pick out at least 3 GHF models: lower bound, best guess, upper bound. As lower/upper bound will likely vary regionally, might eg consider syntheses of MIN(reasonable models) and MAX(reasonable models) for the end members.

5) The GHF at the ice bed interface is not in equilibrium. I just checked a couple of my simulations, and GHF for one ice core site decreased by 27 mW/m^2 for AIS, and 17 *mW/m^2 for GRIS over the Holocene. So thermodynamically equilibrating an ice sheet model with a present-day GHF inference is problematic Nevertheless, whatever GHF maps you initially choose, run them through some ice sheet models (preferably glacial cycle models for consistency checks with borehole temperature profiles)."* *(Cryosphere, Modelling)*

-"Magnetic models for Antarctica/Greenland need more thorough (nearly always larger!) uncertainty bounds placed on them before being incorporated into any combined models. As the Curie depth/temperature is often shallower than other models it often has a large impact. I think in general that the multivariate models are the best of the bunch so far to use for things like ice-flow modelling (Stal et al. and Loesing et al. for example). (I assume individual responses will not be published and attributed, just collective summaries and anonymized responses? Please email me if otherwise as I may need to get approval from my boss to include the affiliation. And apologies for the delay in responding to this survey I was away on leave for 2 weeks.)" *(Solid Earth, Modelling)*

-I feel magnetic data inversion is still the most reliable method to build a continental scale GHF model. Magnetic data also have the highest resolution data in Antarctica. Deep learning and integration of available multi-geophysical data have the potential to improve accuracy and resolution. Moreover, we can try to make full use of ice penetrating radar data to help other geophysical data to build GHF model, especially in improving the resolution. *(Cryosphere, Observing)*

-"Point 1) It is important to use a more detailed GHF model for ice sheet modelling at catchment scale. Don't use a zoomed in continental-scale model for regional scale modelling.

Point 2) East Antarctica still contains domains which are underconstrained in the best models, while West Antarctica is surveyed a sufficient resolution (although it could still be better)." *(Both Cryosphere and Solid Earth, Both Modelling and Observing)*

-"For Antarctica, despite agreement of all GHF data on continent scales with high values under WAIS and low values under EAIS, there is a lot of variability in the predicted GHF from one data set to the next on smaller scales. Some of the discrepancies between data sets might come from differences in the horizontal resolution of the models. As a result of these discrepancies in modelling GHF it is essential to use an ensemble of data sets to provide the best constraints on GHF and therefore on the ice-bedrock interface temperature. In addition, independent GHF constraints, such as ice core data, but also the presence or absence of subglacial lakes can improve our knowledge of GHF. As for Antarctica, Greenland basal constraints remain scarce and model output have to be combined to provide the best boundary conditions ==> combined output is key in my opinion

But, due to the variability of the GHF data sets and the necessity for (some model or

method) one single data set for the temperature calculation, we can imagine to use the weighted mean of the published GHF data sets as our GHF boundary condition and each data set's standard deviation error for the weights. The higher the standard deviation, the lower the weight of the data set or such (one idea).
Best, Brice" (Cryosphere and Solid Earth, Both Modelling and Observing)

-"It is very useful to make heat flux available in the ocean (at least on the continental shelf). Some ice sheet models do the initialization by running paleo simulations in which the ice sheet can expand on the continental shelf). It is also important to have a map of the uncertainty. I support methods that aggregate all types of data (seismic, magnetic, gravity, ...)" (Cryosphere and Solid Earth, Both Modelling and Observing)

-Having GHF provided on a 500 m grid would be helpful -- e.g., the same as BedMachine Antarctica. (Cryosphere, Modelling)

-First, thanks for putting together this survey. Taking it was more fun than I expected. I've heard lots of opinions about subglacial geothermal flux and its importance over the years. A possibly prevailing perspective in that glaciology community is that geothermal flux does not "matter" to projections of future ice-sheet mass balance, which leads it to be deprioritized relative to other matters. This perspective is most in evidence by the choice of the severely out-of-date Shapiro & Ritzwoller (2004) maps for most ISMIP6 models. I get it – people have many competing priorities – but many of the newer maps and readily available and easily ingestible into the modeling environments, yet these models don't hesitate to update their bed topographies when possible. Further, the surprisingly large range of basal temperatures generated by these models strongly suggests that, as projection timelines extend beyond this century, getting geothermal flux right will matter more and more, and that there may be structural weaknesses in either their initializations or process parameterization that are not yet resolved. Separately, I strongly believe that studies that synthesize inferences from multiple fields (seismics, gravity, magnetic, etc.) will result in more robust and physically self-consistent fields that will receive greater uptake across the ice-sheet modeling community (Cryosphere, Observing)

-"1. Would be good to have an agreement about the ice sheet model resolution in ISMIP7.
2. Would be good to have a community agreement, that estimate heat flow from looking single component of the earth system to a multi-variable constrained heat distribution."
(Cryosphere and Solid Earth, Modelling)

