The influence of tides on the sub-Amery Ice Shelf thermohaline circulation: An application of the Princeton Ocean Model to an ice shelf cavity

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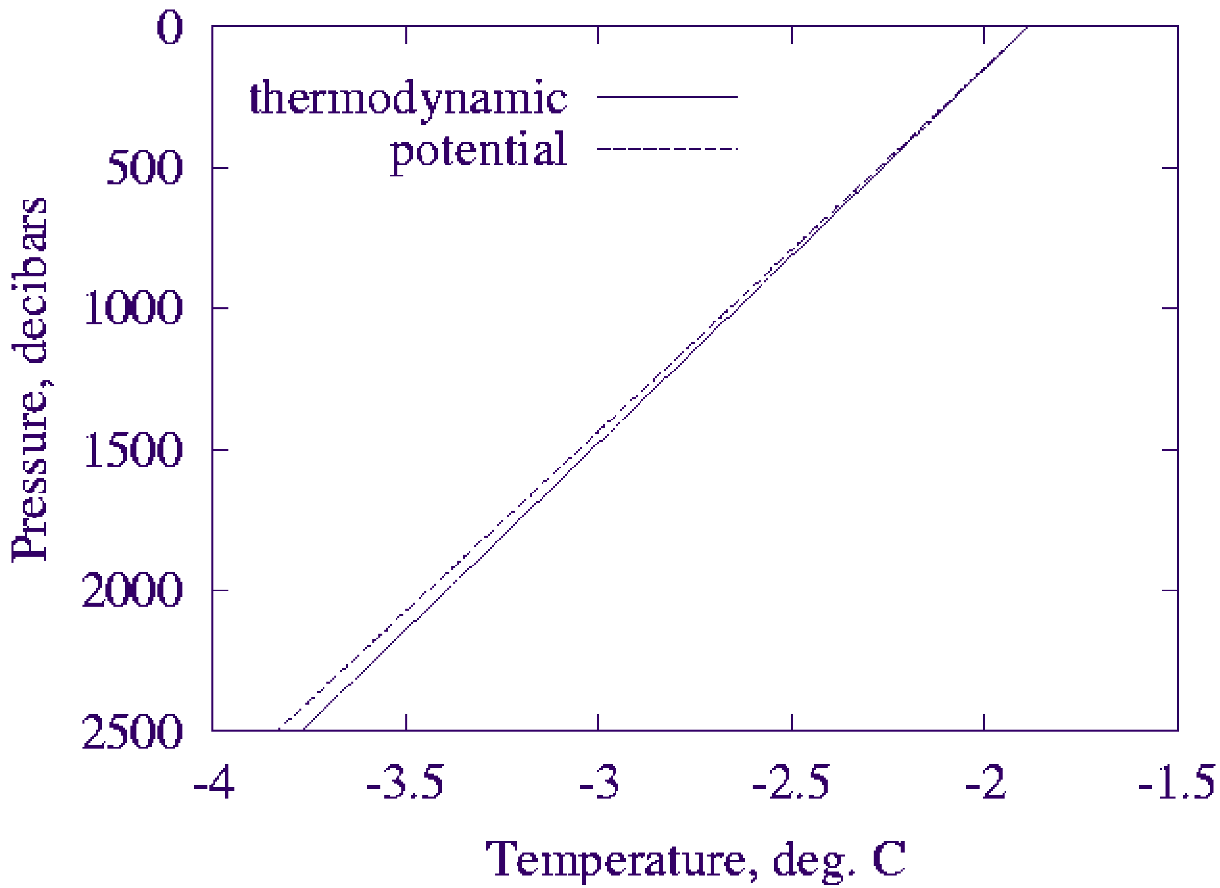
Antarctica

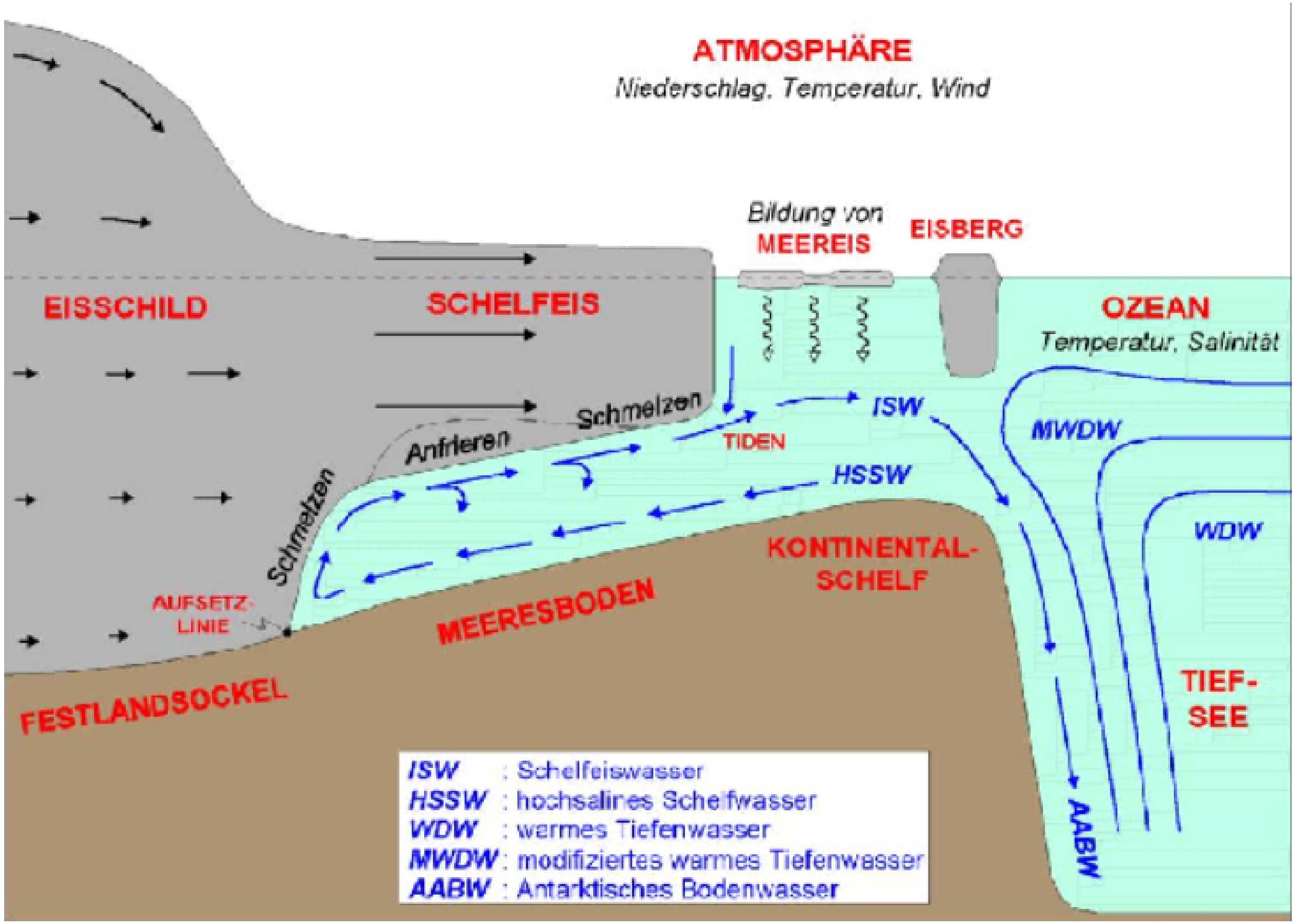
South Atlantic Ocean
Indian Ocean
South Orkney Islands
Weddell Sea
Queen Maud Land
Graham Land
ice shelf
Amery Ice Shelf
South Pole
Marie Byrd Land
Amundsen Sea
ice shelf
Wilkes Land
South Pacific Ocean
Ross Sea
Victoria Land
0 400 800 km
0 400 800 mi
Indian Ocean

The Amery Ice Shelf front

Freezing point at Salinity of 34.4



The ice-pump mechanism



A Jade Iceberg

Jade iceberg - Australian Antarctic Division photo by K.Sheridan

Why are we interested in the Cavity beneath the Amery Ice Shelf?

