Detailed response to the reviewers' remarks and for the technical corrections

In the following, we give our answers to the reviewers' remarks and state the technical corrections. Our answers are given in green color. The corrections have been incorporated in the revised manuscript.

Remarks from the preceding review file validation

1) Your short summary system section includes scientific abbreviations (GNSS). Please avoid abbreviations to make it better understandable for non-experts and please pay attention to use only 500 characters including spaces.

   Done. Instead of "GNSS and seismic networks" we used the term "geodetic-geophysical networks". The total number of characters of the revised summary is now 499 (including spaces).

2) Affiliation 16 must be split into two separate ones (Alfred Wegener Institute Helmholtz Centre of Polar and Marine Research… and University of Bremen…).

   We have done so. There are also updates w.r.t. two affiliations for another three co-authors, where we followed the rule to split it into separate ones.

3) Your reference list includes a work "submitted to". Such works can be cited upon submission if being available to the reviewers. They cannot be cited in the final, accepted manuscript, unless published, accepted for publication, or available as preprint with a DOI.

   We corrected the respective reference. Also, two further references had to be updated:

   Manassero2025a: submitted to JGR Earth Surface → Manassero2026a
   Matsuoka2025a → Matsuoka2026a (Reviews of Geophysics)
   Houriez2025a (EGUSphere) → Houriez2025a (The Cryosphere)

Review remarks

RC2, CC1: *Heat flow measurements*

The new section 2.7 is well written. Because of this addition, the mentioning of geothermal heat flow in lines 630-632 should refer to, and be consistent with, section 2.7.

Added link to Sec. 2.7 in Sec. 2.8.2. We also checked consistency between both sections, which is okay from our point of view.

RC2: *terrestrial gravity*

L498: It is not clear what is meant with "more datasets could be provided consistently inferred in the same processing".

"(...) which provided sufficient information for quantitative uncertainty measures for the gravity anomaly to be determined. Aside from the free-air anomaly and Bouguer anomaly, more datasets could be provided consistently inferred in the same processing (Scheinert et al. 2024)."

changed to:

"This processing was based on the usage of the so-called disturbing potential and the application of the least-squares collocation which enabled to calculate uncertainty measures for the gravity anomaly to be predicted. Thus, beside the free-air anomaly and Bouguer anomaly, further datasets could be provided consistently inferred from the disturbing potential such as height anomaly (which equals geoid height in the ocean area) and the second derivative of the potential (Scheinert et al. 2024)."

L739: Geothermal heat-flow datasets are not generally used to derive viscosity models in Antarctica as far as we know, whereas there is an example where gravity data is used (pappa et al., 2019). We suggest to at least add gravity in the list of constraints for mantle viscosity models.

Changed to "seismic tomography, geothermal heat-flow and gravity datasets"; and citation Pappa et al. (2019) added.

RC2: *radar observations*

We think the discussion on radar datasets in section 2.8.2 is a valuable addition to the existing literature. However, there seem to be ground-based measurement campaigns that are used in Antarctica, for example as mentioned in Saintenoy and Léger (2025). Because the paper focuses on ground-based measurements and their possible integration across disciplines we think a short mention of some of ground-based radar measurement could be useful

L636: We think BedMachine could be a valuable addition to the reference list.

Saintenoy, A., & Léger, E. (2025). Studying cold regions with ground-penetrating radar: a review. Comptes Rendus. Géoscience, 357(G1), 283-298.

Rignot, E., An, L., Arndt, J. E., Bamber, J. L., ... Zinglersen, K. B. (2017). BedMachine v3: Complete bed topography and ocean bathymetry mapping of Greenland from multibeam echo sounding combined with mass conservation. Geophysical Research Letters, 44, 11,051–11,061. https://doi.org/10.1002/2017GL074954

We have been aware of the paper published by Saintenoy and Léger (2025). However, we do not regard it as relevant in the context of our manuscript (especially in Section 2.8.2). Saintenoy and Léger (2025) treat the application of the ground-penetrating radar (GPR) technique in cryospheric sciences in general but not especially for ice sheets. We think that the references given in our manuscript do well represent the current status, and they refer to a wealth of further reading. Furthermore, in the case of Antarctica ground-based measurements make up only less than 1% of the total radar data, the vast majority recorded by airborne measurements.

BedMachine was already referenced in the paragraph above. We added a reference to the latest version BedMachine Version 4 (Morlighem 2025), and corrected the year in the first citation (to Morlighem et al. (2020)). The sentence now reads:

“Constraints on bedrock topography have been improved by incorporating remotely sensed ice-flow velocities (MEaSUREs BedMachine Antarctica; Morlighem et al., 2020; Morlighem, 2025).”

The reference given by the reviewer, Rignot et al. (2017), is not correct, it should be Morlighem et al. (2017); it refers to respective product for Greenland and is, therefore, not cited here.

