Modelling Amery Ice Shelf/Ocean Interaction

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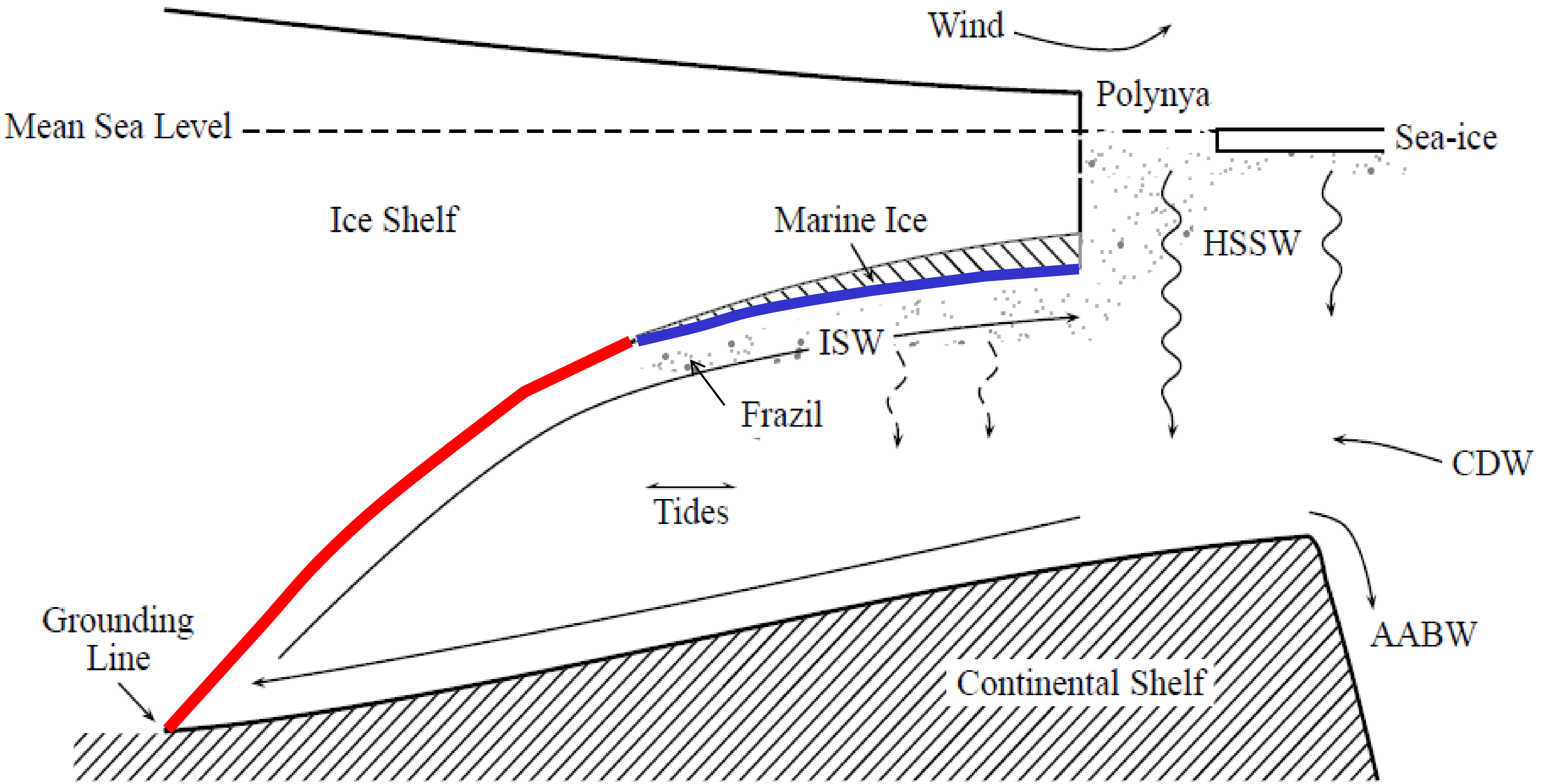
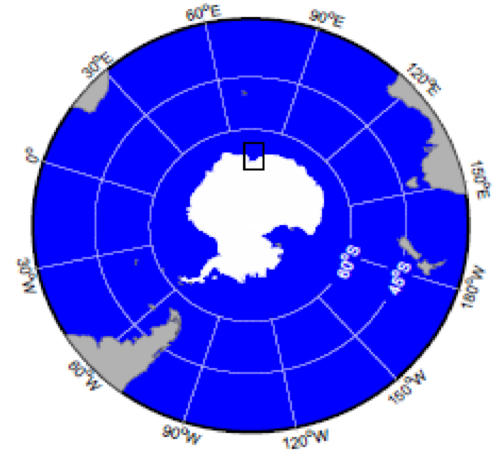
Ice shelf/ocean interaction