- The circulation controls the rates of melting and freezing underneath the ice shelf.

- The circulation affects water mass formation in Prydz Bay and beyond

- Melting is an important way in which Antarctic glaciers lose mass (the other is by calving at the ice front).

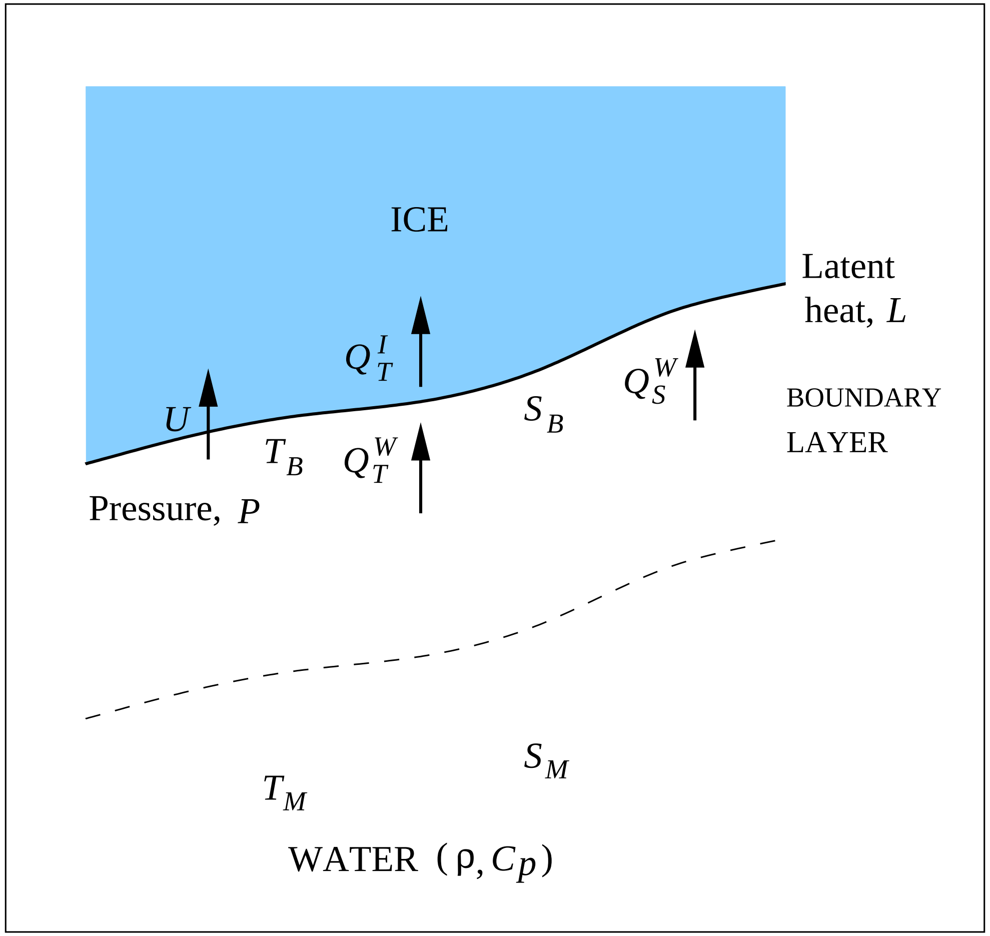
- Removal of an ice shelf by melting and/or calving may affect the rates at which Antarctic glaciers flow, and hence affect the mass balance of ice over the continent.

- How are the above affected by global warming, both in the past, and in the future?

Models

- Determann/Gerdes (AWI), 1994: Idealised cavities
- Grosfeld/Gerdes (AWI/Bremen), 1997: Idealised cavities and Filchner-Ronne
- Gerdes/Determann/Grosfeld (AWI), 1999: Filchner-Ronne
- Grosfeld/Sandhager/Lange (Bremen/AWI/Munster), 2001:
  Idealised cavity ($\rightarrow$ Larsen + Flichner-Ronne) coupled with ice model
- Beckmann/Hellmer (AWI): Whole Southern Ocean (BRIOS2.2)
- Holland/Jenkins (New York/BAS):
  Filchner-Ronne and Ross based on MICOM model.
- Williams/Warner/Budd (Antarctic CRC), 1998-2002:
  Amery (Gerdes/Determann/Grosfeld model) - without tides.
- Hunter/Hemer (Antarctic CRC):
  Amery (based on POM) - with and without tides.

The Ice-Water Interface



3-Equation Method:

(∼Holland and Jenkins, 1999)

Freezing point:

$$T_B = T_B(S_B, P)$$

Heat:

$$Q_T^W = (E_T(T_M - T_B) + UT_B)\rho C_p$$

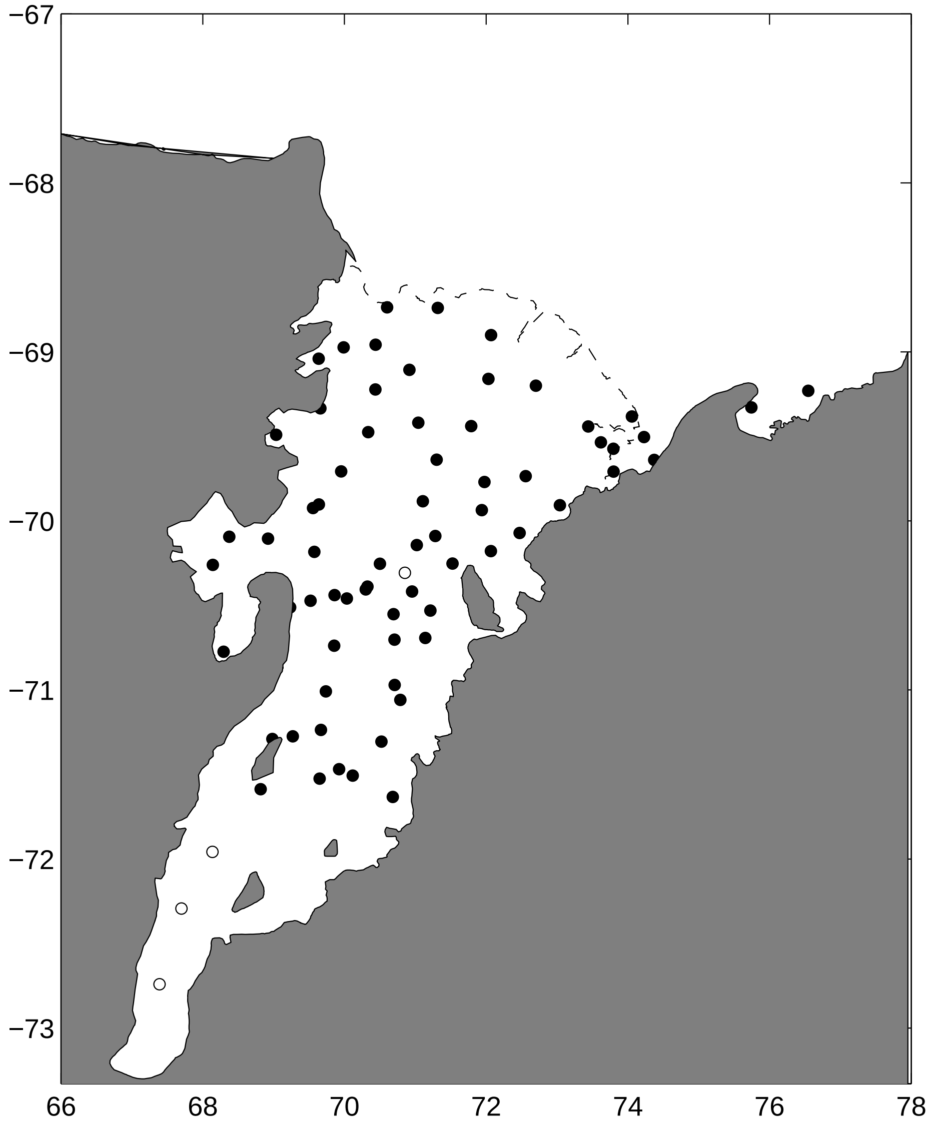
$$= Q_T^I - U\rho L$$

Salt:

