

Spatial characterization of near-surface structure and meltwater runoff conditions across Devon Ice Cap from dual-frequency radar reflectivity

Chan et al.

Response to comments from Editor:

General comment:

Ice-penetrating radar: I understand your wish to keep this terminology, but keep in mind that IPR is not very often used. For comparison, IPR about 2 million times compared to radio-echo sounding 30 million times in a common search engine. I support the statement of the reviewer here. In fact, we recently argued to get rid of this term altogether (Schlegel et al., Ann. Glac., 2023).

Ice-penetrating is nothing else than ground-penetrating, where the ground is made of ice (but could also be dry sand or alike). However, GPR is usually referred to as ground-based. This distinction now becomes obsolete as GPRs are also flown underneath helicopters.

To be more consistent with the most used convention I suggest to replace IPR with RES (airborne radio-echo sounder) or simply radar. RES is the term most often used in literature by now and also extended its meaning from the initial analog systems to modern multi-antenna phase-sensitive systems, for instance, basically inherent in the name of HiCARS, MCoRDS or MARFA. None of the systems you use in your study carries the denomination "ice" in its name. So why do you want to keep IPR?

Thank you for the comment. We understand the desire to adopt a common terminology for these radar systems. Given that the Schlegel et al. paper is not yet published and publicly available, we cannot evaluate the arguments that favor one term over another for these systems. Moreover, we believe that ice-penetrating radar, compared to radio echo sounding, is more appropriate for this work, because we only utilize the surface return to investigate near-surface properties and are not sounding to subsurface depths. The comments from the reviewers were focused on distinguishing between airborne and ground-based radar, which we initially referred to as IPR vs. GPR. That has since been changed to clarify when we are referring to airborne ice-penetrating radar vs. surface-based radar. While the airborne radars HiCARS, MARFA, and MCoRDS don't carry the term "ice" in them, they were designed with the intent to study ice, and we would like to reflect their main purpose when referring to them in this study as ice-penetrating radar. We also added "also known as radio echo sounding" when first introducing "ice-penetrating radar" in the manuscript.

The second general comment addresses the usage of operators & variables, which is partly ambiguous. I would ask you to check thoroughly and please clarify where marked in the annotated manuscript (e.g. epsilon (absolute or relative), k , $||...||$, ...).

We reviewed the operators and variables in the manuscript and clarified their usage.

Colour scale: (e.g. Fig. 2) Rainbow is the worst color scale in general one could use, not only for color-blind people, but also to indicate changes. Nothing to change here now, but keep in mind for future publications. See e.g.

<https://eos.org/features/visualizing-science-how-color-determines-what-we-see>

Thank you for the note. The color scale used in this figure is actually Turbo, which is an improvement over the traditional Rainbow. We found it to be a good balance between a linear color scale capable of capturing changes in P_c and being colorblind-friendly in most cases (<https://ai.googleblog.com/2019/08/turbo-improved-rainbow-colormap-for.html>).

Figures: Boundary of firn zones: I find the dashed black line makes it partly difficult to see the line correctly. Consider changing to solid black or decrease the gap between dashed (e.g. fine in Fig. 5) Explain this also in the new captions that gray lines indicate elevation contours, only shown for 600 m and higher. Dashed black lines indicate firn region boundaries.

We clarified that thin gray lines indicate elevation contours in the captions. We also revised the firn zone boundaries by decreasing the spacing between dashes, similar to Fig. 5.

Specific comments (P = page, Number = line in annotated author track changes pdf):

P1

12: *see general comment - change:
airborne radar or airborne radio-echo sounding*
Please see above.

23: *higher*
I don't get this argument in the abstract, because not mentioned before.
Undefined, what higher frequency means here, can't be HF. Do you mean UHF?
Or rather high-resolution (cm-dm scale)?
We changed this to high resolution.

P2

68/69: *This is not true in general, e.g. for ultrawide band radars such as MCORDS5 - they can resolve firn layers of 1 m resolution. I would rephrase to be less strong.*
We rephrased this sentence to be less strong and more focused on previous data collected.

75: *earth -> Earth*
We made this edit.

P3

90: *GOG3: explain/write out once*
We defined this acronym in the revised manuscript.

96: */bandwidth*
a bit unclear like this - rather dual-frequency (i.e. different bandwidth)
We reworded this to clarify that we are using airborne radars at two different frequencies and bandwidths for this work.

P4

120: *Mention elevation contours in caption (i.e. from 600 m to ... m every 200 m). I suggest to change dashed black to solid black, as dashed is particular unclear for zone IIb.*
We mentioned the elevations contours in the caption and decreased the spacing between dashes similar to Figure 5.

130: *by -> with*
130: *shouldn't this be CReSIS?*
We changed 'by' to 'with' and added CReSIS.

P5

145: *unclear. Suggested rewrite: "the radar return from the surface is influenced to a depth"*
We made this suggested edit.

150: below, k is the wavenumber. Chose a different letter here (please do not use k_w)
We simplified this equation to express it in terms of wavelength instead of wavenumber.

150: relative or absolute effective permittivity?
later you use the ordinary relative permittivity. Please specify in the text, which one ϵ_{eff} denotes.
Distinguish

between absolute a relative permittivity by using subscript $_r$, if necessary.

163: ordinary relative permittivity

All permittivities mentioned in the manuscript are relative. We clarified this in the text, where appropriate.

170: why between? Rather "of"?
We changed this to "of".

P6

201: change to "permittivity changes"
We made this change.

