Modelling marine ice accretion beneath ice shelves

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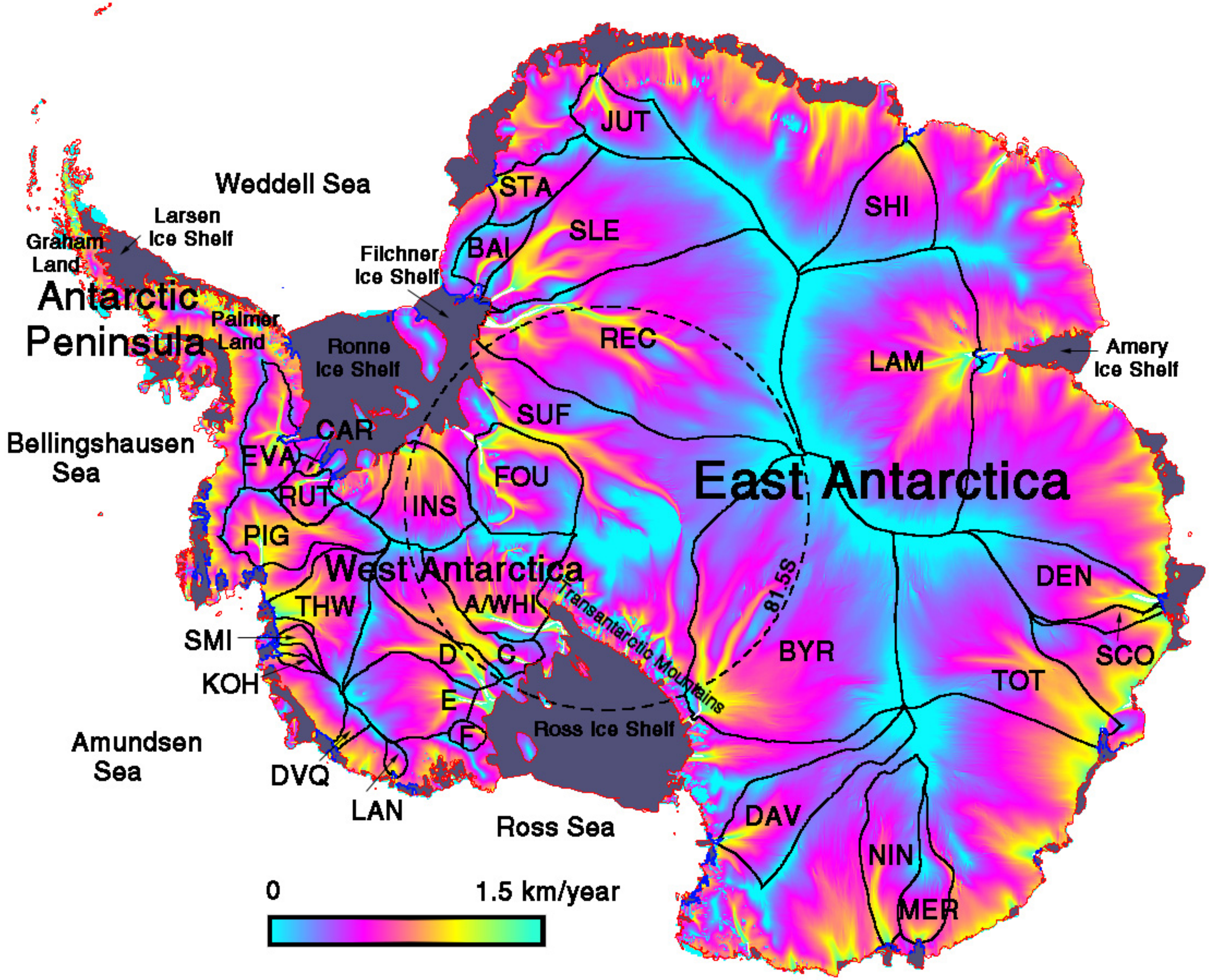


Rignot, JPL

An ice shelf is a thick (up to 2800 m!), floating platform of ice that forms where a glacier or ice sheet flows down to a coastline and onto the ocean

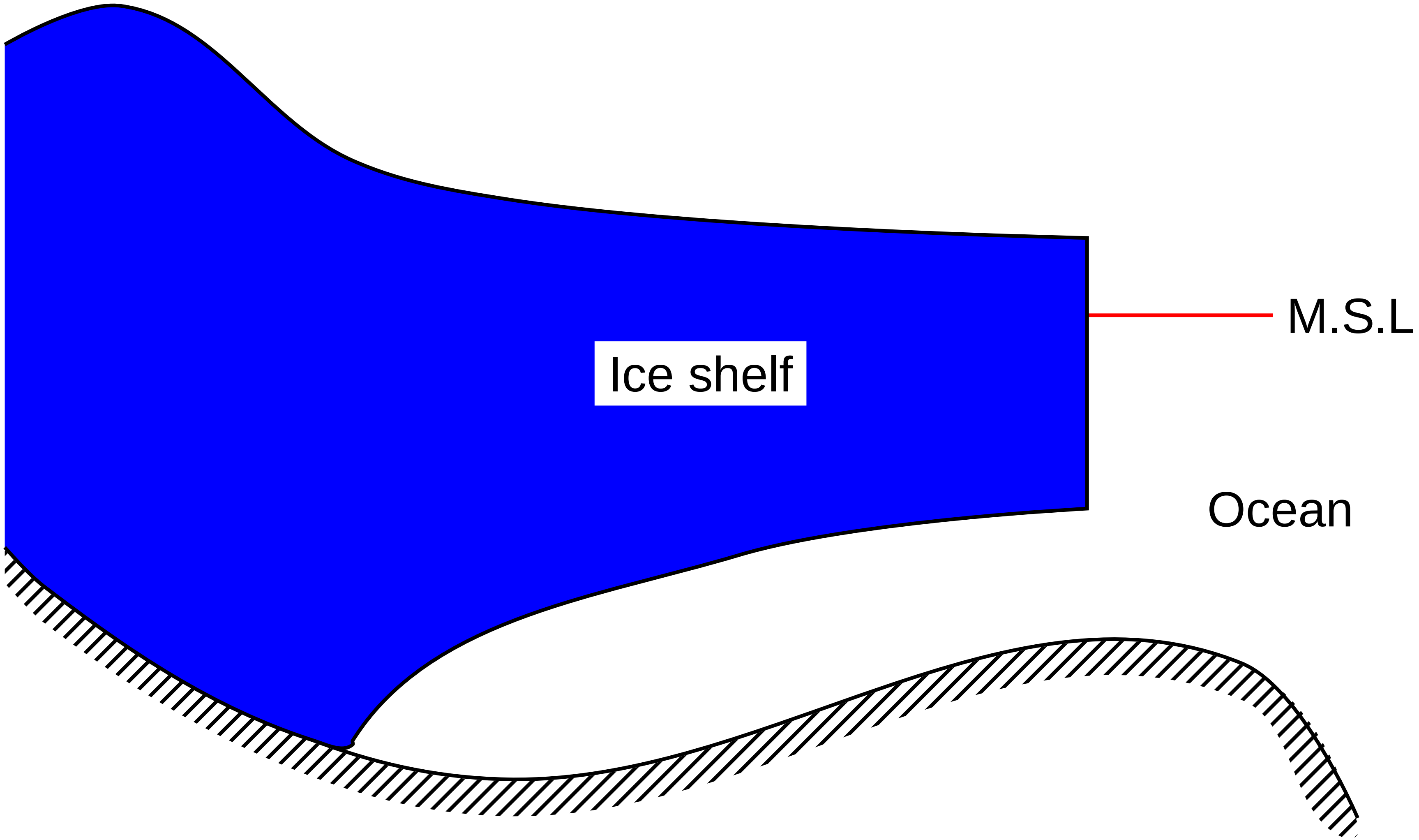
Motivation

- “The corresponding increased ice sheet mass loss has often followed thinning, reduction or loss of ice shelves ...” p 7.