-"The biggest challenge in GHF estimations is that most models don't account for subglacial geology and variations in the crust due to spars geological and crustal property information. To capture local GHF variation, better crustal models, knowledge about thermal conductivity and heat production is required. Most models treat the crustal layer with constant values, therefore neglecting geology. Furthermore, most geophysical derived estimates are based

on single geophysical datasets. A more interdisciplinary data approach is required. Machine learning approach overcome the singularity of geophysical data. However, machine learning approaches don't necessarily reflect physical realistic systems." (Solid Earth, Modelling)
-Many studies produce unrealistically high and and geographic large geothermal values. This is particularly true of the ones based on magnetics. (Cryosphere, Modelling)
-"Empirical models are more robust than forward models; however, forward models are important. The resolution controls the robustness. Most models are robust if the resolution is low enough; however, when we get under 100 x 100 km, the methods and data processing make a huge difference. Also, a few scattered direct observations do very little to contain the geothermal heat when integrated over larger areas. In parallel with modelling efforts, we must collect more in situ data. Talalay's papers are very important in this regard." (Cryosphere and Solid Earth, Both Modelling and Observing)
-Quantitative estimation and assessment of geothermal flux in the Greenland and Antarctic ice sheets should be further strengthened. Seismic and aeromagnetic observations need to be enhanced to improve data resolution as much as possible. Meanwhile, based on accumulating more geological and environmental observation data, the inversion of geothermal flux should be combined with these environmental data to analyze which factors have a strong correlation with geothermal flux. Therefore, machine learning or deep learning, especially interpretable deep learning methods, may be the direction that requires further research in the next step. In addition, three-dimensional coupled models of ice flow or ice sheet, as well as reversible approaches, are also important aspects that need to be further studied for the inversion of polar geothermal flux. (Cryosphere and Solid Earth, Both Modelling and Observing)
-I think it is important that the community acknowledges and appreciates every single effort from scientists who provide an estimate of geothermal heat flow at the rock-ice interface in Antarctica and in Greenland. It is very challenging to provide a view of this parameter in such remote regions which also have limited amount of data. The fact that a variety of methodologies have been applied to understand GHF in polar regions is also something to appreciate. (Solid Earth, Both Modelling and Observing)

Model Specific Comments:

Shapiro & Ritzwoller (2004):
- Excellent background methodology, but has been superceded by models with better resolution (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-It was a precursor for the seismic approach. (Cryosphere, Both Modelling and Observing)

-My neutral comments are more that I don't know enough about the details to have a strong opinion. But the lack of detail and structure in the GHF is concerning, particularly through the East Antarctic Ice Sheet. (Cryosphere, Modelling)
-Probably fine for EAIS, but overestimates heat flow in WAIS (when we compare calculated to observed temperatures) (Cryosphere, Modelling)
-This was the most commonly used geothermal heat flux model for ISMIP6, published 14 years prior to those results. This study was certainly a significant and well-articulated advance for its time, and subglacial geothermal flux remains poorly constrained overall. However, any continued use thereof in ISMIP7 would imply that all efforts subsequent to this benchmark to improve geothermal flux knowledge for either ice sheet are virtually meaningless. I certainly don't think that's the case. (Cryosphere, Observing)
-The concept is good but considering the improvement of heat flow data coverage and seismic tomography model resolution, a new version of should be used in ISMIP7. In addition, there is some assumption is not hold (e.g. seismic velocities are related to temperatures in the mantle, which will underestimate the heat flow in East Antarctica). (Both Cryosphere and Solid Earth, Modelling)
-SR04 was groundbreaking at the time, given that it was the first estimate of Antarctic GHF based on global seismic tomography. It is broadly consistent with our large-scale geologic knowledge, in that it shows a clear divide between hot West Antarctica and cold East Antarctica. It also used a probabilistic approach, which is good, and included an uncertainty estimate as well. (Cryosphere, Both Modelling and Observing)
-At the time of publication this has been an great model, with robust methods and results. perhaps now its a bit outdated and the spatial resolution might be too low to meaningful ice sheet dynamic studies, particularly in East Antarctica. Its still one of my favourites. (Solid Earth, Both Modelling and Observing)
-This model has an unrealistically narrow range of GHF values (Begeman et al. 2017, Figure 3), probably due too strict optimization. (Cryosphere, Observing)
-solid grounds for building more accurate heat flux models, but in itself it is very coarse and does not honor ice core data. (Cryosphere, Both Modelling and Observing)
-This legacy study was well conducted and included state-of-the-art methods and data for the time. The results are much more reliable than many more recent studies. The main advantages of the study: Using empirical computations rather than forward calculations enables some means to capture crustal heterogeneity, which is the main factor determining varying geothermal heat distribution. Understanding that seismic data (especially tomograph results) has the strongest association with observed geothermal heat, much more than any relation from potential field data. The main limitation is the resolution due to the wavelengths of the underlying tomography model and the sparse seismometer network on the continent

at the time. *(Both Cryosphere and Solid Earth, Both Modelling and Observing)*
-This is a global model based on seismic data. There were not many seismic stations in polar regions at the time this model was published. So, the detail of the crust and lithospheric structures in polar regions is very poor for this model. (Solid Earth, Both Modelling and Observing)