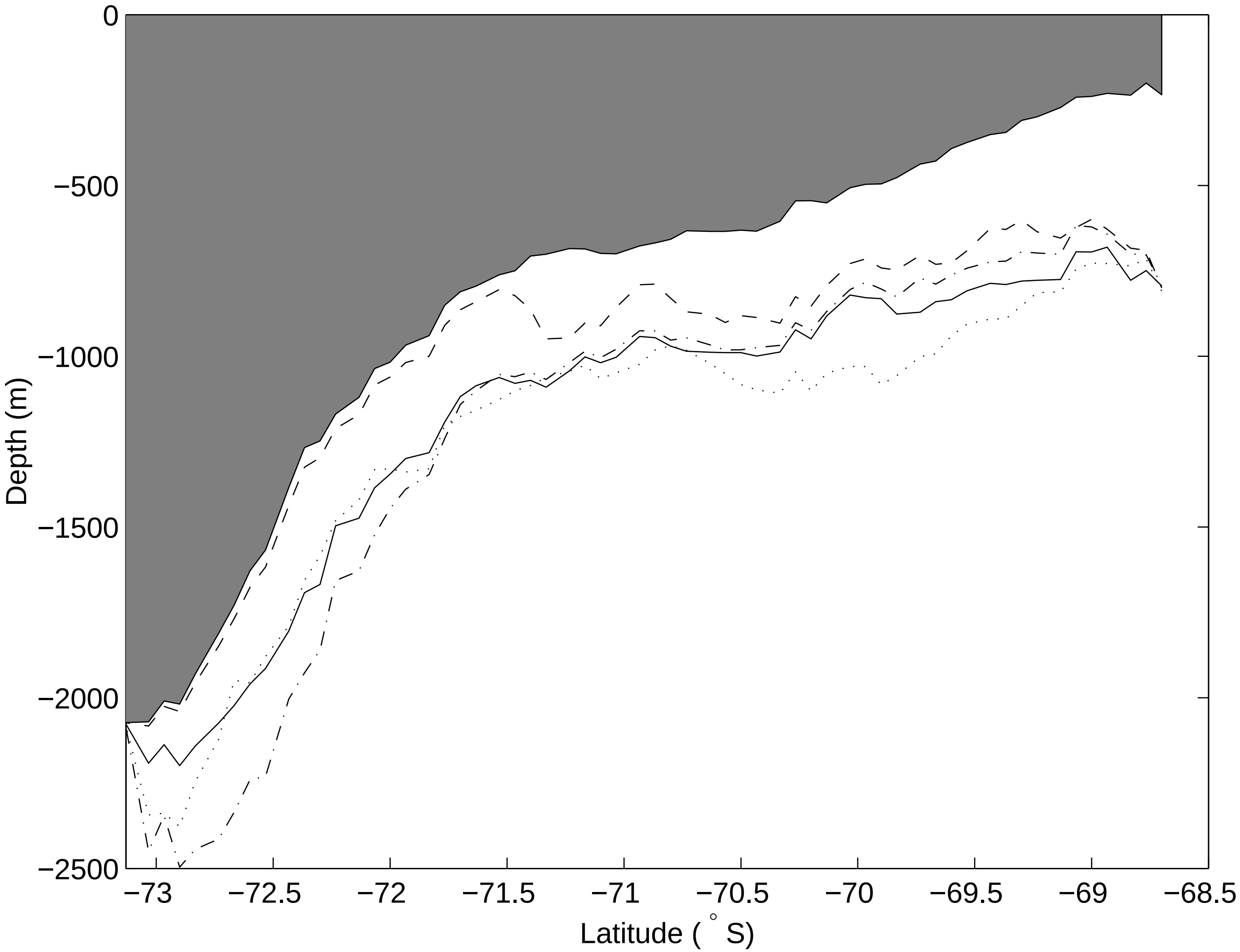
$$Q_S^W = (E_S(S_M - S_B) + US_B)\rho$$

$$= 0$$

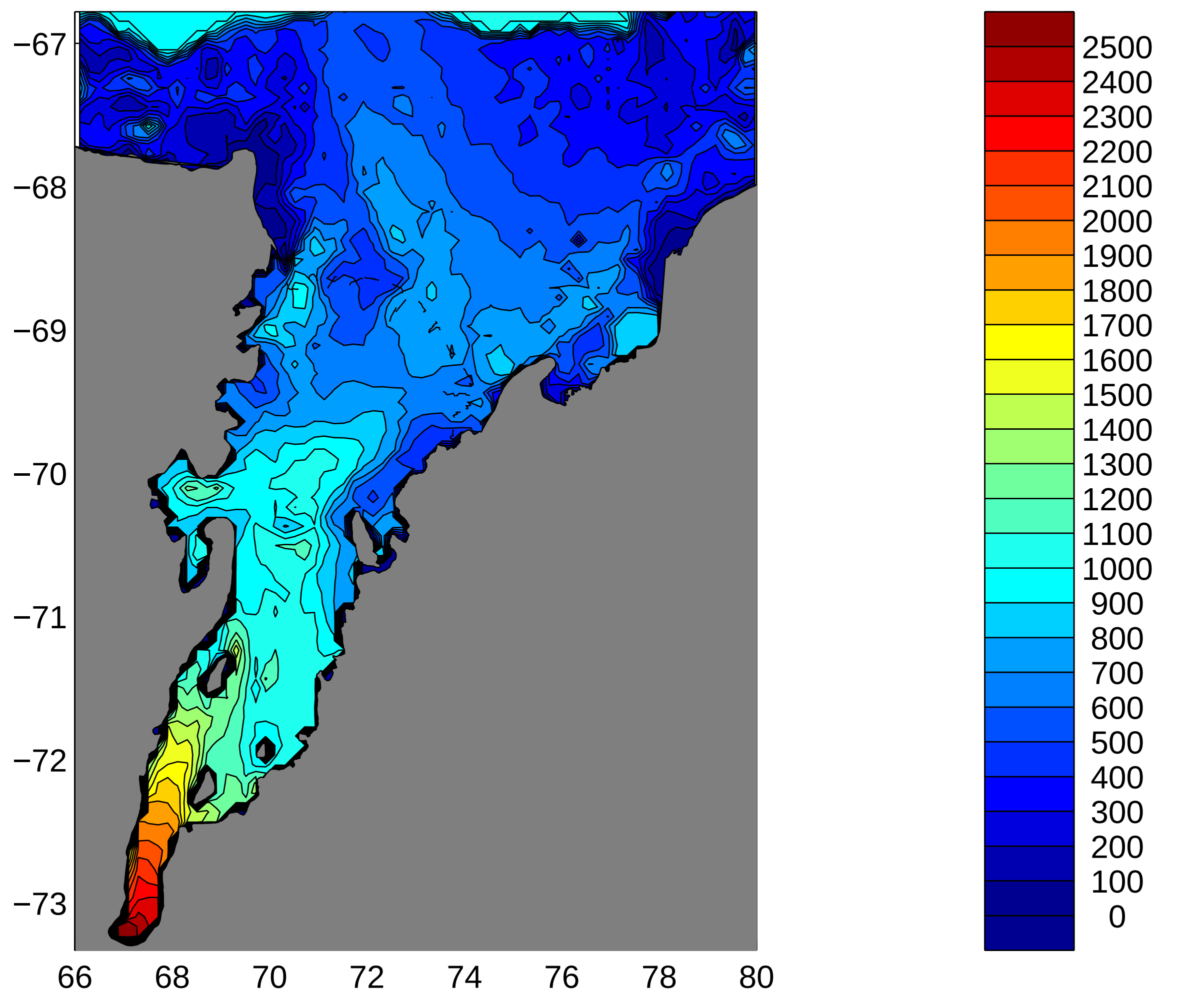
Bed elevation (•) and Ice Draft (all) measurement locations.