- “Dynamical processes... ...could increase the vulnerability of the ice sheets to warming, increasing future sea level rise. Understanding of these processes is limited and there is no consensus on their magnitude.” p 17.

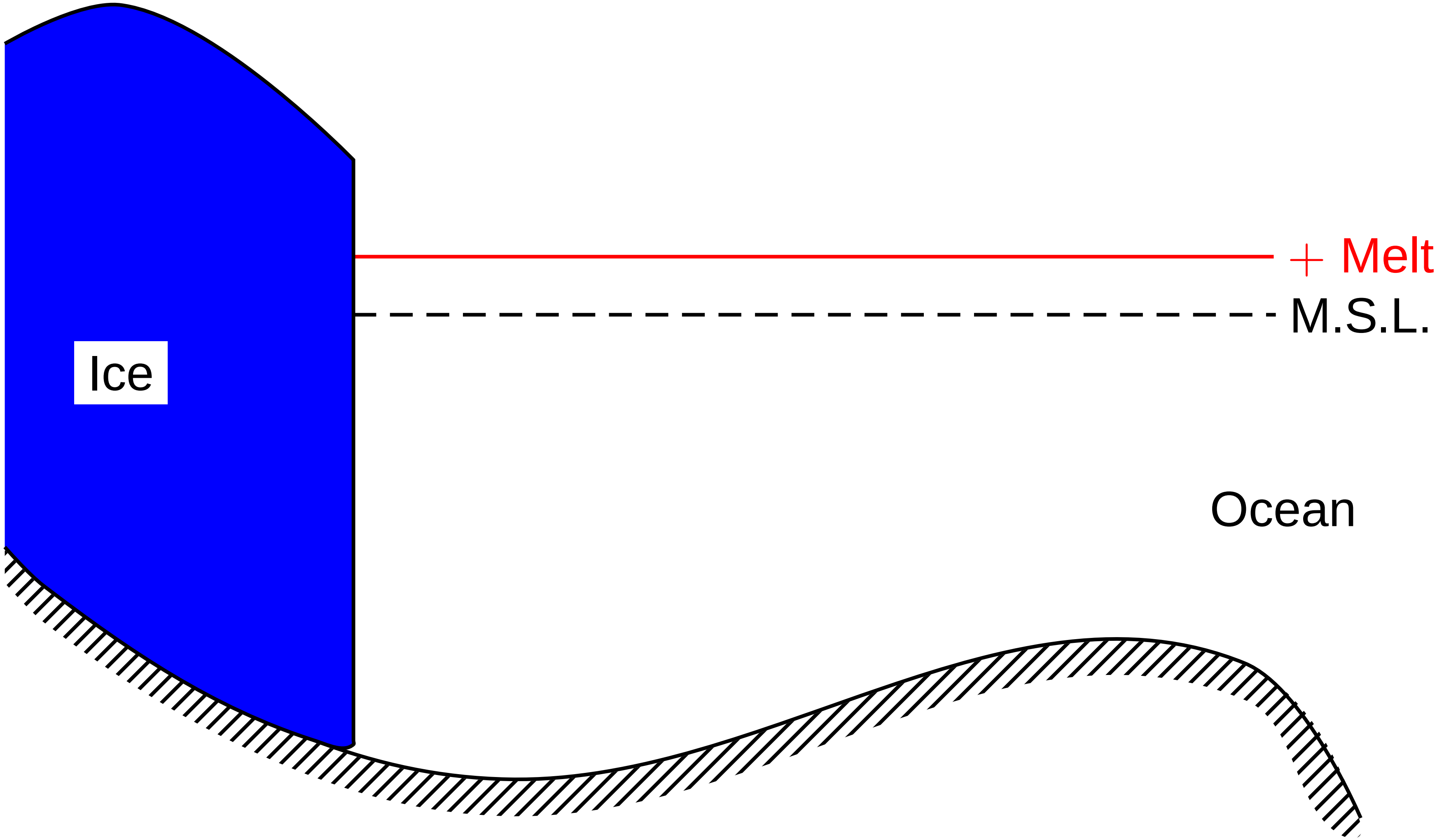
IPCC, 2007: Summary for Policy Makers

Sea level rise



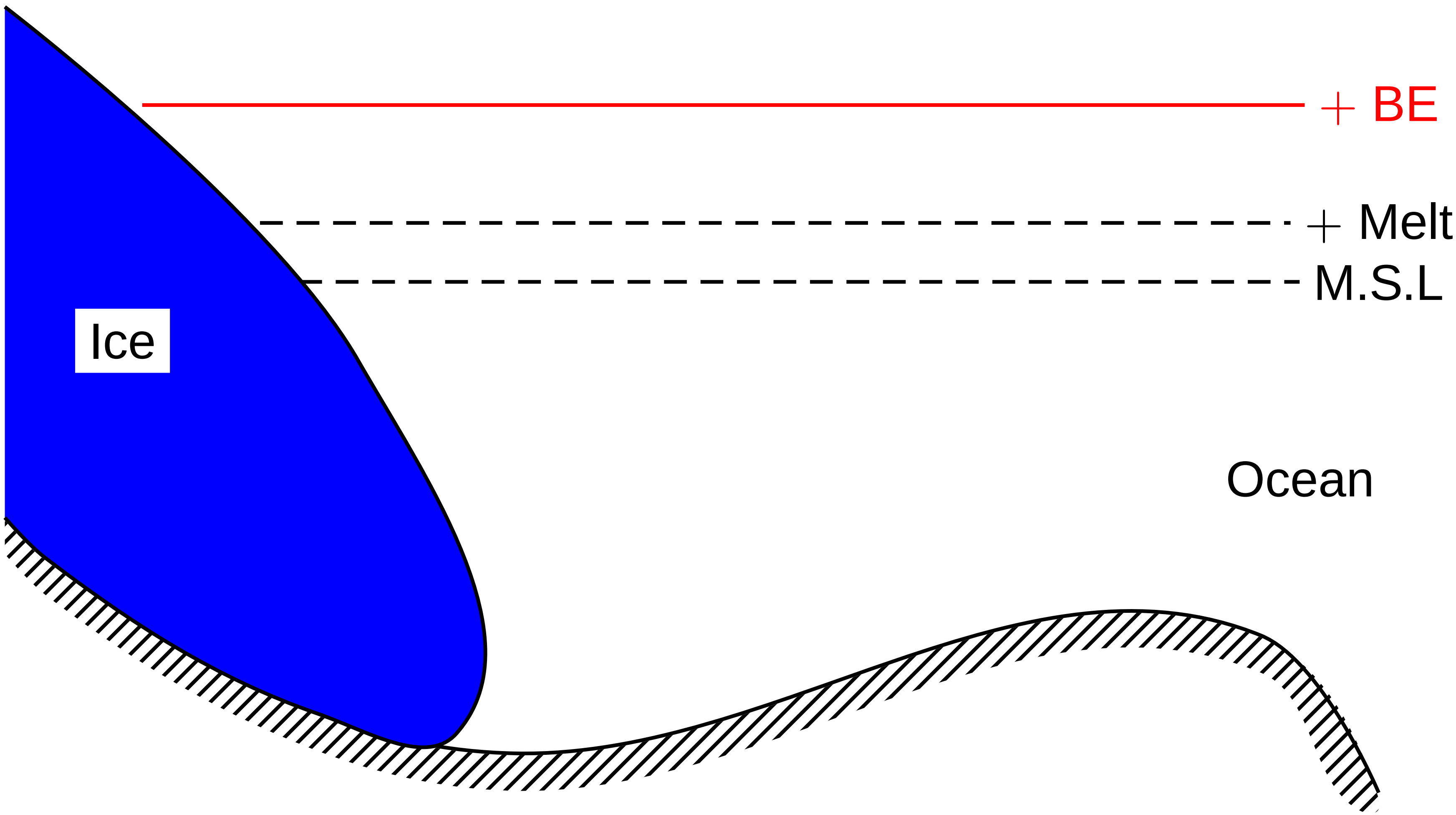
- The collapse of ice shelves can cause sea levels to rise through 2 main effects:

1. Directly: Ice shelf melt



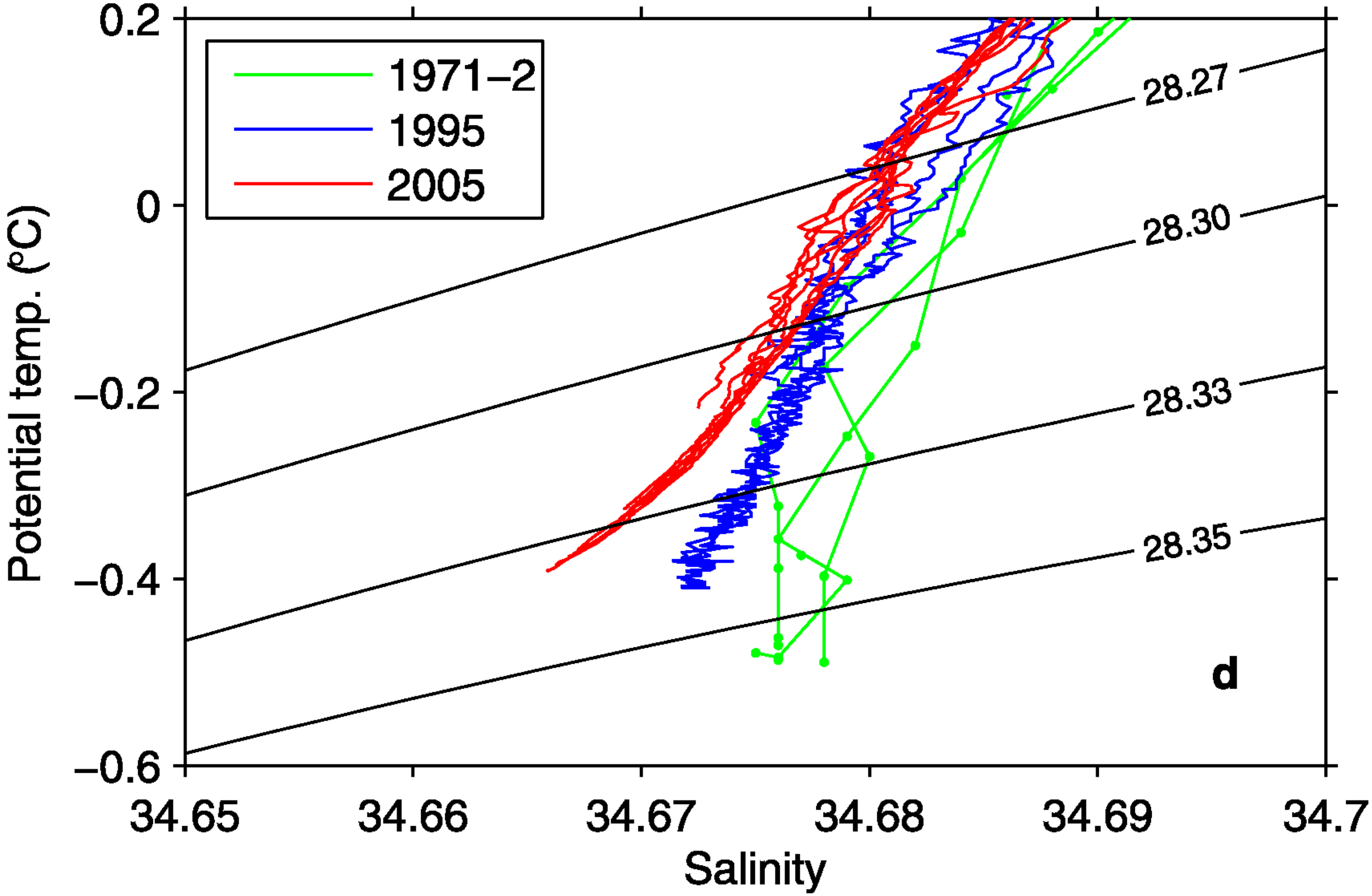
- Melt of all Antarctic ice shelves: 35–52 mm of sea level rise. A small effect. Unstable.

2. Indirectly: Buttressing effect



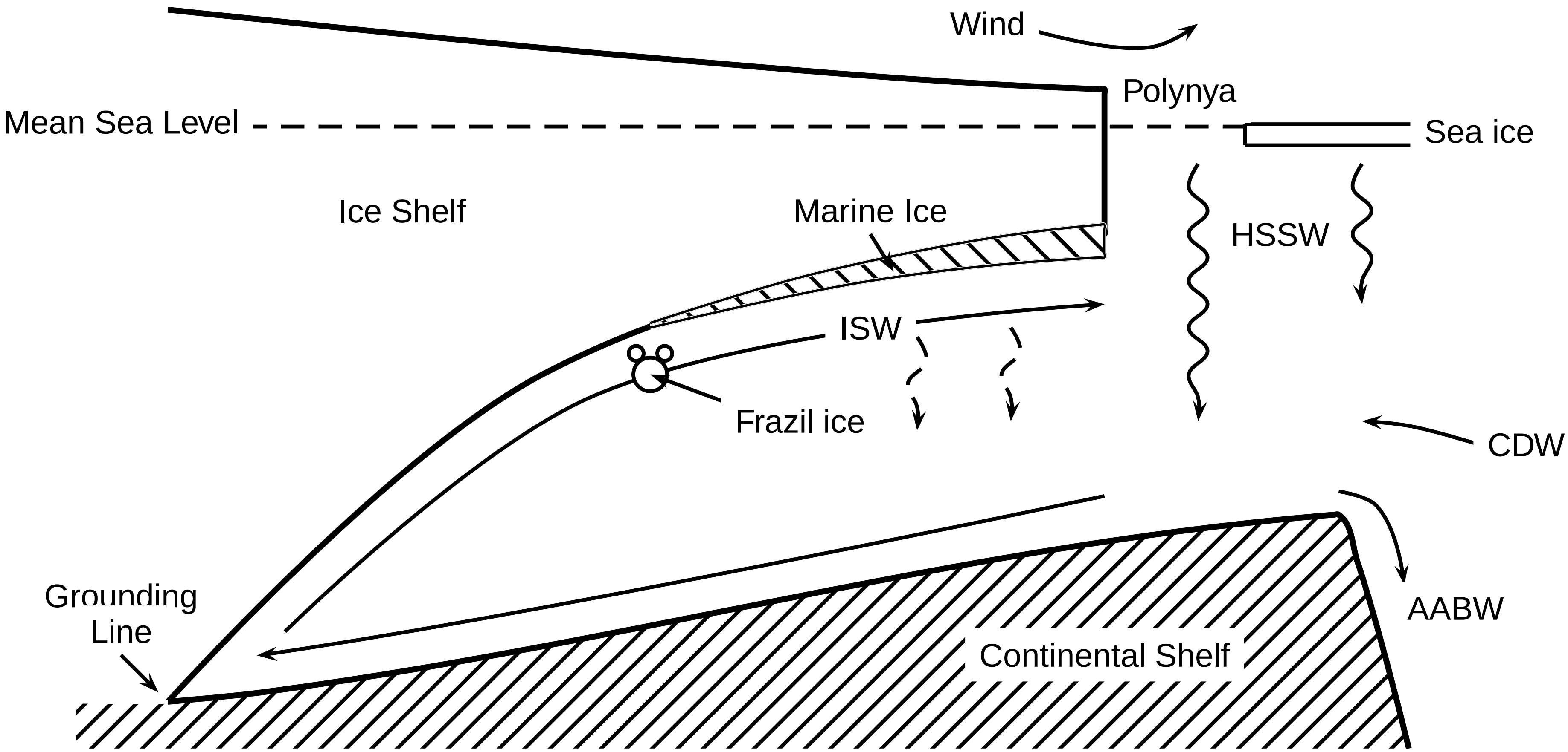
- The rate that the ice sheet drains into the ocean can increase which can also cause sea level to rise.

