

Microstructure-based simulations of the viscous densification of snow and firn.

1 General comments

This is a well-written paper presenting new and important results which will be of interest to all those interested in the densification of snow. Using information on the microstructure of snow samples from micro-CT scans, the authors calculate macroscale compaction rates under various assumptions about the relationship between strainrate and stress for the ice grains. For dense snow (firn) using an isotropic power-law with $n=3$ on the microscale leads to macroscale compaction rates very similar to those observed in the field, supporting the suggestion that firn behaves as a “foam” of polycrystalline ice. On the other hand, the simulated compactive viscosities for lower density alpine snow are significantly larger than the observed values, both for rounded grains and for depth hoar. This discrepancy cannot be removed by changing the power-law exponent or by using an anisotropic flow law on the microscale.

The authors note that grain-boundary sliding has been identified as a mechanism for compaction in lower density snow, but explain that simulation of this process on the microscale would require more complex numerical methods than those used in this paper. Nevertheless this is probably the next problem to tackle in this field. In the meantime this paper is a valuable contribution to the series of papers deriving various macroscale properties of snow from microphysical analysis.

2 Specific comments

1.325 The comment here that use of a Newtonian rheology cannot be directly motivated by an underlying physical argument seems at odds with the earlier reference to Nabarro-Herring creep (1.49) which is the physical basis for Arthern’s use of a linear relationship between strain rate and stress.

3 Technical corrections

- 1.1 The distinction between snow and firn according to density (not age) needs to be introduced here as well as in the Abstract, bearing in mind that it may not be familiar to all readers
- 1.3 maybe “are still largely based on macroscale experiments” would be better?
- 1.10 “firn *densification* can be reasonably well simulated”
- 1.12 “contradiction”
- 1.16 “firn as a foam”
- 1.21 “in the cryospheric sciences”?

- 1.24 it is not clear what “different layers” means here. Different depths maybe? Or different samples with the same density and/or overburden pressure but different microstructure and/or composition?
- 1.25 “This situation is remarkably similar in snow”
- 1.34 “*The effective material properties*” implies that all these properties can now be derived. Better to say “Effective material properties...” which only implies that some can be derived
- 1.40 How about “Despite the pressing need for an accurate model,...”
- 1.43 “ so far only.....have attempted to estimate”
- 1.47 would “ of the material” be better here?
- 1.56 “...who considered three different”
- 1.59 “can be simulated consistently..”
- 1.60 similar to what?
- 1.63 why not simply “where observed densification rates are available”?
- 1.64 “computational platform as it is already established in the ice flow modelling community”
- 1.71 Do you mean “ it would be impossible/impractical to represent... in a snow or firn model”?
- 1.76 “modelling purposes a macroscopic constitutive law is required. Here f is a function....”
- 1.95 The colon product will be unfamiliar to many readers - explain or avoid?
- 1.139 “in order to compare our simulations with independent estimates” and “These estimates are used for the comparison” seem to be saying the same thing
- 1.145 RG and DH need to be defined here
- 1.153 “acceleration due to gravity”
- 1.155 “data include”
- 1.159 “in order to estimate the uncertainty”?
- 1.159 “a total... was” or “ 25 time series were”
- 1.178 “B54 core was drilled”
- 1.180 “profile”
- 1.181 “.. density profile represents a steady-state”
- 1.184 Maybe use a variable like τ to represent age?

- 1.185 “As in the case..”
- 1.187 “weighing”
- 1.188 “in a 1 m core”
- 1.192 “still fluctuate”
- 1.193 “As with the alpine case...”
- 1.195 “envelopes”
- 1.202 “The goal of these simulations was...” Similarly in 1.206 and 1.209 “was” is better than “is” since the rest of the description of the method is in the past tense
- 1.223 “ice sheet modelling”
- 1.260 Eq. 3
- 1.267 “evaluated as...”
- 1.271 flattened or flat
- 1.284 “ Several works in the literature have proposed” or maybe “Several authors propose”
- 1.287 “subsequent work by...”
- 1.290 described by Glen’s law? known fluidity values?
- 1.292 “ice fluidities”
- 1.302 “who reached a similar conclusion”?
- 1.304 “Moreover, Fig. 6 shows that while...”
- 1.326 “increase our understanding”?
- 1.328 “following Wautier et al.”
- 1.337 “confirmed from the simulated stress distribution...”
- 1.343 “whether linear or non-linear”
- 1.353 “ driven by a transition in density”
- 1.396 space missing after “dislocation creep”
- 1.402 “ ice rheology based on ...”?
- 1.404 “ In this way, the difference in scales...”