Review:

Egusphere-2024-3513: Stratified suppression of turbulence in an ice shelf basal melt parameterisation

Overall Statement:

The team of authors have submitted a much-improved version of this bear of a manuscript that tackles the difficult, but important problem of including stratification in ice shelf-ocean models. Overall, the manuscript is quite good, with improved clarity and readability throughout. It is a big, chunky manuscript with a lot of detail that will inspire further work. Apart from some parts of the text needing improved writing structure and some improvement of the Methods Section, I feel that this manuscript will only need a minor review to be ready for publication. I have provided an assortment of comments below that are trivial and should not take much time to address. Great job turning around a solidly-revised manuscript!

-Peter Washam

Larger Comments:

Some poorly written sections that can benefit from: https://writersdiet.com/writing-test/ and https://www.amazon.com/Elements-Style-Fourth-William-Strunk/dp/020530902X .

Part of Methods section is still unclear – see comments below.

I don't think it is appropriate to cite manuscripts in review.

Specific Revisions:

Abstract:

Li 2 – 15: This now fits within the 250 word limit of The Cryosphere. Still, it is quite a long abstract, so consider shortening it somewhat.

Li 4 – 5: This sentence is hard to follow. Please rewrite improve readability.

Li 7: rewrite to "stratification by accumulation of buoyant meltwater beneath a flat ice interface"

Introduction:

Li 19 – 21: Insert somewhere in here that ice shelves have already entered the ocean and displaced sea level.

Li 25 – 26: add "in the ocean models that produce melt rate projections (IPCC, 2023; Bennetts et al., 2024)."

Li 28: As someone who does observations, I appreciate it when modelers define a relative scale for models to place them into context. Can you express what scale this "large-scale ocean, climate and earth system models" are operating on? Is this referring to global or circum-Antarctic?

Li 52: You have not defined the sections of the ice-ocean boundary layer yet, so change this to "the far-field flow below the ice-ocean boundary layer"

Li 57 – 60: This is a quite verbose sentence with poor structure. Please rewrite to improve readability and be sure to mention that meltwater accumulation and stratification inhibits melting on ice that is flat or has low slopes. This then will lead into the next sentence.

Li 62: The Washam et al., (2023) reference is fine if you'd like to cite it, but I think the Schimdt et al., (2023) reference is more appropriate.

Li 67 – 68: This is an incomplete sentence.

Li 73: "Vertical discretisation of the basal melt parameterisation" is a little heavy on the jargon. Please rewrite this to make it more clear what is trying to be communicated.
Li 80: Not sure about citing a paper in review unless it will be out before this one.

Li 81: Specify what you mean by "future ice shelf regime changes."

Li 86 – 92: This sentence is incredibly hard to understand. I understand that the authors are trying to summarize the important missing processes in models, but please rewrite this with improved sentence structure to improve readability.

Li 99: State the scale of "large-scale." Is this regional scale (1 large ice shelf or several small ones) or circum-Antarctic?

Li 100: The previous statements on scale should help the reader better understand the goal of the paper now.

Li 106 – 109: I think these sentences also refer to Schmidt et al., (2023).

Li 112: What is "large-scale" here? Is this a regional model or a GCM? I would be amazed if a GCM had this sort of resolution.

Li 119: Start this sentence with: "In this paper,"

Li 134 – 142: Nice summary of the upcoming contents of the paper.

Li 161: "Independent of these three unknowns" is vague. Please change to "is known" or something similar.

Melt Parameterisation Design and Validation:
The Three-Equation Melt Paramterisation and Transfer Coefficients

Li 145 – 146: Correct me if I am wrong here, but the problem is not the three-equation melt parameterisation, it is the inability to resolve the fluxes all the way up to the viscous sublayer, where then heat and salt diffuse at the molecular rate. The wording of these two sentences makes it seem like there is an inherent problem with the three equations that are: 1. Freezing point at ice base, 2. Conservation of heat, 3. Conservation of salt. Please clarify this.

Li 186 – 187: Correct me if I'm wrong here, but I think the take home message from Schmidt et al. (2023) was that while maybe missing the physics, the unstratified shear-driven parameterisation performed closest to the observations under steep slopes.

