Dear Dr. Franke,

We thank you for the time and effort in reviewing our manuscript. We sincerely appreciate the positive feedback and insightful comments, which have been incorporated into the revised manuscript. Below, we provide a detailed, point-by-point response to your comments. For each point, we reproduce the referee's comment in italics, followed by our response and a description of the corresponding changes in the manuscript. We believe these revisions have substantially improved the manuscript, and we hope you agree that it is now suitable for publication in The Cryosphere.

Sincerely,

Shuai Yan, on behalf of all authors

Yan et al. investigate the basal unit of the central Antarctic Ice Sheet, a critical yet poorly understood component of the ice-sheet system. They use new high-resolution radar data to examine the reflection and scattering properties in this region. Through Delay-Doppler analysis, they characterize two areas with different scattering properties. These results are used and discussed to determine possible englacial causes for the differences observed in these two regions, with variations in ice temperature and subglacial geology likely being responsible.

This paper is very well written, well structured, and addresses a relevant aspect of the Antarctic Ice Sheet. The basal unit is a region where complex and poorly understood processes lead to the loss of englacial layering and coherence in radar signals. Yan et al. provide a clear and comprehensive introduction to this complex topic, thoroughly describe the survey region, data, and methods, and make a valuable contribution to the field through their interpretation and critical discussion. In my opinion, this article is of high scientific quality, sheds light on a significant topic, and presents new insights, making it relevant for The Cryosphere.

I have two main points that need clarification and a few minor suggestions that could make the paper clearer. Once these points are addressed, I look forward to seeing this article published in The Cryosphere.

Response: We sincerely appreciate the positive feedback and insightful comments, which have led to substantial improvements in the manuscript.

Main points:

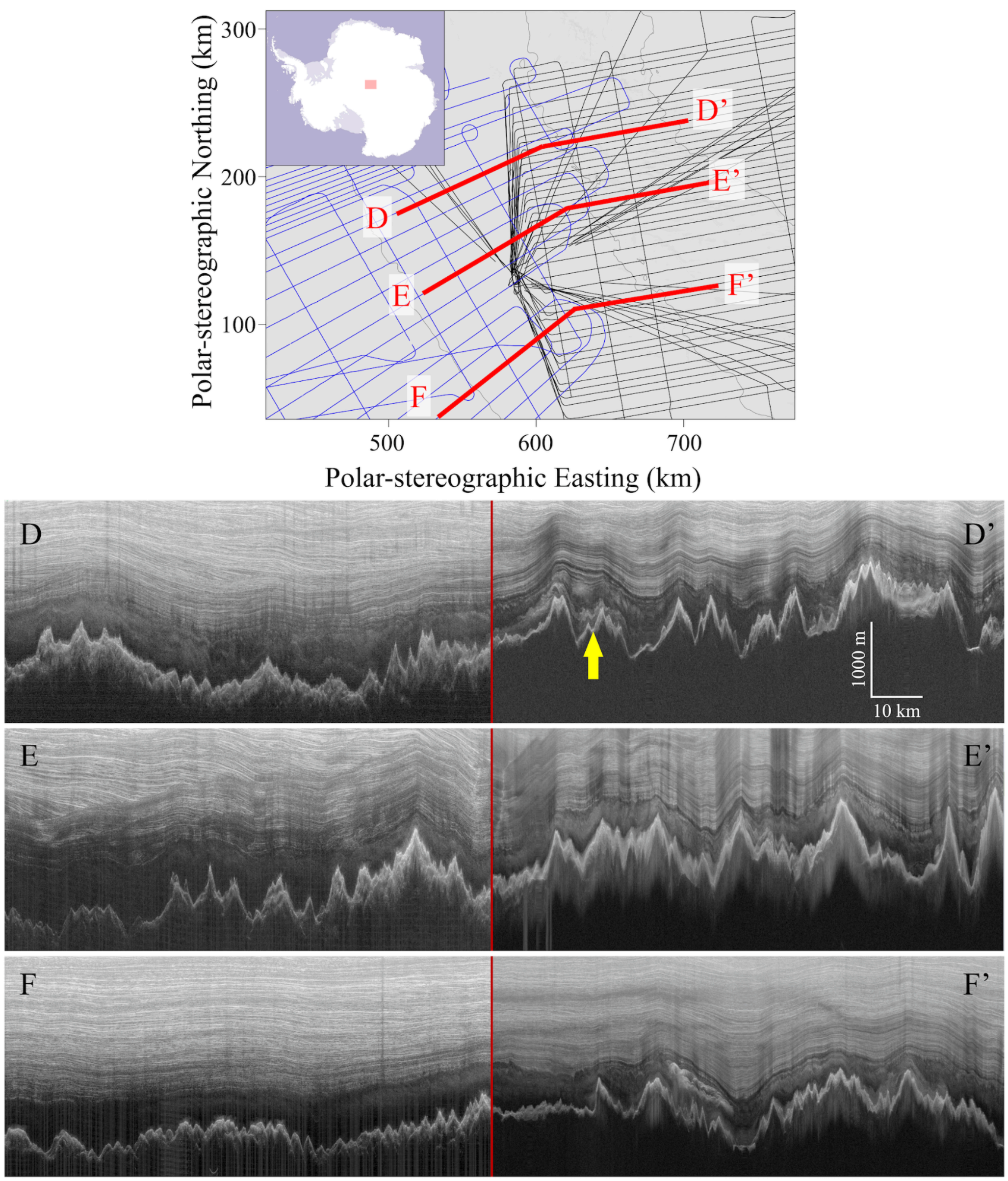
1)L220 - 223: "During this freeze-on process, debris may become entrained in the ice, potentially contributing to the incoherent scattering observed in IPR sounding. Given the similar radar signature, we infer that the incoherent scattering observed in the upstream portion of the COLDEX survey region may have formed through the same mechanism."

