

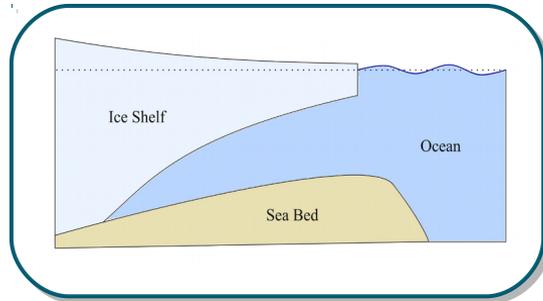
Modelling the Ice Shelf-Ocean Boundary Layer with a General Circulation Model

Ryan D. Patmore, Paul R. Holland and Catherine A. Vreugdenhil

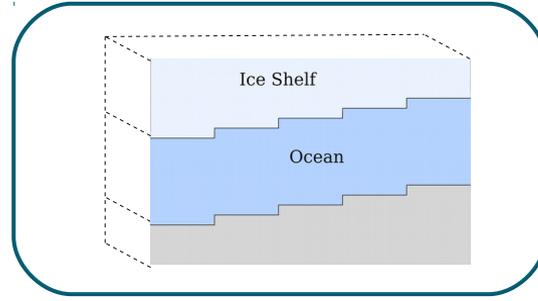


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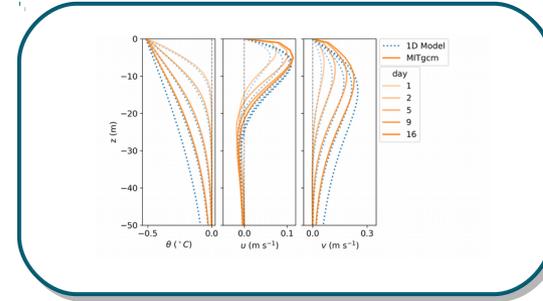
Introduction



Model Set-up

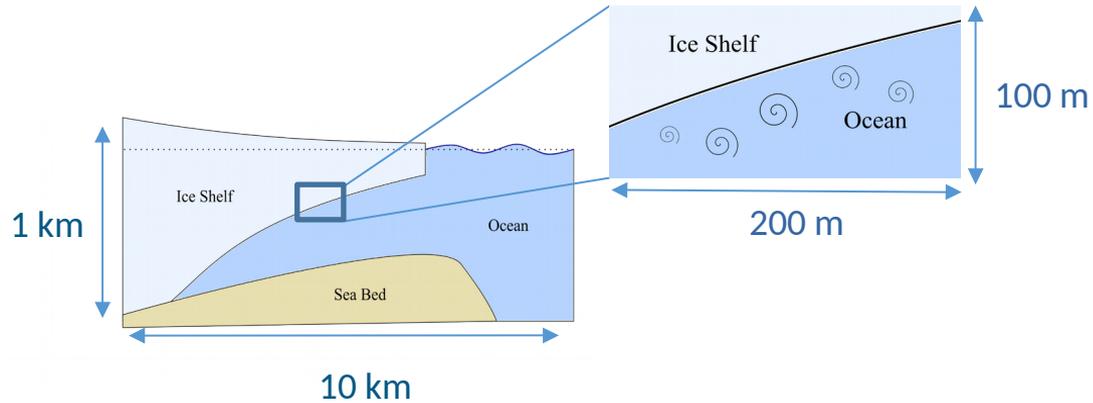


Results



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The main aim of this study is to gain insight into the ability of a General Circulation Model (GCM) to accurately model the ice shelf-ocean boundary layer.

Many models of the ice shelf cavity use, at best, a resolution of 10 m in the vertical. This resolution is too coarse to accurately represent the small-scale processes at the ice shelf-ocean boundary layer. As such, GCMs often rely on parametrisations of heat and salt fluxes at the ice-ocean boundary via models such as the Three Equation model. The Three Equation model has parameters that are relatively unconstrained with limited knowledge on which to base parameter choice.

