Dear Julian,

We appreciate your thorough and thoughtful read of our manuscript. We're glad you found the work informative and are excited to clarify the text and make figure improvements following your suggestions. Here, we *provide a response to each of your comments* and describe anticipated changes to the manuscript.

> Discussion section (Section 4): The authors mentioned early in the paper that the scattering or lack of signal may also be related to data acquisition and processing (see end of Section 2). This is again briefly mentioned in the conclusions. This is something that has repeatedly been on my mind whilst reading this paper, and I wonder whether this could be mentioned/discussed again somewhere in the Discussion section as a caveat. Would the authors expect to see more (or less) scattering if the radar data shown in Figure 3 and 4 be processed differently (i.e. using a homogenous processing workflow from the raw data to all the radar products analysed here – i.e. in a similar way to what the Open Polar Radar project aims to do) and thus, if the authors think that the conclusions drawn from Figure 3 in particular may be potentially different as a result? This is seldom discussed in the paper, but I wonder whether there is scope to add a few sentences on this, and perhaps the discussion section is a good opportunity to add this as a potential caveat.

For radars of identical design, image processing could significantly affect the way diffuse and specular reflections are expressed in radar imagery (as you rightfully point out). SAR focusing can collapse diffraction hyperbola from diffuse scatterers to point targets, which (if concentrated in ice of a particular age) may look similar to the more specular isochrons. Incoherent and coherent averaging (or "multi-looking") could result in destructive interference of incoherent scattering that reduces the signal to noise ratio. For both qualitative interpretation (like the work done here) and quantitative interpretation (through methods like delay-doppler analysis), data-preprocessing could change the way the data are interpreted, and we will work to incorporate some of those caveats into the discussion.

Separate from the way the scattering is interpreted, differences in radar architecture (most notably differences in center frequency and bandwidth) can change the nature of the recorded scattering itself. Apparently coherent, specular horizons can turn into diffuse scatterers as the scale of dielectric heterogeneity (or interface roughness) approaches the frequency-dependent Rayleigh Roughness Criterion. And at some frequency limit, it is likely that all layering within ice sheets will appear as diffuse scattering. What we interpret here is most relevant for the typical ice penetrating radar frequencies and bandwidths. We will also add a caveat to the text to account for expected differences for ultrawideband or ultra high-frequency systems.

> There is also, of course, the subjectivity in identifying whether the incoherent layering is diffuse, laterally homogeneous, or laterally heterogenous (and how does one set of eye, with one image processed in a certain way to emphasise specific sections or patterns in the ice that may be not be optimised for the type of analysis made in this paper, determines the type of scattering observed as "*strictly*" as it is done in, for example, Figure 4)? I see this paper as a good opportunity to discuss these in some more details, if possible.

You're absolutely right that the types of qualitative interpretation we do here is subjective – we will try to provide more descriptive language to explain how we did our categorization

to try and help future ice core site selectors standardize their practice. But underlying your comment here is a desire for a quantitative framework for layer categorization. We can provide some guidance for how that might work when you have standardized data, which could be a nice contribution for future studies. Thanks for hinting at this, as it provides a clear way to increase the reach of our work.

Figures: Overall, I found the figures very interesting but lacking in clarity or additional information in the text/caption that may help the reader understand them. This is particularly true for Figure 3 (see below for specific comments), which has a lot of information, and the reader is left to do a lot of the work to try to piece together all the information that is being presented. The authors may want to consider whether they could split this figure up into several ones, perhaps ordered by region (Greenland vs Antarctica), make labels and legends bigger and much more simplified, and provide a full caption which may help guide the reader. The other figures also need much better captions to explain the different elements being presented (again see my below comments).

Structuring the figures was one of the hardest parts of writing this figure for us – we agree that they are information dense, and there may be ways to make them more accessible. See our responses to your specific requests below.

Data availability: There is no mention of where readers can access the data presented in this paper. Could you please add this for all the radar data and other associated datasets presented in this paper?

We will link to a data repository with all of the radar data used to generate the figures in this study, and in the supplementary material we provide referencing and identifying flight information for each line in its original repository (for those radar images drawn from open access repositories). We will also provide code to reproduce the figures. We were simply waiting to finalize our data repository at the publication stage, but thank you for maintaining accountability for open access, we agree that it is an important attribute of any study.