I would disagree with the authors' claim that the radar signature observed is "similar" to those in studies analyzing the entrainment of englacial debris. My comment is based on a purely visual comparison of the radargrams in this study (e.g., Figures 1, 3, 7) with those shown below in studies addressing entrained basal debris in the basal ice unit: Bell et al. (2011), Wrona et al. (2018), and Franke et al. (2023, 2024). When comparing the radar signatures in Figures 1, 3, or 7 of this study (where it is most visible) with those in the mentioned studies, I do not believe we are referring to the same signature. In my view, the signatures in Bell et al. (2011), Wrona et al. (2018), and Franke et al. (2023, 2024) exhibit (i) higher return power (sometimes comparable to *the bed return power), (ii) are directly connected with the ice base, and (iii) are located in regions where subglacial freeze-on was modeled. I would argue that the signatures referred to in this study correspond to those seen, for example, in Figure 2 of Wrona et al. (2018) or Figure 2 of Franke et al. (2024), but located above the layer defined as sediment entrained.*

This does not mean that the incoherent scattering detected in this study cannot originate from entrained particles, but it is not comparable to what the aforementioned studies refer to.

I leave it to the authors to decide how to address this comment and they might disagree. However, it should be clarified that—at least based on a visual comparison of the radargrams—we are not discussing the same phenomenon.

Response: We appreciate your detailed and thoughtful comments here. In the figure below, we provide side-to-side comparisons of the COLDEX survey (used in this study) and the AGAP survey (used by Bell et al., 2011, and Wrona et al., 2018) at some of their intersection points:



Based on visual comparison, we agree that the incoherent scattering observed in the COLDEX data does not resemble the basal freeze-on packages shown in Bell et al. (2011) and Wrona et al. (2018). An example of such basal freeze-on packages is highlighted by the yellow arrow in the figure. Instead, the incoherent scattering indeed closely resembles the radar signature of the layer overlying the sediment-entrained unit.

Based on this observation, we interpret the incoherent scattering as arising from either (1) deformation and folding caused by ice flowing across alternating slippery and rough frozen patches of the bedrock (as suggested by Wolovick et al., 2012), or (2) variations in ice crystal orientation fabric (as suggested by Mutter and Holschuh, 2025).

We have revised the manuscript to include this comparison and changed our interpretation, which can be found at line #202-212 of the revised manuscript (line #264-278 of the track-change version). Specifically, we state: “The COLDEX survey is situated directly downstream of the Antarctica's Gamburtsev Province (AGAP) Project (Corr et al., 2020). It has been hypothesized that the AGAP IPR sounding reveals packages formed by freezing of subglacial water and subsequent entrainment of debris (Creyts et al., 2014; Wolovick et al., 2013). We provide side-by-side comparisons of this basal unit as imaged by the COLDEX and AGAP IPR sounding at several intersection points in Fig. 7. We notice that (1) the incoherent scattering exhibits characteristics similar to the unit directly overlying the basal freeze-on package, and (2) this incoherent scattering is widespread within the AGAP survey in the region intersecting the COLDEX survey, that is, around and downstream of the area where widespread basal freeze-on was inferred by Bell et al. (2011). Based on this observation, we consider the incoherent scattering unlikely to represent the basal freeze-on package given its distinct radar signature. Instead, we interpret the incoherent scattering as arising from either (1) deformation and folding caused by ice flowing across slippery patches of the bedrock (as suggested by Wolovick et al., 2012), or (2) variations in ice crystal orientation fabric (as suggested by Mutter and Holschuh, 2025).”