Fox Maule et al. (2005) + Fox Maule et al. (2009):
-There are quite large uncertainties and assumptions in these magnetic models but they are mostly noted in the text. They also selected some thermal parameters to force the average continental heat flow estimates in Greenland and Antarctica to ~65mW/m2 (the average continental heat flux from Pollack et al. 1993) (e.g. 2.8W/mK for Antarctica, 2.4W/mK for Greenland). I am not sure this is the best way to go about selecting these parameters. (Solid Earth, Modelling)
-the method used does not really stack up to modern data (Solid Earth, Both Modelling and Observing)
-Well-explained background methodology, but has now been superceded. (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-I will provide a general comment later. (Cryosphere, Both Modelling and Observing)
-Precursor for the "magnetic approach" (Cryosphere, Both Modelling and Observing)
-As per previous comment. The resolution of the data product is not suitable. (Cryosphere, Modelling)
-This is an outlier. Overestimates GHF in EAIS. We don't comment on Greenland. (Cryosphere, Modelling)
-This model seems somewhat inconsistent with most others (especially in Antarctica), is coarse, and has been surpassed both methodologically and by the datasets it could use for the method. (Cryosphere, Observing)
-Satellite data only, hence no suitable spatial resolution (Solid Earth, Modelling)
-The spatial resolution is not suitable. And better source data (airborne magnetic data) is now available. (Both Cryosphere and Solid Earth, Modelling)
-My opinion of the Fox Maule dataset (and of its successor, Purucker et al., 2012) has always been that it looks like they chose spherical harmonic coefficients with a random number generator. Perhaps that is a bit harsh, but it really looks like low-pass filtered randomness. They claimed that they had high heat flow on the ""shoulder"" of the West Antarctic Rift System, but really it looks by eye as though the high heat flow is really not where it should be. Of course, it was quite novel at the time of publication, as there were no other continental scale magnetic estimates of GHF, but it still looks quite poor to me.
I don't have much experience with Greenlandic GHF, so I make no comment about that

dataset." (Cryosphere, Both Modelling and Observing)

-I can only speak for the Antarctic model, where my opinion is that the satellite magnetic resolution is way to coarse for curie depth estimates, particularly at shallow depths. Although I like the innovative and forward thinking approach of the study. The model does not capture the variations well and the inferred GHF map always seemed off to me. (Solid Earth, Both Modelling and Observing)

-This model has an unrealistically narrow range of GHF values (Begeman et al. 2017, Figure 3), probably due to too strict optimization. In addition, the hot spots seem unrealistic. (Cryosphere, Observing)

-we can probably do better in terms of spatial resolution. Plus, I recall that the supplemental information had robust error analysis, but errors were quite large. (Cryosphere, Both Modelling and Observing)

-"I am happy to acknowledge this study as being pioneering in many regards, and they also took some essential steps for validation and quality control and are fairly transparent in the assumptions and shortcomings. Later studies (e.g. Gard and Hasterok, 2021) have also shown that equivalent dipole is a more reasonable approach to using magnetic data to calculate a temperature gradient in the crust. The results are not robust. The resolution is low due to the wavelength of the satellite data." (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-These models use satellite magnetic data to constrain magnetic crustal thickness using the equivalent source magnetic dipole method. Magnetism and heat are directly related and for this reason these models provide a reliable heat flow model. The resolution is that of the satellite data. Still this model provides more reliable details and heat flow values than the model from Shapiro and Ritzwoller. (Solid Earth, Both Modelling and Observing)

Purucker (2012):

***-**Well-explained background methodology, but model now superceded. (Both Cryosphere and Solid Earth, Both Modelling and Observing)*

-As per previous comment. The resolution of the data product is not suitable. (Cryosphere, Modelling)

-Too low GHF across AIS. No comments on Greenland. (Cryosphere, Modelling)

-Resolution is not suitable. The magnetic derived product only captures one prospect of heat flow. (Both Cryosphere and Solid Earth, Modelling)

-"My opinion on this updated version of Fox Maule are roughly the same as the original. It is striking to me how much the pattern of GHF changed in the update. I guess all of that talk

about ""the shoulder of the West Antarctic Rift System"" was meaningless then? It still looks like spherical harmonic randomness to me." (Cryosphere, Both Modelling and Observing)
-"The added airborne data from this update did not improve the robustness. Magnetic data have many benefits in surveying the Antarctic continent. These include tectonic segmentation from lineation and the potential of using susceptibility or magnetic fields for inversions or statistical methods. This study (or just the results) is important as one of the early magnetically derived maps of Antarctica." (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-Same opinion as for Fox-Maule et al models (Solid Earth, Both Modelling and Observing)

