Response to Reviewer 1

The manuscript is well prepared and presents a valuable contribution to the field. I have a few minor suggestions that should be incorporated into the revised version to further enhance its clarity, rigor, and overall impact.

Thank you very much for your careful evaluation of our manuscript and for the constructive comments on our submission. We appreciate your positive assessment of the relevance of the topic and the Antarctic-wide application. We will revise the manuscript in response to your suggestions regarding methodological clarity, interpretation, and presentation. Please find below our point-by-point responses (in red).

1. The manuscript would benefit from stating even more consistently, particularly in the Abstract, Introduction, and Conclusions, that the retrieved grain size represents an effective ASCAT-conditioned parameter. Likewise, the FAC-related analysis should be explicitly framed as a proof of concept rather than an operational retrieval product.
   In the revised manuscript, we will state the interpretive framing of both the retrieved grain-size parameter and the FAC-related analysis more consistently in the most visible sections of the manuscript. We will revise the Abstract, the final paragraph of the Introduction, and the Conclusions to clarify that the retrieved grain size is interpreted as an effective parameter inferred within the adopted FDM–SMRT framework, rather than a direct physical grain-size measurement. We will also refine the text in these sections to state more explicitly that the FAC-related analysis is presented as a proof of concept that helps inform future development of a FAC retrieval framework, rather than as an already operational retrieval product.

2. Section 3 contains all the necessary methodological details; however, the overall workflow could be presented more clearly. In particular, it would be helpful to state explicitly, ideally at the beginning of the Methods section or in a brief schematic overview, that firn stratigraphy (including density, temperature, liquid water content, and layering) is prescribed from IMAU-FDM; that the inversion estimates only a single column-integrated grain-size parameter; and that the ANOVA and grain-size standardization are applied as post-inversion diagnostic analyses. This clarification would greatly improve the transparency of the methodological framework without altering the underlying approach.
   In the revised manuscript, we will add a short overview paragraph at the beginning of Section 3 to state explicitly that firn stratigraphy (including layer thickness, density, temperature, and liquid water content) is prescribed from IMAU-FDM, that the inversion estimates only a single column-wide grain-size parameter, and that the

ANOVA and grain-size standardization are applied as post-inversion diagnostic analyses. We will also revise the subsequent roadmap paragraph to clarify the purpose of each methodological step.

3. The manuscript appropriately notes that the excellent agreement between the optimized FDM-SMRT backscatter and ASCAT should be interpreted as internal consistency within the adopted modelling framework, rather than as an independent validation. Given the strength of the reported fit, however, this important caveat should be highlighted more prominently in the main Results section and/or in the caption of Appendix Figure A1, so that readers encounter this interpretive context alongside the performance metrics.
   In the revised manuscript, we will make this caveat more visible alongside the performance metrics by revising the text in Section 4.3 to state more explicitly that the agreement between optimized FDM–SMRT simulations and ASCAT should be interpreted as internal consistency within the adopted framework, not as independent validation. We will also add this clarification to the caption of Appendix Figure A1 so that readers encounter this context directly alongside the fit statistics and comparison figure.

4. The manuscript correctly acknowledges that the ANOVA should be interpreted as a conditional diagnostic within the adopted framework, since the optimized grain size is itself derived from ASCAT observations. However, some instances of the term "explained variance" may inadvertently imply a stronger degree of independence or causality than intended. To enhance interpretive precision, I recommend consistently adopting terminology such as "variance partitioning within the adopted framework" in Section 3.4, Section 4.4, and Appendix B, and, where appropriate, in the corresponding figure captions. This refinement would strengthen the rigor of interpretation without requiring additional analyses.
   In the revised manuscript, we will describe the ANOVA results more consistently as a conditional variance-partitioning analysis within the adopted framework. Specifically, we will revise the terminology in Section 3.4, Section 4.4, Figure 5, and the corresponding appendix figure and discussion to replace stronger expressions such as "explained variance" with more precise wording including "variance partitioning," "fractional contributions," and "residual term/component." We will also clarify in the text that the ANOVA is intended to describe how ASCAT variability projects onto FAC and grain size within the adopted framework, rather than implying independent or causal attribution.

5. One of the manuscript's key strengths is its clear recognition of the conditions under which the inversion is more or less informative. For example, grain-size identifiability appears stronger in certain regimes and weaker over shallow-slope plateau regions, while unmodelled near-surface processes may become increasingly important in dry, high-FAC environments. Similarly, the FAC-related interpretation is appropriately presented as a proof of concept. To further enhance clarity for readers, I recommend adding a concise synthesis paragraph, either at the end of the Results section or at the beginning of the Limitations section, summarizing where confidence in the retrieval is relatively high, where it is lower, and the physical reasons underlying these differences. This would improve accessibility and interpretability without altering the scientific content.

   In the revised manuscript, we will add a concise synthesis paragraph at the beginning of the Limitations and Future Scope section summarizing where confidence in the retrieval is relatively higher, where it is lower, and the physical reasons underlying these differences. Specifically, we will state that confidence is relatively higher in dry-snow and intermediate-FAC regimes where ASCAT is sufficiently sensitive to grain size, lower in shallow-slope or strongly depleted regimes where the response becomes more strongly governed by density/FAC, and additionally limited in some dry, high-FAC regions by unmodeled near-surface processes. We will also reiterate there that the FAC-related interpretation remains a proof of concept for future retrieval development.