Dear Dr. Védrine,

We thank you very much for your comments to improve the manuscript further.
Please find your comments below in blue font and our responses in black font.
The manuscript contains relevant revisions that have been marked in magenta.

Thank you for this revised version of the manuscript. The clarifications provided regarding the methodology and results have helped to better articulate the approach, thereby enhancing the overall quality of the manuscript. This work is original and addresses a significant experimental challenge: investigating the effect of temperature on the creep response of firn with microstructural variability, both due to sampling conditions and ongoing structural evolution during testing.
Nevertheless, I retain serious reservations concerning several aspects of the methodology:

1. There is no clear justification for assuming that the pre-factor B remains constant with density in firn (Lines 424–427). The sole reference provided—Li and Baker (2022a)—is questionable in this regard. For instance, Scapozza et al. (2003) reported substantial variations in both the stress exponent and pre-factor as a function of snow density, extending up to firn. It is therefore important to state clearly that the dependence of creep behaviour on density is embedded in the effective stress formulation, and that the stress exponent is derived under this assumption.

Yes, we agree with your point that "the dependence of creep behaviour on density is embedded in the effective stress formulation, and that the stress exponent is derived under this assumption."

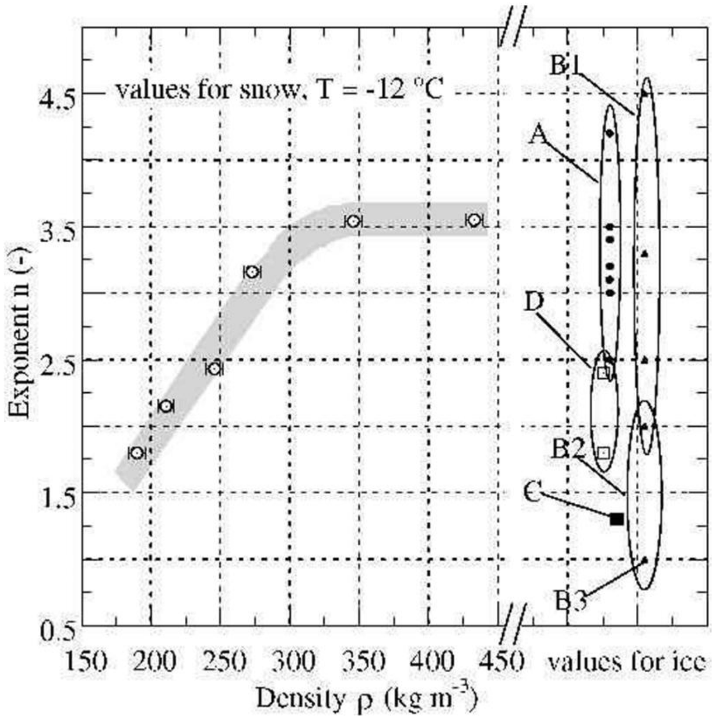

Fig. 3. Calculated power-law exponent n for snow as a function of density.

This is supported by **Fig. 3** from Scapozza & Bartelt (2003), copied below. Their data show that while the stress exponent *n* increases with snow density (below ~340 kg m⁻³), it plateaus and remains nearly constant at higher densities, extending into the firn regime (as indicated by the // symbols). This finding directly supports our derivation that the stress exponent is approximately constant across different firn densities.

Regarding the prefactor *A* in Glen's flow law for porous materials:

1) Deformation Behavior under Constant Strain Rate: We observe a difference between the firn samples from Li (2024) and the snow samples from Scapozza & Bartelt (2003). In their study, the prefactor *A* appears to be a function of density, likely because the effective dynamic viscosity increases with density, as evidenced by the rising axial stress with strain (their **Fig. 5**). In contrast, our work assumes a constant *A* because the flow stress remains constant after the yield point (our **Fig. 4**). This key difference arises from the distinct microstructures: snow has a near-complete open structure, while firn undergoes partial pore close-off. The reference to Li (2024) is provided to enable a comparison under similar mechanical testing conditions (Scapozza & Bartelt, 2003).