We also note in the figure caption that: “the radar system used in the AGAP survey operates at a different center frequency (150 MHz), which results in different vertical resolution and may alter the appearance of the same reflector—particularly for reflectors whose characteristic dimensions are comparable to the radar wavelength.”

2) The authors interpret that the cause for the appearance and disappearance of incoherent scattering in the basal unit is spatial variability in englacial temperature. They mention that other processes can also contribute, but warmer ice seems to be their main interpretation, and this is also very prominent in the abstract.

I wonder how robust this is or if other mechanisms, such as equally warm/cold ice with different degrees of internal mixing could be an equally likely cause. There is not much other data or information presented in the paper (basal reflectivity, estimates on englacial attenuation, ...) that would support temperature differences to be the main cause (or I did overlook them). Maybe the authors could comment on that and (if possible) strengthen this interpretation, or consider to say that other mechanisms could be equally likely in relevant parts of the paper (e.g., abstract and conclusions).

Moreover, a connection between incoherent scattering and subglacial roughness is being made. Is there also a correlation between incoherent scattering and ice thickness?

Response: Thanks for the detailed and thoughtful comments and suggestions. We have expanded the discussion of the other mechanisms that are outlined in the introduction section, which can be found at the Section 4 and Section 5 of the revised manuscript. Specifically, we discuss the freeze-on hypothesis at line #202-210 of the revised manuscript (line #264-274 of the track change version), leveraging the direct side-to-side comparison of the COLDEX and the AGAP radar survey. Following this discussion, we discuss the deformation and folding hypothesis at line #210-212 of the revised manuscript (line #274-278 of the track-change version), in addition to what was included in the original manuscript at line #231-239 of the revised manuscript (line #293-329 of the track-change version). The hypothesis around englacial temperature variation was already discussed extensively in the original manuscript.

We do not see a strong correlation between the ice thickness and the presence and the thickness variation of the incoherent scattering.

Minor points:

● *I hope I didn't overlook this, but the paper does not provide the specific years of the radar flights. This should be pointed out more clearly in the abstract and data and methods section.*

Response: We appreciate your suggestion. We have provided a clarification about the specific years when the surveys were conducted (2022-23 and 2023-24) at line #103 of the revised manuscript (line #131 of the track-change version).

● *Would it be possible to draw the dashed lines you have in Figure 3, also in the radargrams in Figure 4?*

Response: Thanks for the suggestion. We have added dash lines to Figure 4a to highlight the basal unit and incoherent echo.

● *Figure 5: Ice thickness is reducing from right to left in the conceptual figure. From your radargrams and bed topography map it seems that ice thickness is however fairly constant and probably even thicker in your Type II boundary. Maybe this could be addressed or corrected to avoid conclusions drawn from this figure (e.g., that the Type II region has thinner ice).*

Response: We have revised the figure caption to explicitly note that "the variations in ice thickness and subglacial topography shown in this conceptual sketch are intended only as a schematic illustration and do not necessarily correspond to actual correlations between such variations and basal unit boundary types."

● *L129: [... 2D focusing was applied following the procedure described in Peters et al. (2007), which helps correct for off-nadir scattering...] – I believe this refers to along- track off-nair scattering and not cross-track off-nadir scattering?*

Response: We have made the corresponding correction at line #129 of the revised manuscript (line #170 of the track-change version).

● *L53-58: Franke et al. (2024) could be cited here as well with regard to freeze-on of subglacial water and sediment entrainment at the onset of Jutulstraumen Glacier, but I'll leave it entirely optional for the authors because it concerns one of my own publications.*

● *L64: Regarding radar signatures and COF, I'd suggest to cite the work of Lilien et al. (2021) as well.*

● *L220: Regarding freeze-on of subglacial water, I'd suggest to cite Creyts et al. (2014) next to Wolovick et al. (2013) as well.*

Response: Thank you for the suggestions. We have included these references in the revised manuscript.