Freshening Antarctic Bottom Water

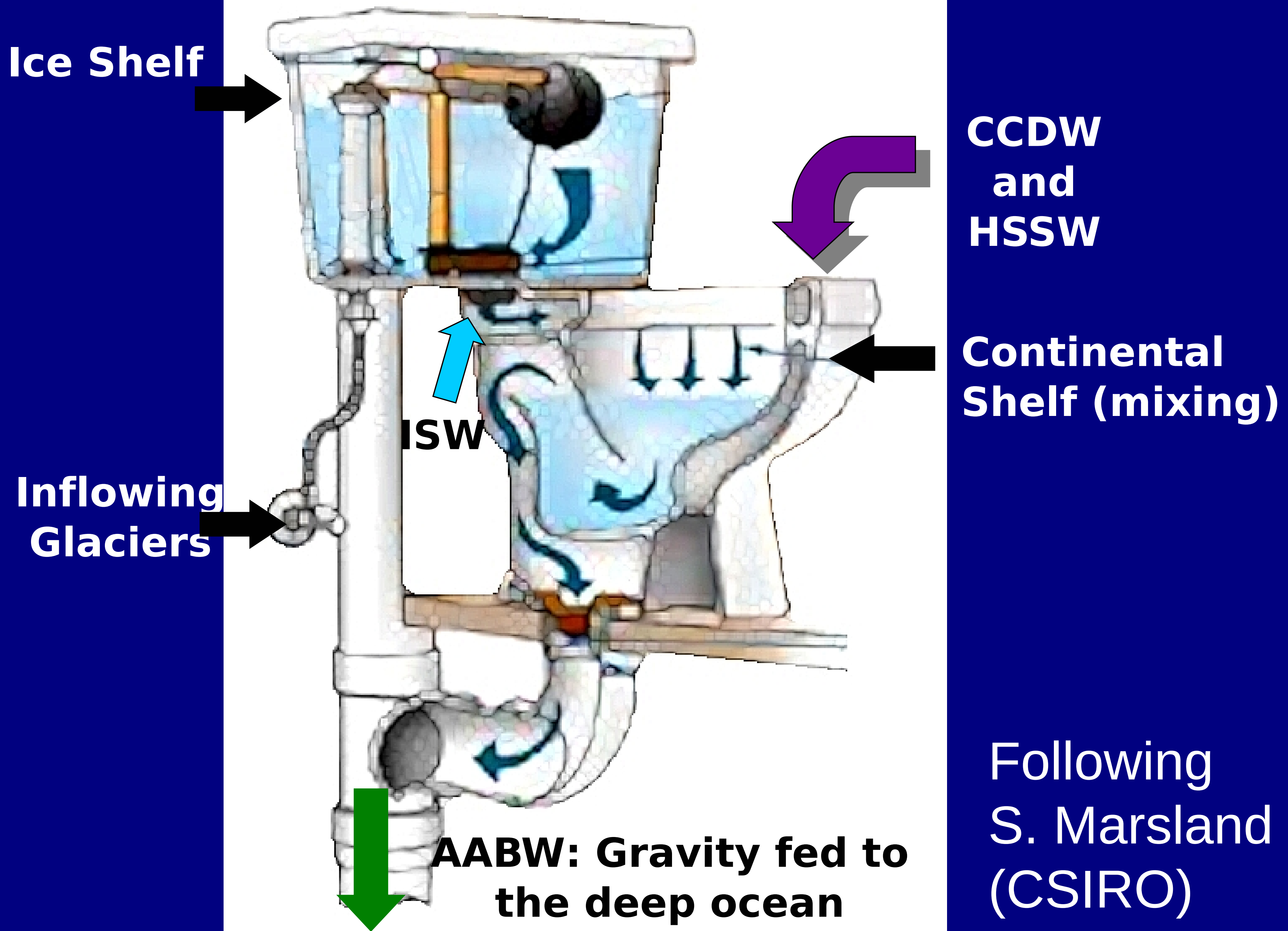


Rintoul (2007) GRL

The ice-shelf/ocean system



Marine ice is formed by seawater that freezes directly onto the base of the ice shelf and by the precipitation of frazil ice crystals.

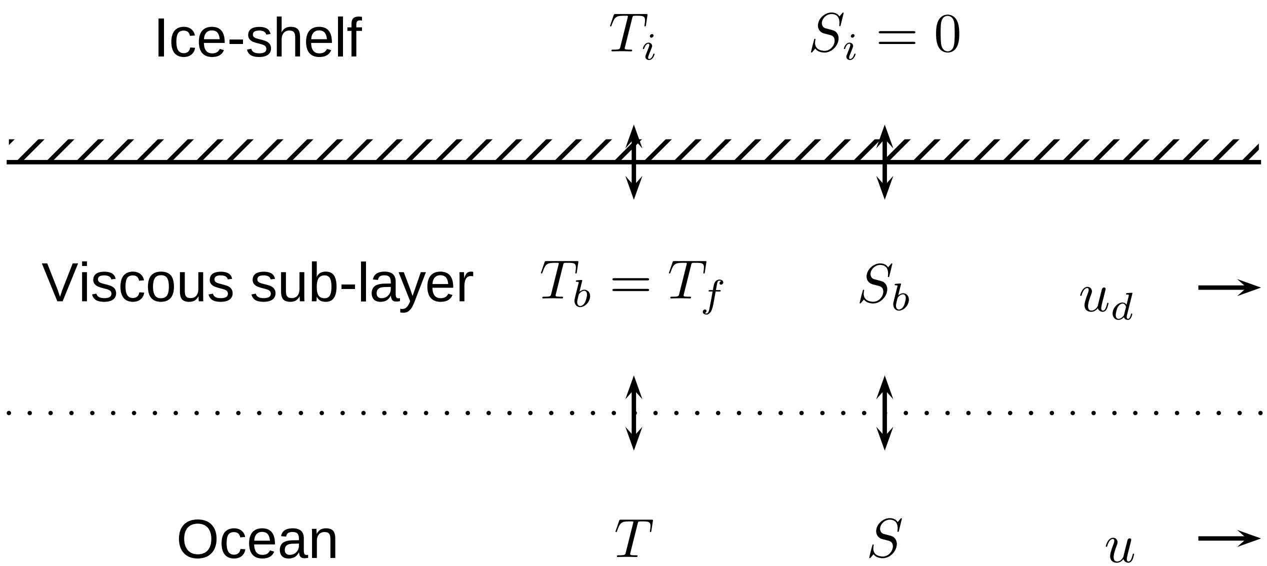


Following S. Marsland (CSIRO)