3. Response to further comments

Our comment: *Section 2.6. It is not clear why space weather is discussed in a separate section.*

Authors' reply: "... We agree the topic was not introduced well on line 73, and we adjusted the text in the last paragraph of the introduction to better describe why this section (2.6, new section number: 2.10) is included as a separate section."

We think it provides more clarity that the introduction now mentions that there are interconnections between space weather and geophysical research. However, it is not clear in the text what these interconnections entail, and it would be helpful for better integration of section 2.10 if this section would start with an elaboration on these interconnections.

We added short statements to better clarify the interconnection, as recommended by the reviewer. The first paragraph of Section 2.10 now reads:

Space weather refers to phenomena that occur in the upper atmosphere, mainly in the thermosphere and ionosphere. Space weather and geophysical research have many interconnections including shared research questions and synergies in logistics and instrument deployment. For example, the processing of GNSS measurements for geodetic research requires understanding of variations in the ionosphere that affect signal propagation. As another example, GNSS receivers are often deployed by both the space weather and geophysical research communities, with both communities needing GNSS receiver coverage in the same Antarctic regions. Today, space weather is

considered a natural hazard that increasingly threatens both human life and technology, particularly as we move toward further reliance on infrastructure that is vulnerable to extremes in space weather phenomena.

Our comment RC2: Section 3.1 presents subsections organized by categories of scientific questions but they do not always align with the topics introduced earlier in the manuscript. For example, the topic of section 3.1.4 ("Structure of the deeper mantle and the Earth's core") is introduced only briefly in section 2.3.2. We suggest to merge section 3.1.4 with section 3.1.3. There should also be more discussion on the lower mantle, given the difficulty in imaging it with seismic measurements and its importance for GIA and mantle convection (science question 17 and 18).

Authors' reply: We added more details to Section 2.4.2 (former 2.3.2) regarding the importance of the lower mantle for GIA estimates.

The added clause in line 396-402 is a great addition but in the motivation for the question 18 and 19 in section 3.1.4 there is mainly motivation for questions on the core and core mantle boundary, and not yet research questions 18 and 19 and the state-of-the-art on the lower mantle that is now added to section 2.4.2. We suggest adding in 3.1.4 a few lines about what is currently unknown about the deeper mantle structure and the link with GIA and convection to properly ground questions 18 and 19.

According to the suggestion, we added a short paragraph at the beginning of Section 3.1.4 to better motivate research questions 18 and 19. It reads:

"Antarctic seismic investigations are critical in terms of addressing questions about deeper mantle structure and the Earth's core. At greater depths, the mantle transition zone provides an important bridge between Antarctic lithospheric and upper-mantle processes, and the dynamics of the deeper mantle, as discussed in Sections 2.4.1 and 2.4.2. Variations in the depths of the 410-km and 660-km discontinuities and in transition-zone thickness can constrain thermal anomalies and potentially distinguish shallow upper-mantle processes from deeper upwelling. Existing observations suggest localized transition-zone anomalies beneath parts of West Antarctica and the Transantarctic Mountains. However, present seismic coverage remains insufficient to determine their lateral extent or whether they reflect processes extending from the lower mantle. Expanded broadband seismic coverage would, therefore, help establish whether Antarctic volcanism, rifting, and other upper-mantle anomalies are primarily shallow phenomena or are linked to deeper mantle dynamics."

The following (originally first) paragraph starts now as "Further topics do directly influence the continent itself, (…)".

In relation to that, we also slightly revised the heading of Section 3.1.4 to "Structure of the deep mantle and Earth's core".

Our comment: RC2: Section 3.1.7 (“Improved general circulation models”) introduces general circulation models (GCMs) for the first time. Since the discussion extends beyond GCMs alone, it would be better to introduce the role of geodetic observations in constraining atmospheric and climate models earlier in the manuscript and to rename this subsection to “Improved atmosphere and climate models.”

Authors reply: We edited the wording of this section.

L856-861: This is a bit generic and does not fully clarify the link between geophysical and geodetic observations discussed in the paper and “global change” We recommend to add a few examples. For example, the possibility of measuring water vapor with GNSS (e.g. Negusini et al., 2021) .

Negusini, M., Petkov, B. H., Tornatore, V., Barindelli, S., Martelli, L., Sarti, P., & Tomasi, C. (2021). Water Vapour Assessment Using GNSS and Radiosondes over Polar Regions and Estimation of Climatological Trends from Long-Term Time Series Analysis. Remote Sensing, 13(23), 4871. https://doi.org/10.3390/rs13234871

We added a statement for the use of GNSS and referenced Negusini et al. 2021:

For example, long-term precipitable water vapor trends can be obtained via GNSS techniques using networks such as POLENET (Negusini2021a), and regular radiosonde launches can be used to monitor several parameters (e.g., pressure, temperature, relative humidity) relevant to global climate change and ice-atmosphere interactions (see Alfonsi et al., 2022, for a detailed discussion of this topic).