Zonal Mean Bed Elevation and Ice Draft of Amery Ice Shelf Cavity. (Dashed - A; Solid - B; Dash-Dot - C; Dotted - CADA)

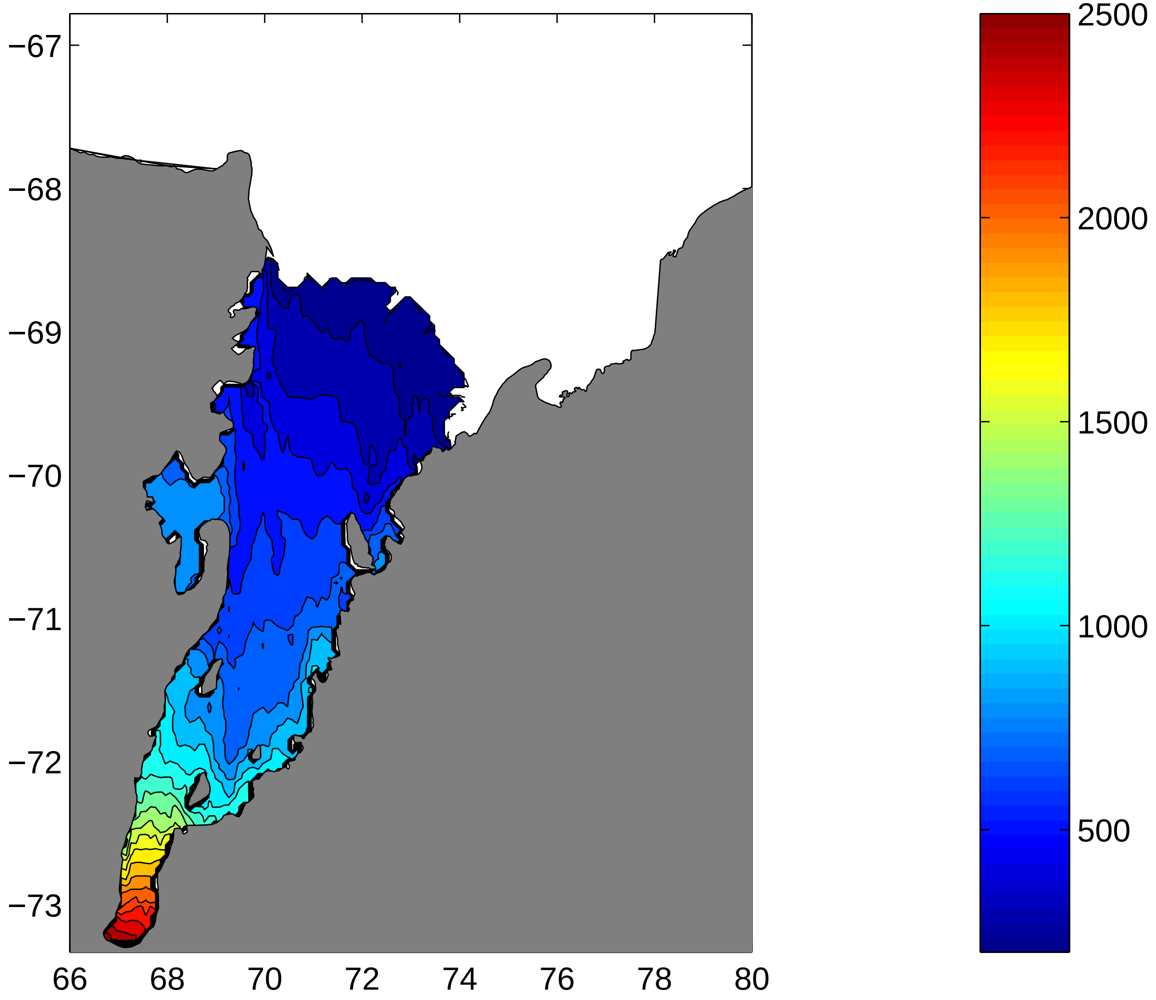


Bathymetry



−67
−68
−69
−70
−71
−72
−73
66
68
70
72
74
76
78
80
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0

Ice Shelf Draft



Modifications to POM for the Ice Shelf application:

- Define additional horizontal U, V and E masks for ice shelf
- Apply surface pressure to depress ocean surface by D (i.e. apply adjustment D to all heights that are multiplied by g, except in baroclinic pressure and buoyancy gradients).
- Dynamics at ice/ocean interface: invert bottom friction code (yields u*).
- Thermodynamics at ice/ocean interface: (2-equation formulation of Holland and Jenkins, 1999 - removes third (salt) equation: $S_M = S_B$)
  - Interface assumed to be at local freezing temperature (T_f) (converted to potential temperature).
  - Heat flux (wtsurf) assumed $\propto u^*(T_{ocean} - T_f)$.
  - Heat flux yields melting or freezing rate. $vflux \propto wtsurf$
  - Melting (freezing) leads to addition (removal) of freshwater at in-situ freezing temperature (i.e. Additional heat and salt flux term).
  - Add source/sink of water to volume conservation equation in external mode.
  - Set $w(i, j, kb) = 0$, reverse order of vertical integration of w and stop at $k = 2$ (puts source/sink of water into top cell).

Initial and Open BC's

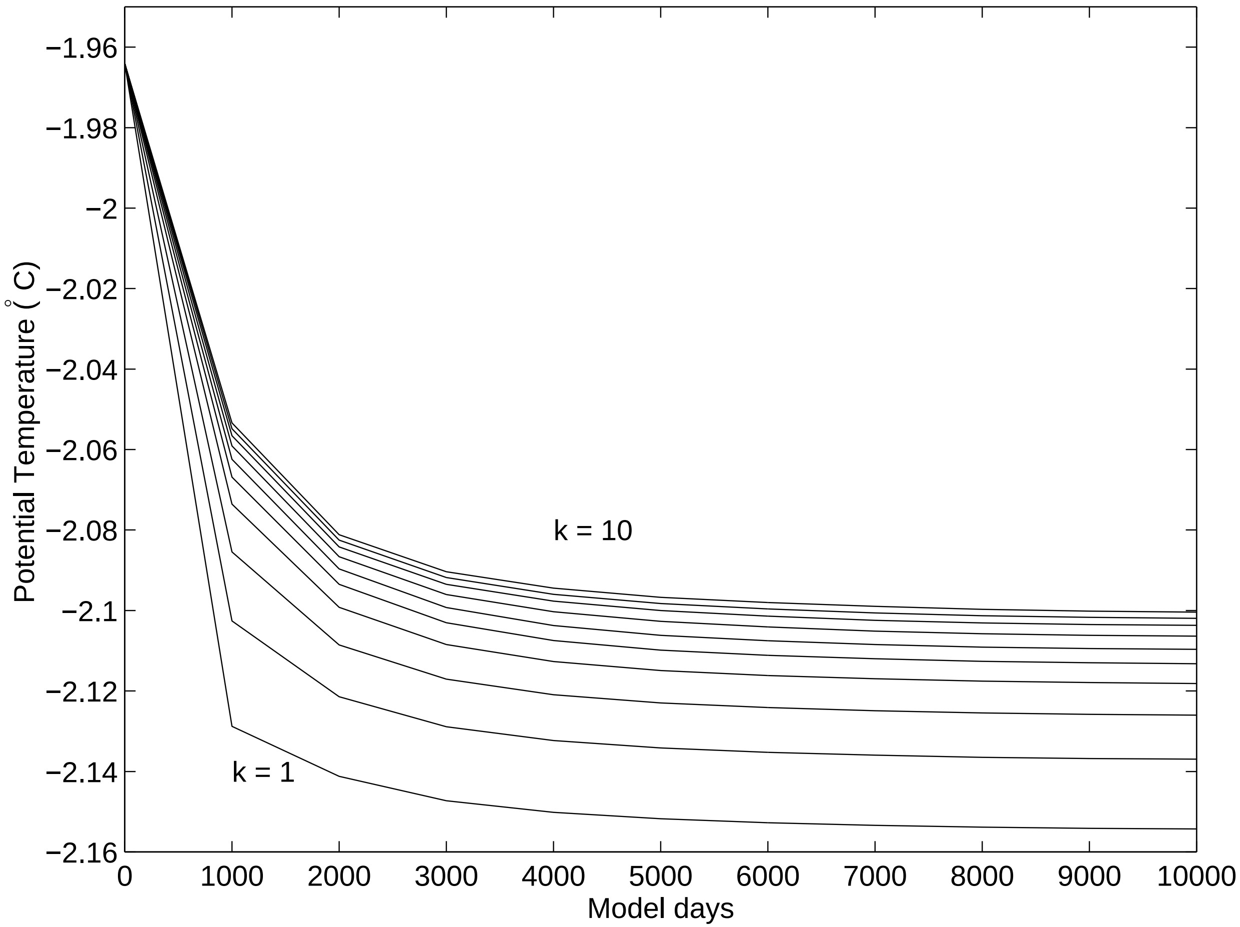
- Initial and Open Boundary conditions based on Winter conditions (deep mixing) in Prydz Bay.
  - Salinity of 34.5, Temperature at surface freezing temperature ($-1.8976°C$) - uniform throughout the water column.
  - S and T are "cobbled" at open boundaries.
- Tidal elevations at OB's are determined from tidal constituents (M_2, S_2, K_1, and O_1) interpolated onto OB gridcells from CADA tide model (Padman et al., 2002).