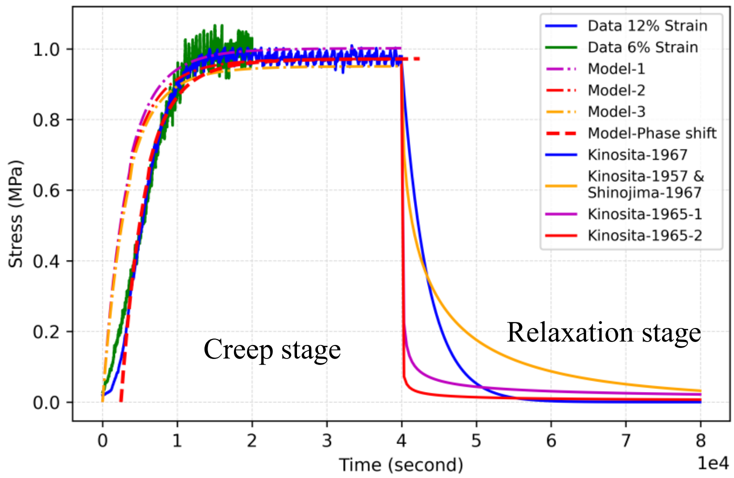

Fig. 4. Plots of the stress with time during the creep and relaxation stages. The solid lines indicate the measured data, while other lines indicate the modeled data as noted in the legend.

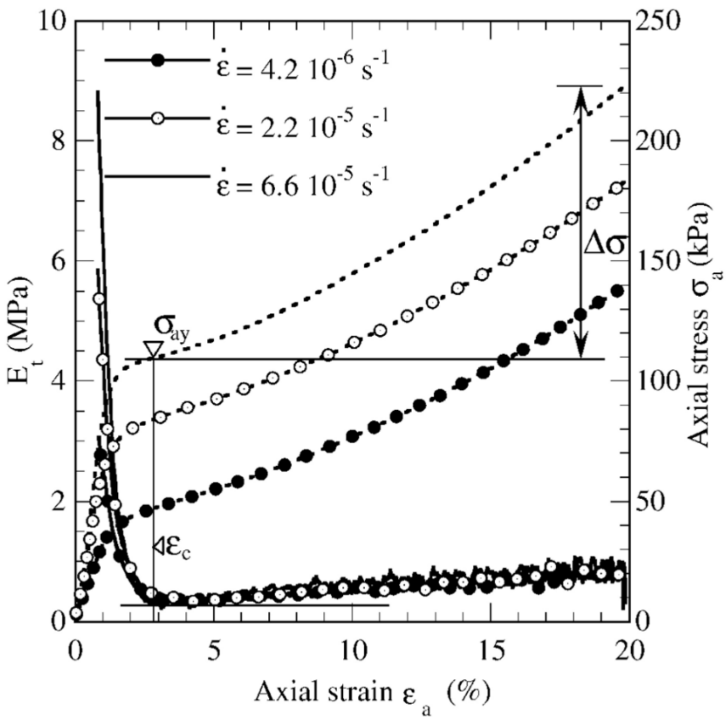

Fig. 5. Stress–strain curve (dashed line) and tangent modulus (continuous lines) obtained in compression tests at various strain rates. Density ρ = 320 kg/m^3; temperature $T = -12$°C; confining pressure $p_c = 0$ kPa.

2) Assumption of a Constant Prefactor *A*: For porous materials like firn, the prefactor *A* is often treated as constant because the effective stress formulation inherently consolidates the influence of multiple physical parameters and processes. This includes two-phase ice-air flow, the incompressibility of individual ice grains versus the compressibility of the ice skeleton, and the interbalance between axial, radial, volumetric, and true strains (e.g. Gubler, 1978; Hansen and Brown, 1988; Mahajan and Brown, 1993; et al.).