Line Item Comments:

Line 23-24: "And while […] future ice coring initiatives hope to build…". Confusing grammar, please rephrase

Changed to: "These cores capture global climate changes over the Holocene and Late Pleistocene (Wolff et al., 2010). Future ice coring initiatives hope to build on that record, both extending it further back in time (Jouzel and Masson-Delmotte, 2010) and measuring regional climate change (Mulvaney et al., 2021) during specific climate periods (Fudge et al., 2023)."

Line 27: "specific ice" – what is meant here? Replace maybe by "stable" or "climatically stable"?

The objectives for ice core collection can actually vary quite a bit – scientists could be targeting ice of a particular age, ice that is extremely old, ice that flowed in from a particular region. In this case "specific ice" just means that there are characteristics desired for the ice core acquisition, and site selection needs to be able to identify those characteristics in advance of drilling.

Line 29: not just “accumulation and ice flow” – add basal melting too

Content changed to reflect reviewer comment.

Line 29: Reference to Schroeder et al. 2020 – could add a few more references here. Examples: Bingham et al. 2024 (in review at TC, https://doi.org/10.5194/egusphere-2024-2593); Chung et al. 2023 (https://doi.org/10.5194/tc-17-3461-2023); Karlsson et al. 2018 (https://doi.org/10.5194/tc-12-2413-2018)

Content changed to include references.

Line 30: “shallow” – replace by “the upper 2/3” as shallow is an understatement and is also a big vague.

Content changed to include “the upper three-quarters”

Line 31: “on what incoherent scattering …” – add “on what incoherent scattering in deep ice” to differentiate with the previous sentence which mentions coherent homogenous layering in the top part of the ice column

Content changed to include addition of “deep”

Line 35: I would add a few references to seminal work on this topic in the existing list of reference you provide here. For example, Millar (1982), Hammer (1980), Harrison (1973) works would be great here.

Content changed to include references.

Line 39: Add Chung et al. (2023 – DOI already provided here) as an additional reference to Lilien et al. 2021)

Content changed to include reference.

Line 39: “16 ice cores” – add “across Antarctica and Greenland”

Content changed to reflect reviewer comment.

Line 48: add Bingham et al. 2024 to the Dowdeswell and Evans reference

Content changed to include reference.

Line 53: “to an (up to)...” – should be “a”. Also please provide a reference to this sentence.

Because the strength of the fabric controls the bulk permittivity, you can have (a) an isotropic crystal fabric with no dielectric contrasts induced by individual crystal anisotropy, (b) a perfect vertical C-axis maximum that transitions to a perfect horizontal C-axis maximum which would induce a ~1.3% contrast in dielectric permittivity (the same difference that exists between the C-parallel and C-perpendicular axes for individual crystals), or (c) any intermediate contrast between those end members. It is for that reason that we prefer the phrasing (up to) rather than “a” in this sentence, as the magnitude of the fabric induced contrast must fall between

~0% and ~1.3%. But we have added a citation to Matsuoka et al., 1997, where the single crystal anisotropy values were measured and published.

Line 59: add Bingham et al. 2024 to the Fahnestock et al reference already provided.

Content changed to include reference.

Line 61: can you provide additional references to the Schroeder et al. 2020 reference here? You provide references to science papers for the previous sentence, but only a review paper for this one. It would help to point the reader to additional science papers that discuss this point.

Content changed to include references (and some "e.g."s to point out that it is difficult to be comprehensive in referencing these broad study topics).

Line 64-65: Please refer to Figure 2b here.

Because we have text that walks the reader through Figure 2 in the following paragraph, we prefer to wait to reference it until we have a more guided introduction to the concept (even though you are right, the text in lines 64-65 is definitely relevant to Figure 2).

Line 106-108: Add reference here. Perhaps Young et al., 2021 (https://doi.org/10.1029/2020JF006023) is a good starting point.

Content changed to include reference.