Runs include:

- Tides switched on and off - 4km and 8km resolution.
- Other initial temperatures (simulating global warming scenarios):
  - $T_f(surface) + 0.2°C$
  - $T_f(surface) + 1°C$

Model Spin Up; No Tides

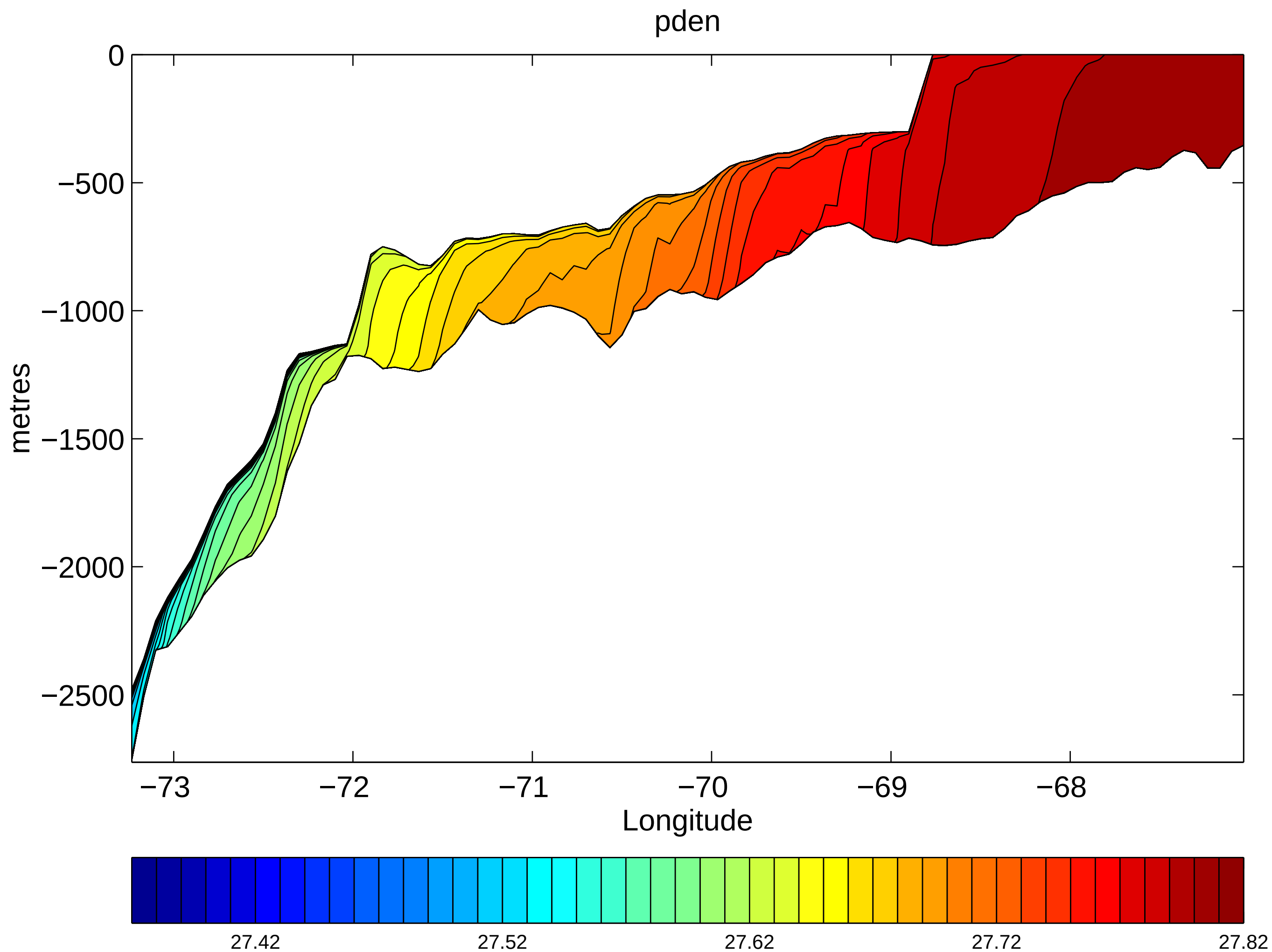
(Top layer: k=1; Bottom layer: k=10)



Hence, spin up time is tens of years

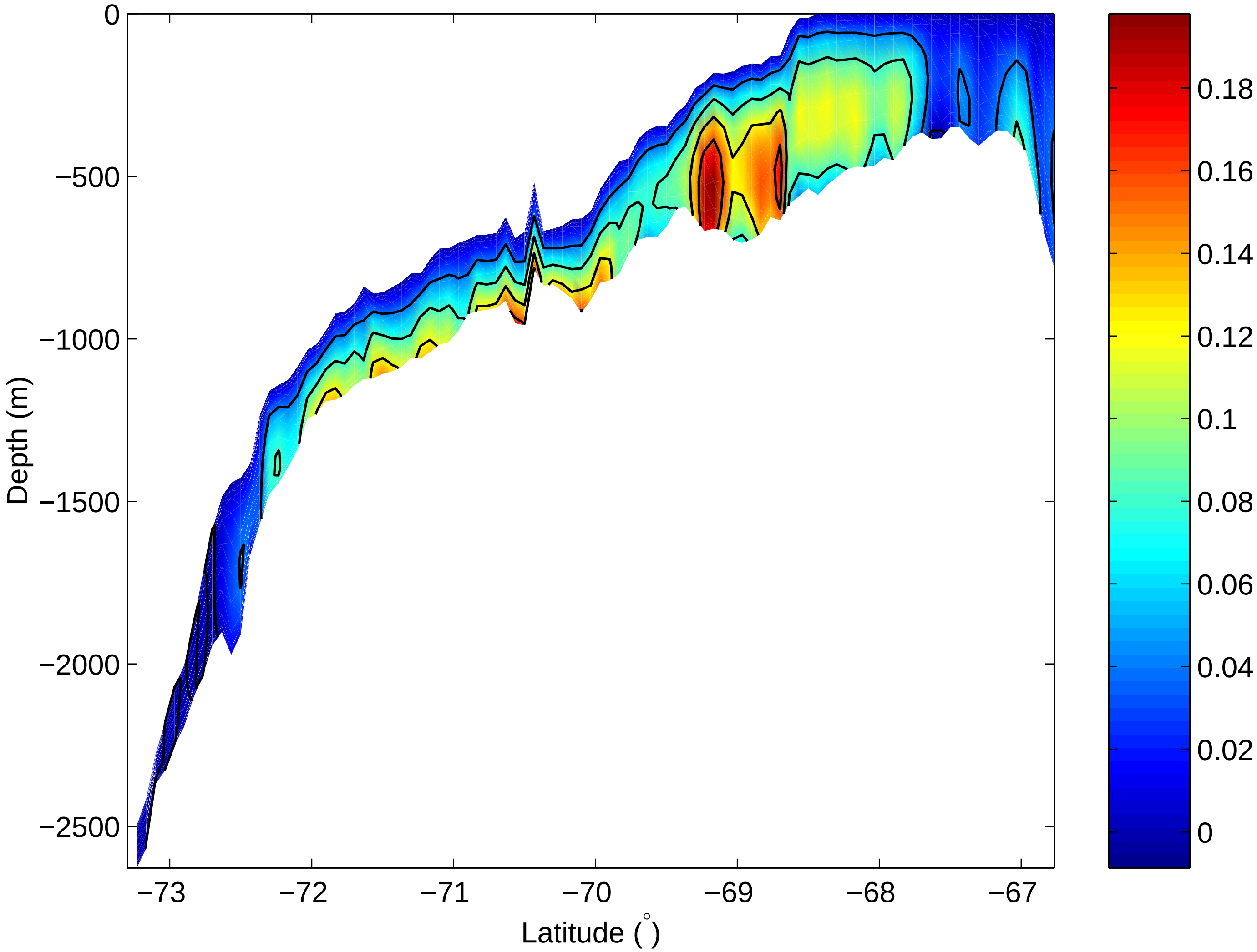
Longitudinal Density Section (σ_θ):