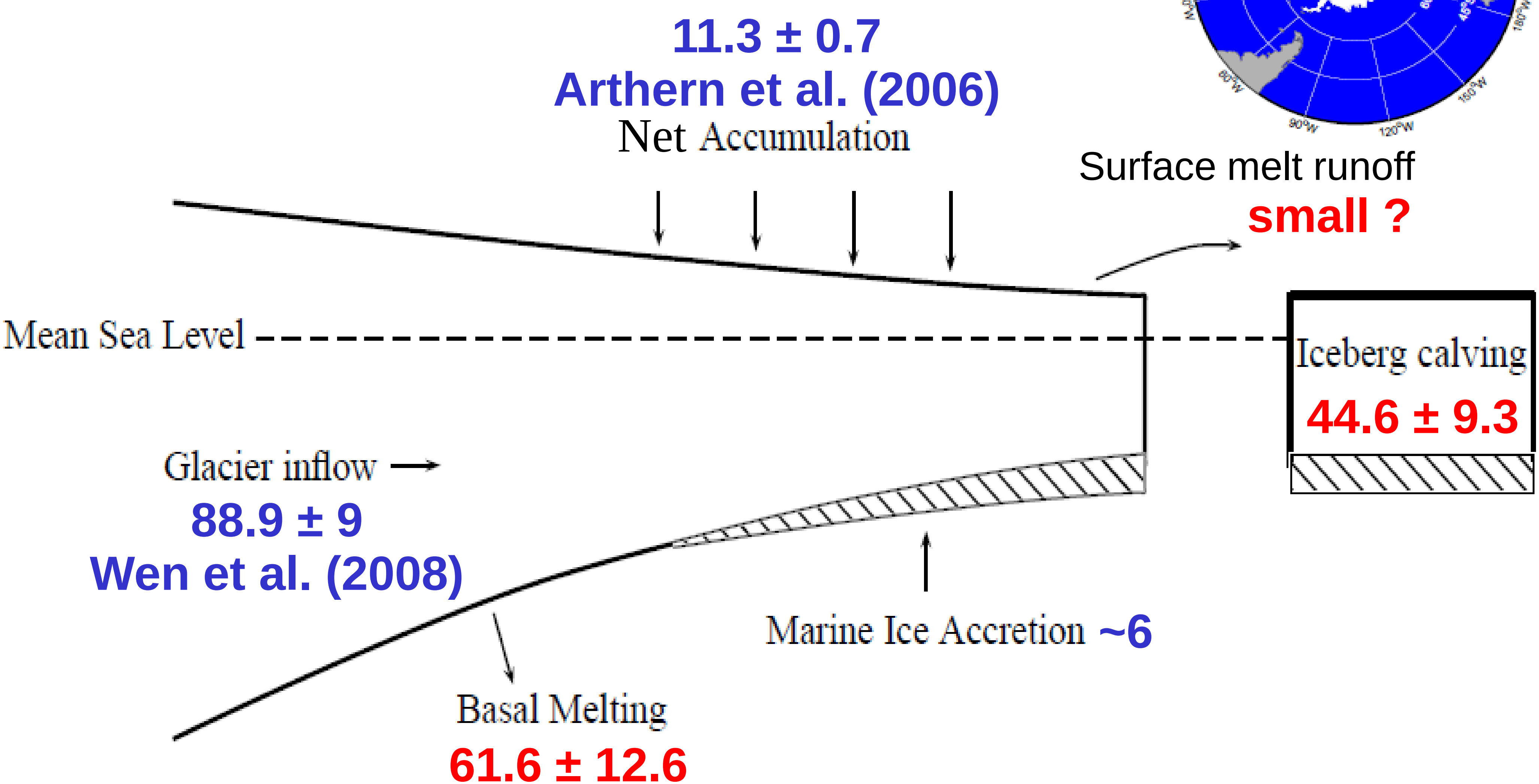


- Melting (red) and accretion (blue) are coupled with the ice-pump circulation
- Marine ice accretion is from both direct basal freezing and frazil precipitation
- Uncertainties with melt/accretion and mechanisms and rates of AABW formation

Amery Ice Shelf mass balance

(Gt year^{-1}, **+ve**, **-ve**)