Jade icebergs

Developing an ice shelf-ocean model

- Mechanical modifications: Adjustment of the surface pressure to account for the floating ice shelf (Already part of ROMS). Depth ranges from 300-2500m below mean sea level
- Thermodynamic modifications:
  - Direct basal ice-ocean interaction
  - Frazil ice dynamics
- Modified equation of state for larger range of θ (Jackett and McDougall 2006)



$$\rho_i(L - c_i\Delta T)m = \rho c_w \gamma_T (T_b - T)$$

$$\rho_i S_b m = \rho \gamma_S (S_b - S)$$

$$T_f = -5.73 \times 10^{-2} S_b + 8.32 \times 10^{-2} + 7.61 \times 10^{-4} zice$$

Frazil ice modelling

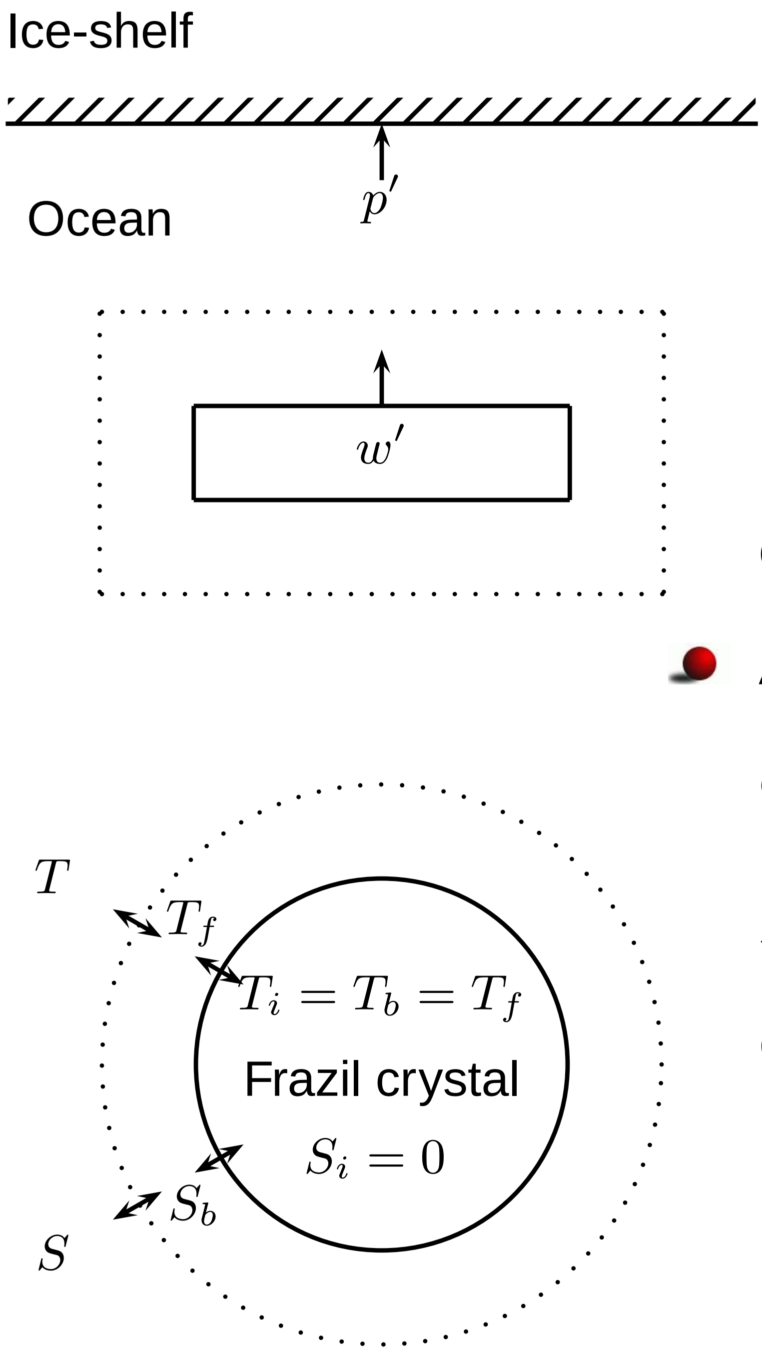
- Following implementation of sediment (Warner et al. 2005) solving advection-diffusion equation:

$$\underbrace{\frac{\partial \mathcal{C}}{\partial t}}_{\text{Transient}} + \underbrace{\nabla \cdot (\mathcal{C}\mathbf{v})}_{\text{Advection}} + \underbrace{\mathbf{w}'\frac{\partial \mathcal{C}}{\partial \mathbf{z}}}_{\text{Buoyant rising}} = \underbrace{\nabla \cdot (K \nabla \mathcal{C})}_{\text{Mixing}} + \underbrace{\mathcal{S}}_{\text{Source/Sink}}$$

Frazil tracers are included in ROMS using hijacked sediment code. Modifications:

- Buoyant rising (Morse and Richards (2008)
- S = Primary and Secondary Nucleation, Precipitation, Melting/Freezing
- Modified equation of state to consider ice density

Frazil ice modelling



Following plume models of Holland and others (2007)

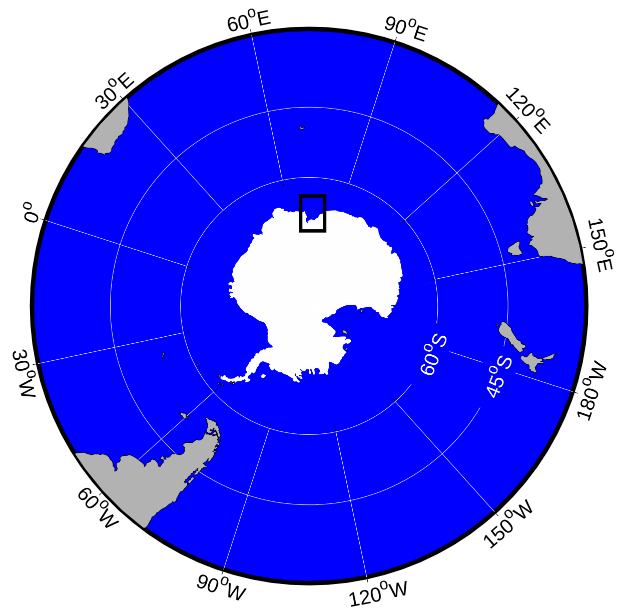
- Assume $S_b = S$

$$G_n = \frac{c_p N u_i K_t}{L\Theta_i}(T_f - T)\frac{2}{r_i^2}C_i$$

$$M_n = \frac{c_p N u_i K_t}{L\Theta_i}(T_f - T)\frac{2}{r_i}\left(\frac{1}{r_i} + \frac{1}{2a_r r_i}\right)C_i$$