No Tides

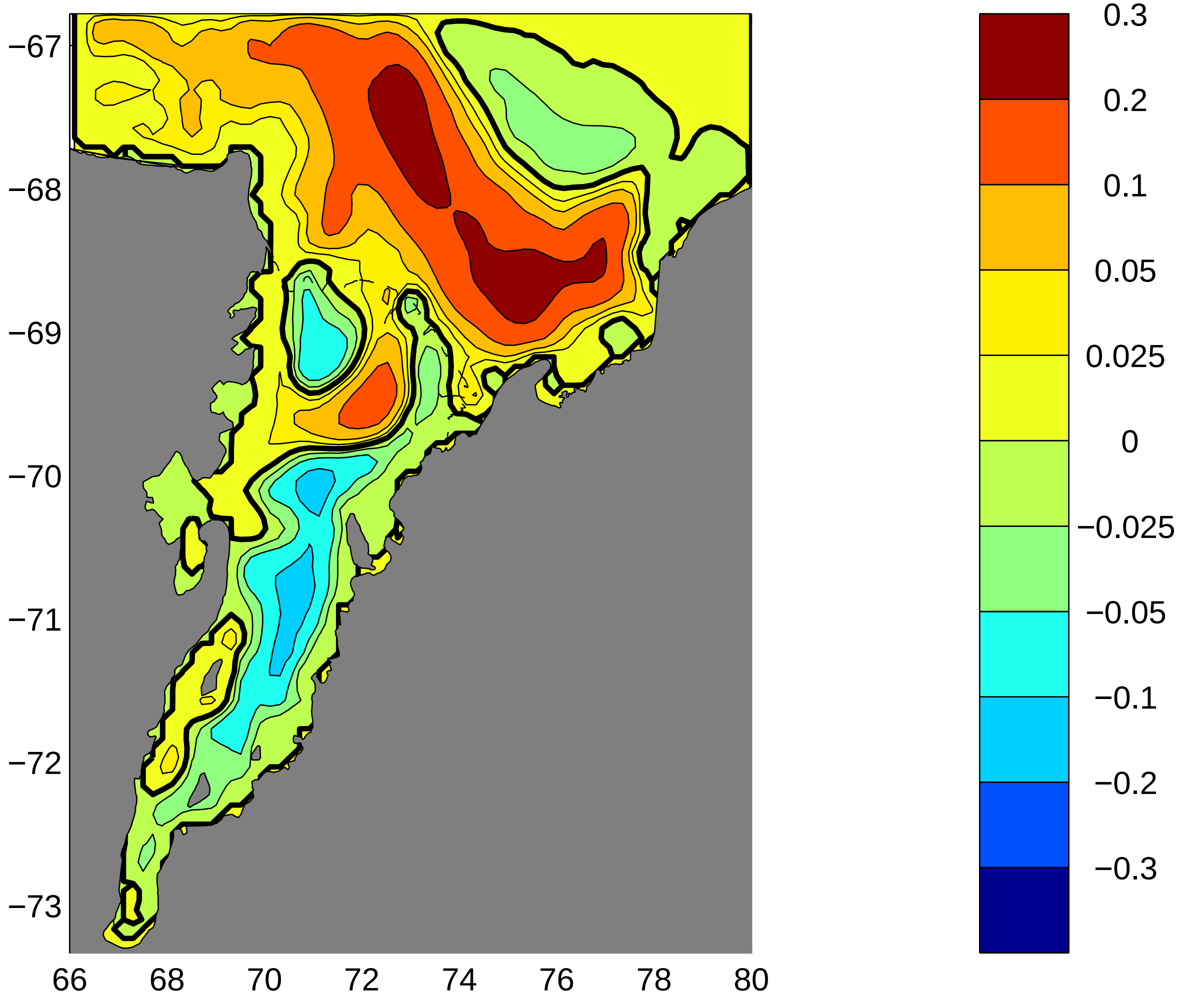


Zonally-Integrated Streamfunction (Sv): No Tides

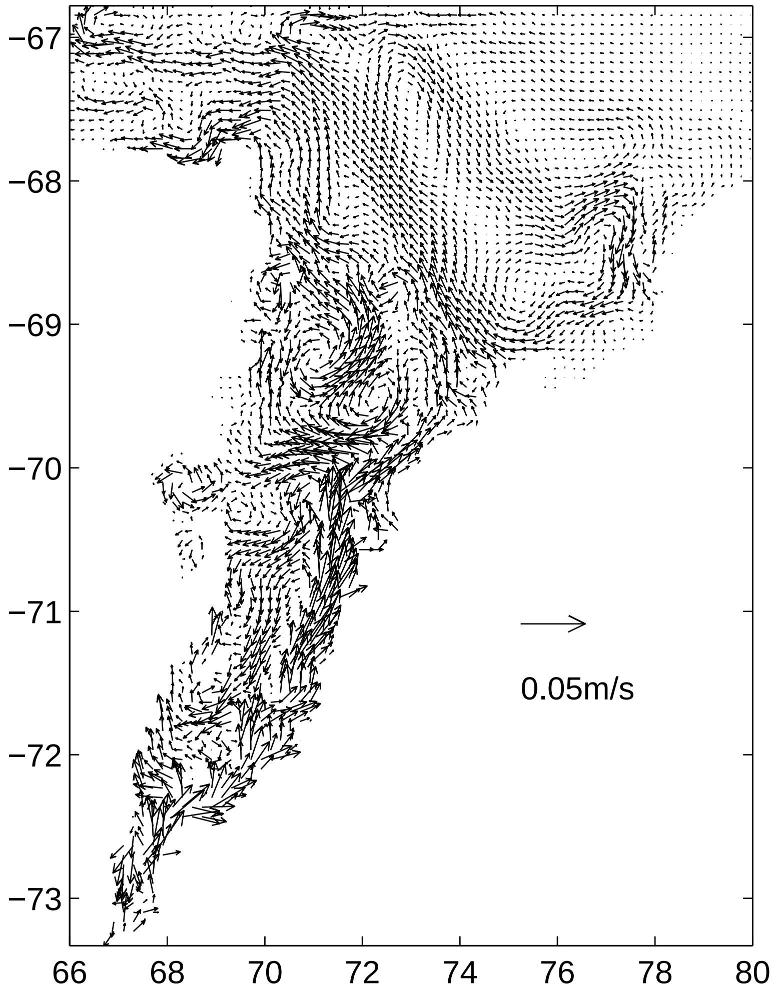
(Circulation clockwise around +ve features)



Vertically-Integrated Streamfunction (Sv): No Tides
(Circulation clockwise around +ve features)

