Review of "*Investigating firn structure and density in the accumulation area of Aletsch Glacier using Ground Penetrating Radar*" - egusphere-2025-615

Dear Authors,

I read your manuscript with interest – it's good to see links being made between properties derived from geophysical observations and climate models. Your approach parallels one that we applied for Norway's Hardangerjøkulen ice cap, and initially for Storglaciaren, hence I was intrigued to see further development of similar ideas and thus was keen to provide a review.

In general, I found your paper to be nicely presented and to provide good motivation for linking GPR and firn densification models. I fully agree that a suite of observational data are required if a reliable estimate of density is to be derived, including GPR velocity analyses ground-truthed against data from snow-pits and/or firn cores.

However, I am concerned that you may not have correctly evaluated your GPR velocities, and therefore that all quantities estimates and inferences derived from your GPR velocity model are likely in error. From what I understand of your reporting, you have taken velocities directly from your semblance picks (e.g., Figure 4 and Figure 11) and used them in Equation (1) to evaluate firn density. This would seem to be the case since, when Figures 4 and Figure 11 are overlaid (see below) the velocity plot and semblance picks appear to superimpose.

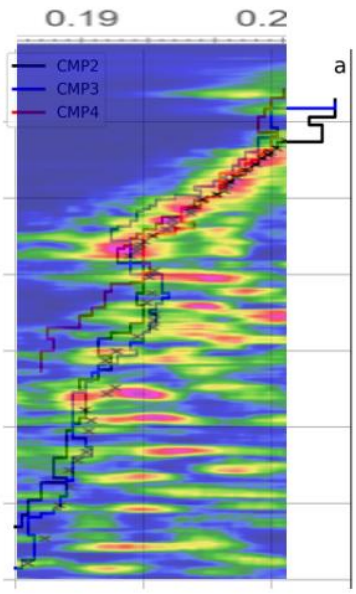

Figure 1. Comparison of velocity picks in semblance (authors' Figure 4) and velocity data ahead of density conversion (authors' Figure 11). The velocity trend in 'CMP2' looks to be very similar to that in the semblance picks.

The velocities that are picked from semblance analysis approximate "root mean square" velocity, v_{RMS}, a travel-time weighted average velocity of all velocities above a given reflection – i.e.,

$$v_{RMS_n} = \sqrt{\frac{\sum_{i=1}^{n} v_i{}^2 t_i}{\sum_{i=1}^{n} t_i}} \qquad (1)$$

where v_i is the *interval* velocity through layer i, t_i is the two-way transit time through layer i, and n is a layer index. In order to establish any physical property, it is the interval velocity that is required from the velocity analysis, and it is the Dix Equation (Dix, 1955) that converts v_{RMS} to v_i:

$$v_i = \sqrt{\frac{{v_{RMS}}_i^2 t_i \; - \; {v_{RMS}}_{i-1}^2 t_{i-1}}{t_i \; - \; t_{i-1}}} \qquad (2)$$

noting here that t_i and t_{i-1} are two-way travel-times to the i^{th} and i-1^{th} interfaces.

It may well be that you have implemented the Dix's Equation in your analysis and have just not reported it clearly in then main text, but the similarity between the above velocity trends suggests to me that this is not the case. For your v_{RMS} model, which shows velocity progressively decreasing from 0.22 to 0.18 m/ns, converting to v_i would give you a model that shows a more exaggerated velocity decrease with depth – and consequently, a more marked densification with depth.

In the figure below, I took ~25 v_{RMS} points from Figure 4, assuming a decrease from 0.220 to 0.198 m/ns over travel-times from 60-140 ns, and expressed them as interval velocity. The divergence of these two trends is evident. If we apply the deepest v_i in this model (~0.162 m/ns) in the CRIM equation used in the paper, and assuming ρ_{ice} = 920 kgm^{-3}, the corresponding density is 1031 kgm^{-3} (i.e., the interval velocity is lower than the reference value used for ice): your equivalent estimate is ~620 kgm^{-3}, which I indeed approximate if I use the deepest v_{RMS} from the plot below.

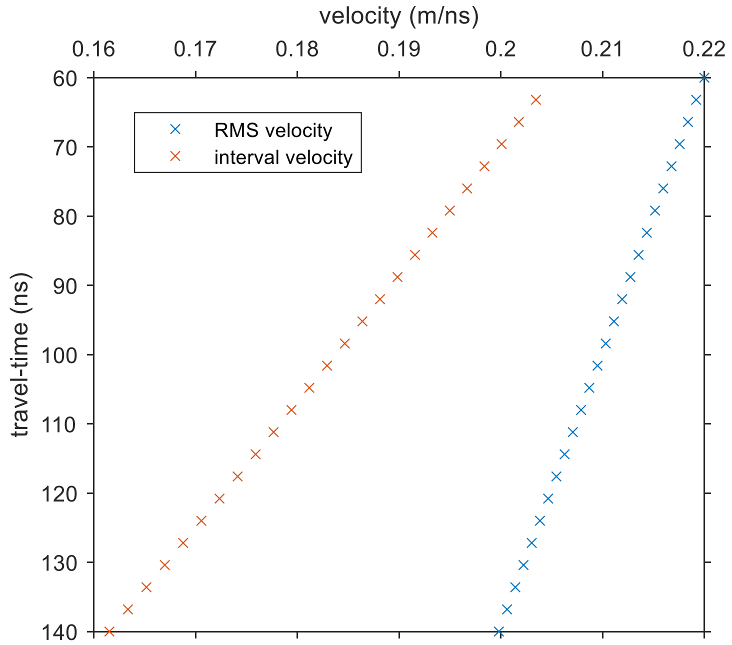

Figure 2. Converting authors' picks of v_{RMS} in Figure 4 to interval velocity. If I use (incorrectly) the deepest v_{RMS} to evaluate density, I obtain something similar to the authors' values. If I use (correctly) the deepest interval velocity, the density is much higher.

Depending on which version of ReflexW is being used for analysis, the interval velocity model corresponding to any set of semblance picks is shown as a velocity model on the left-hand side of the display. It is this model that you should use for parameter estimation, rather than that from the semblance picks themselves.

Unfortunately, until the GPR interval velocity (and thus density) is correctly evaluated, any correlation with products from climate models is invalid. Either that, or the manuscript must include detail of how interval velocity was actually defined.

I anticipate that you would want to correct their analysis and reconsider the match to climate models, and therefore I offer the following advice for any rewrite of the GPR analysis.

1. The presentation of the GPR data in Figures 3 and 4 could be improved. Although there is low signal-to-noise ratio at depth, it is almost impossible to see even the hyperbolae at shallower depth because picked reflection hyperbolae have been overlaid. I would consider plotting data with reflections unannotated for ease of comparison.
2. The semblance picks beyond ~200 ns depth lack credibility, especially when the corresponding reflection hyperbolae cannot be seen in the CMP gather.
3. A further refinement of semblance-based v_{RMS} picks can be found here: this paper establishes that it is first-break travel-times which yield the most accurate physical properties, but only the higher amplitude half-cycles in the coda that yield semblance responses. The paper therefore presents a correctional methodology that the authors may wish to consider.
4. The authors appropriately consider the precision with which the semblance panel can be picked, suggesting a 0.005 m/ns picking error. It would be good to see this represented as error bars in the plots, and how it converts to density. I also think that this precision is greatly underestimated for the semblance picks with travel time >200 ns, and perhaps a larger uncertainty should be quoted for these.

I appreciate that this review will come as a disappointment, but I would encourage the authors to re-evaluate their velocity models and perhaps there may even be a better match to climate models.

Best regards,

Adam Booth