REVIEWER #2

We are very thankful to this referee for their insightful feedback that has improved the accuracy and clarity of this manuscript. We especially appreciate the time taken to review it a second time and clearly explain their thoughts. Our responses to the below comments can be found in blue text.

Thanks for the answer and revision, but the revised text is still incorrect: one cannot calculate melt rate from surface temperature, as the latter is constant during melt. To calculate melt rate, the full surface energy balance must be known or some approximation (degree days) must be used.

Independent of the firn model physics, to force any firn model at its upper boundary, one needs surface temperature, surface accumulation and surface liquid water flux (melt and rain). These can be obtained as follows:

1) Prescribe all from a model or observations.

2) Prescribe (observed, modelled) surface accumulation, rain, near-surface meteorology and radiation fluxes (T2m, V10m, SWnet, LWin), and then use those to close the surface energy balance, which yields surface temperature and melt rate (if the surface is at melting). If no radiation data are handy, a simplified (degree day) method can be used to estimate melt.

If I remember correctly, in SNOWPACK there is a switch to choose between these options.

We appreciate this comment and thank the referee for clearly explaining this. We apologize for not correctly understanding the original comment. In an effort to make this section accurate and clear, we have simply removed the problematic phrase. It was originally incorporated to set SNOWPACK apart from other models. However, we have removed it and are now keeping this section solely focused on SNOWPACK.

The following has been removed “While many other firn models rely on surface skin temperature from the atmospheric forcing to calculate melt (e.g., Steger et al., 2017; Medley et al., 2022), SNOWPACK does not take this approach. Instead”.

REVIEWER #3: ERIN PETTIT

Review of Thompson-Munson paper on Greenland's Firn

I really appreciate all the effort the authors went to to revise the paper acknowledging the reviewers comments. Specially, I appreciate that I better understand the overarching goal of the paper - and that is now more clearly communicated in the new draft.

The paper reads much more smoothly now and I understand why some decisions were made.

I have just a few additional specific comments:

We are very thankful to this referee for their insightful feedback that has improved the manuscript. We especially appreciate the time taken to review it a second time. Several changes have been made, and our responses to comments can be found below in blue text.

Abstract
Line 11 - There are a few more places where it can be made even more clear that the intent is specifically to study Greenlands firn air content. "warming and cooling on *Greenland's*firn air content in an idealized *climate* experiment" - when I think of the phrase idealized model, I think of idealized geometry, idealized parameter spaces, etc. So it is helpful to the reader to be clear that in what way this is idealized.

Thank you for this suggestion. We have made the recommended changes in line 11.

Line 13 - "warming decreases the *integrated* air content… "

We have added "spatially integrated" to this phrase.

Line 15 - dependence (not y)

Done.

Intro
Line 57 - *Greenland's* firn behavior

We have changed this phrase to "Greenland firn's behavior"

Line 63/64 - either use pore-space loss (hyphenated). Or "loss in pore space" I prefer the latter - also "gain in pore space"

To be concise, we have added hyphens per this suggestion. This sentence now reads as: "Specifically, temperature–firn interactions amplify pore-space loss more in a warming climate than they amplify pore-space gain in a cooling climate"

2.1 Model Description
The model description still can use a few more elements. Some variation stating that it is a 1-d conservation of energy and mass, Lagrangian framework. The thermal conductivity for each layer is based on ?? varies with density/crystal structure?? (which isn't stated here, but is referred to later in line 273)… Specifically, I don't know what this statement means: "uses an energy balance model to calculate melt in a way that incorporates processes occurring

throughout the firn column in addition to those at the surface" does that just mean that energy is conserved within/across each layer in the model (i.e. a 1D conservation of energy model)?