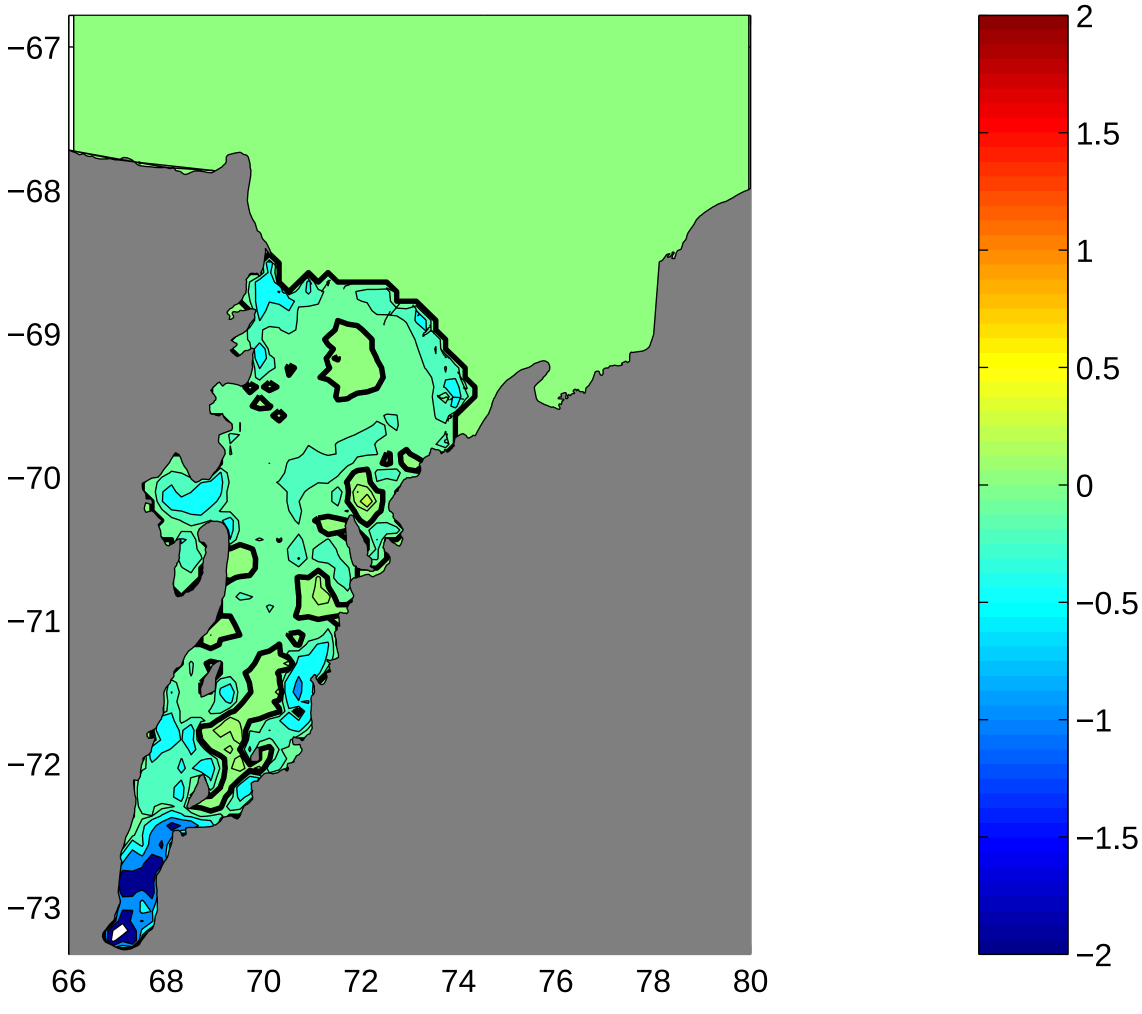


Horizontal Currents in Top Layer: No Tides

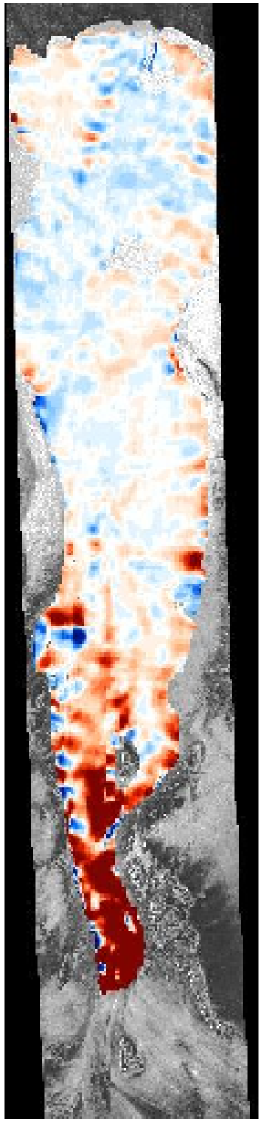


Freezing rate (ma^{-1}) : No Tides

(Positive is freezing; bold separates freezing/melting)



'Observed' Freezing/Melting



Blue: 10 m a^{-1} *freezing*

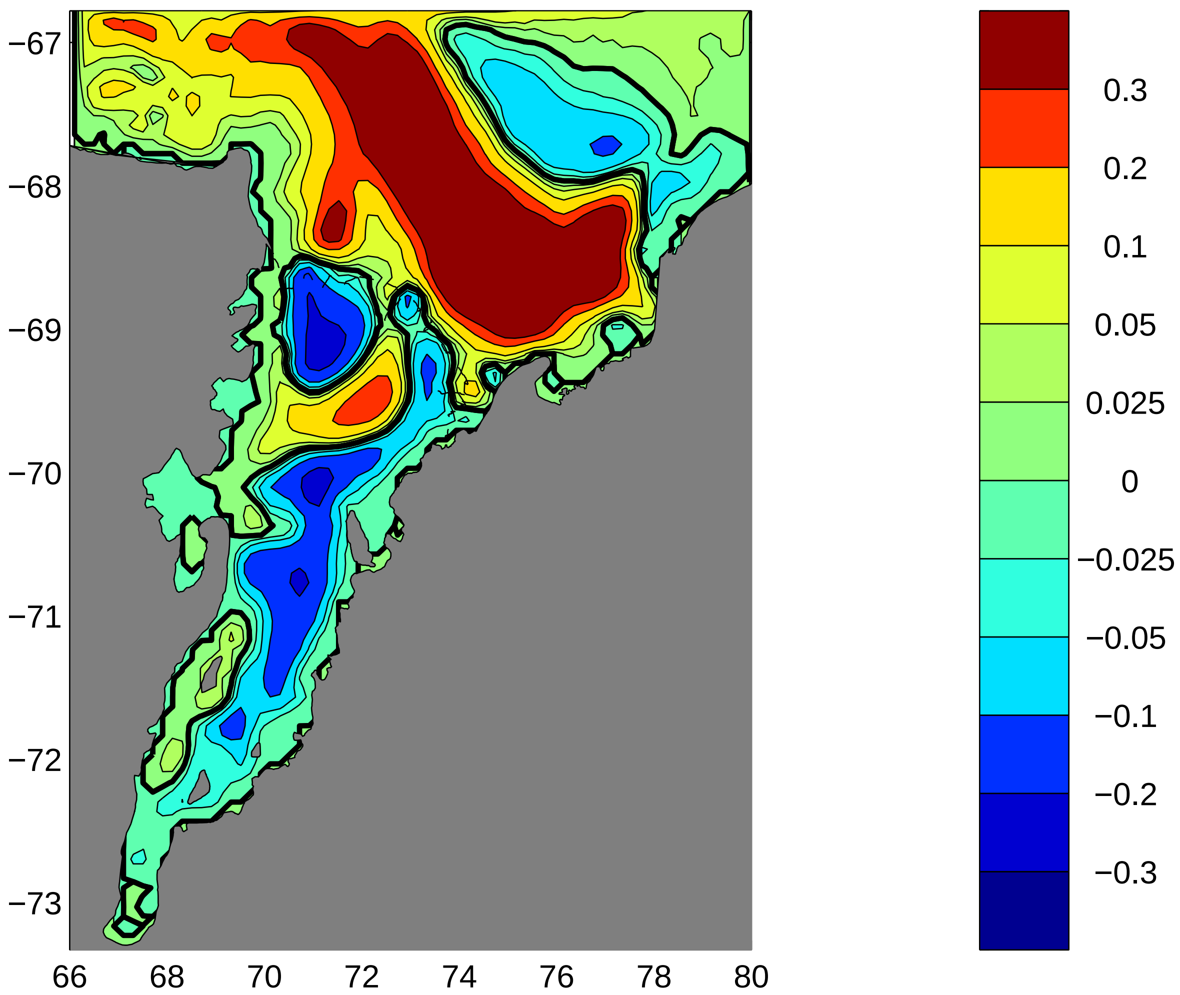
Red: 10 m a^{-1} *melting*

Kinematic estimation based on SAR, altimetry and ice density model

(Young, Hyland and Gale)