An et al. (2015):
-In a recently published History Matching for last glacial cycle AIS, we have an ensemble parameter interpolate between the An et al and Martos et al geothermal heat fluxes though used at 4 km depth (our ISM (GSM) includes a 4km deep bed thermal model). The history matching strongly favoured the weighting to extrapolate beyond Martos. So overall, at least for our study, An et al is on the "wrong side" of Martos. (Cryosphere, Modelling)
-This model is more like an indication of how the heat flow would look, based on the seismic tomography model. It isn't robust, and the seismic tomography model has now been superceded. (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-"The method is similar to that used by Shapiro and Ritzwoller (2004). They analyse the Earth's mantle properties using a new 3D crustal shear velocity model to calculate crustal temperatures and the surface GHF. ==> Their spatial distribution of GHF differs quite a bit from the other data sets, particularly in East Antarctica where GHF . !values differ by ~10 mW m-2 from those of Shapiro and Ritzwoller (2004) e.g. !! The model is invalid for GHF values exceeding 90 mW m-2." (Cryosphere, Both Modelling and Observing)
-Globally good. (Cryosphere, Modelling)
-I was unfamiliar with this particular result, but upon examination, it seems at the very least an Antarctic-specific improvement upon the methods of Shapiro and Ritzwoller (2004). (Cryosphere, Observing)
-This heat flow model is mainly based on the resolved mantle temperature from Vs. It has limited information for crustal heat production. (Both Cryosphere and Solid Earth, Modelling)
-This is the first update of GHF based on the seismic method since SR04, so of course that is a good thing. The GHF in West Antarctica seems a bit low (peak of ~75 mW/m^2, which is barely higher than the global continental average of 65 mW/m^2). Overall the spatial pattern seems broadly reasonable though. (Cryosphere, Both Modelling and Observing)
-This model has an unrealistically narrow range of GHF values (Begeman et al. 2017, Figure 3), probably due too strict optimization. (Cryosphere, Observing)

-"I have issues with the underlying tomography model, but the heat calculations are reasonably robust and transparent. Importantly, the authors explain the shortcomings and assumptions and refrain from making claims that are too far-reaching. The main problem is the lack of spatial heterogeneity in the crust, which has recently been discussed by Hazzard and Richards (2023, 2024) and Stål et al. (2020, 2024)." (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-Seismic model relying on few seismic stations. From the layered model obtained using the seismic data a number of parameters need to be calculated and assumed before the thermal modeling is performed to calculate the geothermal heat flow. Not a very reliable heat flow model for this reason. In addition, the heat flow values are much lower than for most of the Antarctic models (Solid Earth, Both Modelling and Observing)

Martos et al. (2017) + Martos et al. (2018):

***-**This is a valiant attempt to calculate the curie depth and includes some estimate of the uncertainty, which was most welcome. However, it is based off the older Tanaka 1999 method of curie depth calculation, which is highly subjective. (Solid Earth, Modelling)*

-Cf previous comment for An et al model (Cryosphere, Modelling)

-"The spectral method is okay for estimating Zb, but the published uncertainty estimates on the heat flow part of the model I believe are considerably too small - some parameters and assumptions were missed in the uncertainty propagation equation used (e.g. Surface heat production was excluded, the vertical distribution variability not fully captured). I also am not entirely convinced of their calibration of heat production model due to the values they use. They state they used a range of measured values to optimize these, but don't expand on the methodology for this. The heat production model selected is identical to Maule 2005 (and Maule selected them based on Sandiford and McLaren 2002 and references therein, as 'generic' values)." (Solid Earth, Modelling)

-This model is without question unsuitable for use in ice sheet modelling studies. The fundamental premise, i.e. CPD connecting to heatflow is not robust and without a doubt the geotherm implied by the model is not physically possible at many points in the model. The model has some value in highlighting tectonic domains and raising questions on continental structure and processes. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-"'+ high resolution GHF, map based on the spectral analysis of airborne magnetic data. They use a compilation of all existing airborne magnetic data to determine the depth to the Curie temperature and infer the GHF using a thermal model. Their continent-wide spatial distribution of GHF obtained agrees with previous studies, but they show higher overall magnitudes of GHF including East Antarctica. They report an error of ~ 10 mW m-2 which is interestingly smaller than for the other data sets" (Cryosphere, Both Modelling and

Observing)

-This model does not give heat flux in the ocean, this may be a difficulty for some simulations (including initialization for ISMIP7) *(Cryosphere, Both Modelling and Observing)*

-I have only looked at this model with respect to Antarctica, so that is what my replies are meant for. *(Cryosphere, Both Modelling and Observing)*