While a detailed discussion on effective stress was provided in Section 3.4 of Li and Baker (2022a), we've revised our previous text to provide further clarification on this point from

"From Glen-King's results deriving the activation energy (Glen, 1955) $\dot{\varepsilon}=A\exp(-Q_c/RT)=B\sigma^{n}\exp(-Q_c/RT)$*, the pre-factor A, the material parameter B (Glen, 1955; Goldsby and Kohlstedt, 2001), and the stress exponent n (Li and Baker, 2022a) are assumed to be constant, as reported in the literature."* to:

"Glen-King's model $\dot{\varepsilon}=A\exp(-Q_c/RT)=B\sigma^{n}\exp(-Q_c/RT)$ *treats the pre-factor A, material parameter B, and stress exponent n as constants ((Glen, 1955; Goldsby and Kohlstedt, 2001). This simplification is valid by using the unifying concept of normalized effective stress. The effective stress captures the complex multi-physical behavior of the two-phase ice-air system, accounting for: 1) The incompressibility of individual ice grains versus the compressibility of the porous ice skeleton, 2) The coupled flow of ice and air; and 3) The interplay between different strain components (axial, radial, volumetric, and true). This framework is grounded in the principles of poromechanics, originally developed for soils and later applied to snow and ice (Gubler, 1978; Hansen and Brown, 1988; Mahajan and Brown, 1993; Chen and Chen, 1997; Lade and deBoer, 1997; Ehlers, 2002; Khalili et al., 2004; Gray and Schrefler, 2007; daSilva et al., 2008; Nuth and Laloui, 2008)."*

Please see Lines 456–466.

2. Obtaining a stress exponent of approximately 0.1 or –1.2 is not merely inconsistent with Li and Baker (2022a), as stated in the manuscript—it is physically implausible. This result must be critically examined, especially given the assumption of linear dependence on the solid fraction within the effective stress model. The manuscript must also clearly justify why a "calibration" is required in light of such results. Adopting stress exponent values that differ from those measured in the dataset is highly questionable and not justified by the current analysis. The authors revert to a previously reported value from their earlier work, n=4.3667 (Li and Baker, 2022a), yet, as mentioned on line 516, a stress exponent around 3 are commonly observed (e.g. Glen, 1955; Kamb, 1961; Raymond, 1973; Thomas et al., 1980; Weertman, 1985; Goldsby and Kohlstedt, 2001; Cuffey, 2006). The sensitivity of the

method to the choice of n should be investigated in the determination of the activation energy.

The computation of the activation energy was derived based on a stress exponent value of ~4.3, which was obtained from the same Greenland firn core (Li and Baker, 2022a). This value is highly reliable and closely aligns with the literature average of ~4.25 (reported values range from ~1 to ~7.5). Further, the methodology used to calibrate the minimum strain rate for determining both the stress exponent and activation energy originates from the work of Glen (1955). To improve clarity, we've revised the previous text to emphasize this point.

From "We found n to be ~0.1 and ~ –1.2 for the –5°C and –18°C samples, respectively, which contradicts the reported n = ~4.3 by Li and Baker (2022a) and other values around 3 (Glen, 1955; Kamb, 1961; Raymond, 1973; Thomas et al., 1980; Weertman, 1985; Goldsby and Kohlstedt, 2001; Cuffey, 2006). This significant discrepancy implies that the uncalibrated SRMin value from all of the samples is not appropriate for estimating the stress exponent, and hence the activation energy during their deformation."
to:
"We determined stress exponent (n) values of approximately 0.1 and –1.2 for the –5°C and –18°C samples based on observed data, respectively. This result directly contradicts the value of n ≈ 4.3 reported from the same Greenland firn core by Li and Baker (2022a). Further, these values fall entirely outside the established range of ~1 to ~7.5 (mean ~4.25 ± 3.25) documented across decades of ice mechanics literature (Glen, 1955; Hansen and Landauer, 1958; Butkovich and Landauer 1960; Kamb, 1961; Paterson and Savage, 1963; Higashi et al, 1965; Mellor and Testa, 1969; Raymond, 1973; Hooke, 1981; Thomas et al., 1980; Duval et al., 1983; Weertman, 1983,1985; Azuma and Higashi, 1984; Pimienta and Duval, 1987; Budd and Jacka, 1989; Jacka and Li, 1994; Goldsby and Kohlstedt, 2001; Bindschadler et al., 2003; Cuffey, 2006; Chandler et al. 2008; Cuffey and Kavanaugh, 2011; McCarthy et al., 2017; Millstein et al., 2022; Colgan et al., 2023; Li, 2025). The wide range of reported n-values is governed by a complex interplay of deformation mechanisms—including grain boundary sliding, diffusion (lattice and grain boundary), and dislocation processes, e.g. hard-slip-dominated, dislocation-accommodated grain boundary sliding, and grain boundary sliding-limited basal dislocation—across varying stresses, temperatures, crystalographic fabrics, impurity contents, and grain-size-to-sample-size ratios. We attribute the significant discrepancy in these findings to the experimental conditions. The lower temperatures used (down to –30°C) induce slower strain rates, which prevented the tests from reaching a critical strain rate minimum (SRMin). Therefore, to accurately estimate the activation energy for deformation, it is necessary first to calibrate the SRMin value for all noised samples."

