Comment on the manuscript: Recommendations for distinguishing process representation from projection outcomes in Antarctic projections

The manuscript presents a useful and timely benchmark of FastIsostasy against a full 3-D GIA model. The results convincingly demonstrate that FastIsostasy closely reproduces the response of the full model while remaining computationally efficient. Providing FastIsostasy as a publicly available tool capable of representing realistic 3-D Earth structure in a computationally inexpensive framework is a significant contribution that lowers the barrier for incorporating GIA feedbacks into ice-sheet models.

While the study is comprehensive and scientifically valuable, the abstract, introduction and discussion of the manuscript emphasize the need for capturing 3D GIA in the context of centennial scale projection of Antarctic Ice Sheet contribution to sea level (e.g., ISMIP7), while emphasizing the advantages of representing continental-scale 3-D Earth structure over simplified Earth models such as ELRA, ELVA and 1-D GIA. However, demonstrating that a physical process is represented more realistically is fundamentally different from demonstrating that the added realism materially changes the quantities for which Antarctic projection models are ultimately used, and the current manuscript does not establish the latter in a broader sense.

In particular, the manuscript could be improved by distinguishing the following three related, but distinct, statements:

1. 3-D Earth models provide the most physically realistic representation of solid-Earth and sea-level feedbacks.
2. Continental-scale 3-D Earth structure can greatly influence Antarctic ice-sheet evolution under certain retreat geometries.
3. Representing continental-scale 3-D Earth structure materially changes projected Antarctic ice-sheet contributions to sea level over centennial timescales.

The experiments mainly presented in this manuscript are designed to examine a scenario in which substantial retreat occurs across both West and East Antarctica over a 500-year simulation period under RCP8.5 scenario with Marine Ice-Cliff Instability (MICI). Under these conditions, it is scientifically important and expected that lateral variations in Earth structure exert a strong regional influence on Antarctic ice-sheet evolution. The manuscript therefore provides convincing evidence for Statement (2).

However, the broader applicability of these conclusions to the range of scenarios typically considered within ISMIP6/7 is less clear. It is worth noting that ISMIP6/7 extend through until 2300, and most of the Tier 1 experiments conducted in ISMIP6 – even under the most aggressive RCP8.5 and SSP5-8.5 scenarios – have shown ice mass loss largely limited to West Antarctica (Seroussi et al., 2024).

Even though the manuscript makes a conditional statement as to when 3-D GIA is needed (e.g., "*laterally-constant Earth structure is not well-suited for AIS projections if retreat occurs in both West and East Antarctica*"; L333) and stresses that "*the aim of this work is not to provide estimates of future sea level rise but rather to demonstrate that FastIsostasy can accurately approximate the 3-D GIA response, even under extreme ice loss scenarios...*" (L357), it repeatedly motivates and discusses the implications of this work in the broader context of future Antarctic projection efforts (ISMIP7). In that context, the manuscript naturally leads readers to interpret the results as evidence for the practical importance of representing continental-scale 3D Earth structure in centennial Antarctic projections.

While the introduction broadly motivates the need for continental-scale 3D Earth structure in Antarctic projection studies, the discussion ultimately recognizes that the importance of 3D Earth structure depends on the location of ice retreat and the underlying mantle viscosity.

In this context, it would also be valuable to discuss previous work examining the sensitivity of Antarctic projections to Earth structure. For example, Han et al. (2025) investigated Antarctic Ice Sheet projections using a coupled ice-sheet–1-D GIA framework under the ISMIP6 Antarctica-2300 protocol experiments (Seroussi et al., 2024). Although that study did not explicitly incorporate laterally varying Earth structure, it explored sensitivity to contrasting Earth structures representative of the mantle structures beneath West and East Antarctica. Across the Tier-1 ISMIP6 Antarctica-2300, the largest projection sensitivity occurred in the Amundsen Sea Embayment, where most projected retreat remained concentrated through 2300. These results further suggest that comparing the effects of 3-D GIA with those of a 1-D GIA model based on a global- or Antarctic-wide average mantle viscosity can overemphasize the importance of lateral Earth structure when projected ice retreat remains largely confined to West Antarctica.