Li 194: Did Davis & Nicholls (2019) explicitly state that the ice base of Larsen C was smooth? I would expect there to be scallops or ripples from the strong turbulence there.

Li 196: See Table 1 of Washam et al. (2023) for a summary of observed C_D beneath ice shelves, including what was observed in the Ross Ice Shelf crevasse.

Stratification Feedback on Turbulence – Insights from Large Eddy Simulations:

Li 221: Love the specification on Beta/alpha

Stratification Feedback Parameterisation Design:

Li 246: This is a small point, but does \Gamma_{T,S} refer to the combined Gamma for the two-equation parameterisation or the individual Gammas for the three-equation parameterisation? I have not seen anything about a two-equation formulation at this point in the text.

Li 260: Davis et al. (2023) and Schmidt et al. (2023) also published using a heat conductive flux term. I would check through all the values from the published papers before downplaying the importance of heat conduction.

Li 281 – 284: This is not correct – In a stratified setting, $S_b < S_M$ and therefore $T_b > T_M$. So, by choosing a fully mixed setting in (9), you are artificially raising the thermal driving. This can be quite significant in stratified settings – take a look at the Washam et al. (2020) and Schmidt et al. (2023) estimates of T_b and S_b.

Li 276 – 296: I realize that the authors attempted to clarify this paragraph to make it more digestible, but I am still having a hard time sifting through the unclear presentation of what has been done here. I realize that in the actual work, they are solving the 3 equations, but here it is a 2 equation formulation with no salt gradient through the boundary layer. Please rewrite this section of remove it, as it is quite confusing.

Comparison to Observations:

Li 298 – 300: Consistent with the above comment, I do not understand if StratFeedback here is considering salt flux or a 2 equation formulation, as I interpreted the above section to state. This

is so important for the reader to understand, since this paper is all about boundary layer stratification.

Li 298 – 321: This is a nice section that could be in the results after clarifying the above comment. Although, I understand that it is still motivation for the approach that will then be applied to the model.

Limiting to a Velocity-Independent Parameterisation:

Model Configurations
ISOMIP+ Setup and Modifications

Li 407: Can you please provide a sentence that defends your selection of the standard value for C_D.

Idealised MOM6 Configuration

Idealised MITgcm Configuration

Idealised Explicit Tidal Forcing:

Pine Island Glacier Configuration:

Li 460: Perhaps it would be worthwhile to mention here that subglacial discharge could interact with the ice-ocean boundary layer in ways to alter the StratFeddback parameterization in locations of the ice shelf.

Results:
Idealised ISOMIP+ Results:

Sensitivity to the Low-Velocity Limit:

Energetic Ice Shelf Cavity Regimes:

Realistic Pine Island Glacier Simulation:

Li 589: Please note the weakness of satellite-derived melt rates here. While they provide excellent coverage, they are only a first order estimate of what the true melt rate is (See Vankova & Nicholls, 2022 Fig. 8 for comparison with ApRES obs).

Li 587 – 642: This section is much improved!

Discussion:

Li 669: Was Davis et al. (2023) in the diffusive convective regime? I think it is worth double checking and also taking a look at Davis et al. (2025): “Lateral Fluxes Drive Basal Melting Beneath

Thwaites Eastern Ice Shelf, West Antarctica." This paper should be cited somewhere in the manuscript.

Figures:

There is a labeling convention switch for velocity units from m/s to ms^-1 in the figures. Please change them to be consistent throughout. Also, make m/yr or m yr-1 consistent throughout the manuscript. I suggest to make it consistent with the notation from the text.

Fig. 1d: Totally optional, but it might be worthwhile to plot the Washam et al. (2023) means from Table 1 in here as grey lines, as well.

Fig. 5: there is a space missing in the m s^-1 labels on this figure

Fig. 6: there is a space missing in the m s^-1 labels on this figure

Fig. 7: there is a space missing in the m s^-1 labels on this figure

References:

Davis et al. (2025): "Lateral Fluxes Drive Basal Melting Beneath Thwaites Eastern Ice Shelf, West Antarctica."