Please see Lines 562–581.

3. The sensitivity of the stress exponent to factors such as density (e.g. Scapozza et al., 2003) or loading conditions must be considered in the analysis, given the variability documented in the literature. If such sensitivity is assumed negligible, how then do the authors explain the stress exponent values they have obtained? The adoption of a constant stress exponent—and the specific value chosen—must be

clearly stated as an analysis assumption and explicitly acknowledged as a limitation of the study.

Our analysis, presented in Li and Baker (2022a), did not identify a sensitivity of the stress exponent to firn density. This finding is supported by the results of Scapozza and Bartelt (2003) (their **Fig. 3**). The discrepancy between these two uncalibrated stress exponent values and those reported in the literature is likely due to the lower experimental temperatures in our study, which resulted in slower strain rates that did not reach the minimum required for a robust derivation of the stress exponent.

To clarify this point, we've added the following text:

"A constant stress exponent value of $n \approx 4.3$ (Li and Baker, 2022a) was used to compute the activation energy. This necessary simplification—an acknowledgement of current methodological limitations rather than a dismissal of the underlying physics—introduces a key uncertainty that highlights the need for future advancements in observational methodology within firn research."

Please see Lines 581–585.

Finally, the selection of cited references remains biased towards the authors' own previous work. Although additional references have been included, they are listed without meaningful integration, critical discussion, or comparison with the broader literature.

We've expanded the discussion regarding other literature in the text:

"The rheology of polycrystalline ice, particularly its temperature-dependent creep deformation, is a cornerstone of glaciological modeling. Numerous studies have established a robust framework for understanding ice deformation, primarily through laboratory creep experiments (e.g. Glen, 1955; Weertman, 1983; Budd and Jacka, 1989; Durham et al., 2001; Goldsby and Kohlstedt, 2001; Petrenko and Whitworth, 1999). This body of work has confirmed that ice creep is strongly governed by temperature, typically described by an Arrhenius relationship with a well-constrained activation energy for grain-scale processes like dislocation glide and climb (e.g. Jacka, 1984; Hooke, 2005). In contrast, the mechanical behavior of firn, the intermediate porous material between snow and glacial ice, remains comparatively poorly characterized, especially with respect to temperature. It is important to note that the experimental observations are discussed with respect to the mechanical properties of polycrystalline ice, which is the constituent material of the load-bearing ice skeleton (Scapozza & Bartelt, 2003), sharing poromechanics-based deformation mechanisms between the two via continuum mechanics and homogenization framework (Gagliardini and Meyssonnier, 2000; Coussy, 2004; Hutter

