Review of, "Exploring the conditions conducive to convection within the Greenland Ice Sheet", by Law et al.

Large plume-like folds are important features observed in the Greenland Ice Sheet, with significant implications for reconstructing past ice dynamics and projecting future ice-sheet mass balance. This paper investigates the formation of these plume-like structures. It is exciting to see the authors apply the well-established geodynamic modeling software ASPECT—commonly used in mantle plume studies—to test the hypothesis that thermal convection can produce such features. The modeling results are robust, as the authors present a comprehensive set of simulations exploring a wide range of enhancement factors, surface velocities, ice thicknesses, snowfall rates, temperature profiles, and model dimensions. Some of the simulated structures closely resemble those observed in radar profiles. The study finds that surface velocity, accumulation rate, and ice rheology exert the strongest controls on plume formation, which can also explain the spatial distribution of plume-like folds across northern and southern Greenland. Overall, this is a well-executed study, particularly valuable for improving our understanding of ice rheology in inland ice-sheet regions, where the ice may initially be frozen on the ground.

General comments

The model results clearly demonstrate that thermal convection can generate plume-like folds. I find the numerical results convincing, especially as they align with findings from my own modeling work on buoyancy effects (Y. Zhang et al., 2024). I also conducted tests using lower viscosities that show a more pronounced buoyancy-driven response. I'm excited to see this paper, as it represents a significant step forward in systematically constraining the controlling factors on convection and thoroughly analyzing the formation of plume-like structures. However, I have several concerns when relating the model results to the realistic world:

Ice rheology. The authors use a Newtonian and isotropic rheology. While the inclusion of an enhancement factor can approximate some aspects of natural ice behavior, this rheology may not be widely accepted. It would be good to include a paragraph at the end of Discussion section to carefully discuss the limitations of this ice rheology to the results. Actually I think a nonlinear and anisotropic rheology is likely to enhance convection, but am not sure how much initial perturbation would be required to trigger convection if the flow law is changed. It would also be helpful to explicitly state the range of effective viscosities in the convection models and, if possible, include representative viscosity maps. It is important to know the viscosity values.

Initial perturbation Setup. What are the detailed differences of the medium and large perturbations? (The height of the initial fold core?) Furthermore, how do these perturbations form? (Bedrock topography, variable snowfall, or other mechanisms which can form the initial fold core?) It would be good to point out in the Conclusion (maybe also Abstract) that convection in these models requires an initial perturbation; without it, convection may not initiate (?)

Fold axis direction. The paper primarily presents results in the along-flow direction (e.g., Figs. 4A–D). However, many observed plume-like folds, especially those associated with ice streams and convergent flow regimes, are oriented in the cross-flow direction with fold axes extending along the flow (e.g., Jansen et al., 2024, Nat. Commun., https://doi.org/10.1038/s41467-024-45021-8; Franke et al., 2022, Nat. Geosci., https://doi.org/10.1038/s41561-022-01082-2). It would be good to include some statements in the Discussion that, such as, the final plume geometry is associated with the initial 3D perturbation or other three-dimensional mechanisms.

Specific comments

Plain Language Summary, Line 8, “where the ice is old (therefore soft) and slow-moving”. Why is the old (and slow-moving) ice soft?

Introduction, Paragraph 2, Lines 11-14. “Viscosity gradients” can be deleted because Y. Zhang et al. (2024) claim that viscosity gradients do not play a significant role. Anisotropy alone can produce small-scale folds (fold amplitudes <<100 m) (but I feel you don’t need to mention small-scale folds here?). And convergent flow, rheological anisotropy and a rough bed can form large-scale folds (>100 m), but that tall plume-like folds require density gradients …

Figure 1. The captions for panels B and C appear to be mixed up (also in the main text).

Figure 2. Consider marking the location of panel A within Figure 1. Also, please clarify whether vertical exaggeration is applied in panels B-D.

Figure 3. The “red” labels A-E can be labeled as Fig.4A-4E or anything else. It is easy to mix up labels A-E for Fig.3 and Fig.4.

Figure 4E. Convection appears to develop in the cross-flow (y) direction as well. Is there an initial velocity component or perturbation applied in the y-direction?

Discussion, Paragraph 5, Lines 4-8. The overall viscosity values are dynamic along with c-axis rotations, which lead to lower viscosities as a result of directional alignment of the c-axis and anisotropic rheology. This directional softening not only enhances buoyancy effects but also contribute directly to plume growth.

Figure S5. “As for Fig.5 …” I think it is Fig.4?