Review:

Modelling the evolution of Thwaites Glacier over the 20th centry

Bett et al., 2026

Summary:

Bett et al., 2026 use a combination of aerial imagery analysis and coupled ice sheet-ocean modeling to generate a representation of Thwaites Glacier pre-1940s, when it is assumed to be in a stable state. Potential 1940s states are evaluated based on their ability to evolve into the present-day glacier under idealized forcings. This work makes use of observations to validate models of the historical and present day glacier. Ice damage and increased ocean forcing are analyzed as potential triggers for destabilization resulting in a glacier retreat pattern similar to observations of Thwaites Glacier in the present day. The authors find that healing the damage to the present day ice sheet is necessary to well represent the historical state.

General Comments:

This paper is interesting and overall quite well written. The main results seem sound and well reasoned, and the combination of coupled modeling with historical observations is nice to see. My main critique of the paper is that the methodology section remains convoluted, which makes it rather difficult to initially assess the experimental design and results. It would be very helpful to have a figure of some type to supplement the description of the initialization procedure and to distinguish the various experimental simulations. Perhaps a schematic or flow chart could be produced, but at the minimum it would be good to see a table identifying the various simulations. A naming convention for experiments would also help the audience to follow along when different simulations are discussed.

Improvements to the explanation of the damage factor, specifically, and how it is applied is needed in the methods section. It is completely understandable to not implement a physics based damage model given the complexity of that challenge, as is true for many other studies. This approach to represent damage is interesting, but I think more detail is necessary, especially given that damage is an often ignored component of ice sheet physics in modeling studies and that the key results follow from its inclusion here. The assumption of damage being the primary source of viscosity enhancement is fair, but can you explain more regarding where the viscosity enhancement factor field comes from? Is there an inversion step to calculate viscosity as part of the initialization procedure? How are variations in viscosity due to temperature being calculated so as to be able to identify the component due to damage?

The figures in this paper are an integral component of the analysis as comparison to historical observations is done via visual inspection of photos. While I find the analysis to be successful, some of the figures would benefit from additional information provided, and generally all figures would benefit from some refinement. Specific suggestions are listed below.

Specific Comments:

Abstract

L10: Repetitive use of make/making, suggest changing

L15-17: This sentence took me a few reads through to understand. It is quite dense and a bit confusing. I suggest breaking up the ideas here so that the model ensemble as methodology is addressed first. Then state the result afterwards that it was necessary to use an intact ice shelf to achieve the best fit to observations

L21: "eliminate these quasi-steady states" is an odd way to phrase this. Maybe "destabilize" is more clear?

Introduction

L65: The large intact iceberg is not initially obvious. I think the discussion of the 1973 image could use a bit more detail. From what is written, it isn't obvious to me that we can assume the Thwaites Ice Shelf was undamaged for centuries.

L66: Missing possessive apostrophe when describing western ice shelf

L102: It is unclear which paper, this manuscript or the 2024 paper, is being referenced for "These simulations retreat …"

Analysis of 1947 aerial imagery:

Generally super interesting.

Methods

L170: "outside of this area we apply a constant value $C = 10^4$ Pa $m^{-⅓}$ $a^{⅓}$"
Does this mean that constant friction is applied to grounded regions in the model that are floating in the present day?

L175: Why is the Pine Island Glacier cavity modified?

L195: 20 days strikes me as a large timestep for the ice sheet model. What is your grid resolution? Is 20 days small enough to ensure solution convergence?

L205: Why don't you initialize the model with the extended ice front? I would think that changing the geometry after initializing would introduce inconsistencies in the stress balance that can be avoided.

L207: extensive → extended

L213: More information regarding the calculation of damage is needed here.

L225: Does damage evolve in time during simulations?

L243: What is the damage feedback? It seems to me that this is more of an applied forcing than a feedback.

Results

L276: The healed damage field is applied to grounded ice as well? I thought changes to ice damage were only applied to floating ice? Please make this more clear in the methods

L345: I would remove this statement regarding the passage taking longer to open up due to no melt on partially grounded cells. Applying melt to partially grounded cells has been shown to over-represent ice sheet response and perform less accurately on idealized model domains unless a sufficiently small spatial resolution is used (e.g. Seroussi & Morlighem, 2018). I would not use the choice of melt representation at the GL here to explain the retreat pattern you see in the model output. If your model is converging properly, this choice should not determine the GL behavior, but rather the applied melt rates and internal ice sheet dynamics will dictate how the GL evolves.

Seroussi, H. and Morlighem, M., 2018. Representation of basal melting at the grounding line in ice flow models. *The Cryosphere*, *12*(10), pp.3085-3096.

L346: open up upstream →open upstream

4.3 Multiple quasi-steady states:

- The experimental design of these experiments isn't clear to me

Discussion

L580: Thwaites → Thwaites's, possessive nouns in APA style

L602: ungrounding of eastern Thwaites pinning point → ungrounding of the eastern Thwaites pinning point

L603: Notably → Notably,

L612: Maybe use "tipping in the parameter space defined by thermocline height and damage" for added clarity

L612-613: Some typos here with the citation Thom, 1975

L626: I would rephrase this sentence to avoid saying "state 2 is potentially the best". In your analysis of the options presented here, it is the best. The rest of this paragraph could also use a bit of editing. The argument is a bit hard to follow with the long sentence structure and additional context in parenthesis.

L682-685: The structure of this sentence is somewhat confusing with many different clauses. I suggest breaking it up or rephrasing.

L691-693: Summarizing what you did in this way undercuts the experimental design and your results. It begs the question of why you did not produce further simulations using state 2. I do not think that additional modeling work needs to be done for this work to be published, but I would reframe this summary of your results.

L696: Remove "additionally"

L729-734: There are some grammar issues with this first sentence, revisit. It is unclear what "this model" refers to- the published studies cited here or the work described in this paper.

L745: Does this process refer to ice thickening or to damage healing?

Conclusions

L786: Maybe I'm missing something, but aren't changes in ice damage always applied to the model in these simulations as opposed to something that can come out of the simulation results? I don't understand how rapid acceleration can lead to increasing damage given the methodology.

L796: Remove "to advance", typo

Throughout: Capitalize state when referencing the name of a specific model simulation- e.g. State 1

Figures

General: It would be helpful to increase the linewidth across all the figures for things like flow lines and grounding line locations.

Figure 1: Pinning points are labeled Eastern PP and Western PP in panel a. It would increase clarity to point these out in the caption with the abbreviation written in full.

Is this figure supposed to have outlines of the attached iceberg from 1947 and 1966 included? The text makes it seem like there might be some information missing here.

Figure 2: Super cool!

Figure 3: In the caption: model ice speed → modeled ice speed.

Panels b, d, e: Suggest increasing linewidth showing ice fronts and GL location

This is nitpicking, but subpanel labels in this figure do not match labels in previous figures, i.e. a vs a). It would be nice if figure style choices were consistent throughout the paper- notation choices, font sizes, etc.

Figure 4: I would increase the linewidth in all panels to make the solid lines easier to see.

Are the present-day modeled values shown in this figure from the initialization in present-day step? Or a simulation modeled from pre-1940s to present-day?

Is the simulation shown in panel (d) using a healed ice shelf?

Figure 7: Grey grounding line is especially difficult to see across all panels

Figure 8: Maybe make the cross more prominent in panels b and c so that the starting point can be easily identified for each simulation.

Figure 11: Caption is confusing, especially in the description of panel b.