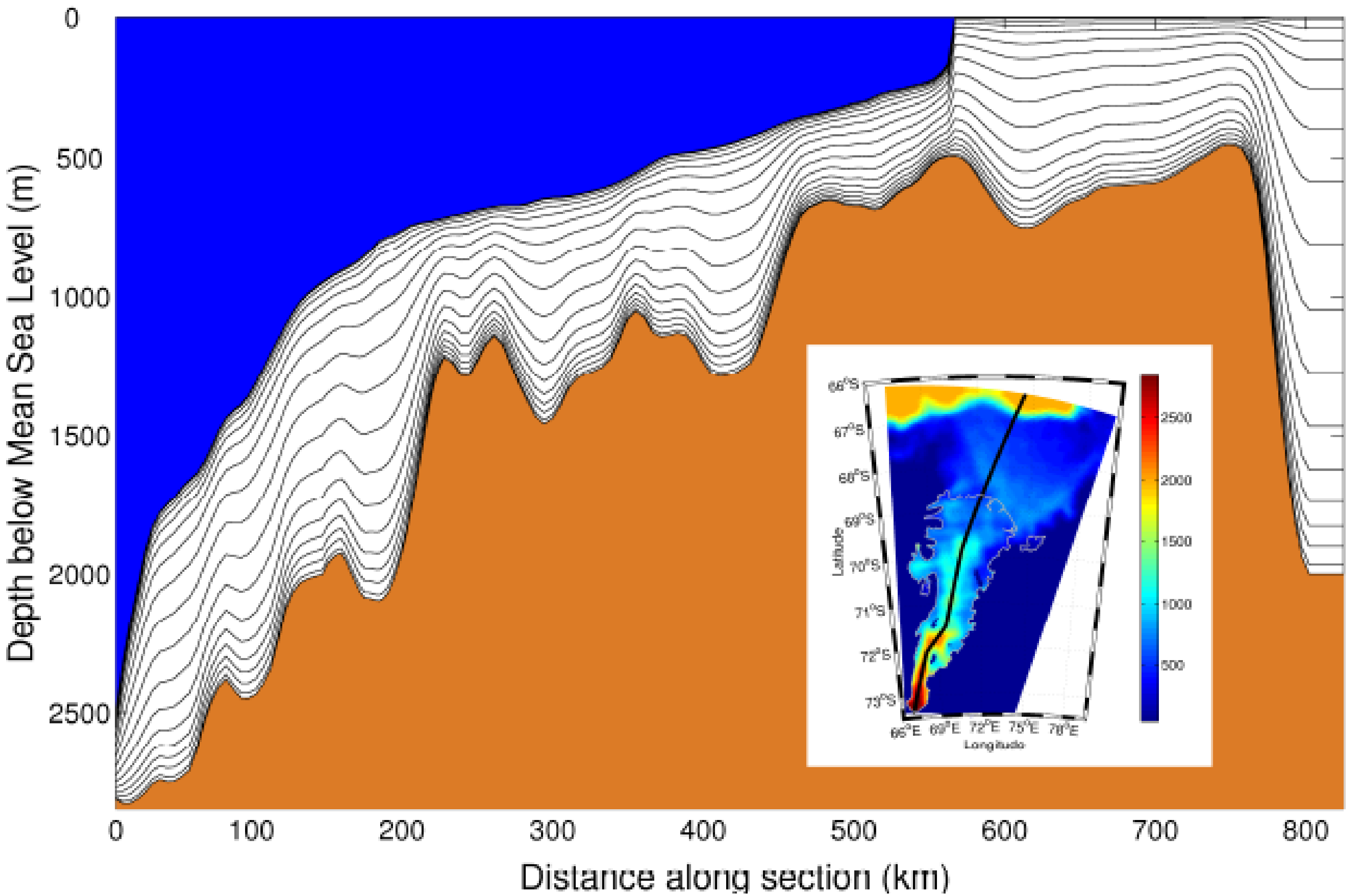




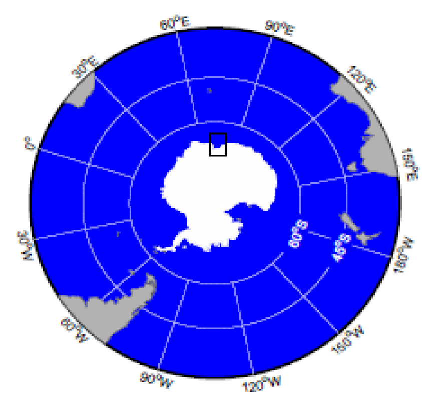
- Net basal melt = 55.6 ± 12.6 Gt year^{-1}
- Marine ice accretion and iceberg calving calculated using fluxes and estimates of ice shelf and marine ice layer thicknesses

Ice shelf/ocean modelling

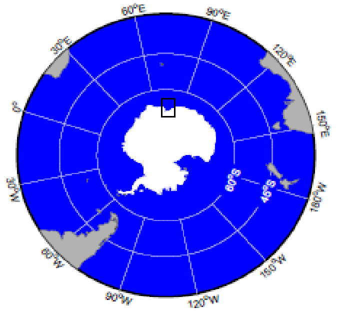
- Based on the Rutgers version of ROMS: Regional Ocean Modeling System (Hernan Arango; Shchepetkin and McWilliams, 2005)
- Adjustment of surface pressure for floating ice draft (Already part of ROMS; Dinnniman et al., 2003)
- Modified equation of state of larger range of temperature (Jackett & McDougall 2006) and frazil
- Thermodynamic modifications:
  - Direct basal ice/ocean thermodynamics: ‘standard’ 3-eqns of heat, salt conservation and freezing point (e.g. Holland & Jenkins, 1999)
  - Frazil ice dynamics (following Holland & Feltham 2006) with modifications that scales thermal exchange to allow for effect of salt
  - Frazil is implemented using hijacked sediment code of Warner (2005) with modifications



- 83x171 horizontal grid cells (2-5 km)
- 16 vertical layers
- Stretched terrain following vertical coordinate
- Geometry: Galton-Fenzi et al. (2008)
- Timestep: 300 s baroclinic, 20 s barotropic

