Dear Dr. Ayele and reviewers,

Thank you for your comments on the manuscript. We have addressed them to the best of our ability (including the markup on the PDF) in the revised manuscript. Our responses below are in italics.

Sincerely,

Hannah Mark, for the authors

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Reviewer 1

I have read and commented on the paper by Mark et al. regarding the anisotropy of the Patagonian slab window. The paper provides excellent insight into mantle flow patterns in this complex area, where a mid-ocean ridge subducted approximately 15 Ma. The results are well discussed in the context of the study area, with comparisons to other seismic studies and mantle flow inferred from geochemical data. The paper will be a valuable contribution to the understanding of slab window processes in general, and even more so for the specific study area. Although the paper is well written and the figures are clear, I recommend moderate revisions, with only one major comment and several minor suggestions aimed at improving clarity and strengthening the discussions.

The main comment concerns the lack of referencing geodynamic modeling studies. While geochemical proxies are an appropriate tool to infer mantle flow (e.g., Lines 218–225), geodynamic models are equally valuable, as they allow tracking of temporal changes and along-trench variations (for 3D cases). Several studies address the general process of mid-ocean ridge subduction in 2D (Wu et al., 2022) and 3D (Cui and Li, 2024), and some focus specifically on the Patagonian slab window in 2D (Sanhueza et al., 2023a) and 3D (Sanhueza et al., 2023b). I recommend that the authors compare their results with these models as well, which would enhance the discussion on mantle flow patterns and anisotropy across the different mantle sub layers.

*Thanks for pointing this out – the initial manuscript did lack some context from modeling. We have added some references and model-related text in response to the comments below.*

Throughout the paper, the authors refer to shallow versus deep structures. I suggest adding one or two sentences to quantify these depths, ideally early in the Introduction (near Lines 56–58). Although it is mentioned in the Conclusions (Lines 215–216), an earlier clarification would help avoid confusion, particularly as "lower mantle sub layer" could be misinterpreted as referring to the entire lower mantle.

*This is an excellent point. Text has been added to the last paragraph of the introduction to clarify the “shallow vs deep” terminology (L61-62 in revised manuscript).*

A minor comment is that the paper assume a high level of prior knowledge, meaning that only experts may grasp all the details. I recommend expanding some explanations and adding general features to the Figures to make the paper more accessible to a broader audience (noted in the line-by-line comments). Despite my previous work in the area, it took some time to fully follow certain arguments.

*We have made some updates to the figures following the comments below, which hopefully make the paper easier to follow.*

Line-to-line comments:

Lines 38-39 and 54: You could also mention that toroidal flow is observed in 3D geodynamic models (Sanhueza et al., 2023b).

*References have been added (L40-41).*

Lines 48: Consider mentioning 3D GIA studies (Russo et al., 2022; Hollyday et al., 2023), where mantle viscosities are lower in the younger parts of the slab window and higher to the south.

*The references have been added, though we did not include specific discussion of them since GIA is not a focus of this paper (L48-49).*

Line 83: define CPO.

*The acronym is now defined (L88).*

Lines 107: typo: “sub-lyaer” → "sub-layer."

*Corrected.*

Lines 113-115: Here the mantle sub layers are mentioned and that their thickness are sensitive to the magnitude of the fast directions rather than the direction itself. But how this thickness was chosen in the first place? Did you consider the depth of the lower velocity anomaly from the tomography? Clarifying this would strengthen the argument without requiring an extensive sensitivity analysis.

*The thickness was chosen primarily based on sensitivity: we wanted to make sure that the data would still have some sensitivity in the lower mantle sub-layer, which basically meant that the upper sub-layer couldn’t be super thick. This is now clarified in the text (L113-116). We did test the effects of varying that layer thickness, as described in the manuscript, and found that precise placement of the upper/lower boundary didn’t seem to matter much for orientations.*

Line 117-118: I appreciate the inclusion of this point. Consider adding it to the figure captions if it is important to highlight.

*The criterion for a “resolved” anisotropy measurement has been made more clear in the captions of figures 3 and 4.*

Figures 3,4: Please draw the trench on these maps. Given the trench curvature at this margin, visualizing it would help readers assess the anisotropy orientation.

*We have added the convergent plate boundary to Figures 3 and 4.*

Clarify whether "mantle 1" and "mantle 2" refer to the mantle sub layers shown in Figure 2. If so, please use consistent terminology throughout the manuscript and figures.

*Yes, “mantle 1” is the “upper mantle sub-layer” and “mantle 2” the “lower mantle sub-layer.” The labels in Figures 3 and 4 now match Figure 2 for clarity.*

Adding labels for the younger and older parts of the slab window, or showing the slab window geometry, would help readers unfamiliar with the area.

*We have added the projected slab window location from Breitsprecher and Thorkelson 2009 to the maps.*

Line 151: define APM, are you referring to plate velocities right?

*Yes, to Absolute Plate Motion directions – the acronym has been expanded in the text (L161).*

Lines 153-154: Please clarify the meaning of "largely present." Also, while there is limited imaging of the Antarctic slab, there is adakitic volcanism associated with it, such as at Lautaro volcano, being the first from north to south. This suggests the Antarctic plate tip may be melting.

*“Largely present” is just intended to acknowledge that the slab window, while present under much of Patagonia, is graadually being filled in by the Antarctic slab as the triple junction moves north. We have added text that hopefully clarifies the sentence by referencing that filling-in as marked by adakitic volcanism (L168-170).*

Lines 154-155: Please be more specific about the "long history of subduction" because this margin experienced two slab windows during the Cenozoic, which can complicate this argument. Can it be that the anisotropy seen in the south part of the slab window already switched to a normal subduction with the Antartic plate? That way you do not need to rely on the previous events in the margin.

