Response to reviewers for “Ice-shelf ocean boundary layer dynamics from large-eddy simulations”

Carolyn Branecky Begeman[1], Xylar Asay-Davis[1], and Luke Van Roekel[1]
[1]Los Alamos National Laboratory, P.O. Box 1663, Los Alamos, New Mexico, USA 87545
Correspondence: Carolyn Begeman (cbegeman@lanl.gov)

1 Response to Reviewer 1

Abstract:

Line 2: “Yet these small scale processes, which regulate heat transfer between. . . .” Should be heat and salt transfer.
The suggested change has been made.

Introduction:

Line 27: “. . . .an overturning circulation known as “ice pump” Could talk about the refreezing process.
We have added the following sentence to this paragraph:

> “Supercooling of the IOBL and frazil ice accretion to the ice-shelf base are also regionally important processes for cold cavities, but are not the focus of this work (Galton-Fenzi et al., 2012; Jordan et al., 2015).”

Line 31: “ IOBLs present unique conditions in the global ocean, involving a stabilizing flux from phase change” The stabilizing flux mostly comes from the freshening of the boundary layer not from ‘phase-change’.
We intended to specifically refer to the stabilizing buoyancy flux at the boundary associated with ice-shelf melting. We hope this revision is more clear:

> “IOBLs present unique conditions in the global ocean, involving a stabilizing buoyancy flux from melting ice and a boundary layer that is positively buoyant against a sloping boundary.”

Line 36: “ Numerical studies addressing intermediate scale” Please define ‘Intermediate scale’. Also to my knowledge Mondal et al., 2019 was a DNS study that resolved the Kolmogorov scale.
We have avoided this vague term in our revision. The revised sentence reads:

"IOBL turbulence has been explored through laboratory experiments, direct numerical simulations, and large-eddy simulations (Middleton et al., 2021; Mondal et al., 2019; Vreugdenhil and Taylor, 2019; McConnochie and Kerr, 2018)."

should clearly mention the author used a Lewis number =1.

This comment wasn't entirely clear to us. If the reviewer is referring to this study, it isn't the case that the Lewis number=1 either in the melt parameterization or the AMD turbulence closure model.

It would be interesting to see how friction length changes over slope, assuming eddy viscousity is estimated as a product of friction velocity and mixing length.

Unfortunately, we have not output the 2-d friction velocity and momentum flux fields at the ice boundary necessary to compute a friction length as you define it. Furthermore, since the momentum fluxes at the boundary is defined by our subgrid near-wall scheme (Equation 8), you could express the friction length as $\frac{\kappa}{\Delta z}(ln\left(z_{\frac{1}{2}}/z_0\right) - \Psi_m\left(\zeta_{\frac{1}{2}}\right))^{-1}$*. Thus, the friction length is chiefly a function of the Monin-Obukhov length. We can show how the Monin-Obukhov length varies with slope, as well as the ratio of resolved TKE 2* m *from the boundary to the friction velocity used by the near-wall scheme (figure below). However, we interpret these relationships to be primarily driven by the relationships between slope, mean velocity (and TKE) of IOBL, and melt rate already discussed in the manuscript.*

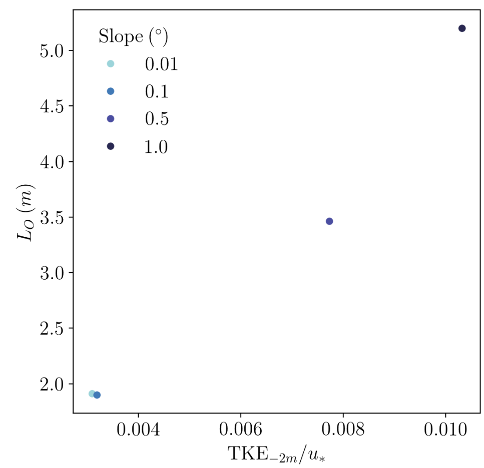

Figure A1. Relationship between Monin-Obukov length and the ratio of TKE at 2m below the boundary to the friction velocity evaluated at the boundary. All quantities are horizontally-averaged and time-averaged over the last inertial period.

Methods:

General Comment: I would love a schematic of the model set up.

We have added a schematic figure, now labeled Figure 1.

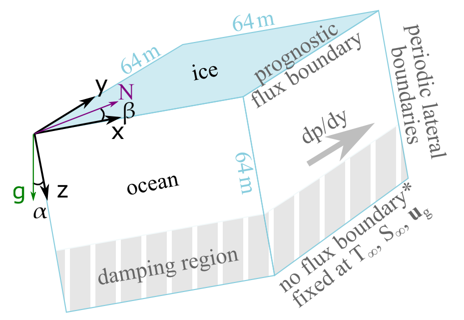

Figure 1. Schematic of the simulated ocean domain with background pressure gradient dp/dy. Purple arrow is oriented north and green arrow is aligned with gravitational acceleration. *The bottom boundary condition is Dirichlet, but there is also no flux as a result of damping.

Overview of the LES model: It would help the readers if you clearly mention whether you have used a linear or non-linear equation of state.

Thanks for catching the omission. We have added the following text:

> "We use the nonlinear equation of state from Jackett et al. (2006) to compute densities."

Simulation set-up:

Line 150: What about the time step?

We have added the following text:

> "PALM employs adaptive timestepping; timesteps for the simulations presented here range from 0.5 s to 2.75 s after 2 h."

We also realized that the following information might be useful to the reader:

> "We initiate turbulence over first 50 min of the simulation with perturbations to the horizontal velocity components on the order of 0.01 $\mathrm{m\,s^{-1}}$."

Line 167: I don't think 1 degree is a relatively high slope for Antarctic ice-shelves.

That's fair. We have deleted the judgment so that it now reads:

> "and a slope of 1°"

Result:

A plot with temporal evolution of melt rate, obukhov lengthscales could help the reader.

We have included a plot with the temporal evolution of melt rates, Figure 1 c,f. We believe that the obukhov lengthscale doesn't provide much additional context beyond that given by the melt rate and friction velocity in Figure 1, as it is computed from them. However, we added the following text to provide some context for the reader:

> "Average melt rates over the last inertial period range from 0.3–2.5 m (Fig. 2a,d) and average Monin-Obukhov lengthscales are 3–5 m (not shown)."

Discussion:

Line 397: 'The relationship between melt rate and distant thermal driving' : the sentence is hard to read.

To make our point clear, we have rewritten the latter portion of this paragraph:

> "The relationship between average ice-shelf melt rates and the thermal driving for the cavity as a whole can be conceptualized in two components. The first is the relationship between the local thermal driving and melt rate, determined primarily by the local ocean turbulence. The second is the relationship between distant thermal driving (i.e., the water masses entering the ice-shelf cavity) and the strength of sub-ice-shelf circulation (Holland et al., 2008). Only the former is addressed by this study. Our simulations do not capture the large-scale increase in overturning circulation that accompanies an increase in distant thermal driving. Our simulations partially capture the increase in IOBL velocity due to an increase in thermal driving but the far-field velocity is unaffected. We note that the often cited quadratic relationship between distant thermal driving and melt rate involves both local turbulent processes and large-scale processes (Holland et al., 2008); studies generally find this exponent on distant thermal driving to be between 1.5 and 2 (Favier et al., 2019; Jourdain et al., 2017; Little et al., 2009)."

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