-Probably too high GHF across both WAIS and EAIS. *(Cryosphere, Modelling)*

*-These datasets apply a consistent magnetic method to updated magnetic datasets for both Antarctica and Greenland. They also generate *uncertainties* in these fields, however imperfect these may be given the structural limitation of the method. I'm uncertain if the Curie depth inversion is the best-suited to this problem, but inter-continent consistency seems like a good thing.* *(Cryosphere, Observing)*

-Spatial coverage is good. The long wavelength information in ADMAP2 is not well constrained, which would cause issue for the resolved curie depth. *(Both Cryosphere and Solid Earth, Modelling)*

-Satellite data is not able to resolve a thin layer such as the curie isotherm. Furthermore, the study is not reproducible since information of the window location and the power spectrum are not provide. In addition, in the supplementary information it is revealed that two different wavenumber ranges are used for east and west Antarctica. Therefore, forcing a priori West Antarctica to be hotter. *(Solid Earth, Modelling)*

-"Martos was a definite improvement over Fox Maule/Purucker. Airborne magnetics provide better resolution and more information than satellite mag. The middle of West Antarctica is hot in the model, which is reasonable. I have less experience with Greenland GHF, so I can't say whether that is also reasonable. Martos GHF is generally higher in East Antarctica than other models, but my own research suggests that, at least in the Gamburtsev Subglacial Mountains, this isn't necessarily unreasonable (on the other hand, work that I was a coauthor on suggests that the higher Martos GHF may not have been reasonable in the Totten catchment). There aren't many magnetic estimates out there, and Martos is a definite improvement over Fox Maule/Purucker, in my opinion." *(Cryosphere, Both Modelling and Observing)*

-"Inferring GHF from curie depths requires high resolution, good quality magnetic data. While i believe it adds an important layer of information, a more comprehensive modelling of the crustal structure is required. To be honest I still struggle with confidence in the robustness of the method...." *(Solid Earth, Both Modelling and Observing)*

-better data and better geologic sleuthing. Important tectonic history are utilized to help explain the results (specifically the Greenland paper), but the main challenge is the souther part of Greenland. Our ground truth data are gold, and we have Dye3 ice core were basal temperatures are quite low and cannot explain the high heat flux estimates in this paper.

(Cryosphere, Both Modelling and Observing)

-"The method choice is the worst of all the methods reviewed here, and there is no association between spectrographically derived Curie temperature depth and geothermal heat values. Multiple studies (Gard and Hasterok, 2021, Stål et al., 2021, Demarco et al., 2021), including studies that themselves apply the method, e.g., Li et al. (2017), have shown this. The study also makes claims that are not met (e.g. in the title of the paper). It also contains rather serious errors. I'll try to list the main shortcomings below briefly:

1. There is not enough data to perform spectral analysis of windows—simply not enough flight lines then or now, except in a few limited regions.

2. Spectral analysis, even if it would work, will only give a maximum value as the wavelengths of magnetic anomalies are determined by tectonic history, not the present temperature.

3. Satellite data is just not valid for computations of such short wavelengths.

4. Even if the errors above had been addressed and somewhat corrected, the isotherm would still not be valid as the deep crust and shallow crust heat production are not correlated. With magma removal from the lower crust of incompatible elements up to the upper crust, the heat production and temperature in the lower crust decrease, and the heat flow increases.

5. The study invents some artificial crustal values to match the expected results. The East-West boundary is just wrong.

6. The study uses values from Siberia to validate their results. This data point confused the North with the South and had nothing to do with the geothermal heat in West Antarctica; it was from Franz Joseph Land.

I get very sad every time I see ice sheet models that use this study, and honestly, I don't think it was honest to present it as a dataset for interdisciplinary studies. I would have been much more supportive if it had just been presented as a modelling study to test and learn something about the Antarctic lithosphere." (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-These models are calculated by applying spectral methods to airborne magnetic data (high resolution grids). In this case, Curie depth is related to the bottom of magnetic sources. For Fox-Maule et al. models it was the bottom of the magnetic crustal thickness. For Martos et al. models magnetic properties are directly related to heat which make the thermal modeling much more reliable than for those done from seismic models, for example. (Solid Earth, Both Modelling and Observing)

Rezvanbehbahani et al. (2017):

-This is a nice method development contribution. (Both Cryosphere and Solid Earth, Both

Modelling and Observing)

-"'++ for the first time machine learning techniques to derive GHF from relevant geologic features (gravity measurements, magnetic anomaly) and GHF measurements (derived from crustal thickness, rock composition and active thermal feature). resolution" (Cryosphere, Both Modelling and Observing)

-This was a novel and forward-looking application at its time, but it produced a result for the northern two thirds of Greenland that is difficult to reconcile with what else we think we know about the ice sheet, and its resolution is coarse. (Cryosphere, Observing)