Here, we use high resolution GCM simulations of the ice shelf-ocean boundary to identify the small-scale processes often missing in larger ice shelf cavity scale models – these differing scales are represented in the schematic above. We first assess the ability of our GCM to model the ice shelf-ocean boundary layer by comparing against sophisticated 1D theoretical results. In this presentation we discuss these comparisons.

To identify the effects of coarsening the resolution the next phase of this study will be to compare these high resolution results against lower resolution equivalents. This resolution comparison is yet to be done.

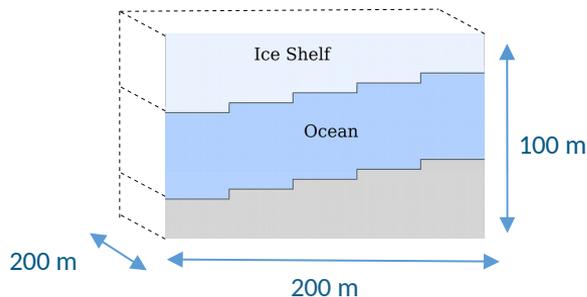
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General Set-up

We implement an idealised 3D box model using MITgcm. The domain is doubly periodic with a sloping ice shelf and 'bed' topography. The 'bed' is sufficiently far from the ice shelf to not influence the sub ice shelf boundary layer. The implementation of the slope is shown in the schematic below.



All models are initialised from a uniform temperature field. Velocities are initialised with random noise, with a maximum amplitude of $5e-4$ m/s. Simulations are transient and run for approximately 32 days. All MITgcm simulations are run with 1 m vertical and horizontal resolution.

Single Scalar Model

A single scalar version of MITgcm is presented. This set-up represents salt and temperature via a single scalar by adjusting the equation of state as shown below and time stepping temperature only.

Equation of State

$$\Delta\rho = -\alpha_T(T - T_m)$$

$$\alpha_T = 2.5e - 4$$

The heat flux at the boundary is then prescribed as a forcing term to the heat equation:

$$K_0 \left. \frac{dT}{dz} \right|_b = C_d^{1/2} |\mathbf{u}| \Gamma_{TS} T_m$$

where initially

$$C_d^{1/2} |\mathbf{u}| \Gamma_{TS} = \gamma_{TS} = 0.006$$

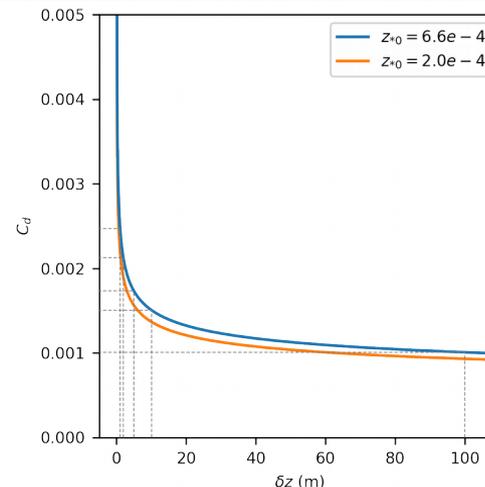


Figure 1: drag coefficient against vertical grid resolution for roughness lengths of $6.6e-4$ (blue) and $2.0e-4$ (orange). The dashed lines highlight resolutions of 1, 2, 5, 10 and 100 m.

Wall Model

Additional to the simple formulation above we also implement a wall model in MITgcm. This wall model is equivalent to applying a variable diffusion and viscosity at the ice base and is calculated according to the equations on the right.

The drag coefficient is variable and dependent on the grid resolution. Figure 1 shows how this value changes with resolution for two different roughness lengths. Here we use a roughness length of $6.6e-4$. The Stanton number is a constant of 0.006 and $|\mathbf{u}|$ is taken to be the speed of the flow at the ice base.

