We thank Elizabeth Morris for her review and her constructive remarks on the manuscript. Please find below our point by point response to the review. The comments of the referee are shown in blue and our corresponding responses in black below. Proposed modifications to the manuscript are provided as highlighted text with the lines corresponding the submitted manuscript.

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

l.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 (l.49) which is the physical basis for Arthern’s use of a linear relationship between strain rate and stress.

Indeed there exist creep mechanisms (such as Nabarro-Herring) characterized by a linear strain rate-stress relationship. What we wanted to convey in the article is that our exploration of rheologies besides n=3 is not motivated by the existence of underlying deformation mechanisms (for instance N-H) but rather as an exploration of homogenous isotropic deformation law (and this independent of the existence of physical mechanisms that could justify such a form).

In order to better explain this point (and taking into account the technical comments below) we propose to modify the manuscript **L324**:
“Macroscopic Newtonian rheologies are also used in low-density firn studies (Schultz et al, 2022). Therefore, exploring rheologies besides Glen’s law, with related numerical experiments, would benefit our understanding of homogenization in snow compaction. Accordingly, we conducted a sensitivity analysis on microscopic, isotropic constitutive laws using different exponents (n=1, n=2, and n=4 in our case) following Wautier et al., (2017). We note that while some of these rheologies could be justified based on mechanisms of ice deformation (such as the Nabarro-Herring creep resulting in n=1; Herring, 1950, Arthern et al., 2010), our analysis of n≠3 was not conducted with specific physical mechanisms in mind. Rather, our motivation is to determine if an isotropic deformation law could explain snow compaction, independently of a specific underlying physical mechanism.”

3 Technical corrections

• l.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

We have moved the distinction between snow and firn in terms of density directly in the first sentence of the abstract **L1**:

"Accurate models for the viscous densification of snow (understood here as density below 550 kg m^{-3}) and firn (density above 550 kg m^{-3}) under mechanical stress are of primary importance for various applications, including avalanche prediction and the interpretation of ice cores."

• l.3 maybe "are still largely based on macroscale experiments" would be better?

We think that the word "empirical" is more suited than "macroscale experiments" here as experiments could be understood as controlled conditions (while field observations are also used to adjust models). Moreover, the word "empirical" implies that the underlying theory/understanding behind snow/firn compaction is still to be refined.

Thus, if the referee and editor agree, we propose to keep the manuscript as such.

• l.10 "firn densification can be reasonably well simulated"
• l.12 "contradiction"
• l.16 "firn as a foam"

We will reformulate the manuscript following these suggestions.

• l.21 "in the cryospheric sciences"?

We used "cryospheric sciences" to span both snow sciences and glaciology, as they are sometimes considered as two separate fields. To clarify the sentence, we propose to simply remove "in cryospheric sciences" **L21**:

"Accurate prediction of the rate of the compaction is of primary importance for various applications. For instance, [...]"

• l.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?

We meant the second, i.e. that layers with similar density and understand similar overburden stress can show clearly different compaction rates. We propose to reformulate **L24** to:

"However, observed variations in the densification rate of different layers with similar density and subjected to similar overburden stress still lack a conclusive explanation in view of either microstructural or compositional origins (Hörhold et al., 2012, Fujita et al., 2016)."

• l.25 "This situation is remarkably similar in snow"
• l.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
• l.40 How about "Despite the pressing need for an accurate model,…"
• l.43 " so far only.....have attempted to estimate"

We will reformulate the manuscript following these suggestions.

• l.47 would " of the material" be better here?
We propose to reformulate **L47** to:
"[…] the dominating mechanism(s) driving the mechanical deformation of the ice material at the micro-scale."

• l.56 "...who considered three different …."
• l.59 "can be simulated consistently.."
We will reformulate the manuscript following these suggestions.

• l.60 similar to what?
By "similar" we meant common between the firn and snow samples. We will rephrase **L60** replacing the word "similar" with "common".

• l.63 why not simply "where observed densification rates are available"?
We propose to rephrase **L63** to:
"[…] where observed densification rates are also available."

• l.64 "computational platform as it is already established in the ice flow modelling community"
We will reformulate following this suggestion.

• l.71 Do you mean " it would be impossible/impractical to represent... in a snow or firn model"?
We propose to reformulate the sentence **L71** to:
"In snowpack and firn models, it would be impossible to explicitly represent the 3D microstructure of a whole snowpack or firn column."

• l.76 "modelling purposes a macroscopic constitutive law .... is required. Here f is a function.…"
We will reformulate **L76** to:
"For snow or firn modelling purposes, a macroscopic constitutive law $\dot{E} = f(\Sigma)$ is required. Here, f is a function [...]"

• l.95 The colon product will be unfamiliar to many readers - explain or avoid?
We will provide the definition of the double dot product between a fourth and second order tensor using index notation **L99**:
*"The double product **a**:**s** yields a second-order tensor whose ijth component is $\Sigma_{kl}\, a_{ijkl}\, s_{kl}$."*

• l.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
Indeed. We propose to remove the second part "These estimates are used for the comparison".

• l.145 RG and DH need to be defined here
We will specify that RG and DH refers to Rounded Grains and Depth Hoar **L145**:
"Four snow layers have been carefully tracked and measured with several instruments over the entire season, including a Rounded Grains (RG) snow layer and a Depth Hoar (DH) snow layer (following the classification of Fierz et al., 2009)."

• l.153 "acceleration due to gravity"
• l.155 "data include"
• l.159 "in order to estimate the uncertainty"?

• l.159 “a total... was” or “ 25 time series were”
• l.178 “B54 core was drilled”
• l.180 “profile”
• l.181 “.. density profile represents a steady-state”
• l.184 Maybe use a variable like τ to represent age?
• l.185 “As in the case..”
• l.187 “weighing”
• l.188 “in a 1 m core”
• l.192 “still fluctuate”
• l.193 “As with the alpine case...”
• l.195 “envelopes”
• l.202 “The goal of these simulations was...” Similarly in l.206 and l.209 “was” is better than “is” since the rest of the description of the method is in the past tense
• l.223 “ice sheet modelling”
• l.260 Eq. 3
• l.267 “evaluated as...”
• l.271 flattened or flat
• l.284 “ Several works in the literature have proposed” or maybe “Several authors propose”
• l.287 “subsequent work by...”
We will reformulate the manuscript following these suggestions.

• l.290 described by Glen’s law? known fluidity values?
We propose to reformulate **L290** to:
“The viscoplastic deformation of polycrystalline ice is nowadays reasonably well understood and usually described by Glen's law, an isotropic power-law rheology with n=3 and known fluidity values depending on the temperature of the ice (Schulson and Duval, 2009, Cuffey and Paterson, 2010).”

• l.292 “ice fluidities”
• l.302 “who reached a similar conclusion”?
• l.304 “Moreover, Fig. 6 shows that while...”
We will reformulate the manuscript following these suggestions.

• l.326 “increase our understanding”?
We propose to reformulate **L326** to:
“[…] would benefit our understanding [...]”

• l.328 “following Wautier et al.”
• l.337 “confirmed from the simulated stress distribution...”
• l.343 “whether linear or non-linear”
• l.353 “ driven by a transition in density”
• l.396 space missing after “dislocation creep”
• l.402 “ ice rheology based on ...”?
• l.404 “ In this way, the difference in scales…”
We will reformulate the manuscript following these suggestions.