Our comment RC2: *527: suggest to add van Calcar et al. (2025) to the references.*

Author's reply: Thank you for this suggestion; we’ve done so. Even more, we made a more complete reference list of coupled modelling studies at the start of the section, where the reviewer suggested to add van Calcar et al. (2025). Indeed this was missing, and so were a few other relevant studies. Drawing from our list on the ISMIP7GIA protocol, here is what we came up with there: Gomez et al. (2015), Konrad et al. (2015), Larour et al. (2019), Kachuck et al. (2020), Coulon et al. (2021), Book et al. (2022), Gomez et al. (2024), Houriez et al. (2025), Han et al. (2025) and Van Calcar et al. (2025).

Great improvement that all relevant literature is cited. We just couldn’t find Coulon et al. in the text and list of references.

Sorry, this was a mistake. Reference Coulon et al. (2021) has now been added (in Section 2.9).

Our comment 531: Coupled models are the means to investigate how the solid Earth influences the ice sheet. They are referred to in the abstract and form critical need 2 (line 1025) It seems appropriate to discuss them in more detail and we suggest this location in the text. Ice sheet coupled to 3D solid earth models include Gomez et al. (2018), van Calcar et al. (2023), Albrecht et al. (2024). They have the draw-back of long

computation time. Swierczek-Jereczek et al. (2024) and van Calcar et al. (2026) introduce methods to approximate solid earth deformation from 3D viscosity which could be very suitable for ensemble modelling that is necessary to get projections of Antarctica ice sheet melt with uncertainties.

Author's reply: We agree that coupled model frameworks are a key point that deserves more discussion, and thank the reviewer for raising that topic. In our revision we expanded this paragraph to include a broad overview of recent developments, such as ISMIP7, including but not limited to the suggested publications. The revised text addresses process representation, mantle structure and rheology models, and emulation and other scalable approximations to address increasing computation costs.

We appreciate the effort to extend section 2.9 and believe the section now covers all the relevant aspects.

The structure of the text in lines 716-722 is not entirely clear. As currently written, the connection between solid earth response, the exclusion of MISI/MICI from the likely-range GMSL projections and the discussion of submarine portions is not clear.

The paragraph up to this point covers 3D rheology and the availability of faster models. We suggest splitting what follows into a new paragraph with a clearer internal structure: (1) solid-Earth response is important for sea-level rise projections (with references), (2) 'water expulsion' adding more details on one of the pathways , and (3) IPCC projections and ISMIP6 projections have so far only marginally incorporated solid-Earth feedback

ISMIP7 could be mentioned as ongoing efforts to include solid Earth feedbacks in upcoming projections.

We thank the reviewer for this suggestion. We have restructured this part of the section according to their suggestion: a separate paragraph clarifies the progression from the implications of solid Earth and regional sea-level feedbacks, to water expulsion as a distinct mechanism, and finally to their representation in large-scale Antarctic ice-sheet projections. We removed the discussion of MISI/MICI from this paragraph and expanded the discussion of ISMIP6, highlighting the limited representation and physical fidelity of solid-Earth feedbacks in these projections. We also note ongoing ISMIP7 efforts to address this gap in future projections.

Our comment RC2: Other remarks. Topics of science questions 13 and 22 are not really found in the paper. Could this be addressed with a short text on marine geophysics? Reflection seismic could and sonar can reveal past grounding lines and sedimentation and the shape of the ocean basin where it interacts with the ice sheet.

Author's reply: Since the focus of our paper is on the onshore part of Antarctica and on groundbased observation systems in geophysics and geodesy, adding a description of marine geophysics would go beyond the scope of our manuscript. We added respective reference to these questions in Section “The ice-bedrock interface zone from multidisciplinary studies” (2.8.2, new numbering). (The numbers are now 14 and 23, according to the further revisions made in the text.)

Regarding Question 14, we understand and agree that offshore work is outside the manuscript's scope, but it is in the questions proposed, which are an important outcome of the paper; we suggest at least adding short context, for example about why the connection between on-shore and off-shore structure is relevant.

We added a short paragraph at the end of Section 3.1.3. It reads:

Further, ground-based geodetic-geophysical measurements also contribute to gain a better understanding of the ice-bedrock interface across the transition from the grounded ice sheet to the ocean. This region records interactions on grounding-line migration, changes in ice loading, solid-Earth deformation, and relative sea-level change, all of which can influence the stability and evolution of marine-based ice sheets (e.g., MISI, see Sec. 2.9). Characterizing the IBIZ (see Sec. 2.8.2), its offshore extension, and the underlying lithospheric and mantle structure is, therefore, important for linking the solid-Earth structure beneath Antarctica to that beneath the surrounding Southern Ocean. Tide gauges provide a particularly valuable ground-based observations by recording relative sea-level change (see Sec. 2.3) and linking solid-Earth deformation with ocean observations. More generally, resolving the onshore–offshore transition requires integrating ground-based geophysical measurements with marine, airborne and satellite-based observations (see Matsuoka et al., 2026, for a comprehensive review).