and Johnk, 2004; Srivastava et al., 2010). While numerous studies have investigated firn and ice deformation (e.g. Steinemann, 1954; Landauer, 1958; Mellor, 1975; Salm, 1982; Maeno and Ebinuma, 1983; Ambach and Eisner, 1985; Li et al., 1996; Meussen et al., 1999; Bartelt and von Moos, 2000; Jacka and Li, 2000; Song et al., 2006a, 2006b, 2008; Theile et al., 2011; Treverrow et al., 2012; Hammonds and Baker, 2016, 2018; Li and Baker, 2021, 2022a), existing firn data are sparse and fragmented. A critical knowledge gap persists in the systematic experimental quantification of firn's mechanical response across a broad range of temperatures. Temperature is a first-order control on firn densification and deformation rates, yet most laboratory studies have been conducted at a limited number of isothermal conditions, often focused on a single density or at temperatures near the melting point (e.g. Mellor, 1975; Maeno and Ebinuma, 1983). Consequently, there is a pronounced lack of experimental data necessary to derive the systematic activation energy for the creep of firn over its full density spectrum. This parameter is not merely a scalar but is likely a function of density, microstructure, and the dominant deformation mechanism (compaction versus shear), transitioning from grain-boundary sliding in low-density firn to dislocation creep in high-density firn and ice (Hammonds and Baker, 2018; Li, 2022; Li and Baker, 2022a). The absence of comprehensive, temperature-variable creep data for firn across its density range renders it insufficient for constraining the temperature-dependence terms in modern, physics-based firn models. Our work fills this gap via X-ray micro-computed tomography-analyzed mechanical examinations, e.g. a systematic series of constant-stress creep experiments on firn cores of varying density, conducted across a thermally controlled range from -30°C to -5°C. This allows for the direct determination whether the apparent activation energy is a function of density, thereby providing the essential experimental foundation needed to improve predictions of firn densification in ice-sheet and glacier models."

Please see Lines 43–79.

Sincerely,
Yuan Li, Kaitlin Keegan, Ian Baker

References:

Scapozza, C. and Bartelt, P., Triaxial tests on snow at low strain rate. Part II. Constitutive behaviour. Journal of Glaciology. 49(164), 91–101, 2003.

Li, Y. Changes in grain size during the stress relaxation stage of viscoelastic firn. Philosophical Magazine. 104, 239–259 (2024).

Li, Y. Comments on Linear-viscous flow of temperate ice. ESS Open Archive. June 24, 2025. DOI: 10.22541/essoar.175080283.36935396/v1.

Dear Reviewer #2,

We thank you very much for your comments to improve the manuscript further.
Please find your comments below in blue font and our responses in black font.
The manuscript contains relevant revisions that have been marked in magenta.

The manuscript has been revised well in accordance with comments from reviewers. I believe it is important to mention the unavoidable uncertainties and points to note in interpreting the results of the present study. However, I still have some questions, comments, and suggestions regarding the results and their interpretation, which may require further explanation.

Throughout the manuscript, there are many comparisons and references to the authors' previous studies, but there seems to be little comparison with other previous studies on the firn deformation experiments.

We've expanded the discussion to include relevant literature in the text:

"The rheology of polycrystalline ice, particularly its temperature-dependent creep deformation, is a cornerstone of glaciological modeling. Numerous studies have established a robust framework for understanding ice deformation, primarily through laboratory creep experiments (e.g. Glen, 1955; Weertman, 1983; Budd and Jacka, 1989; Durham et al., 2001; Goldsby and Kohlstedt, 2001; Petrenko and Whitworth, 1999). This body of work has confirmed that ice creep is strongly governed by temperature, typically described by an Arrhenius relationship with a well-constrained activation energy for grain-scale processes like dislocation glide and climb (e.g. Jacka, 1984; Hooke, 2005). In contrast, the mechanical behavior of firn, the intermediate porous material between snow and glacial ice, remains comparatively poorly characterized, especially with respect to temperature. It is important to note that the experimental observations are discussed with respect to the mechanical properties of polycrystalline ice, which is the constituent material of the load-bearing ice skeleton (Scapozza & Bartelt, 2003), sharing poromechanics-based deformation mechanisms between the two via continuum mechanics and homogenization framework (Gagliardini and Meyssonnier, 2000; Coussy, 2004; Hutter and Johnk, 2004; Srivastava et al., 2010). While numerous studies have investigated firn and ice deformation (e.g. Steinemann, 1954; Landauer, 1958; Mellor, 1975; Salm, 1982; Maeno and Ebinuma, 1983; Ambach and Eisner, 1985; Li et al., 1996; Meussen et al., 1999; Bartelt and von Moos, 2000; Jacka and Li, 2000; Song et al., 2006a, 2006b, 2008; Theile et al., 2011; Treverrow et al., 2012; Hammonds and Baker, 2016, 2018; Li and Baker, 2021, 2022a), existing firn data are sparse and fragmented. A critical knowledge gap persists in the systematic experimental quantification of firn's mechanical response across a broad range of temperatures. Temperature is a first-order control on firn densification and deformation rates, yet most laboratory studies have been conducted at a limited number of isothermal conditions, often focused on a single density or at temperatures near the melting point (e.g. Mellor, 1975; Maeno and Ebinuma, 1983). Consequently, there is a pronounced lack of