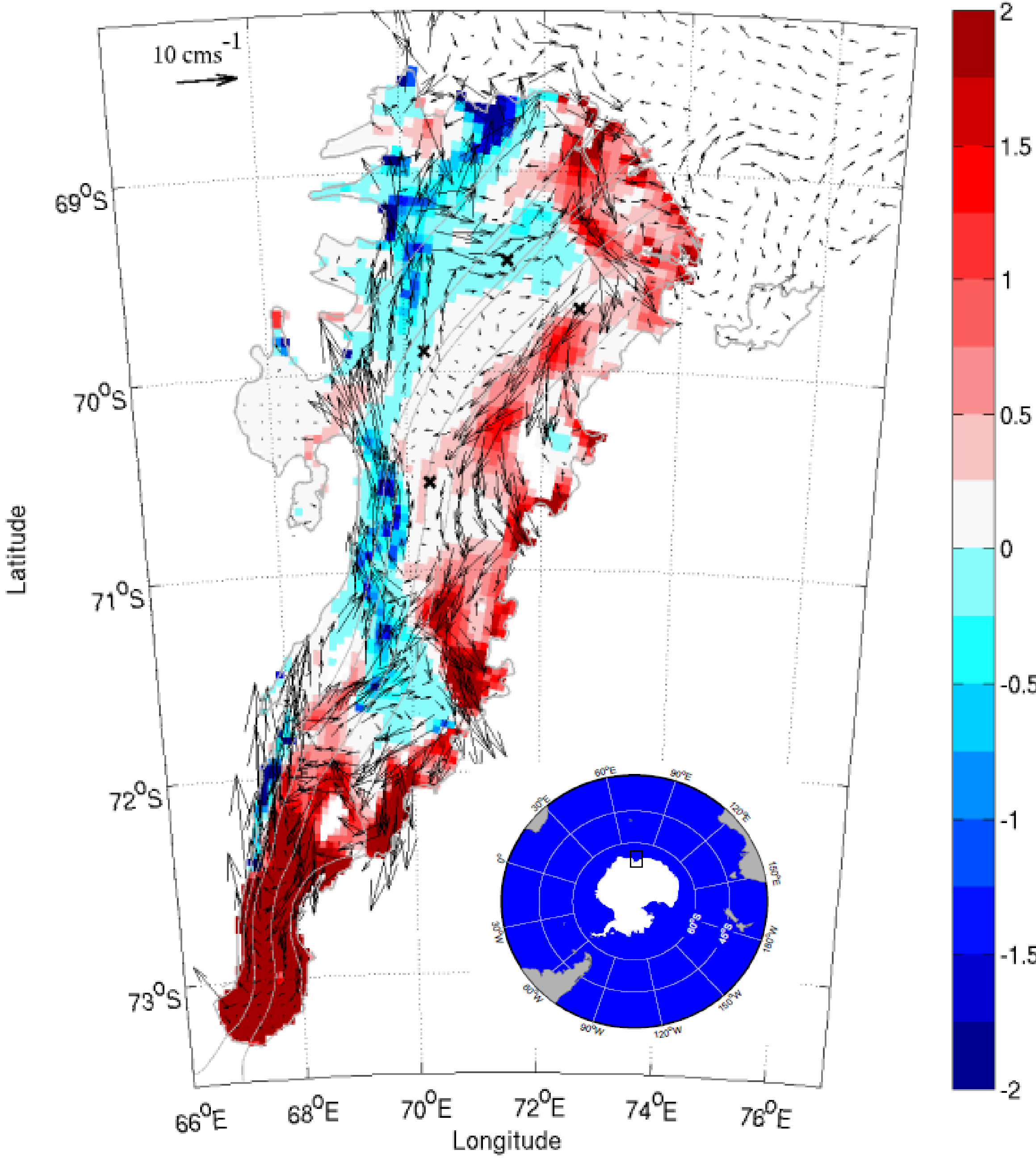


Forcing



- 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.