-I am worried about the impact of including NGRIP measurements which will skew the entire region towards higher GHF (Cryosphere, Both Modelling and Observing)

-The spatial distribution of GHF seems unrealistic. It seem to reflect the distribution of ice sheet thickness too much. (Cryosphere, Observing)

-It is nice that it honors various Greenland-specific geology, and incorporates all available data from ice cores. The main caveats are two-fold: building statistical models based on global borehole data will inherently be biased, because heat flux data are collected at places that are probably higher and have economic incentives. Second, with such small data sets, machine learning models particularly suck at interpolation. So it is a bit hard to expect them to provide any deep insight that cannot be tectonically or geologically explained. (Cryosphere, Both Modelling and Observing)

-A good pioneering study. Very important, but the results are not suitable for ice sheet models. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Artemieva (2019):

-This is a contribution that has value in raising questions with regard to plate tectonic settings etc, but is not suitable as a basis for ice sheet modelling. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-It's just an opinion, but this GHF distribution seems more realistic, particularly given the passage of the hot spot beneath Greenland. (Cryosphere, Observing)

-This study gives a fresh look at the Greenland lithosphere, and the results are likely rather good. However, a lot of useful data is not included. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Greve (2019):

***-**Essentially this is just an interpolation of point data. I believe the author has been very up-front about this limitation. Nevertheless, it is probably very unsuitable for ice sheet modelling. (Solid Earth, Observing)*

-Interesting result, but low resolution. Interpolating between sparse observations doesn't

take into account the spatial scaling of GHF (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-'- in my opinion the data are to influenced by deep ice core measurements ! (Cryosphere, Both Modelling and Observing)

-This model is mainly tuned for the interpretation of ice cores. Although it may be interesting in this domain, it is not suitable for ISMIP7 which need information in the coastal areas (Cryosphere, Both Modelling and Observing)

-I appreciate the impetus for this model (matching the borehole temperature observations), but the apparent overfitting leads to what resembles a borderline non-physical pattern that only makes sense at the coarsest (north vs. south) scale. Also, because it leverages an ice-sheet model, it may be too circular a candidate for ISMIP7. Finally, it seems to ignore what we know of Greenland geology and doesn't make much sense along the Blosseville Coast (east coast of central Greenland). (Cryosphere, Observing)

-The result mainly driven by the data distribution and might be impact by particular site. (Both Cryosphere and Solid Earth, Modelling)

-This model is heavily influenced by the findings at NGRIP - a point measurement that is likely not representative for the region. Furthermore, I see the results of this study as a modelling exercise rather than an attempt to get GHF (Cryosphere, Both Modelling and Observing)

-Unrealistic distribution (Cryosphere, Observing)

-Very rudimentary analysis. Not much depth. Simple IDW itnerpolation. (Cryosphere, Both Modelling and Observing)

-All respect the author, but this is just an interpolation from some point of data. It's not really a relevant input as a data layer. Good discussion in the paper. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Lucazeau (2019):

-"Global heat flow compilations are always welcome :-) The most up-to-date compilation I'm aware of is https://dataservices.gfz-potsdam.de/panmetaworks/showshort.php?id=e6755429-fbbf-11ee-967a-4ffbfe06208e" (Solid Earth, Modelling)

-I do not work specifically on Antarctic or Greenland heat flow but I have previously assessed the Lucazeau (2019) model as one of the better (if not the best) developed and validated global models of heat flow. The validation points are necessarily concentrated in parts of the world with good data coverage, but the methodolgy should be valid for extrapolation to all parts of the world. (Solid Earth, Observing)

-Antarctic datasets used to generat this model have been superceded, but its a good

approach (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-'- in my opinion, not suitable for Antarctica (homogenous value) (Cryosphere, Both Modelling and Observing)
-"Great work in general, but some points in the datasets are erroneous (missing ""-"" signs or lat/lon swapped), not focused on polar regions" (Solid Earth, Both Modelling and Observing)
-This good global model is still one of the best and would be suitable for Greenland if produced in higher resolution. However, due to limited data coverage, some other challenges exist for the Antarctic continent. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Guimarães et al. (2020):
-This is an interesting result, but it doesn't have robust uncertainty estimates, so not suitable for MIP use. (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-It seems like one of the best options (Cryosphere, Observing)
-"This study is often overlooked and is very useful as it provides an entirely independent look at and evaluation of geothermal heat transfer in Antarctica. The use of interdisciplinary observations is very inspiring. The results are mainly interpolation and unsuitable as data inputs for ice sheet models, but it is a useful map to keep in mind." (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Shen et al. (2020):
-A reasonably detailed model based on US tectonic domains, so some patches are very good, but overall its unsuitable for MIP use as some key tectonic settings are not represented. (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-According to our modelling , this seems the database that results overall in the best fit with all validation methods. (Cryosphere, Modelling)
-By the time that this was published, using seismic tomography to infer GHF wasn't exactly novel, but this is still a solid dataset. The GHF in West Antarctica is higher in this dataset than in An et al, but still lower than Shapiro and Ritzwoller. There is a lot of small-scale speckle in the map that is probably erroneous. (Cryosphere, Both Modelling and Observing)
-This GHF map seems only marginally better than the very old approach of assuming a single low value for East Antarctica and a single high value for West Antarctica. (Cryosphere, Observing)
-"This is a welcome update on Shapiro and Ritzwoller, which are using a new (at the time) continental tomography model. It is a good study, one of the best.
It's a very neat study. However, the shortcomings are:
1. Assuming that all of Antarctica can be represented by the geology in the lower 48 USA.