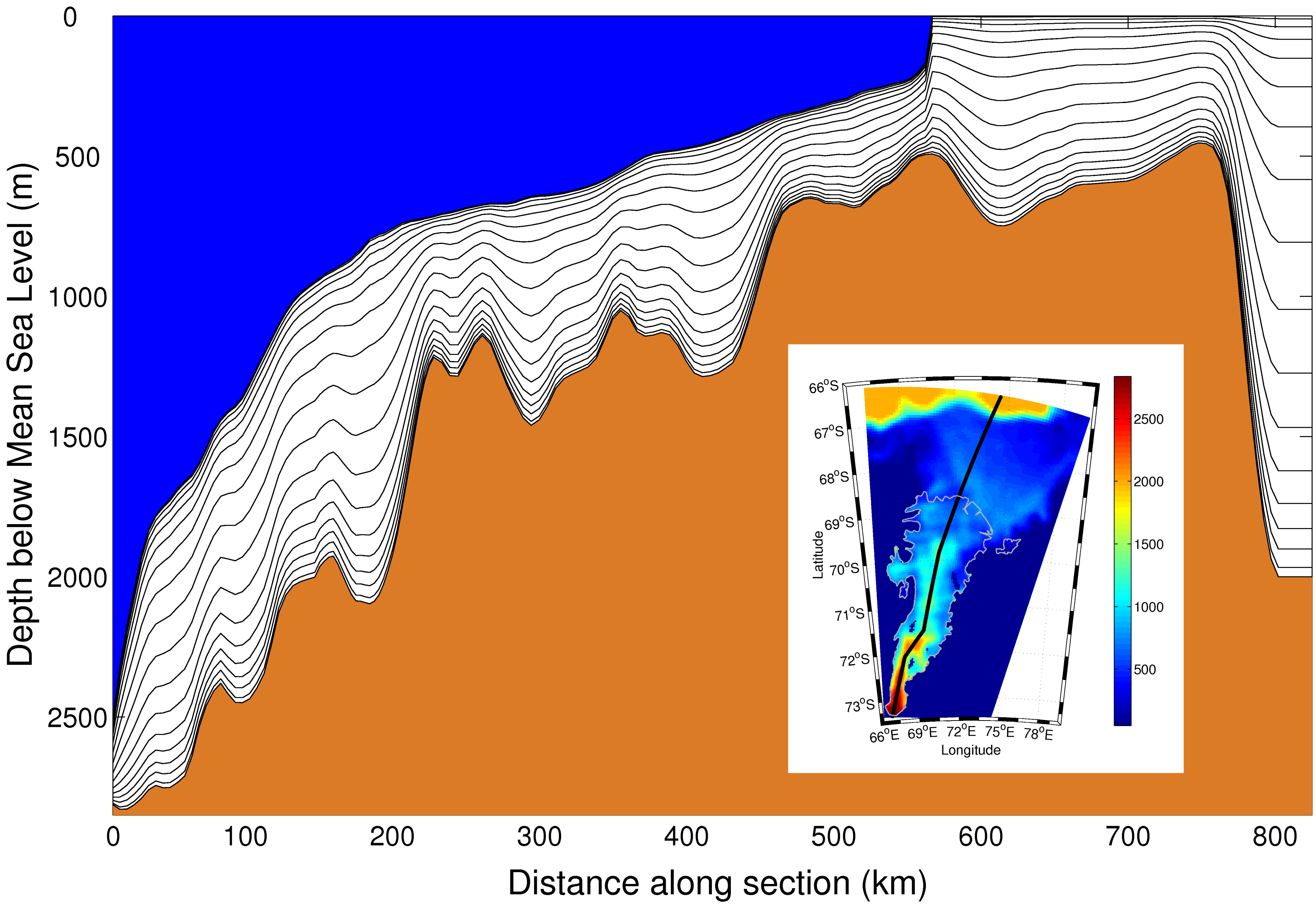
Calculate heat and freshwater (salt) fluxes into the ocean due to melt/freeze.

Amery Ice Shelf Ocean Model



- Time stepping: 600 seconds on baroclinic and 20 seconds on barotropic
- Run time 1 week on 16 cpus (Computationally intensive)
- 60 % longer using 5 frazil size classes
- Geometry: Galton-Fenzi and others (2008)

Grid



- 171x83 Horizontal grid cells. 16 Vertical layers. Polar grid ∼ 2 to 5 km

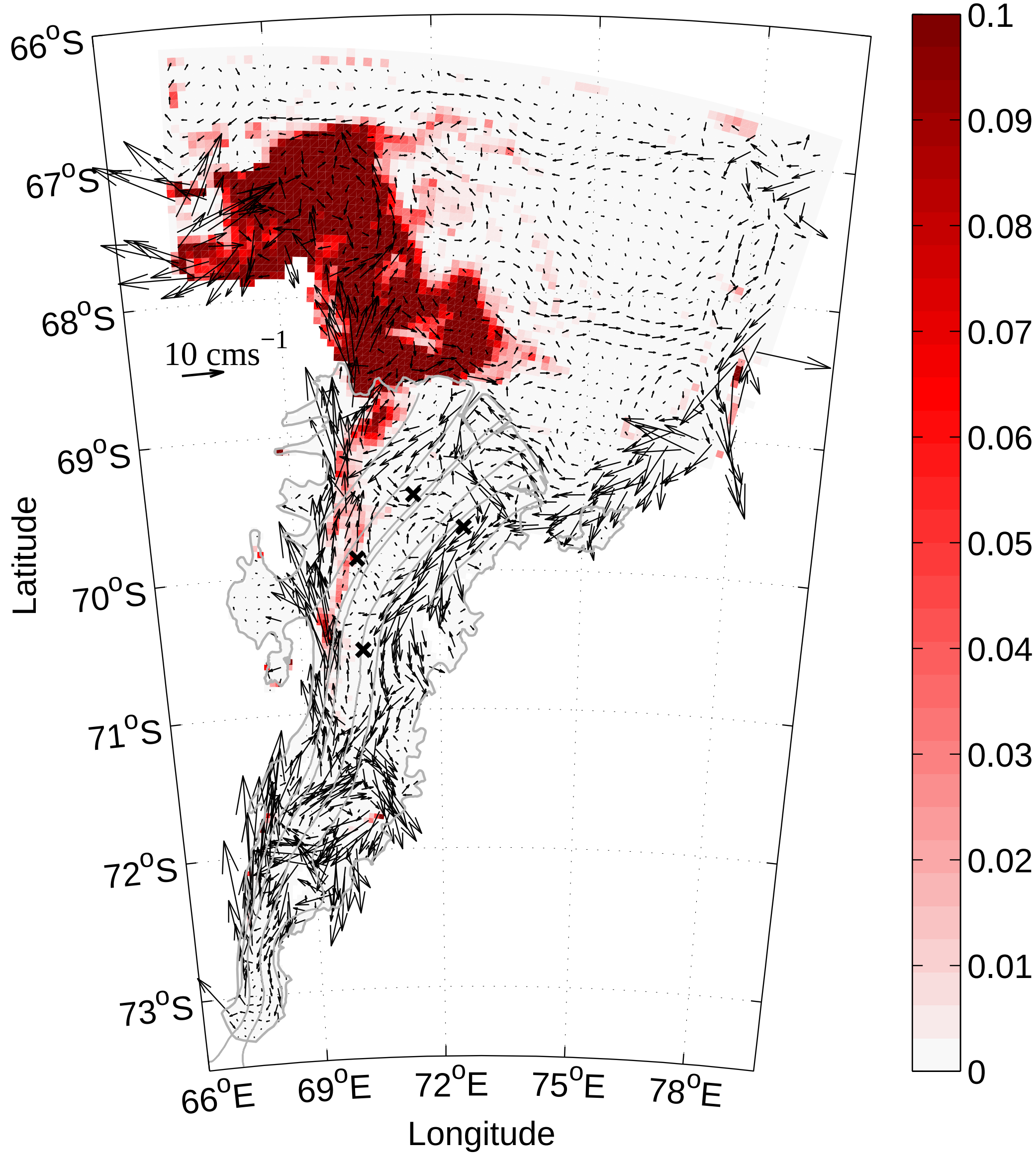
Forcing

- Following Dinniman and others (2007) JGR:
  - Imposed sea ice from Tamura (2007). Heat and salt fluxes computed from thermodynamic calculation of ice freezing or melting, but ice is not accumulated or transported
  - Daily wind stress and wind speed from NCEP2 reanalysis, which compares well with available AWS observations
- Tidal forcing – TPXO6.2
- Lateral boundaries forcing with climatology from ECCO2 global model.
- Compare model with and without frazil ice dynamics

