Review of: “Grain-size evolution controls the accumulation dependence of modeled firn thickness”
by Jonathan Kingslake, Robert Skarbek, Elizabeth Case, and Christine McCarthy

Summary

This paper examines how the accumulation rate, which is a commonly used parameter in firn-densification models, influences the firn thickness. The authors develop a non-dimensional firn model that allows them to consider how the advection rate affects the firn. They find that the accumulation rate controls the downward advection of porosity and grain size, and higher accumulation rates cause faster downward advection of firn. This faster advection of high-porosity firn from the surface leads to greater firn thickness. Conversely, grain growth leads to larger grains, which slows firn compaction; faster advection leads to smaller grains (faster compaction) through the depth of the firn column and thereby a shallower firn column. When the surface grain size is zero, these effects balance exactly.

In general, I found this paper to be insightful and well written. Its scientific arguments were convincing. I appreciate the method used (a non-dimensionalized model) in that it clearly elucidates how inherent assumptions in firn models manifest in model outputs. The authors’ detailed analyses of these implicit assumptions are an important contribution to the field. This paper will help push firn modeling towards more physically based models that describe microstructural processes. I am happy to recommend that it be published with minor revisions.

General Comments

- The model used assumes that the firn is isothermal. The conclusion states that including heat transfer should not qualitatively affect the results, but does not include any specifics as to why I should believe that. For example, the grain growth rate is determined by an Arrhenius dependence, which means that grain growth rates vary significantly through the year. I think it will be not too much work or new text to strengthen the argument that the isothermal assumption is valid here and discuss possible implications. (This comment was specifically spurred by the discussion at Line 172-173 – after reading that I was expecting more discussion about temperature effects.

- I would appreciate a bit of discussion of what you mean (or has been meant historically in the studies you cite) by ‘grain size’. I hear some people in the firn community talk broadly about ‘grain size’ and others talk about specific, measurable microstructural properties of the firn (e.g. specific surface area, optical-equivalent grain size, etc.). When we talk about normal, Gow-type grain growth, what is the property we are actually referring to? I think this is important given that a take-away message of your paper is that models need to be considering grain size. Can you provide recommendations of what field studies should be measuring?

- You provide a single value for k_c, which is the value suggested by Arthern et al. (2010) for low density snow (i.e. stage 1 densification). The value of k_c for higher density firn ($3.7*10^9$) is significantly lower. Can you justify your decision to use the single, low-density-snow, value for the entire firn column? I would suspect that this would consistently lead to modeled values of

z_{830} that are too shallow. Will this affect your results, especially concerning the point at which the grain-size- and porosity-advection balance exactly? (Ok, now I see that it is mentioned near the end of the paper, but I would still like to see a bit more discussion of this – using a different k_c for higher density firn will change the vertical velocity for a substantial portion of the firn column)

- Figures: I found that the font size on figure axis labels and ticks was too small (figures 1,2, 5, 6, 7); I had too zoom in on the pdf to read them. (Figure 8 is good!)

Specific Comments

Abstract: you state, "the downward advection of porosity and of grain size are both affected by b, but have opposing impacts on firn thickness. The net result is that firn thickness increases with b and that the strength of this dependence increases with the surface grain size." I don't disagree, and it is clear to me what you mean after I have read the paper. But, I think this could be clarified here by explicitly stating how the porosity and grain size affect firn thickness (i.e., larger grains = slower compaction). When you say increases with surface grain size, do you mean increases with increasing surface grain size?

Line 42: should be "and/or" grain size

L52: You could mention that some models circumvent this issue by using the average accumulation over the lifetime of the firn layer, and is done in Li and Zwally and Stevens et al.

L57: It is not clear to me what you mean by your statement that a Lagrangian approach obscures advection. I agree that the advection is more explicit in an Eulerian model, but the advection rate and vertical velocity of layers can easily be tracked in a Lagrangian framework as well.

L177: sentence starting with 'While' – a bit of a run on sentence, can you break up to make it easier to parse for the reader? (I had to read it several times to get the gist.)

L182: do you mean that the firn compaction rate will approach zero? And can you be more specific about what 'at depth' means? i.e. at the bottom of the model domain, or beyond some defined threshold?

L186: do you mean grain growth rate increases? "Grain growth increases" implies that there is more grain growth, which I am not sure how to interpret – more of the grains are experiencing growth?

L191: "combination of conditions are likely" → 'is likely'

L226: Is the fact that that nondimensional time is 0.83 purely coincidental or related to the fact that you are nondimensionalizing and 0.83 is the close off porosity? (Or, perhaps I am asking if you prescribe a densification rate change at 830 kg/m^3.)

L226/Figure 2: I am a surprised to see that the porosity becomes zero in the lower region – given the prescribed conditions and a domain depth of 100m, I would expect that there is a small bit of porosity remaining at 100m (i.e. that the firn would not have reached 918 kg/m^3 at that depth) – is this a result of the use of the low-density-snow coefficient I mentioned above?

Line 233/Figure 2: Is there anything to be read from the structure of the mismatch (e.g., porosity at z=0.3?)

Figure 3: can you explain the inset more clearly? I think that you mean the three dotted lines the same in each inset – is that correct?

Figure 5 is a bit challenging to interpret because it is plotting “dependence” – I understand how you calculated it, but I suggest adding to the caption to include the takeaway message from that figure, i.e. I think that the figure is showing that as surface grain size increases, the firn thickness is more dependent on the accumulation rate (?). Perhaps describe in the context of Figure 6a – a horizontal line drawn across at r^2_s = 0.01 will not change the value of z_{830} very much, while a line drawn across r^2_s = 0.09 will lead to increasing z_{830} with increasing B. (Hopefully I am interpreting that correctly.)

L403: I think this no-accumulation dependence is also demonstrated in your Figure 1?

L434: ‘effect’ → affect

L437: This observation that compaction rate is zero at the surface is astute. I am not sure where/how, but potentially it deserves to be highlighted a bit more.

L538: This paragraph appears to be unfinished.