$$\nu_0 = C_d |\mathbf{u}| \delta z \quad \kappa \quad \text{- von Karman's constant}$$

$$\frac{K_0}{\delta z} = C_d^{1/2} |\mathbf{u}| \Gamma_{TS} \quad \delta z \quad \text{- distance from ice}$$

$$C_d^{1/2} = \left[\frac{1}{\kappa} \ln \left(\frac{\delta z}{z_{*0}} \right) \right]^{-1} \quad \Gamma_{TS} \quad \text{- Stanton number}$$

$$z_{*0} \quad \text{- roughness length}$$



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Laminar

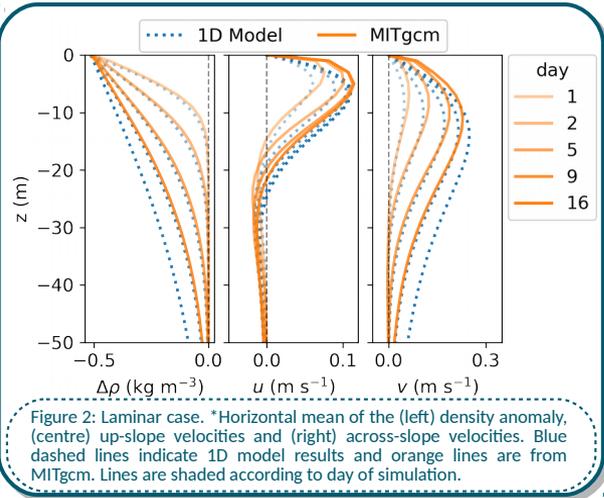


Figure 2: Laminar case. *Horizontal mean of the (left) density anomaly, (centre) up-slope velocities and (right) across-slope velocities. Blue dashed lines indicate 1D model results and orange lines are from MITgcm. Lines are shaded according to day of simulation.

Turbulent

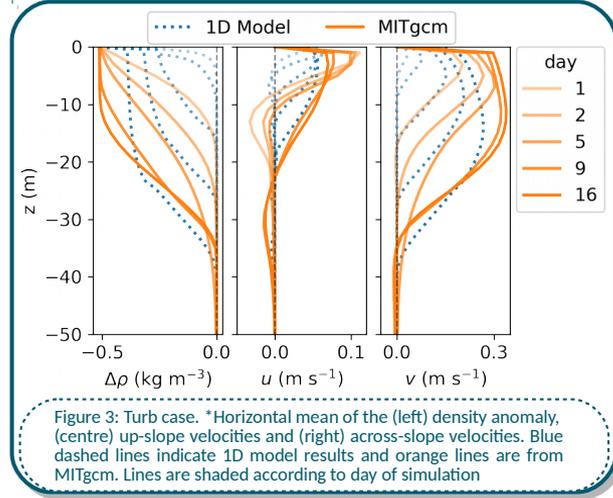


Figure 3: Turb case. *Horizontal mean of the (left) density anomaly, (centre) up-slope velocities and (right) across-slope velocities. Blue dashed lines indicate 1D model results and orange lines are from MITgcm. Lines are shaded according to day of simulation.

Turbulent with wall model

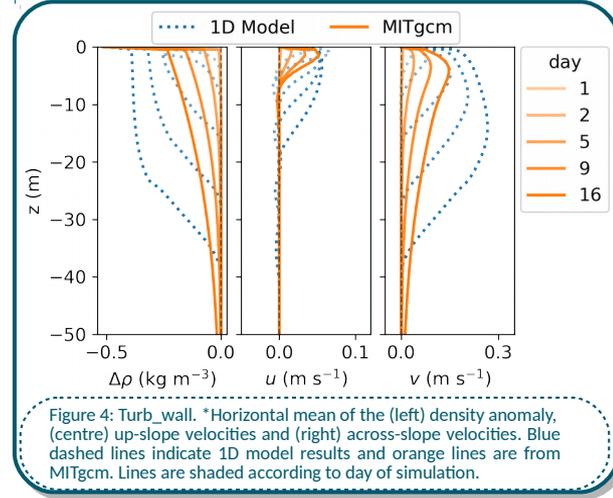


Figure 4: Turb_wall. *Horizontal mean of the (left) density anomaly, (centre) up-slope velocities and (right) across-slope velocities. Blue dashed lines indicate 1D model results and orange lines are from MITgcm. Lines are shaded according to day of simulation.