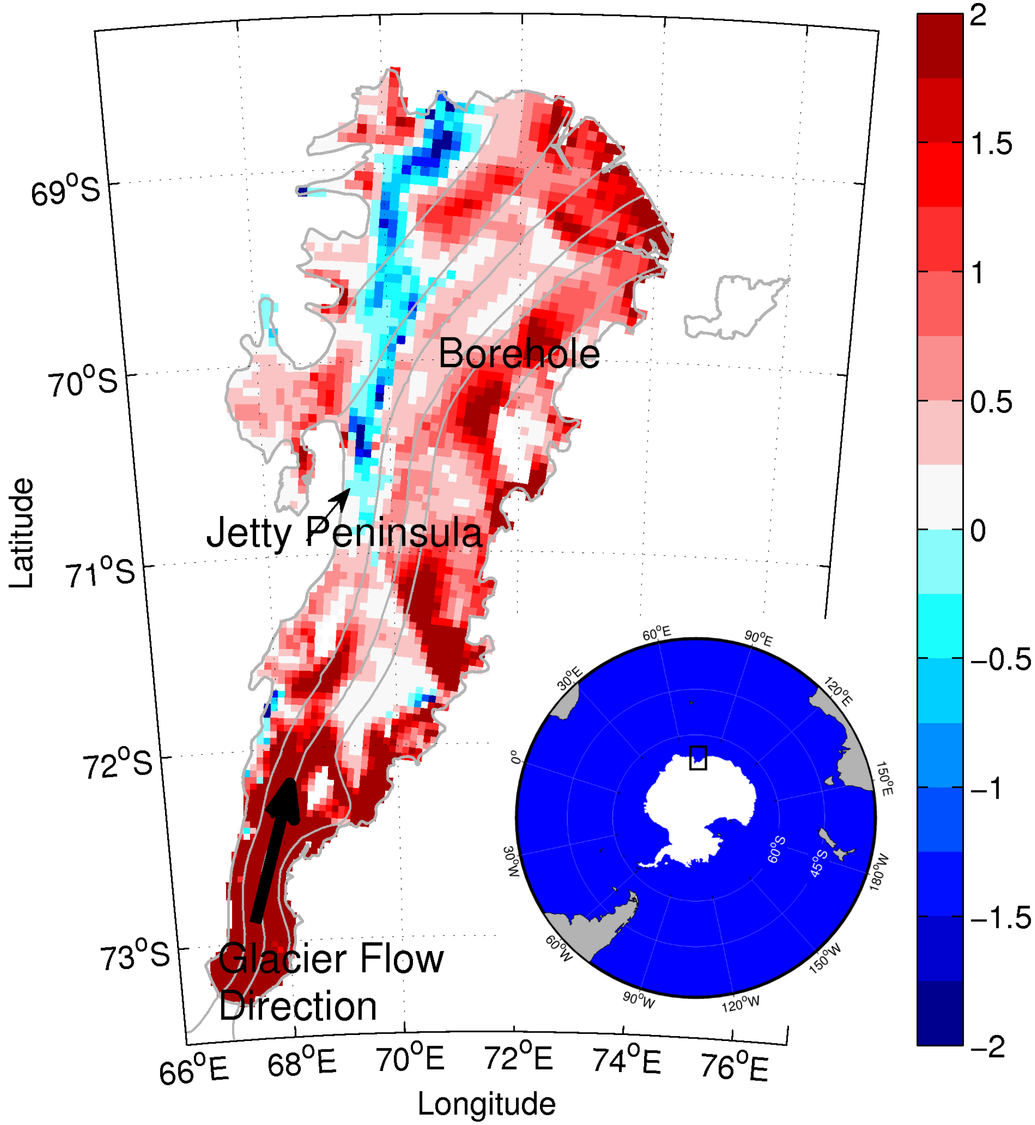
Glaciological Mass Balance Estimates

Component	Gt ice year^{-1}	Study
Glacier Inflow rate, $\mathcal{G}$	88.9 ± 8.9	Wen and others (2008)
Net Accumulation, $\mathcal{A}$	11.3 ± 0.7	Arthern (2006)
	11.7 ± 1.0	Vaughan (2001)
Calving rate, $\mathcal{C}$	41.5 ± 5.2	from Fricker and others (2002)
	44.6 ± 9.3	from Young and Hyland (2002)
Net melt rate, $\mathcal{G} + \mathcal{A} - \mathcal{C}$	**57.4** $\pm$ **14.1**	
Modelling Net Melt rate	**72.8 (0.9 + 5.8)**	**With Frazil**
	79.2 (1.7)	**Without Frazil**
	14.2	Williams et al (2002)
	17.65	Hellmur (2004)
	7.5	POM, Hunter et al (2004)

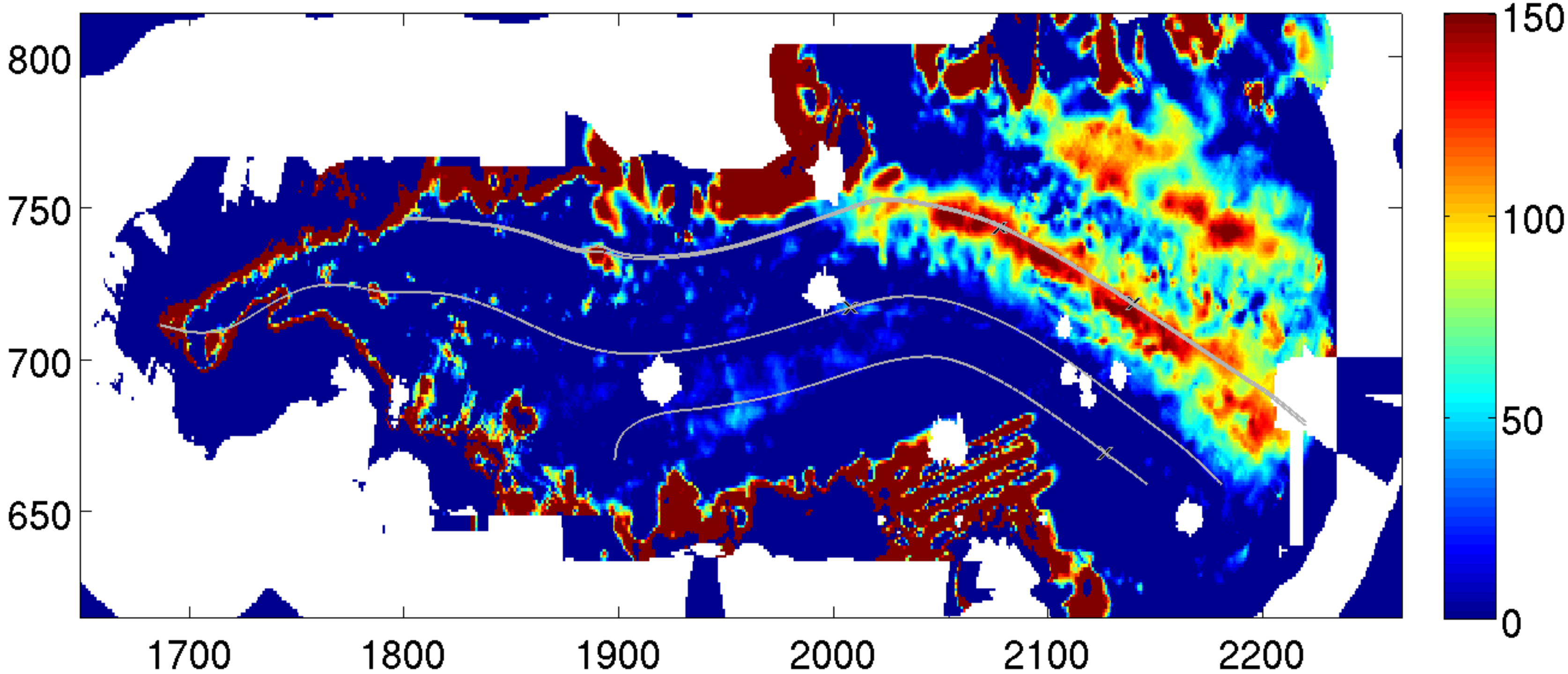
Total column frazil concentration (g/L)