Melt (+ve)/accretion (m year^{-1}) & depth avg. currents

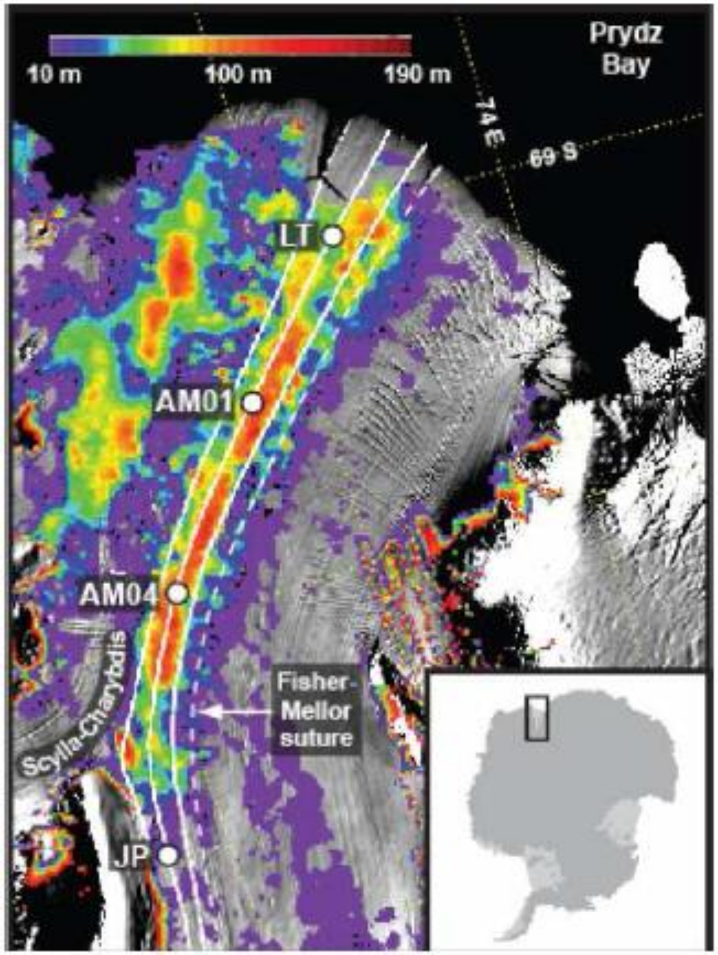


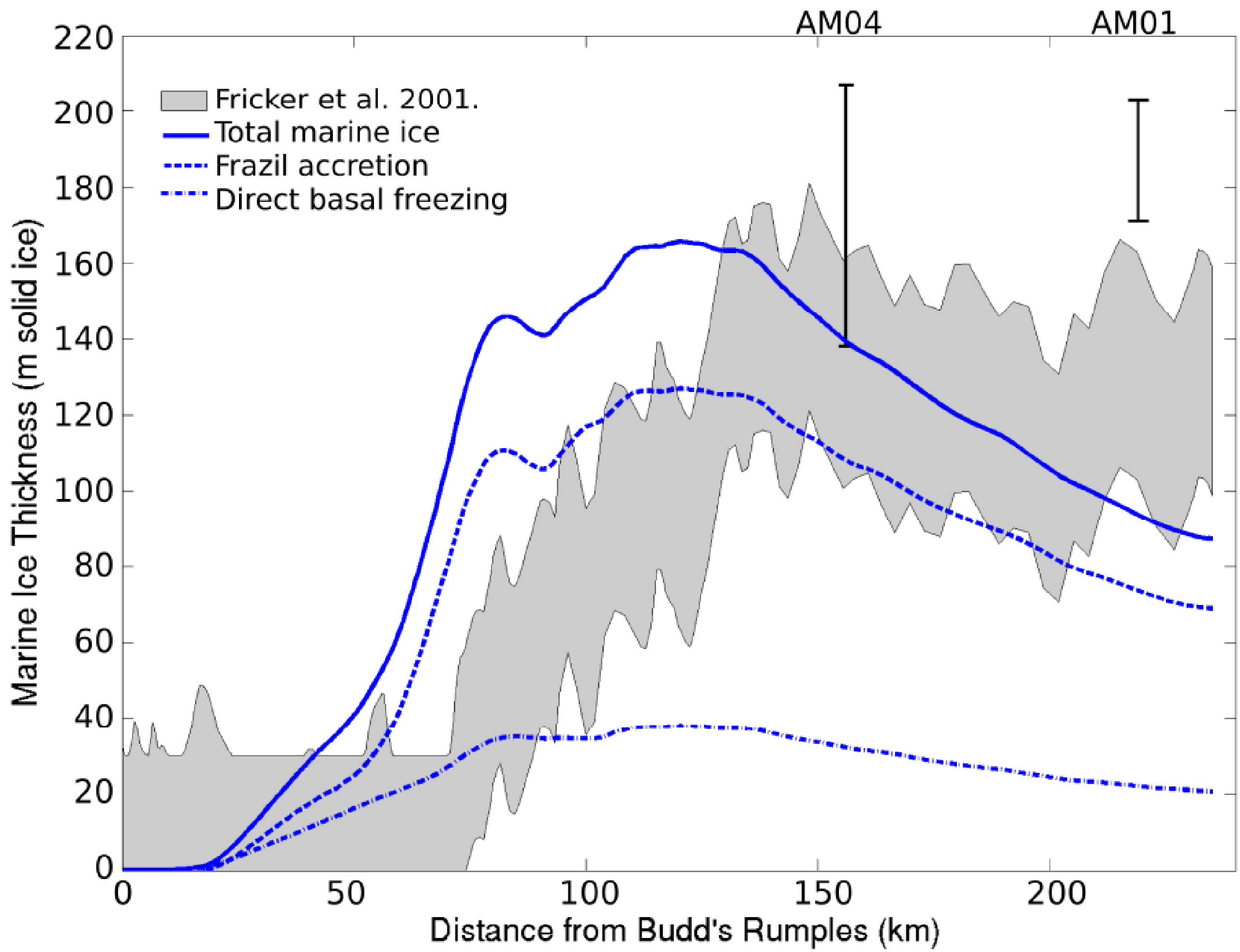
Effect of frazil

Model	Net	Melt	Accretion
+ Frazil	45.63	50.89	5.26 F=70%
- Frazil	50.9	52.97	2.07
Obs	55.6 ± 12.6	61.6 ± 12.6	~ 6

- Melt is enhanced and marine ice accretion is decreased by 2.5x in model without frazil
- Frazil destabilises cool ISW plume, enhancing mixing with waters that melt base.

