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The Cryosphere Discussions

Interactive comment on "Strain localisation and dynamic recrystallisation in the ice-air aggregate: A numerical study" *by* Florian Steinbach et al.

Anonymous Referee #2

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Full-field numerical analysis of high density cold firn.

This paper aims to study the competing processes of normal grain growth, polygonization, and migration recrystallization in cold firn (very close to the density of ice). Their 2D model shows the importance of strain localization triggered by air inclusions that gives rise to locally high strain energies that drive grain boundary migration.

Overall, this paper is well written and I think this is a valuable analysis and the expressions of strain localization apparent in the model show that there is much more heterogeneity in recrystallization process in ice than we usually assume.

My primary concern with this paper is that some of the assumptions make it difficult, at best, to compare to the EDML firn thin sections. That does not say that the simulations aren't valuable, I just think the authors need to be upfront and clear from the beginning

what the simplifying assumptions are and how that affects their comparison. They state in the last sentence of the discussion that the comparison should be taken only approximately, but up until then they give the impression that they believe it is a very valid comparison.

In particular:

1. 2D versus 3D

2. The size and distribution of air pockets is set for each run but no information is given as to why those values were chosen. I would expect more smaller air pocket to behave differently than fewer larger air pockets, even with the same percentage of air. And visually, it looked like too few air pockets (although perhaps they assume the ice has undergone significant grain growth before reaching their initial microstructure).

3. The model air in the mixture is incompressible (yet, in real firn, it is highly compressible).

4. The stress regime is designed to generate 50% compressive strain along the vertical axis, this is accommodated by extension laterally (i.e. pure shear). The firn at EDML may have undergone 50% compressive strain along the vertical axis, but this was accommodated by densification including compression of air pockets (i.e. uniaxial compression). These are two very different stress regimes.

5. The grain size is HUGE compared to real polar plateau firn. This is not really discussed until the very end of the discussion. I had a difficult time figuring out why they started with such large crystals. Similarly the increments of 1% strain are high, how does this large crystals with fast strain rates affect the solution - does this prevent recovery from acting?

The overall conclusions of the model as it is presented are still valid. I would prefer to see the following changes:

1. Better explaining the effects of assumptions 1-5 above on the comparison between

model and real firn.

2. Either provide additional models that show better how the size of air pockets affects the results or at the very least, discuss the effect of this assumption on the results.

3. Either provide additional models that allow for some compression of the air, which might minimize some of the strain localization if deformation of the air can accommodate the changes needed in the ice crystals. Or, minimally, discuss the effects of this assumption on the solution.

Specific Comments:

Abstract: P1 Line 9/10: The first two sentences seem redundant.

Introduction P2 Line 1: “very” doesn’t add anything

Line 13 and 16 - I am puzzled by some citations, Treverrow did not discover that CPO causes anisotropy, Montagnat was not the first to describe the effect on flow. While these are good papers, please cite papers that added to the discussion (and tell me why they added). These papers probably should be cited, but there are many more that have also contributed specific new ideas to the discussion, so please be specific as to why you have chosen those papers. There is a similar issue on page 3, Lines 29 and 30 - These two papers were not the first to describe folding in ice sheets due to anisotropy.

P3 Line 9: operate - present tense (please check all tenses).

P4 Line 28: accommodated

P6 Line 1 - redundant

Line 8 - How did you determine c and Mo and several of the parameters? I’m not sure I saw much in the way of a sensitivity study on the effect of variations in the parameters.

Line 15 - I think you can explain this a little more. Provide a little information as to why

you selected those values - more than just the citation, so we don’t have to go read the other papers.

Lind 30 - “Recover be” ?? perhaps “by”

P7 Line 30 - “on” the results

P8 Line 2 - why was 0,5, and 20 chosen, especially considering that 10% is a commonly assumed volume of air for the bubble close-off depth?

Line 8 - repeated value for c, but still no explanation for that value.

P10 Line 13 - I realize that I haven’t look at firn microstructure as much as Sep Kipfstuhl, but I was not under the impression that air pockets coalescing was a commonly occurring process in polar firn. I typically think of the pockets compressing and getting pushed to trip junctions, but not coalescing.

P11 Line 30 - “Apart from the scale difference. . . “ This is where I have issue with the comparison. This very qualitative comparison for two very different systems seems strange (yes apples and oranges are both round and about the same size, so do we assume they are the same?). I don’t argue that there are likely some of the same processes going on, I just don’t think the comparison is done in a rigorous enough way. If the authors want to maintain this subjective comparison, it might be best shifted to the discussion section, than the results section, even better in a special part of the discussion section, so that it is clear that a direct rigorous comparison is not possible because of the assumptions, but it is still valuable to visually look. That kind of comparison does NOT belong in the results section.

P13 Line 15-20 - I had always understood that dynamic recrystallization was possible everywhere given strain energies, but is a much more dominant process above -10 (an activation energy transition point). Line 30 - “the initiation of this process is not only temperature dependent” - I’m not sure that anyone ever said that it’s “initiation” was “only” temp dependent? In larger scale modeling is it much easier to parameterize the

migration recruits as being temp dependent, but this is a parametrization commonly used. Because the authors don't provide any comparison models, it is hard to tell how "dominant" the process is in -30 firn versus -10 firn. My main concern here is that they state that strain rate controls dynamic recrystallization as if that were a new idea.

This last statement would be more compelling if they presented a sweet of models at different temperature and different stress regimes both with and without the dynamic recrystallization process - to be able to show the effects of this process being active or not. Without any comparison simulations, it is hard to show what the effects are.

P14 Line 5-8 - this discussion about experimental strain rate and grain size selection should be up in methods (or maybe results), not in the discussion.

Line 10 - this should be in the methods section

Line 19 - specify what "it" is to be clear here

Line 25 - awkward sentence structure, please rewrite.

Line 33 - less, not lower

P 15 Line 14-15 - this statement should be early on in manuscript, or at least at the beginning of a discussion section about the comparision, not as an afterthought.

Line 17-25 - A conclusion should be used to talk about the these results in the context of larger questions. This is rather short conclusion that just repeats what has already been said. Please add some kind of bigger picture context. Why is it important to recognize that migration recrystallization happens (although slowly) in the firn? what can we do with this information in the future?

Table 1 - There is no discussion of the sensitivity of the model results to the selected parameters. Please provide some information.

Table 2 - just to reiterate when I saw this table, I was shocked at how large the grains were, the discussion of grain size is buried deeply in the discussion, please bring it up

front.

Figure 1 - I like this figure!

Figure 2 - I also like this figure, nice job explaining the components of the model.

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