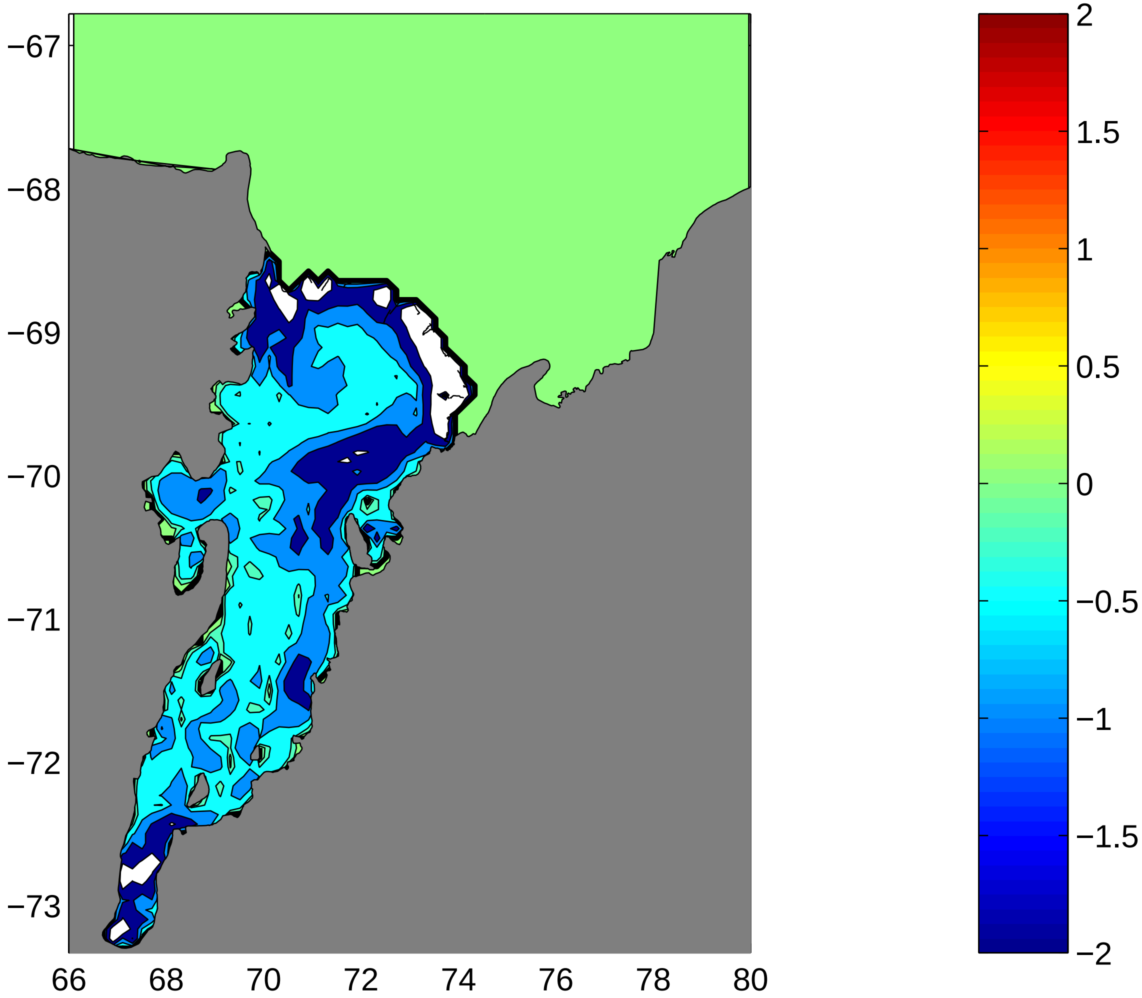
Vertically-Integrated Streamfunction (Sv): No Tides; $+1^{\circ}C$

(Circulation clockwise around +ve features)

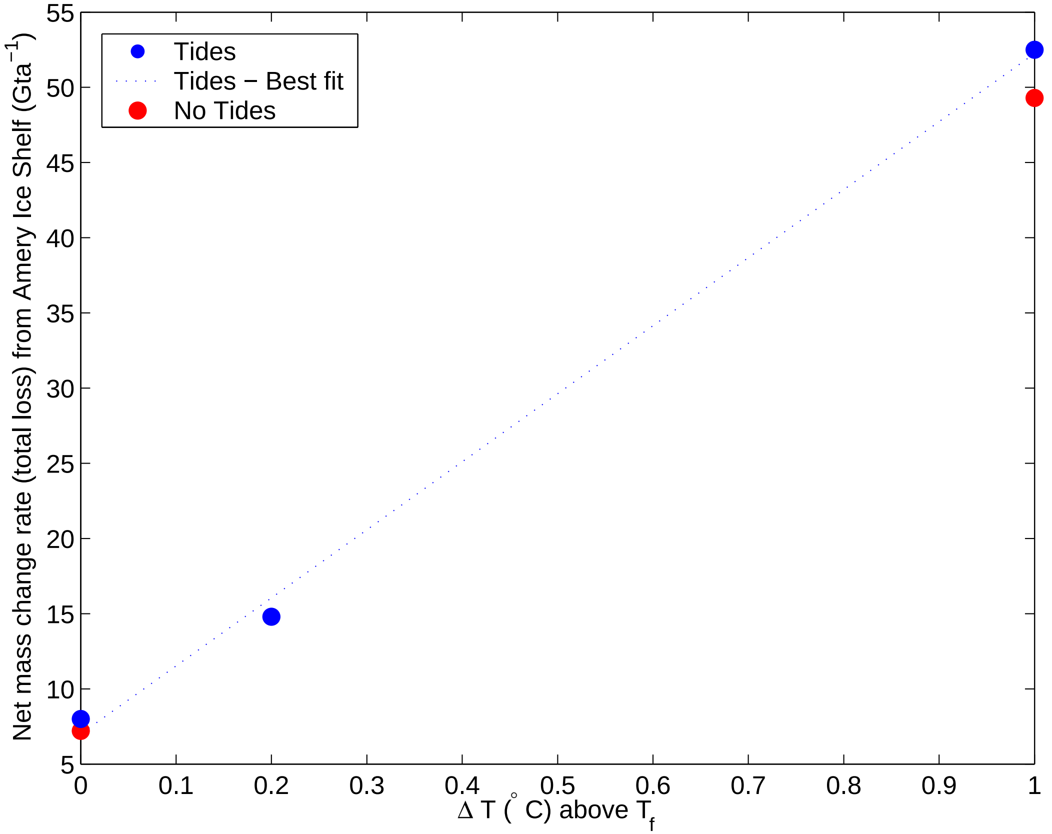


Freezing rate (ma^{-1}) : No Tides; $+1^{\circ}C$

(Positive is freezing; bold separates freezing/melting)



Mass Loss of Ice due to exchange with Cavity



Average slope = $43Gta^{-1\circ}C^{-1}$ (c.f. $25Gta^{-1\circ}C^{-1}$; Williams et al., 2002)

An increase in mass loss of $40Gta^{-1}$ could remove the ice shelf in 1000 years

Future Work

- Coupled cavity/ice shelf model (JH, Hobart)
- Upgraded ice draft from hydrostatics/altimetry and radar (JH, Hobart)
- Incorporation of frazil ice (JH, Hobart)
- Investigation of annual cycle (requires a sea-ice model or prescribed surface fluxes in open ocean). (JH, Hobart; MH Galway)
- Model Intercomparison study for idealised ice-shelf domains (MH Galway)
  - POM; Hemer - NUI, Galway, Ireland, Hunter - ACE CRC, Hobart
  - Generalised coordinate Cox-Bryan model; Williams - NIWA, NZ
  - MICOM; Holland, New York
  - SPEM/SCRUM??; AWI

Marine Modelling Centre, Martin Ryan Marine Institute
National University of Ireland, Galway

Personnel:

- 3 Permanent Staff
- 2 Post-Docs (as of Sept)
- 6 Post-grad students

Projects:

- Hydrodynamic model focussed on the North-East Atlantic - Irish territorial waters. (POM -> ROMS??)
- Operational forecasting model of the Irish Sea (POM or POLCOMS)
- Flushing Studies of Irish Coastal Waters (POM)
- Kinetics and transport of scallop and sea-jelly plankton larvae (POM)