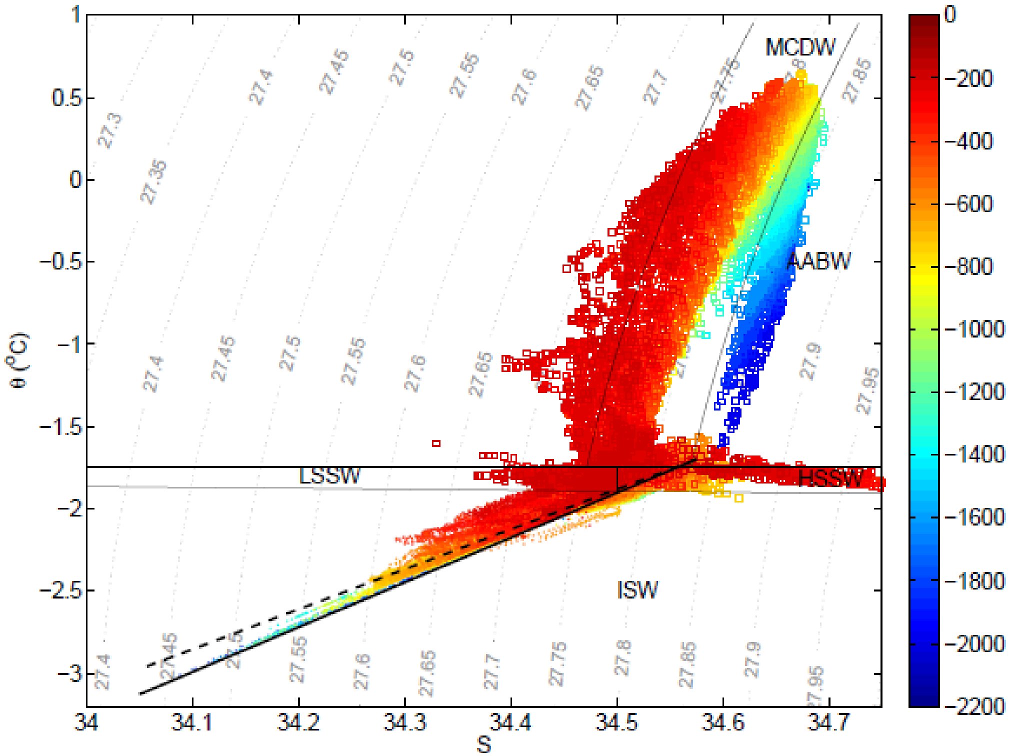
Marine ice accretion from +frazil model

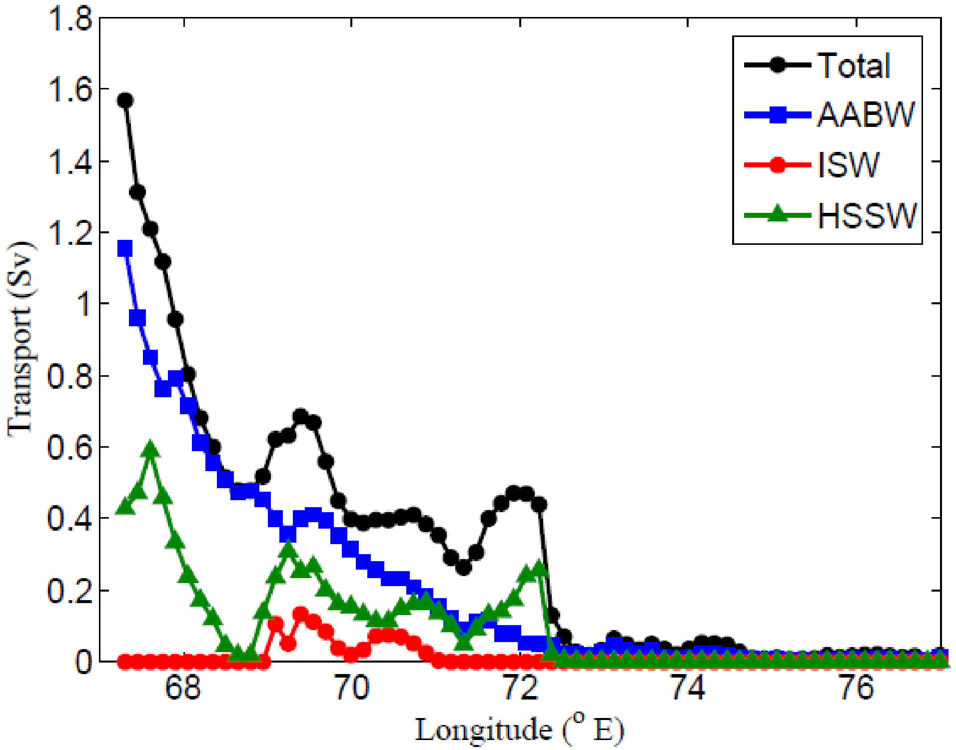




- Integrating along glacier flowline using velocities and strain thinning rates (Young and Hyland, 2001)
- Frazil enhances the basal accretion of marine ice
- Upstream (glacially) accretion in model compared to obs