Taken together, Han et al. (2025) and the present study provide complementary evidence that the importance of continental-scale Earth structure depends strongly on retreat geometry, projection scenario, and the projection quantity being considered. Accordingly, I believe the criticism of van Calcar et al. (2026) and Adhikari et al. (2025) in L322–341 would benefit from additional context. The criticism implicitly extends the present results from Statement (2) to Statement (3), whereas the broader applicability of these conclusions across the range of retreat behaviors relevant to Antarctic projection studies is not clearly established or discussed.

A second, independent consideration concerns the projection quantities analyzed. The analysis in the current manuscript is focused on quantities directly related to local changes in Antarctic Ice Sheet, such as ice thickness at grounding lines, grounded ice areas, relative sea level (RSL) in the ice model domain defined as the height difference between geoid and bedrock. While local quantities analyzed in this study are appropriate metrics for the purpose of model benchmark between FastIsostasy and full 3-D GIA model, and they show big differences between the simple Earth model cases and the 3-D GIA model cases, it is less clear how these local differences translate into differences in the quantities that motivate many Antarctic projection efforts, namely Antarctic ice-sheet contribution to global and regional sea level. Local ice-dynamic sensitivity and integrated sea-level sensitivity are not necessarily equivalent, and I believe this distinction deserves greater emphasis throughout the manuscript.

In summary, the present manuscript convincingly demonstrates that FastIsostasy reproduces 3-D solid Earth deformation captured by full 3-D GIA model. The experimental design and analyses also establish that 3-D Earth structure can matter under the particular retreat geometry considered here. The manuscript appropriately concludes that laterally uniform Earth models become less suitable if retreat occurs in both West and East Antarctica. However, because this conditional statement forms an important part of the motivation for future Antarctic projection efforts such as ISMIP7, I encourage the authors to more explicitly discuss how the importance of continental-scale 3-D Earth structure varies across the range of retreat scenarios considered in the manuscript, and how those scenarios relate to the ISMIP7 core experiments. More broadly, the manuscript would be strengthened by more clearly distinguishing the three statements outlined above and, ultimately, by distinguishing improvements in process representation from improvements in projection outcomes.

Specific locations for recommended refinement

1. L5-6: This statement asserts a universal requirement for "accuracy." Consider qualifying this by noting that the necessity of this coupling depends on the spatial scale of retreat and the degree of rheological heterogeneity in the affected basins.

2. L39: While true, the discussion could more clearly acknowledge that for many Tier-1 ISMIP experiments, these approximations remain a robust and "fit-for-purpose" approach, particularly when uncertainties in climate forcing and ice-sheet initialization dominate the error budget.

3. L52: This sentence exemplifies the tendency to frame 3D-GIA as the singular "best" choice. I suggest replacing "best option" with "highest-fidelity" or "most physically comprehensive" option.

3. L333-334: This is a vital conditional statement. It would be good to elevate the importance of this caveat throughout the manuscript to ensure readers understand that the "need" for 3D GIA is a function of the retreat geometry rather than an inherent failure of simpler models.

4. L322-344: The current tone implies that these 1D-based approaches are largely inadequate. It would be useful to have a more balanced discussion—perhaps by discussing Han et al.'s work—that acknowledges how such models can capture first-order sensitivities. Framing FastIsostasy as a high-fidelity alternative—rather than implying 3D GIA is the only viable path forward—would provide a more nuanced perspective. Furthermore, it is important to acknowledge that global integrated quantities (such as global mean sea level) may exhibit different sensitivities to Earth structure than the local quantities (grounding line position, local ice thickness) analyzed in this manuscript. Distinguishing between local ice-dynamic sensitivity and integrated sea-level sensitivity would provide the reader with a more complete understanding of when the overhead of 3D complexity is truly justified by the projection objective.

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References (excluding those already included in the manuscript)

Han, H. K., M. Hoffman, X. Asay-Davis, T. R. Hillebrand, & M. Perego (2025), Improving projections of Antarctic Ice Sheet contribution to sea-level change through 2300 by capturing gravitational, rotational, and deformational effects, *J. Geophys. Res. Earth Surf.*, **130**(9), e2025JF008388, doi:10.1029/2025JF008388.