Model Melt/Freeze (m/year)

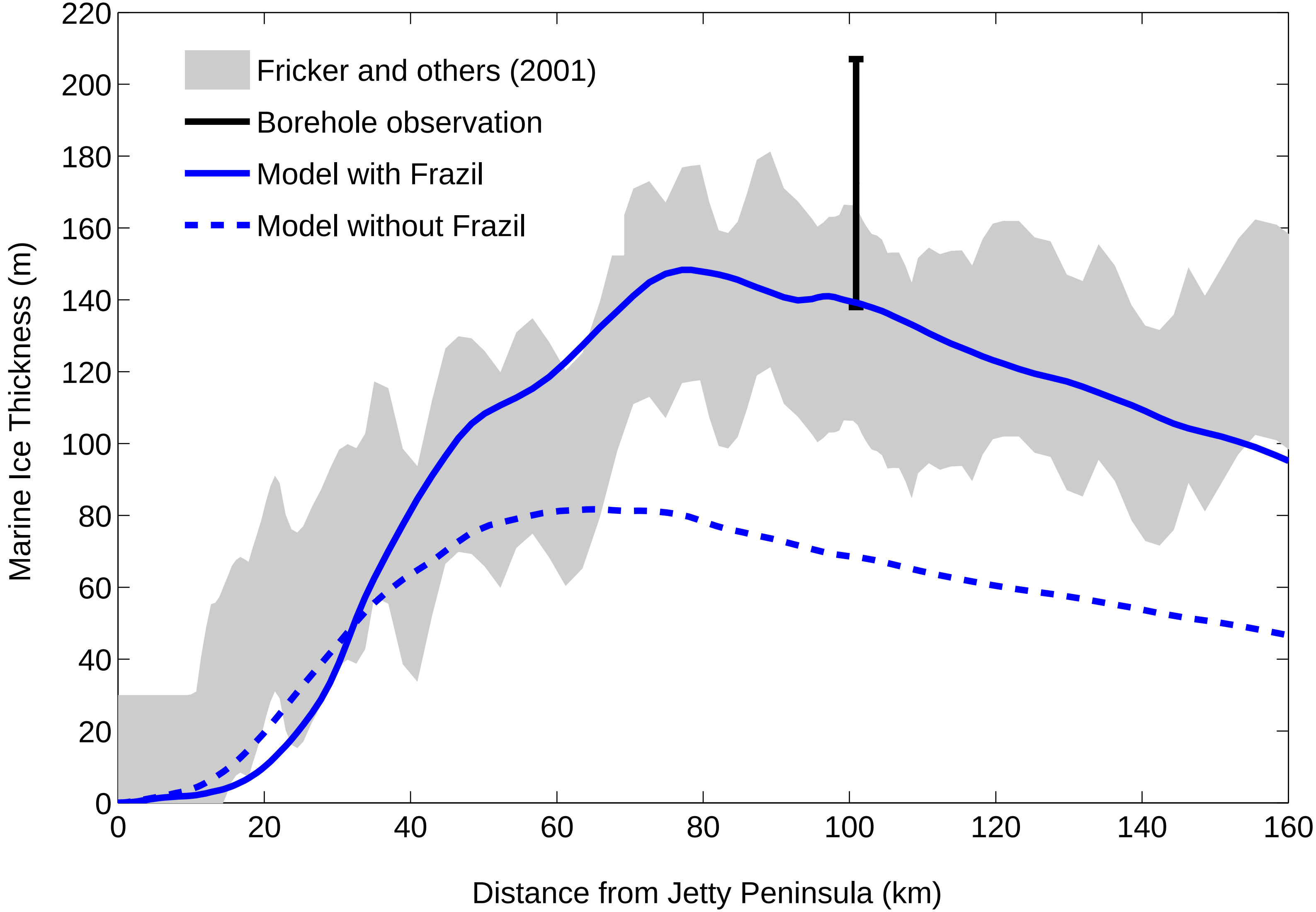


Marine Ice Thickness Map



- Produced from difference between hydrostatic estimate of ice thickness from elevation and ice radar.
- Fricker et al (2001)

Marine Ice Thickness



Conclusions

- Frazil ice forms in a supercooled water layer adjacent to the ice shelf base
- The supercooled water is formed when buoyant water that is created by basal melting begins to rise
- Frazil ice processes improves the simulated pattern of marine ice accretion
- Net mass budgets show improvement over previous modelling studies
- Simulations with Frazil show a range of total mass loss of $\sim$73 Gt year^{-1} which are on the same order as observations.

Future work

- Evolving ice shelf base (*zice*)
- Wetting/drying
- Coupled to:
  - Dynamic sea-ice model (e.g. Paul Budgel/Kate Hedstrom)
  - Ice sheet model (e.g. Las Alamos Ice Sheet Model).
  - Coupled climate model (e.g. ACCESS: CAWCR, CSIRO)
- As part of Community Ice-Shelf Ocean Model effort

Comunity Ice-Shelf Ocean Model

Goal: Develop a fully coupled ice-sheet/ocean model to investigate links between climate change, ice-shelf melting and bottom-water formation and sea level rise.

Some potential collaborators:

- Ben Galton-Fenzi, John Hunter, Nathan Bindoff, Frank Colberg, Roland Warner (UTas, ACE CRC, Tasmania)
- Mike Dinniman and John Klinck (ODU, Virginia)
- Simon Marsland, Siobhan O'Farrell (CSIRO, Australia)
- Rachael Mueller, Laurie Padman, Susan Howard (ESR, U.S.A)
- Robin Robertson (ADFA, Australia)
- Andrea Bergamasco, Ariana Trevisiol, Sandro Carniel (OGS, Italy)
- Mike Williams, Natalie Robinson (NIWA, New Zealand)
- Lars Smedsrud (Bjerknes Centre for Climate Research, Norway)
- Daniel Feltham (CPOM, U.K.)
- Dave Holland (New York Uni., U.S.A)

Community Ice Shelf Ocean Model

- Already dedicated support from:
  - Australian Research Collaboration Service provides support and maintenance http://www.arcs.org.au.
  - Both National and Tasmanian Partnership for Advanced Computing
  - Old Dominion University, Norfolk, US
  - Earth and Space Research, Seattle, US
  - Southern Ocean Physical Oceanography and Cryosphere Linkages (SOPHOCLES)
- What about sea-ice? A much bigger list of users!