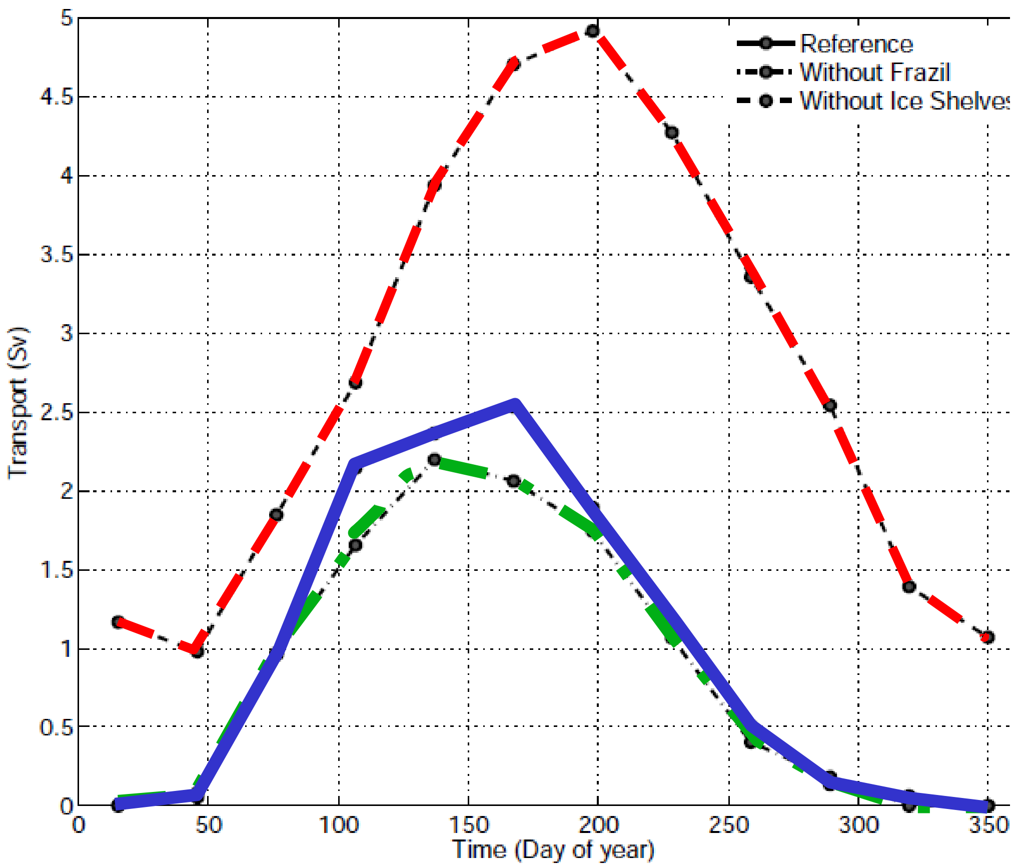
Cape Darnley (west of Amery) is a region of AABW formation