experimental data necessary to derive the systematic activation energy for the creep of firn over its full density spectrum. This parameter is not merely a scalar but is likely a function of density, microstructure, and the dominant deformation mechanism (compaction versus shear), transitioning from grain-boundary sliding in low-density firn to dislocation creep in high-density firn and ice (Hammonds and Baker, 2018; Li, 2022; Li and Baker, 2022a). The absence of comprehensive, temperature-variable creep data for firn across its density range renders it insufficient for constraining the temperature-dependence terms in modern, physics-based firn models. Our work fills this gap via X-ray micro-computed tomography-analyzed mechanical examinations, e.g. a systematic series of constant-stress creep experiments on firn cores of varying density, conducted across a thermally controlled range from -30°C to -5°C. This allows for the direct determination whether the apparent activation energy is a function of density, thereby providing the essential experimental foundation needed to improve predictions of firn densification in ice-sheet and glacier models."

Please see Lines 43–79.

Furthermore, in the refereeing to the previous studies, firn and ice are mixed, the deformation of firn, including metamorphism, is clearly different from that of ice, so it is better to distinguish between firn and ice.

We agree that firn and ice are distinct materials in terms of their density, porosity, and metamorphic processes. However, the core objective of our analysis is not to equate the bulk material properties of firn and ice, but rather to analyze the mechanical behavior of the load-bearing ice skeleton that constitutes the solid matrix of the firn. From this perspective, the fundamental deformation mechanisms of the ice crystals themselves are identical. Our approach is based on the poromechanical framework, where the bulk deformation of a porous material like firn is governed by the constitutive laws of its solid constituent (in this case, ice) and the evolving pore structure. Thus, we've chosen to integrate the discussion for the following reasons:

Focus on the Skeleton's Constituent Material: As a state: *"The experimental observations are discussed with respect to the mechanical properties of polycrystalline ice, which is the constituent material of the load-bearing ice skeleton (Scapozza & Bartelt, 2003)."* This explicitly frames our discussion around the ice phase itself, not the bulk porous firn. The deformation mechanisms we discuss (e.g. dislocation creep, grain boundary sliding) are mechanisms of ice, whether the crystals are in a low-density firn or a high-density glacier ice.

Shared Deformation Mechanisms: The fundamental creep mechanisms for polycrystalline ice, including dislocation glide and climb, grain boundary sliding, and diffusion, are the same across the spectrum from firn to meteoric ice. The difference lies in how the porous microstructure (pore geometry, coordination number, density) influences the local stress state and accommodates strain within the ice skeleton. Discussing the ice properties provides the foundational physics that apply to both cases.

Continuum Mechanics and Homogenization: In the field of poromechanics, it is standard practice to model porous materials by defining the properties of the solid phase and then using homogenization techniques to upscale to the bulk behavior. By referencing studies on dense ice, we are establishing the constitutive law for the solid phase in future model of the firn. This approach is well-established in geomechanics for other porous materials (e.g. soils, rocks) and has been successfully applied to snow and firn.

Bridging Micro-Macro Behavior: Our discussion aims to build a bridge between the well-established microphysics of ice deformation and the more complex macro-scale response of firn. The cited literature on ice provides the known behavior of the solid blocks. The deviation of our firn data from the typical stress exponents of dense ice is a key finding of our study, which we then attribute to the unique porous structure and metamorphism of firn.