Lines 189-194: I was confused when reading this paragraph (and some sentences preceding this) about the lack of figures that would illustrate the description of the patterns found at each ice core locations. I think this is because these are not referred to in the text explicitly. I think that mentions of Figures 3 and 4 throughout the text (with sub panels) would help greatly to guide the reader to these figures. As it stands, I read this paragraph but ask myself why there are no figures showing this in the paper, only to find out later that these exist further down the paper but are not being referred to in the text.

As you point out in your comments on figures, Figure 3 contains a lot of information. We tried to help situate the reader in lines 170-172, suggesting that everything that follows in this section is built on Figure 3. We have modified the text there to be much more explicit that Figure 3 is essential to the following interpretations, with the hopes that readers reference that figure for all of our description.

Line 204: "time" – what do you mean by this? I think you mean age-depth? Clarify

Content changed to "where annual layer thickness is."

Line 210: Again please mention the figures in this sentence and throughout this paragraph

Because almost every sentence in these paragraphs refers directly to content captured in Figure 3, we prefer the strategy of emphasizing its importance at the start of the section. Hopefully the modified text from lines 170-172 accomplishes your intended goal, but feel free to let us know if you still think it is insufficient.

Line 239: “doesn’t” – replace by “does not”

Content replaced with “does not”

Section 3.2: I found this section really interesting – great addition.

Thank you!

Line 265-273: I wonder if it would be interesting to show the returned echo power graph of a (or several) trace(s) in a figure (perhaps in a modified version of Figure 3 or 4). This would help counteract the problem with the size and colorscale of the radargrams presented which make it often hard to see the pattern of scattering.

To counteract the problem with the size, we have increased the size of all of the radargrams in figures 3 and 4.

Line 326: replace “radar data” with “ice-penetrating radar data”

Content changed to “ice-penetrating radar data.”

Line 331: replace “to” with “do”

Content changed to “do.”

Line 334: “time is compressed” – again, the use to the word “time” is maybe a bit confusing to me. Perhaps replace by “age-depth”

Changed

Line 335: replace “is” to “to be”

Content changed to “to be.”

Figure and captions:
Figure 1 (caption): Specify what the colormap and reliefs show and where these data come from (also the grounding line and IMBIE drainage catchments please).

Content changed to include citations.

Figure 1: you could also add another axis in the “Core length” diagram in Figure 1 which shows the age of each ice cores in combination with the depth axis already provided.

While we agree that age information might be useful for the reader, the implementation would not be as straightforward as you describe. The depth-age scale for each core is different, which means none of the cores could share an age axis. We’ve decided to omit this for now, but do provide some age information in the supplemental material.

Figure 2 (caption): Could you add in the caption where the datasets you present are from (source + radar system type)?

We will add a reference to Supplementary Table 1, which has the full system characteristics, and fix the typo which currently references Figures 1c instead of Figure 2c.

Figure 3: I like this figure a lot, however:

The caption does not provide many details that could help guide the reader to each part of the figure (e.g. the left-most plots in each subplot are not explained – are these c-axes plots?). And what about the plots with the green line through them? Perhaps the confusion stems from the fact that there is a lot of information on it, which I don't particularly mind and sometimes I think this is necessary, but it must be properly explained either in the text or in the caption. Having read this multiple times, I am left frustrated that it takes more than a couple of minutes to really get through all the elements presented in the figure.

The "layer slopes" legend is not clear enough and I can't see these very well on the plots

The difference between "no data" and "no visible layering" is too similar and I can't see the difference between the two

The difference between the "+" for the thin and thick sections is not very obvious either. Also, what does "Sampling" mean with regards to these two "+" symbols?

In general, I would say that there is maybe too much information on it, and I would recommend simplifying it a bit but also perhaps making multiple figures from this one, such as by regions or sub-regions. This would also allow for the radargrams to be stretched horizontally a bit so that the patterns are much more visible. Perhaps altering the color scale or adding some gain to the radargrams would also be beneficial, as I'm left having to trust the authors a lot about what they "see", when I can't really see it myself very clearly due to the small size of the figure and the overload of information being presented. This refers also a bit to my general point above with regards to the processing of the radar data that is used to make the interpretations in this paper (of course one could argue this is the case for any dataset, but it would be worth addressing this point in the paper a bit more).