2. Assuming that crustal variations can be captured by upper mantle tomography
The authors correctly present the strong link between seismic wave speeds and heat flow." *(Both Cryosphere and Solid Earth, Both Modelling and Observing)*
-Same opinion as for other models derived by seismic data in polar regions. (Solid Earth, Both Modelling and Observing)

Stål et al. (2020):
***-**I really like the way the authors combine several datasets to predict heat flow. Presumably the same approach can be used as different datasets are iteratively updated. (Solid Earth, Modelling)*
-Novel methods and very thorough explanations of methodology made. Spatial resolution was good. I believe the multivariate models are generally the better results as basically all individual methods have too many assumptions. (Solid Earth, Modelling)
-Well understood model inputs and robust uncertainty bounds make this a good choice for MIP use. The author would provide an update, as there is some new thinking to be incorporated. (Both Cryosphere and Solid Earth, Both Modelling and Observing)
-would be better for modelers if data were profide in the ocean (at least on the continental shelf) (Cryosphere, Both Modelling and Observing)
-This is the GHF model that I use in my ice sheet modelling because it combines different data streams with a robust assessment of uncertainty. Having it provided on a 500 m grid would be helpful. I'm not sure about the last question wrt the most suitable models, but I suspect this is one of the most suitable. (Cryosphere, Modelling)
-Slightly higher GHFs compared to Shen et al., and therefore a lesser good fit with our validations. However, similar category in terms of performance. (Cryosphere, Modelling)
-I found this study intriguing in its methodology and reasonably up to date in terms of the datasets it used. Its resolution is somewhat artificial, though. (Cryosphere, Observing)
-Would love to see an updated version for ISMIP7, as we have some 'better' data. (Both Cryosphere and Solid Earth, Modelling)
-"I'm not sure how to grade the spatial resolution of this model. On the one hand, the claimed resolution (20 km) is clearly better than anything that came before. On the other hand, that claimed resolution is probably bogus. There is no way to verify the fine-scale structure in this model, but we can compare with another multivariable/machine learning data product that also claims very high resolution (Losing and Ebbing, 2021), and we can see that the details of the spatial structure look nothing alike. This dataset has much higher maximum GHF in WAIS than other datasets, which I actually consider to be a good thing. We know that there are volcanoes in WAIS, we know that WAIS should be a high-heat-flow region, and we also know that GHF is highly variable on short spatial scales, and that the

amplitude of this variability increases with the mean (long-wavelength) GHF (Shapiro and Ritzwoller, 2004). Thus, very high local excursions in WAIS are reasonable. HOWEVER, I am highly skeptical that the specific excursions portrayed in this model are real. I am completely convinced that the real GHF in WAIS should have large local excursions to very high values, but I am also equally convinced that those excursions are probably not in the same location where this map put them. Basically, I don't trust the claimed 20km resolution of this dataset." (Cryosphere, Both Modelling and Observing)

-This seems like one of the best options. It has a large spread of GHF values, which seems realistic. (Cryosphere, Observing)

-"This is the most robust model of Antarctic geothermal heat; however, the uncertainties are large in many parts of the continent. It is also getting outdated as new seismic tomography is available. Using a large number of observables makes the most far-reaching attempt to capture crustal variations." (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Lösing and Ebbing (2021):

***-**Using machine learning to predict aspects of the geothermal heat contribution to the thermal budget (e.g. radiogenic granites) is a novel contribution to Antarctic heat flow studies. (Solid Earth, Modelling)*

-I think the methodologies presented in this paper were quite novel given the numbers of unknowns in this region. The larger discussion around uncertainty in this paper and papers from Stal are really necessary for places such as Antarctica/Greenland. Similar comments as Stal AQ1 paper - multivariate analyses making use of combined geological/geophysical data/models all together are the more functional models for use in further modelling such as ice-flow simulation. (Solid Earth, Modelling)

-This is a possible choice for MIP use, but there are some unquantified uncertainties inherent in the method, so it is a good comparison model. It shouldn't be the only choice. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-'==> based on global direct measurements but to few measurements on the EAIS (Cryosphere, Both Modelling and Observing)

-no data in the ocean ! (Cryosphere, Both Modelling and Observing)