In summary, we distinguish between the material (ice) and the structure (firn vs. solid ice). Our integrated discussion focuses on the former to provide the physical basis for understanding the latter. To avoid any potential misunderstanding of the bulk properties of the two materials, we've added the description in the text:

"It is important to note that the experimental observations are discussed with respect to the mechanical properties of polycrystalline ice, which is the constituent material of the load-bearing ice skeleton (Scapozza and Bartelt, 2003), sharing poromechanics-based deformation mechanisms between the two via continuum mechanics and homogenization framework (Gagliardini and Meyssonnier, 2000; Coussy, 2004; Hutter and Johnk, 2004; Srivastava et al., 2010)."

Please see Lines 52–57.

L43–49: It is good that many references have been added, but perhaps the experiments on firn and ice should be separated. With present notation, it is unclear whether there are few experiments on firn deformation. The authors say that there is little information about firn, but I don't know what specifically is lacking. Describing the issues identified in the previous studies and what information is needed for firn model development will clarify the positioning of the present study.

Please see above immediately for the reasons of integrating firn and ice discussion.
In the last revision, we stated *"..., but there are few reports about their mechanical behaviors at different temperatures. Temperature is a key component of firn and ice-flow models, as the deformation of firn and ice is significantly influenced by the temperature."* for indicating the research gap. To further clarify, we've modified this in the text:

"The rheology of polycrystalline ice, particularly its temperature-dependent creep deformation, is a cornerstone of glaciological modeling. Numerous studies have established a robust framework for understanding ice deformation, primarily through laboratory creep experiments (e.g. Glen, 1955; Weertman, 1983; Budd and Jacka, 1989; Durham et al., 2001; Goldsby and Kohlstedt, 2001; Petrenko and Whitworth, 1999). This body of work has confirmed that ice creep is strongly governed by temperature, typically described by an Arrhenius relationship with a well-constrained activation energy for grain-scale processes like dislocation glide and climb (e.g. Jacka, 1984; Hooke, 2005). In contrast, the mechanical behavior of firn, the intermediate porous material between snow and glacial ice, remains comparatively poorly characterized, especially with respect to temperature. It is important to note that the experimental observations are discussed with respect to the mechanical properties of polycrystalline ice, which is the constituent material of the load-bearing ice skeleton (Scapozza & Bartelt, 2003), sharing poromechanics-based deformation mechanisms between the two via continuum mechanics and homogenization framework (Gagliardini and Meyssonnier, 2000; Coussy, 2004; Hutter and Johnk, 2004; Srivastava et al., 2010). While numerous studies have investigated firn and ice deformation (e.g. Steinemann, 1954; Landauer, 1958; Mellor, 1975; Salm, 1982; Maeno and Ebinuma, 1983; Ambach and Eisner, 1985; Li et al., 1996; Meussen et al., 1999; Bartelt and von Moos, 2000; Jacka and Li, 2000; Song et al., 2006a, 2006b, 2008; Theile et al., 2011; Treverrow et al., 2012; Hammonds and Baker, 2016, 2018; Li and Baker, 2021, 2022a), existing firn data are sparse and fragmented. A critical knowledge gap persists in the systematic experimental quantification of firn's mechanical response across a broad range of temperatures. Temperature is a first-order control on firn densification and deformation rates, yet most laboratory studies have been conducted at a limited number of isothermal conditions, often focused on a single density or at temperatures near the melting point (e.g. Mellor, 1975; Maeno and Ebinuma, 1983). Consequently, there is a pronounced lack of experimental data necessary to derive the systematic activation energy for the creep of firn over its full density spectrum. This parameter is not merely a scalar but is likely a function of density, microstructure, and the dominant deformation mechanism (compaction versus shear), transitioning from grain-boundary sliding in low-density firn to dislocation creep in high-density firn and ice (Hammonds and Baker, 2018; Li, 2022; Li and Baker, 2022a). The absence of comprehensive, temperature-variable creep data for firn across its density range renders it insufficient for constraining the temperature-dependence terms in modern, physics-based firn models. Our work fills this gap via X-ray micro-computed tomography-analyzed mechanical examinations, e.g. a systematic series of constant-stress creep experiments on firn cores of varying density, conducted across a thermally controlled range from -30°C to -5°C. This allows for the direct determination whether the apparent activation energy is a function of density, thereby providing the essential experimental foundation needed to improve predictions of firn densification in ice-sheet and glacier models."