209: surface reflection coefficient r : power or amplitude? I assume amplitude, but clarify.
We clarified that this is in amplitude.

209: rms height: calculated over particular window length, all profiles or other? Please specify. (I know it was there but deleted, but a bit more info is required.)
We specified that this is calculated over the wavelength scale.

209: now k is the wavenumber. You must not use the same variable for two different purposes in the same manuscript - here windowing factor and wavenumber. Please clarify.
We kept k for windowing factor and removed wavenumber.

211: laser: specify: laser altimetry or laser scanning? I assume airborne laser, please specify.
We clarified that it's from laser altimetry.

213: "0.22 dB to P_c ": Could you give a percentage of the average value of P_c ? At this stage the reader did not see any P_c value, so does not know how (in)significant this is and later you say it is "conservative". Sufficient to say e.g. "0.22 dB to P_c , i.e. less than approximately $x\%$ in terms of dB."
It's about 1% of the average P_c value, and we added this in the manuscript.

214: sheet - this is an ice cap – replace
We replaced this with ice cap.

214: change to "freshly fallen snow".
We changed this to freshly fallen snow.

214: assume: can you further specify why? E.g. any data which indicate that? Please clarify
Both the GOG3 and SRH1 surveys were conducted in the spring before the melt season. Thus, surface roughness would be mainly influenced by the presence of snow, which we assume to be the case for both surveys. We clarified this in the text.

P7

262: *unlcear: should be along HiCARS2 transects. Please clarify.*
We change “collocated with” to “along”.

266: *add: "picking the firn-ice interface in"*
We added “picking the firn-ice interface”.

288: *gain specify: "ordinary relative permittivity"*
We specified that this refers to relative permittivity.

P8

321: *I suggeset to simply write "firn" layers*
We simplified this to “firn” layers.

327ff: *Please explain operators: "The operator $||...||$ denotes ... IFFT is the ..."*
We explained the operators of Eq. 4.

332: *no tapering used?*
This is an analytical model where the reflection coefficient is calculated at every frequency contained in the chirp, and the maximum is chosen after being convolved with the chirp. Thus, tapering is not applicable here, although the effects of tapering are captured in the actual airborne radar data with the windowing factor, resulting in a degradation of the vertical resolution.

P9

342: *consider to change dashed to solid black.*
We decreased the spacing between dashes.

342: *Add: "Background and contours as in Fig. 1". In fact you could also write "Background, contours and firn boundaries as in Fig. 1." and remove the separate description of the firn boundary here.*
We referred to Fig. 1 and removed the separate description of the boundaries as suggested.

P10

500: *aren't units needed for IQR in legend?*
We added the units for IQR in the legend.

500_ *During copy-editing it might unfortunately be suggested again to put all three panels on top of each other to fill only one column in the final typeset version to save space - in contrast to the reviewer's suggestions. I find the comparability in the previous figure version also more compelling than now.*
We included the figure as is but can rearrange the plots as needed during copy-editing.

P11

529: *inspection of what? The spatial distribution of the ratio?*
Yes, we specified this in the text.

529: *Pc/Pn: This is ambiguous.*

Pc is in dB

Pn is in dB

so their ratio would at first sight be unitless.

Or do you rescale the ratio again to dB by taking the logarithm? Please clarify, as also important for the figures indicating Pc/Pn

We specified that the Pc/Pn ratio is expressed in dB and calculated by taking the difference between Pc and Pn in logarithmic space.

534: firn at the surface

I consider it important to clarify that satellite imagery/measurements can only indicate the properties at the surface, but not below (eg if there is left-over firn below an ice slab).

We clarified that the images indicate the lack of firn at the surface.

554: the surface signal probes

We clarified that it's the surface signal.

P13

648: add "section Discussion)."

We changed it to Sec. 4.1.

P14

661: resolutions of the surface reflection (i.e., z0)

We specified the surface return in the caption.

P16

698: Figure: as for previous figures, please add info on elevation contours in caption. Regarding my comment in previous figures for the dashed black lines, the dash spacing here is small enough to indicate clearly the boundaries, whereas it is too wide in the previous figures.

We added the elevation contours info in the caption.

P17

709: Quite a long subscript. I suggest to put the radar system as a superscript instead to increase readability.

We changed all the subscripts, here and in the text, to place the radar system in the superscript.

P19

796: add "also" before "the first proof"

We added "also".

874: Please don't forget to provide final publication number during copy-editing.

We added the final publication number.

SUPPLEMENT:

P2 Title x-axis Fig S1: Density should be (kg m⁻³)

We changed the units to kg m⁻³.

P3 Figure S2

Either use a) and b) or add explicitly which panel you are referring to, e.g. solid gray lines (a/top).

Explain why the ration Pc/Pn is still in dB (the comment in main).

See main: zone boundaries: they are hard to follow and look a bit chaotic. Please improve visualisation, e.g. by having solid black lines?

Add: "thin grey lines are elevation contours (m).

IQR: how about units for values in legend?

We used solid black lines for the old zone boundaries and decreased the spacing between the dashes for the new zone boundaries. We added info about the elevation contours and units for IQR in the legend. Explanation for the Pc/Pn ratio was added to the main text. We reorganized the caption, such that the first part refers to the top subplot, and the remaining part refers to the bottom subplot.

P4 Figure S3: add: HiCARS2/MARFA (top) ... MCoRDS3 (bottom)

We added (top) and (bottom).

P5 Figure S4: ••• - delete blank in l. 8.

We deleted the blank in between “.” and “8”.