

# Review: “Advection Impacts the Firn Structure of Greenland’s Percolation Zone”

by Leone et al.

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## 1 General

In this paper, the authors study the role of downstream ice advection on firn compaction and meltwater percolation. They find that including ice advection leads to larger pore close-off depths, lower heat content within the firn, and a lower frequency of melt features as compared to one-dimensional simulations. What I like about this paper is that it (1) connects firn physics modeling to ice flow, which is novel and important, and (2) adds a new dimension to the firn compaction problem, where ice advection causes features at a given point on the ice sheet to inherit the upstream history rather than start from a blank slate, as is often assumed in the current paradigm. Astoundingly, the authors show that melt features can have an advection-derived component that is not due to climate change but rather incorrect model initial conditions. There is a lot of very interesting science in this paper and I would certainly like to see it published. Unfortunately, however, this paper requires major revisions before I would recommend publication in *The Cryosphere*.

## 2 Remarks

The overarching concern I have is the presentation of the model results. The methodology is poorly explained (e.g. how does FEniCS fit in?), meaning that it would be difficult to reproduce or verify the results. Moreover, the results that are shown are not very insightful as presented. I suggest: (1) clarifying in a general way how the models are queried and (2) making the figures more accessible. I give some suggestions for how to address these two comments below.

## 3 Specific comments

1. line 13: There are many missing hyphens between words, such as ‘one dimensional’ should be ‘one-dimensional’.
2. line 14: I suggest ‘compaction’ instead of ‘burial’.
3. line 38: I think that it is worth stating that these percentages are area and not volume.
4. line 68: the two-dimensional extension deserves much more explanation!
5. line 71: I suggest adding a paragraph describing the road map for the paper.

6. line 77: could add ‘as well as compaction and advection’, given that this is the topic of the paper and these clearly influence the density and thermal structure. This would strengthen the topic sentence.
7. line 84: ‘rather’ would be a good addition after the comma.
8. line 91: It makes sense that the one-dimension advection does a good job approximating the two-dimensional solution because the downstream gradients are small (viz. Hewitt and Schoof, 2017). The important issue, however, is that the one-dimensional advection *does not* include downstream transport of moisture, which is likely to be very important and is not included in the two-dimensional implementation described in the supplement, correct?
9. line 97: this paragraph is confusing as it makes it sound like the authors implemented everything in FEniCS — is this true?
10. line 120: why wasn’t the Community Firn Model (Stevens, 2018) used? It contains several implementations of meltwater percolation through firn and is open source (<https://github.com/UWGlaciology/CommunityFirnModel>).
11. section 2.3: I think it would be very valuable to write to out the equations in a general way, so that it is clear (1) what advance the authors have made and (2) how the advance is implemented operationally. In other words, I suggest writing the density  $\rho$  evolution equation as
 
$$\frac{d\rho}{dt} = f(\rho, T, \dots), \quad (1)$$
 where the right-hand side is given by Reeh et al. (2005) etc. is a function of the temperature  $T$ . Then, the authors could state that they will add downstream ice advection  $u$  as
 
$$\frac{\partial \rho}{\partial t} + u \frac{\partial \rho}{\partial x} = f(\rho, T, \dots), \quad (2)$$
 and state that this advection process occurs explicitly (my assumption), where the upstream density is advected downstream at each timestep.
12. section 2.3.1: I suggest including some of the figures from the supplement in the main text to demonstrate how the models work.
13. line 276: ‘for much another reason’ should be ‘for another reason’.
14. line 282: typo as there should be parentheses around the figure reference, i.e. ‘(Figure 5b)’.
15. line 302: ‘x’ should be ‘ $x$ ’.
16. line 335: simulations produce data. How do I access the simulations? Also, I suggest putting Leone in parentheses to match the other funding acknowledgments.
17. line 378: error in title
18. figure 1: is this figure useful/insightful?

19. figure 2: I suggest addressing the dot, solid, and dot-dash lines within the caption. Also, an additional figure showing the two-dimensional results for the different models shown in figure 2 could be very useful (i.e. figure 3 but for the figure 2 simulations).
20. figure 3: it would be helpful to label the subfigures on the actual figure. For example, the transect name could be put next to the letter, i.e. '(a) EGIG line' and topography, pore close-off depth, and differences could be labeled on the respective panels.
21. figure 4: I suggest converting this plot to either 3 panels, one for each model, or 4 panels, one for each transect. Currently, it is impossible to decipher.

## References

- I. J. Hewitt and C. Schoof. Models for polythermal ice sheets and glaciers. *Cryosphere*, 11(1):541–551, 2017. doi: 10.5194/tc-11-541-2017.
- N. Reeh, D. A. Fisher, R. M. Koerner, and H. B. Clausen. An empirical firn-densification model comprising ice lenses. *Ann. Glaciol.*, 42:101–106, 2005. doi: 10.3189/172756405781812871.
- C. M. Stevens. *Investigations of physical processes in polar firn through modeling and field measurements*. PhD thesis, Earth and Space Sciences, 2018.