Please see Lines 43–79.

L49: but there are few reports about their mechanical behaviors at different temperatures. Many previous studies have mentioned the importance of the temperature, and they conducted experiments with changing temperature. The authors mention this in L82-92.

Yes. Lines 82–92 present seven studies on temperature-related deformation tests. Compared to the numerous studies (non-temperature relevance) on firn and ice deformation found in tens to hundreds of publications, it is reasonable to describe the results here as *few*. To eliminate any confusion, we've rewritten this section to include a more detailed discussion of the specific citations mentioned above.

Please see Lines 43–79, too.

L392–395: Has the trend for the strain at which minimum strain rate occurs to vary depending on temperature and density been observed not only in the author group's experiments but also in other previous studies on firn deformation experiments? This trend is interesting.

Yes. These established phenomena in firn rheology are based on our group's observations, including those from the present study and previous work (Li and Baker, 2022a).

L512–519: This significant discrepancy implies that the uncalibrated SRMin value from all of the samples is not appropriate for estimating the stress exponent, and hence the activation energy during their deformation. Is it unique to present study (author's group experiments) that it is impossible to estimate the appropriate stress exponent and activation energy without the calibration? Or is also calibration necessary for the firn deformation experiments, including previous other studies?

Yes. Uncalibrated data contain noise that can produce significant inconsistencies, such as stress exponents that are negative or approach zero, results which are non-physical and contradict Glen's flow law. To resolve this pervasive challenge in firn rheology, we employ a calibration methodology. This approach, which involves calibrating the minimum strain rate to derive the stress exponent and activation energy, follows the best practices established for ice deformation in Glen (1955). For further clarity, we've modified this in the text:

"We determined stress exponent (n) values of approximately 0.1 and –1.2 for the –5°C and –18°C samples based on observed data, respectively. This result directly contradicts the value of n ≈ 4.3 reported from the same Greenland firn core by Li and Baker (2022a). Further, these values fall entirely outside the established range of ~1 to ~7.5 (mean ~4.25 ± 3.25) documented across decades of ice

mechanics literature (Glen, 1955; Hansen and Landauer, 1958; Butkovich and Landauer 1960; Kamb, 1961; Paterson and Savage, 1963; Higashi et al, 1965; Mellor and Testa, 1969; Raymond, 1973; Hooke, 1981; Thomas et al., 1980; Duval et al., 1983; Weertman, 1983,1985; Azuma and Higashi, 1984; Pimienta and Duval, 1987; Budd and Jacka, 1989; Jacka and Li, 1994; Goldsby and Kohlstedt, 2001; Bindschadler et al., 2003; Cuffey, 2006; Chandler et al. 2008; Cuffey and Kavanaugh, 2011; McCarthy et al., 2017; Millstein et al., 2022; Colgan et al., 2023; Li, 2025). The wide range of reported n-values is governed by a complex interplay of deformation mechanisms—including grain boundary sliding, diffusion (lattice and grain boundary), and dislocation processes, e.g. hard-slip-dominated, dislocation-accommodated grain boundary sliding, and grain boundary sliding-limited basal dislocation—across varying stresses, temperatures, crystalographic fabrics, impurity contents, and grain-size-to-sample-size ratios. We attribute the significant discrepancy in these findings to the experimental conditions. The lower temperatures used (down to –30°C) induce slower strain rates, which prevented the tests from reaching a critical strain rate minimum (SRMin). Therefore, to accurately estimate the activation energy for deformation, it is necessary first to calibrate the SRMin value for all noised samples."

Please see Lines 562–581.

L512–531 If the appropriate minimum strain rate is estimated by the calibration, what will be the stress exponent calculated using those values? Not only activation energy but also stress exponent is important for firn model development.

To clarify, the minimum strain rates are calibrated using established stress exponent values (averaging ~4.3) derived from the same Greenland firn core (Li and Baker, 2022a). These calibrated strain rates are then used to estimate the activation energy. Therefore, the stress exponent is constrained a priori before the activation energy is calculated.

Sincerely,
Yuan Li, Kaitlin Keegan, Ian Baker