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Estimating the basal melting of ice shelves affected by submesoscale ocean dynamics

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1. INTRODUCTION

Antarctic ice shelves are the floating extensions of the Antarctic ice sheet. Antarctic ice shelves have been losing mass in recent decades, which could trigger the collapse of ice shelves and substantial grounded ice loss and sea level rise [1]. Ice shelf thinning is affected locally by modified Circumpolar Deep Water, a warm, salty water mass at intermediate depths. Recent studies have found that the basal ice melting process has important interactions with submesoscale eddies [2]. In addition, recent observations showed that an eddy travelled beneath Stancomb-Wills Ice Tongue and spun down, lifting isopycnals and likely increasing the local ice shelf melt rate [3]. However, questions remain on the underlying physics, including the influence of submesocale dynamics on the fine scale ice shelf-ocean boundary layer. This study examines submesoscale eddies generated by a salinity front in the ocean mixed layer and the impact of these eddies on the basal melting of ice shelves.

2. APPROACH

In this study, we use numerical simulations of a laboratory-scale ocean model, employing Large Eddy Simulations (LES) to resolve all but the smallest scales. The governing equations are the non-hydrostatic Navier-Stokes momentum equations under the Boussinesq approximation, along with conservation of mass, temperature and salinity. These simulations are set up in Oceananigans, a fast, open-source Julia package. The computational domain has a length x of 6 m, a width y of 7 m and a depth z of 1.5 m.

In order to generate submesoscale currents, a salinity front with a height H of 0.6 m and a width L of 0.8 m is designed in the upper layer of the computation domain. This front has a maximum vertical buoyancy frequency $N_{upper}^2 = 0.05\ \mathrm{s}^{-2}$ and a lateral buoyancy frequency $M^2 = 0.01\ \mathrm{s}^{-2}$. The salinity field has a maximum value of 35.25 psu and a minimum value of 33.9 psu. In addition to a salinity field, the temperature field is initialised with a constant value -1.8 °C across the majority of the domain with slight stratification near the ice shelf. The velocities are initialised with small random noise. A periodic condition is used in the x (along-front) direction, while impermeable walls are utilised in the y (across-front) and z (vertical) directions. The bottom boundary is free-slip and the top boundary is no-slip (to model the ice shelf base). Temperature and salinity have adiabatic boundary conditions at the vertical walls and restoring gradient boundary conditions at the bottom boundary. The melting condition is imposed at the top boundary as static ice using the three-equation condition with resolved vertical temperature and salinity gradients [4]. Additionally, sponge layers are set up near bottom and side boundaries to restore temperature and salinity to initial conditions and damp the velocities to zero. An ensemble of simulations is conducted at different ocean temperatures (-1.8 °C to 1 °C) to model the basal melting in cold and warm cavities.

3. RESULTS

The simulation results show the horizontal ice shelf melting into a two-layer stratified ocean front at various ocean temperatures typical of Antarctic conditions. The initial salinity front quickly breaks into a family of cyclonic eddies and anticyclonic eddies, which inhibit and enhance melting, respectively (Figure 1). This change in ice melting is due to two mechanisms: Ekman dynamics and the advection of local density fronts. The first mechanism is that the stress of the ice on the differential ocean flow drives Ekman suction in anticyclones and Ekman pumping in cyclones, which control the vertical motion near the ice shelf. Ekman suction upwells deeper warm, salty water to the ice base, increasing basal melt rates. Whereas Ekman pumping draws cold meltwater downwards, shielding the ice away from warm water and thereby inhibiting melting. The second mechanism affecting the ice melt rates is the local density fronts associated with the eddies. During initial front meandering, the dense fronts are associated with cyclones, while light fronts are trapped in anticyclones. The water inside the relatively dense cyclonic eddies then downwells (reducing the melt rate), while the water in the relatively light anticyclonic eddies will upwell (increasing the melt rate). Through these two mechanisms, the local basal melting is enhanced by anticyclonic eddies in a manner consistent with past observations [3].

By varying the ocean temperature, we find that eddies, particularly anticyclonic eddies, show a strong localised effect on the basal melting at the low ocean temperatures associated with a cold ice shelf cavity. The impact of the anticyclonic eddies on melting lessens with higher ocean temperatures, such as those associated with warm ice shelf cavities. These findings are useful in understanding submesoscale eddy dynamics and in parameterising the impact of fine scale boundary layer effects and submesoscale eddies on ice melting in large-scale ocean models.

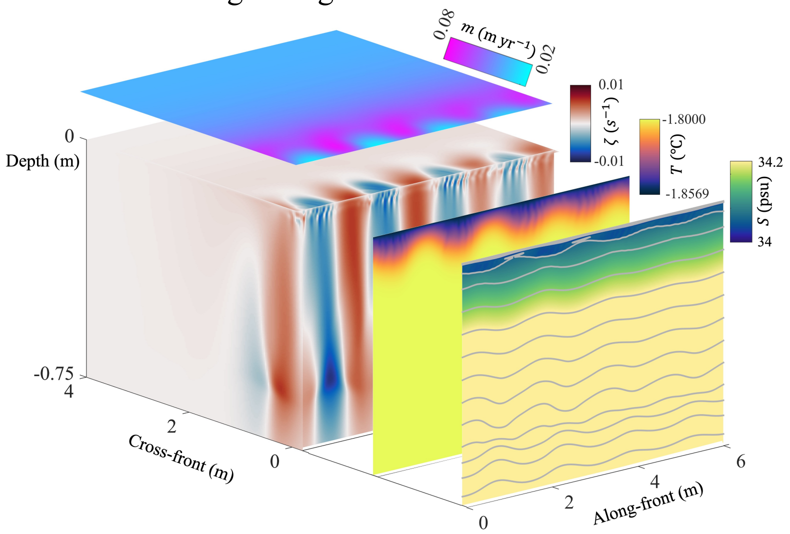

Figure 1. Snapshot of half of the simulated domain with melt rate (top), relative vorticity ζ, temperature T and salinity S taken at $t = 2.3$ h into the simulation run ($T_{initial} = -1.8$ °C). In anticyclonic eddies (red), warm and salty water is identified to increase melt rates, whereas in cyclonic eddies (blue), cold and fresh water is found to lower melt rates.

4. CONCLUSIONS

The high-resolution LES study shows that anticyclonic eddies are associated with strong upwelling of warm, salty water and enhance basal melting significantly in cold cavities. For warm ice shelf cavities, this effect lessens as the ambient ocean temperature is already high enough to induce large melt rates.

REFERENCES

[1] Paolo, F. S., Fricker, H. A., & Padman, L. (2015). Volume loss from Antarctic ice shelves is accelerating. *Science*, *348*(6232).

[2] Shrestha, K., Manucharyan, G. E., & Nakayama, Y. (2024). Submesoscale Variability and Basal Melting in Ice Shelf Cavities of the Amundsen Sea. *Geophysical Research Letters*, *51*(3).

[3] Hancock, C., Speer, K., Janout, M., & Boebel, O. (2025). Under ice-shelf eddy at the Stancomb-Wills Ice Tongue. Journal of Geophysical Research: Oceans, 130, e2024JC021393.

[4] Holland, D. M., & Jenkins, A. (1999). Modelling thermodynamic ice-ocean interactions at the base of an ice shelf. Journal of Physical Oceanography, 29(8 Part 1).