*By “long history” here we’re referring to the fact that the western margin of South America has experienced subduction since the Jurassic. More recent subduction of the Antarctic plate has undoubtedly had an effect on the mantle, but it seems unlikely that it has advanced far enough toward the east to fully explain the patterns we observe – which is why we invoke the history here, even though it is definitely complex.*

*We have added a reference for the “long history,” a global plate reconstruction, and have clarified the text around this point (L171-2, Seton et al.)*

Line 160: If trench-parallel anisotropy can be related to slab rollback, this would agree with the possible rollback of the Antarctic plate seen in geodynamic models (e.g., Sanhueza et al., 2023a).

*We have added the reference to help make this connection (L178).*

Line 166-168: This is intriguing, because previous tomography models (and also this one) suggest that younger parts of the slab window present a thinner lithosphere (mentioned in lines 181-183), while to the south it gets thicker. Could this imply that the slab window effects are more localized? Highlighting this point could support the idea of a return to normal subduction and the anisotropy seen to the south.

*True, although it is difficult to separate the possible effects of “recovering” from the northward passage of the slab window from possible effects of initial conditions, if the continental lithosphere in the south was simply thicker to begin with. This is discussed a bit in Mark et al. (2022), and the present study unfortunately doesn’t give us any additional information that would distinguish between re-establishing normal subduction versus slab window effects just not having been as strong (or acting on something that was initially colder or thicker) in the south.*

Lines 183-186: What about geodynamic modelling? A number of studies have been done in 2D and 3D where mantle flow is indeed more horizontal rather than vertical (upwelling) (e.g, Cui and Li, 2024; Sanhueza et al., 2023a, 2023b; Wu et al., 2022).

*We have added text and references to recognize that models also support horizontal flow within the slab window (L203-204).*

Lines 186-188: This is an important result. Could you provide depth estimates for the boundary separating the different flow domains?

*It’s not entirely satisfying, but the distinction between the upper and lower mantle sub-layers is the best we can do for this. E-W flow seems to be in that lower layer, so deeper than 40 km below the crust, keeping in mind the layer depth sensitivity analysis presented in the paper.*

Also, it would be great to have a sentence or two mentioning why there might be these two layers, is it because of the high temperatures in the upper mantle restricted to a narrow depth range? Some of it is mentioned in lines 202-204, but discussing the origin of this mantle layering is worth mentioning.

*The main way that we think about the mantle layering, which is presented in the paper (and has been clarified in response to Reviewer 2), is that it’s the lithosphere and asthenosphere – the definition of the boundary between these is widely debated but likely strongly related to temperature as well as other factors.*

Lines 221-224: I strongly recommend including a small discussion on geodynamic models. For instance, 2D models suggest flow from the Pacific into South America (Sanhueza et al., 2023a). However, time-evolving 3D studies are still needed.

*Text to this effect has been added to this paragraph in the conclusions (L238-243).*

References:

Cui and Li (2024): <https://doi.org/10.1130/G52355.1>

Hollyday et al. (2023): <https://doi.org/10.1029/2022GC010648>

Russo et al. (2022): <https://doi.org/10.1130/G49388.1>

Sanhueza et al. (2023a): <https://doi.org/10.1029/2023GC010977>

Sanhueza et al. (2023b): <https://doi.org/10.1016/j.epsl.2023.118435>

Wu et al. (2022): <https://doi.org/10.1029/2022gl098428>

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Reviewer 2

The manuscript presents an interesting and valuable contribution to our understanding of anisotropy patterns and mantle dynamics beneath Patagonia. The methodology is robust, and the results offer new insights, particularly in the context of slab window tectonics. However, I believe the concept of cross-basin mantle flow—implied by the E-W fast directions in the asthenospheric layer—deserves further development. This interpretation could be reinforced by referencing previous works (e.g., Gallego et al., 2011) and by explicitly considering how the lithospheric and asthenospheric layers may record different geodynamic processes.

It would also be useful to discuss how the definition and fixed thickness of the mantle sub-layers might affect the results. For instance, the similarity between the anisotropy directions in the upper mantle sub-layer (mantle 1) and those found in previous crustal studies suggests that this layer may be reflecting lithospheric structure and composition rather than asthenospheric flow. In contrast, the lower mantle sub-layer (mantle 2) likely captures flow related to mantle convection and material exchange between the Pacific and Atlantic domains.

I suggest adding a brief paragraph in the Discussion that expands on these ideas.

*In response to this and comments from Reviewer 1, we have added to the text in a few places: in the introduction, to frame the lithosphere/asthenosphere view of mantle layering in this anisotropic model; and in the conclusions, where we discuss the lithosphere/asthenosphere view of the layers more directly (L61-62, 110-111, 244-248). We have also added a brief comparison to the crustal anisotropy results of Gallego et al. 2011 in the results section (L162-166).*

A map of the Austral and adjacent basins would also help illustrate the cross-basin context.

*Since the cross-basin mantle flow refers to Atlantic/Pacific, we hope that the current maps will be enough. The Austral-Magallanes basin is a very interesting region and worth further study, particularly in the context of seismic anisotropy, but since it’s not directly relevant to the mantle anisotropy focus of this work, we think that pointing to the supplementary maps of sediment thickness is enough.*

In summary, the manuscript requires only minor revisions, and I recommend publication after these clarifications are considered.