Review: “Grain-size evolution controls the accumulation dependence of modeled firn thickness”

by Kingslake et al.

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1 General

In this paper, the authors analyze the role of snow accumulation rate on the compaction of dry firn layers on top of ice sheets. The authors' contribution is timely and important; as summarized in their introduction “Some [models] treat accumulation as a boundary condition, as it is in other ice-deformation modelling contexts. Others include b [accumulation rate] in their constitutive relations.” (with the citations removed and two parenthetical additions). This is important because in Herron and Langway (1980), the gold standard for firn compaction, the empirical compaction constitutive relation is proportional to accumulation rate, meaning that if it stops snowing, compaction ceases. However, in the physical system, compaction should continue if snow accumulation stops; this is the problem that Kingslake et al. address in this paper. Building from Appendix B of Arthern et al. (2010), the authors develop a full numerical simulation of very sensible compaction equations including grain growth and complement these results with steady state ordinary differential equation (ODE) solutions to reduced models. Arthern et al. (2010) contends that if the grain size (r_s^2 in the parlance) is near zero at the surface, then the system approaches Herron and Langway (1980), with a direct dependence on the accumulation rate. Here Kingslake et al. show that in the $r_s^2 \to 0$ limit, the effects of porosity advection and grain-size advection cancel and the model firn depth is independent of the accumulation rate — another puzzling result of the Arthern et al. (2010) work. Kingslake summarizes “models that include viscous firn compaction and grain size evolution (e.g. Arthern et al. (2010)) are potentially capable of a much richer array of response to accumulation rate than is usually recognized.” This is a very nice paper that cogently examines the formulation of the predominant firn compaction model. With some small tweaks, this paper is certainly worthy of publication in *The Cryosphere*.

2 Remarks

1. The model observation that the firn depth z_{830} increases with accumulation rate is interesting and challenges my intuition. The weakest dependence comes from Arthern et al. (2010) with $r_s^2 \to 0$, where the depth is independent of b. Yet many of the places with the deepest firn columns, e.g. domes of East Antarctica, have very low accumulation rates, leading me to think that there is a regime where $z_{830} \sim 1/b$. Is that misguided? This would seem to imply that if the accumulation rate increased in East Antarctica, then the firn depths would also increase. This seems to be backwards from the current firn thickness / accumulation rates in Antarctica, where thinner firn thicknesses exist on the coasts where it snows more.

2. Interestingly, rather than leaving the temperature constant for the different accumulation rates, am I understanding correctly that the temperature also changes? It seems like it might be better to change one thing at a time to see the effect of that change more clearly? Or do you change them independently? More generally, I am curious about the effects of temperature on the results.

3 Specific comments

1. Figure 2(left): the ODE and full compaction model results are indeed indistinguishable. Maybe make one dashed (narrow) and the other solid (wide) and embed them? Or use symbols for the full model?

2. Figure 2(right): would the absolute difference normalized by the absolute maximum value of the quantity be more useful?

3. Figures 3, 4: it could be useful to mark the location z_{830} on the plots using a symbol, so that the trend from the inset is visually clear. Maybe it could go on the velocity side, so that it doesn't get compressed at the bottom of the porosity plot.

References

R. J. Arthern, D. G. Vaughan, A. M. Rankin, R. Mulvaney, and E. R. Thomas. In situ measurements of Antarctic snow compaction compared with predictions of models. *J. Geophys. Res.*, 115(F3), 2010. doi: 10.1029/2009JF001306.

M. M. Herron and C. C. Langway. Firn densification: an empirical model. *J. Glaciol.*, 25(93):373–385, 1980. doi: 10.1017/S0022143000015239.