We agree that this figure became overly complex – a reflection of the fact that we (as authors) wanted to compare all the available data before making conclusions, but that the reader doesn't actually need some of what we present. The Schmidt plots do not add any meaningful information to the figure. We will add idealized Schmidt plots of each of the fabric types to the fabric observations section of the legend instead. Similarly, we will pull out the line scan images from EDML, NEEM, NorthGRIP, & GISP2 into a separate figure that showcases visual observations of the different scales of folded layers. That will leave room for doubling the width of the radargrams without extending the figure across two pages. We will also add grid lines across the figures so that people can more easily see the connections (or lack of connection) between the fabric and layering transitions visualized in the colorbars and changing quality of radar backscatter. To improve color contrast between no data and no visible layering, we can make no data black (which would be consistent with the fabric observations). We have also standardized the depth range across the figures, so they each show ice from 850 m above the bed to 50 m below.

We will also update the caption to the following, which provides more context for the reader:

"Synthesis of fabric measurements, layering observations, and radargrams at the nine deep ice core drill sites with comprehensive datasets. The left-most section of each ice core panel presents a 1-D scatterplot that marks sampling depths where thin sections (and, where

*applicable, thick sections) were collected for crystal orientation fabric analysis. *At GISP2, only some of the sampled thin sections have published data (indicated by the black + symbols), and † at Vostok, the original sampling rate is unpublished, with only a few thin sections and general observations available in the literature. The color bars from each ice core panel summarize fabric observations (left) and layering observations (right) as described in the literature. Fabric observations are simplified into a tripartite classification: strong single maximum (white), weak single maximum or elliptical (cyan), or girdle (green). Other fabric observations or depths with no fabric observations are black. Where sampling frequency permits, or where gradual fabric transitions are noted in the literature, color gradients are used to represent gradual transitions. The right color bar presents layering observations, with colors reflecting the scale and nature of disturbances: planar, undisturbed layers appear in purple, while progressively disturbed layers are shown in yellow and then red as disturbance size increases to > 50 cm. Sloping layers are indicated by increasing layer slopes (>15°, >30°, >45°). Diffuse layering appears in lavender, and sections with no visible layers appear in grey. Radargrams from each ice core site span ~700-1000 m of the ice column. Fabric observations sourced from: EDML (Eisen et al., 2007; Faria et al., 2018; Weikusat et al., 2013), Dome Fuji (Saruya et al., 2022, 2024), NEEM (Eichler, 2013; Montagnat et al., 2014), NorthGRIP (Wang et al., 2002), Dome C (Durand et al., 2009), GISP2 (Gow et al., 1997), GRIP (Thorsteinsson et al., 1997), Siple Dome (Gow and Meese, 2007), Vostok (Obbard and Baker, 2007). Layering observations sourced from: EDML (Faria et al., 2010, 2018), Dome Fuji (Dome Fuji Ice Core Project Members, 2017), NEEM (Jansen et al., 2015), NorthGRIP (Svensson, 2005), Dome C (Durand et al., 2009), GISP2 (Alley et al., 1995, 1997; Faria et al., 2014; Gow et al., 1997), GRIP (Alley et al., 1995; Dahl-Jensen et al., 1997; Johnsen et al., 1995; Landais et al., 2003), Siple Dome (Gow and Meese, 2007), Vostok (Lipenkov and Raynaud, 2015; Raynaud et al., 2005; Souchez et al., 2002). Radar system characteristics can be found in Supplementary Table 1."*

> Figure 4 (caption): here and in the main text, it would be great if you could refer to your Appendix A, which describes whether a break in the climate record is visible in ice cores and hence can be seen in the radargrams.

We've included a reference to Appendix A here, and include a reference to it where Figure 4 is introduced (on line 298-299)

> Figure 4: what is the dotted red or black lines in some radargrams (e.g. for GISP2?)

We have added a row to the legend indicating that the dotted red and black line represents "laterally heterogeneous incoherent scattering visible along extended profile (see figure S3)"

> Figure S2 (caption): there is no "(c)" in the figure, but 2x "(a)"

Ah, yes, there are actually two letters superimposed within the figure where c is. We've fixed this – thank you for noticing!

Thank you again for your thoughtful review, we believe the changes made in response to your comments have significantly improved the manuscript.

Ellen + Nick