Thank you for this feedback. We have made changes to section 2.1 in response to these comments. In particular, we have elaborated on the description and clarified the language where appropriate. SNOWPACK is a complex model that is introduced across three papers (Bartelt and Lehning, 2002; Lehning et al., 2002a, b), and is challenging to fully describe within this manuscript. We have followed what other authors have done in recent SNOWPACK papers (e.g., Dunmire et al., 2024; Banwell et al., 2023) and provided an overview of the model without getting into the fine details that detract from the model results. With this approach and the great suggestions from this referee, we hope that section 2.1 is easier to understand and more informative to the reader. Below, please find the specific changes we have made to this section.

In line 72, we changed "SNOWPACK" to "This one-dimensional model" in order to restate that it is a "single-column" model (line 68).

In line 75, we added the following to address the mass/energy conservation comment: ", and SNOWPACK solves the partial differential equations that describe mass, energy, and momentum conservation".

We added the following sentence at the end of this paragraph (line 77) to address the thermal conductivity: "Snow and firn microstructure governs physical properties like the thermal conductivity and is captured in the model's description of grain radius, bond radius, sphericity, and dendricity (Lehning et al., 2002b)."

We have changed the confusing sentence to explicitly mention the processes we alluded to. Line 80 now reads: "It uses this energy balance model to calculate melt in a way that incorporates several processes, including accumulation, snow-albedo feedback, percolation, and latent heat release (Wever et al., 2014, 2015, 2016)."

References:

Dunmire, D., Wever, N., Banwell, A.F., Lenaerts, J.T.M. (2024) Antarctic-wide ice-shelf firn emulation reveals robust future firn air content depletion signal for the Antarctic Peninsula. *Commun Earth Environ* **5**, 100 (2024). https://doi.org/10.1038/s43247-024-01255-4

Banwell, A. F., Wever, N., Dunmire, D., & Picard, G. (2023). Quantifying Antarctic-wide ice-shelf surface melt volume using microwave and firn model data: 1980 to 2021. Geophysical Research Letters, 50, e2023GL102744. https://doi. org/10.1029/2023GL102744

Finally, the one assumption that is left out until the discussion that I think is important for the reader to know up front is the assumption that all pore space is available for water, that ice lenses are not altering the pore space availability. No need to discuss it more in this section, keep the discussion of limitations at the end. But as it is an assumption of model, I think it needs to be here.

This is a great point that we agree is important to include early on. We have added it to the end of the methods in line 124: "We assess how air temperature perturbations impact the firn air content, which we calculate in the same manner as in Thompson-Munson et al. (2023) and assume that all pore space is available for storing meltwater."

The domain, boundary conditions, and initial spin up is explained well.

Sec 3.3
Line 214 - “the mean summer air temperatures in all three experiments are below 0” - I see that the final experiment (f) is above zero, not below.

Thank you for noting this. By “all three experiments”, we were referring to the control, warming, and cooling experiments in panel (d) alone. We now see that this is very confusing so we have changed it to “the mean summer air temperature throughout the 200 years is below 0°C”.

Discussion
To make this clearer I’d suggest enumerating the major pathways through which air temp can alter firn air content:
1. Compaction rate of dry firn
2. Increasing the bulk thermal conductivity
3. Melting fills pore space

We find this to be a great method for introducing these important processes. We have added the following at line 269: “We have identified three categories of processes altering firn air content: (1) dry firn compaction (Fig. 9a, b), (2) thermal property changes (Fig. 9c, g, h), and (3) meltwater production (Fig. 9d, e, f).”

Line 276-277 - The sentence starting “Increasing the air temperatures…” doesn’t seem like it is necessary, the sentence afterwards seems to explain the process sufficiently. I’d suggest cutting the sentence.

We have decided to keep this sentence because it introduces the pivotal idea that the relationship is nonlinear. This is an important characteristic of the relationship because it partially explains the asymmetric response to warming and cooling.

Line 295 - “latent heat *from* freezing” (the “latent heat of freezing” is a constant 334kJ/kg)

Thank you for this correction. We have changed this to “latent heat released from refreezing.” We have also made this change where it appears again in line 305.

Lines 320-340 seems like they belong in the conclusion section.

We appreciate this suggestion. However, since these paragraphs contain references to other work, we feel they belong better in the discussion.