-Similar to Stal et al. (Cryosphere, Modelling)

-This study uses modern methods (ML), combines multiple geophysically relevant datasets (Table 1 is very encouraging), and compares its results to a modern compilation of observations. This is one of the best candidates for a field for ISMIP7. (Cryosphere, Observing)

-As with Stal et al., I do not trust the claimed spatial resolution. 55 km is not quite as

egregious a claim as 20 km, but I still do not trust that they actually can resolve structure that fine. Especially since the details of their fine structure do not at all line up with Stal. Probably 100-200 km is the best resolution that can realistically be achieved by these large-scale geophysical estimates. (Cryosphere, Both Modelling and Observing)

-A decent improvement from Rezvanbehbahani paper. Though the caveats with ML models still persist. (Cryosphere, Both Modelling and Observing)

-"This is a very good model that uses modern computational methods and includes a very informative sensitivity analysis. The few observables used to limit how well the crust can be captured, and some observables might be getting more weight than they deserve. Together with Stål et al. (2021), this is probably the best choice for ISMIP7." (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Colgan et al. (2022):

-"COI: I was a co-author on this study. This study undertook significant effort to generate the most complete database yet of Greenland and Greenland-adjacent geothermal flux measurements. It then applied modern ML methods and multiple geophysical variables to assess geothermal flux. Not just subglacial ones. While the overall values it reports are lower than previous ones, it has the most sober assessment of the NorthGRIP anomaly yet. It is a good choice." (Cryosphere, Observing)

-Need to make decision about the NGRIP (Both Cryosphere and Solid Earth, Modelling)

-This community effort is the best estimate for Greenland. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

Haeger et al. (2022):

***-**One advantage of this model is that it is available at different depth levels, and therefore suits those ice sheet models that use a thermally-modeled bedrock layer of about 2km thickness, such as PISM (Both Cryosphere and Solid Earth, Modelling)*

-This is a good model, but doesn't capture the detail of the crustal component, only the background steady state component. This makes it not the best choice for MIP use in isolation, but it would be a valuable comparison model. (Both Cryosphere and Solid Earth, Both Modelling and Observing)

-Similar to Shen et al. (Cryosphere, Modelling)

-Another seismic model that shows broadly high GHF in WAIS and broadly low GHF in EAIS. I like that this map shows somewhat higher GHF in the GSM, since (as I mentioned in a previous comment) my own research indicates that this area probably has higher GHF than other surrounding areas of EAIS. The peak GHF in WAIS for this model is still pretty low, but given that it is fairly course resolution, you could probably posit short-wavelength excursions

on top of this long-wavelength structure. *(Cryosphere, Both Modelling and Observing)*
-Again, this seems only marginally better than assuming two values for East and West Antarctica. In addition, the range of GHF values seems unrealistically narrow for a large continent with an extensional tectonic province. *(Cryosphere, Observing)*
-"This is a very good study, a forward model that discusses and evaluates the Antarctic lithosphere. The empirical models (Shapiro and Ritzwoller, Stål et al., Shen et al., Lösing and Ebbing) are somewhat more robust; however, forward models are getting closer and provide an unprecedented insight into the lithospheric architecture." *(Both Cryosphere and Solid Earth, Both Modelling and Observing)*

Hazzard and Richards (2024):
-*This is a nice study, but the resolution is too low for MIP use. There is information available that is not factored in.* *(Both Cryosphere and Solid Earth, Both Modelling and Observing)*
-Too low GHF across EAIS, too high across WAIS and very sharp boundary, leading to spurious ice-sheet model behaviour. *(Cryosphere, Modelling)*
-"This is the newest and IMO best of the seismologically derived Antarctic geothermal flux datasets. It uses a modern tomographic dataset and incorporates numerous recent advances in mineral physics understanding to develop a better temperature model. Its only real disadvantage is that it leans heavily on the empiricism of the mineral physics models and does not directly consider inferences from other fields, so that causes me to prefer the ML-based map overall." *(Cryosphere, Observing)*
-The concept is good, but the seismic resolution is poor. *(Both Cryosphere and Solid Earth, Modelling)*
-The WAIS/EAIS divide in this model resembles that found in all of the seismic models, but in this case the magnitude of WAIS GHF is higher than in most of the others (except for maybe SR04). I think that that is probably a good thing, as WAIS has recent rifting and volcanism, so GHF there should be elevated with respect to the continental average. EAIS GHF is mostly low in the map. There appears to be a spot of higher GHF near to the GSM in this model, but by eye it looks like that spot might miss them (as I mentioned in other comments, my own research suggests that the GSM probably has higher GHF than most of these models predict for EAIS). I have not yet had the opportunity to look at this model in detail. *(Cryosphere, Both Modelling and Observing)*
-This is a nice discussion paper; however, the results are unsuitable for ISMIP7. *(Both Cryosphere and Solid Earth, Both Modelling and Observing)*