Here we show a comparison between the 1D theoretical results of Jenkins (2016) and Jenkins (2020) and the *single scalar* MITgcm. There are two 1D models and three MITgcm models displayed. All MITgcm models use a constant background viscosity and diffusion according to the table below. Figure 2 and 3 show the Laminar and Turb cases respectively. Figure 4 shows the Turb_Wall case that uses the wall model outlined on the set-up page. Figure 2 compares against a 1D result that uses the same constant background viscosity and diffusion. Figures 3 and 4 compare against a 1D model where the viscosity and diffusion is calculated according to a theoretical turbulence model. The 1D turbulence model uses the same wall described in the set-up page.

Case	Viscosity	Diffusion	Wall Model
Laminar	5e-3	5e-4	N
Turb	5e-4	5e-4	N
Turb_Wall	5e-4	5e-4	Y

There is good agreement with the 1D model in the laminar case of Figure 2. However, when comparing against the turbulence model in Figure 3, the evolution of density at the boundary (top) is very different. This is an insufficiency of MITgcm. In order to improve the results we have implemented the same wall model that exists in the 1D turbulence model to the top cell of MITgcm. The results of this are shown in Figure 4.

Onset of Turbulence: Convex versus Concave

A convex profile in the density anomaly is associated with a laminar case where there is little eddy activity.

A switch to a convex density anomaly profile signifies the onset of turbulence. Turbulent eddies generate a mixed layer, creating the uniform density profile. The uniform conditions result in a concave curve.

The results in Figure 2 stay laminar throughout the simulation due to high viscosity damping the turbulence and hence the density curve is convex. The switch in the density anomaly from convex to concave can be seen in the 1D turbulent model and MITgcm result in Figure 3 above. This results from lowering the viscosity.

Figure 4 shows a comparison of the turbulent 1D model against MITgcm with the addition of a wall model. Figure 4 shows there is an improvement of results at the boundary but there is an absence of the turbulence seen in Figure 3 (*Turb*). In previous MITgcm results, $C_d = 0.0097$. C_d in *Turb_Wall* is calculated according to an equation that is dependent on Z . Due to MITgcm having partial cells, C_d varies in the horizontal. The wall model produces a mean drag coefficient of around $C_d = 0.0025$. This suggests that some of the difference between *Turb* and *Turb_Wall* is due to changes in C_d . The 1D result uses the same wall model as *Turb_Wall* and unlike our case the 1D result shows signs of turbulence. Although a reduction in C_d to levels seen in *Turb* may introduce turbulence in MITgcm, the main difference between *Turb_Wall* and the 1D result is associated with the simple background viscosity and diffusion used by MITgcm.

* horizontal relates to the axis aligned with the ice base

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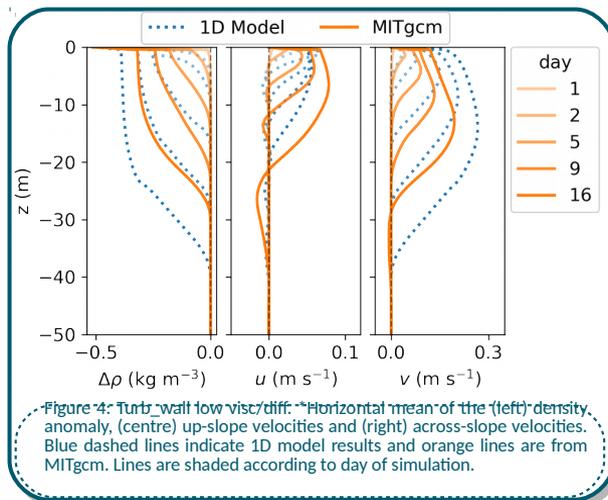


Last minute addition

Relatively high viscosity in Turb_Wall (slide 4, right) was damping out the turbulence. Lowering the level of the constant background viscosity and diffusion in Turb_Wall to $1e-4$ produces result below.

There is now a reasonable agreement between models.

Turbulent with wall model (low visc/diff)



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