Simulations of Ocean Circulation under Static and Dynamic Ice Shelves

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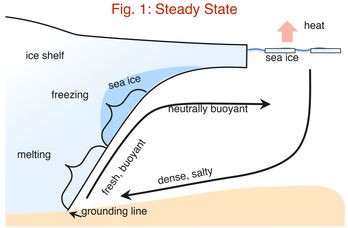
Abstract

We present a method for performing simulations dynamic ice shelves within a dynamical ocean model (the Parallel Ocean Program, POP) using an immersed boundary method (IBM) to represent the geometry of the ice/ocean interface. The IBM is used to couple POP to the Community Ice Sheet Model (CISM). The IBM allows for geometrically correct representation of the boundary conditions at the ocean/ice interface without the need for a grid that conforms to the boundary or changes in time. The interface is free to move in time as the ice sheet evolves.

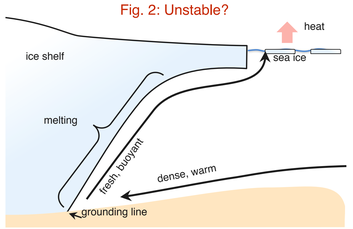
Background

Fig. 1: Steady State



Many Antarctic ice shelves:
- Steady state
- Both melting and freezing

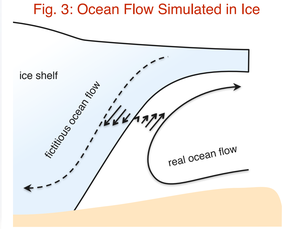
Fig. 2: Unstable?



Vulnerable ice shelves (Amundsen and Bellingshausen Embayments):
- Accessible to warm circumpolar deep water (CDW)
- Only melting: ice shelf retreats
- Instability, further retreat?

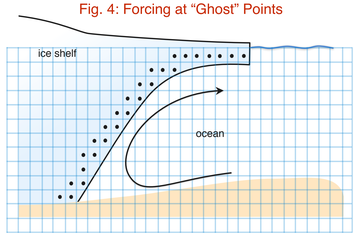
Immersed Boundary Method (IBM)

Fig. 3: Ocean Flow Simulated in Ice



- Enforce boundary conditions on u, T and S
- Fictitious ocean flow in ice shelf/ice sheet

Fig. 4: Forcing at "Ghost" Points

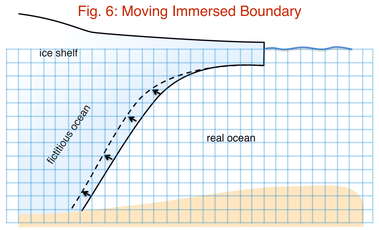


- Forcing at "ghost point" in fictitious flow
- Find u, T, S values that produce desired mass, heat and salt fluxes

Fig. 5: A Single Forcing Point

Image point method:
- Interpolate u, T, S to image point from neighbor points
- Use boundary conditions to extrapolate to ghost point
- Coupled problem if boundary point is a neighbor point

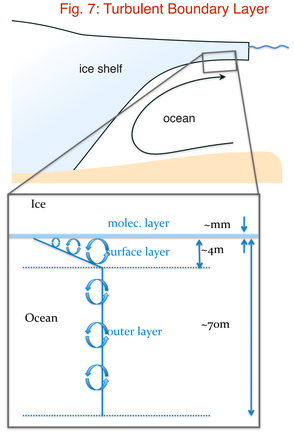
Fig. 6: Moving Immersed Boundary



- No need for time-variant or boundary conforming grid
- Boundary can move freely as ice advances/retreats

Turbulent Boundary Layer Physics

Fig. 7: Turbulent Boundary Layer



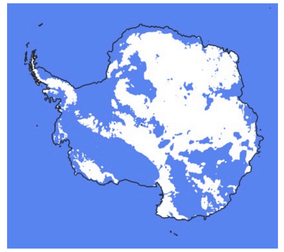
- Analytic sub-grid-scale model
- Based on McPhee (2008)
- Balance of turbulent diffusion and Coriolis force
- Accounts for stratification (η_*)
- Fit to rational polynomials for comp. efficiency

$$u(n) - u(0) = \Phi_u(u_*, \eta_*) u_*$$
$$\Phi_u(u_*, \eta_*) \approx u_* / (a_1 \eta_* + a_2 \eta_* u_* + a_3 \eta_*^2 u_*)$$

$$S(n) - S(0) = \langle w' S' \rangle_0 / u_* (\Phi_{\mathrm{turb}}(n, \eta_*, u_*) + \Phi_{S,\mathrm{mol}})$$
$$\Phi_{\mathrm{turb}}(n, \eta_*, u_*) \approx n u_* / [n(c_1 + c_2 u_* + c_3 \eta_* u_*) + c_4 u_*^2]$$

Retreating Ice Sheet

Fig. 8: Melting Ice, New Ocean



- In black, current ice sheet/ice shelf extent
- In blue, bedrock below sea level
- IBM: blue areas are "true" or "fictitious" ocean
- Map base on RTopo-1(Timmermann et al. 2010)

Future Work

Development of the IBM is nearing completion, with a series of tests on simplified problems (e.g., the Ice-Ocean Model Inter-comparison Project, ISOMIP, experiment) currently in progress. Coupling of the ice sheet and ocean models in the Community Earth System Model (CESM) is also in progress.

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