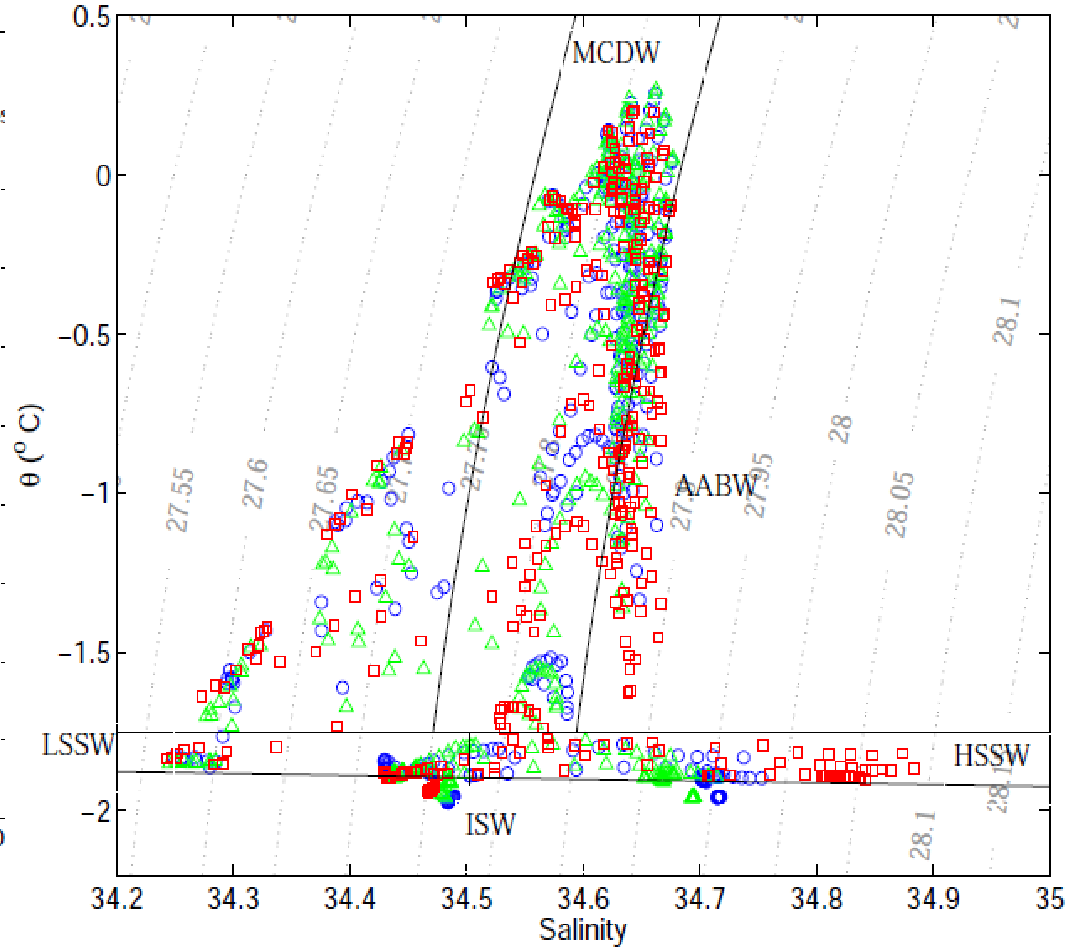




- Classified as AABW if -1.75 ≤ θ, S > 34.5, ρ > 27.83 and must also be transported off the continental shelf to the deep ocean.
- Model shows westward and downslope transport of AABW near Cape Darnley, in agreement with observations (Meijers et al. 2009)
- Production is ~3 Sv in winter (not shown)

Sensitivity of AABW to ISW and frazil



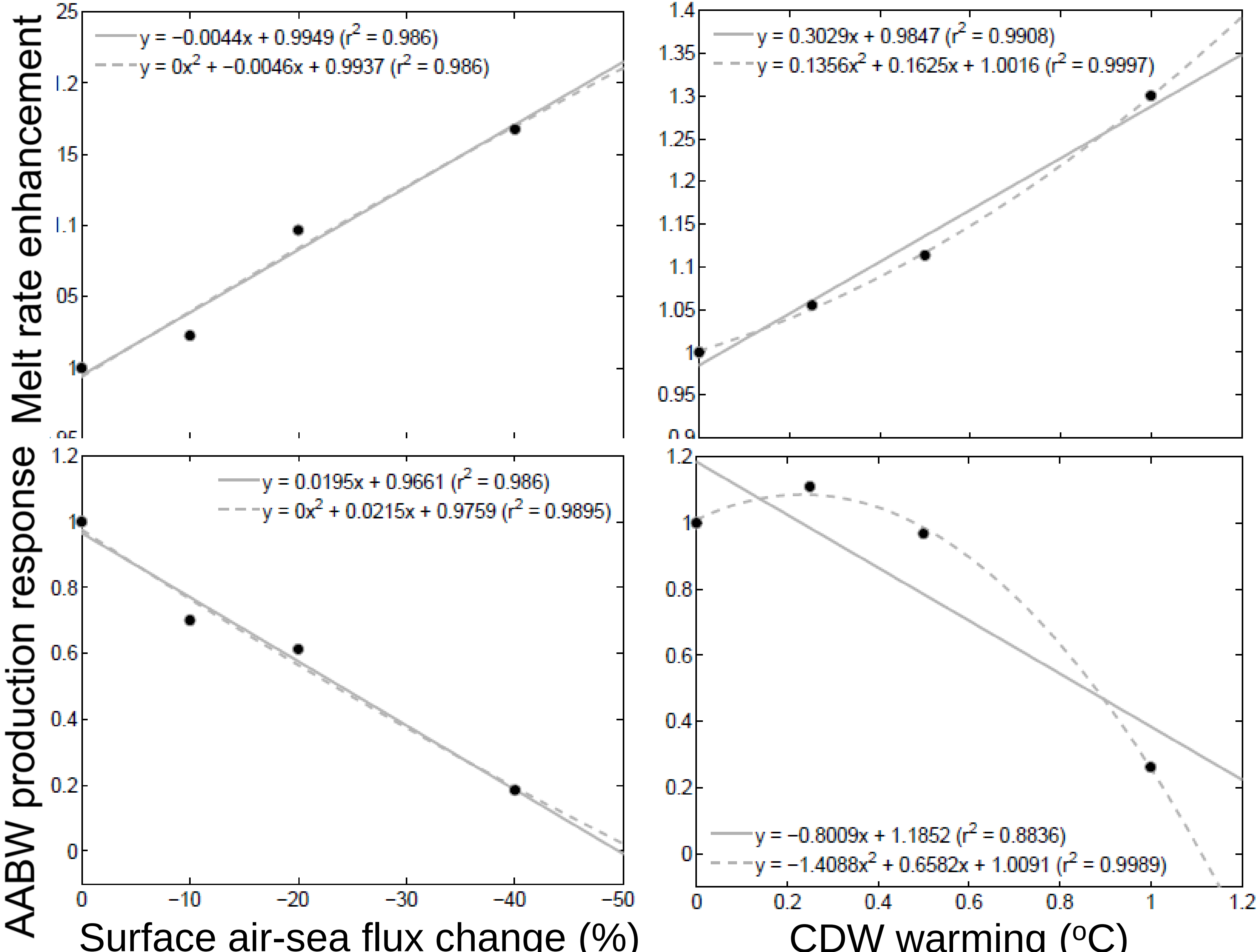


- 3 Models: **+ frazil**, **- frazil**, **- ice/ocean thermodynamics**
- HSSW and AABW is freshened by ISW
- Model without ice/shelf ocean interaction (red) 2-3x overestimate AABW production
- Brine rejection due to frazil formation reduces freshening

Response to climate change

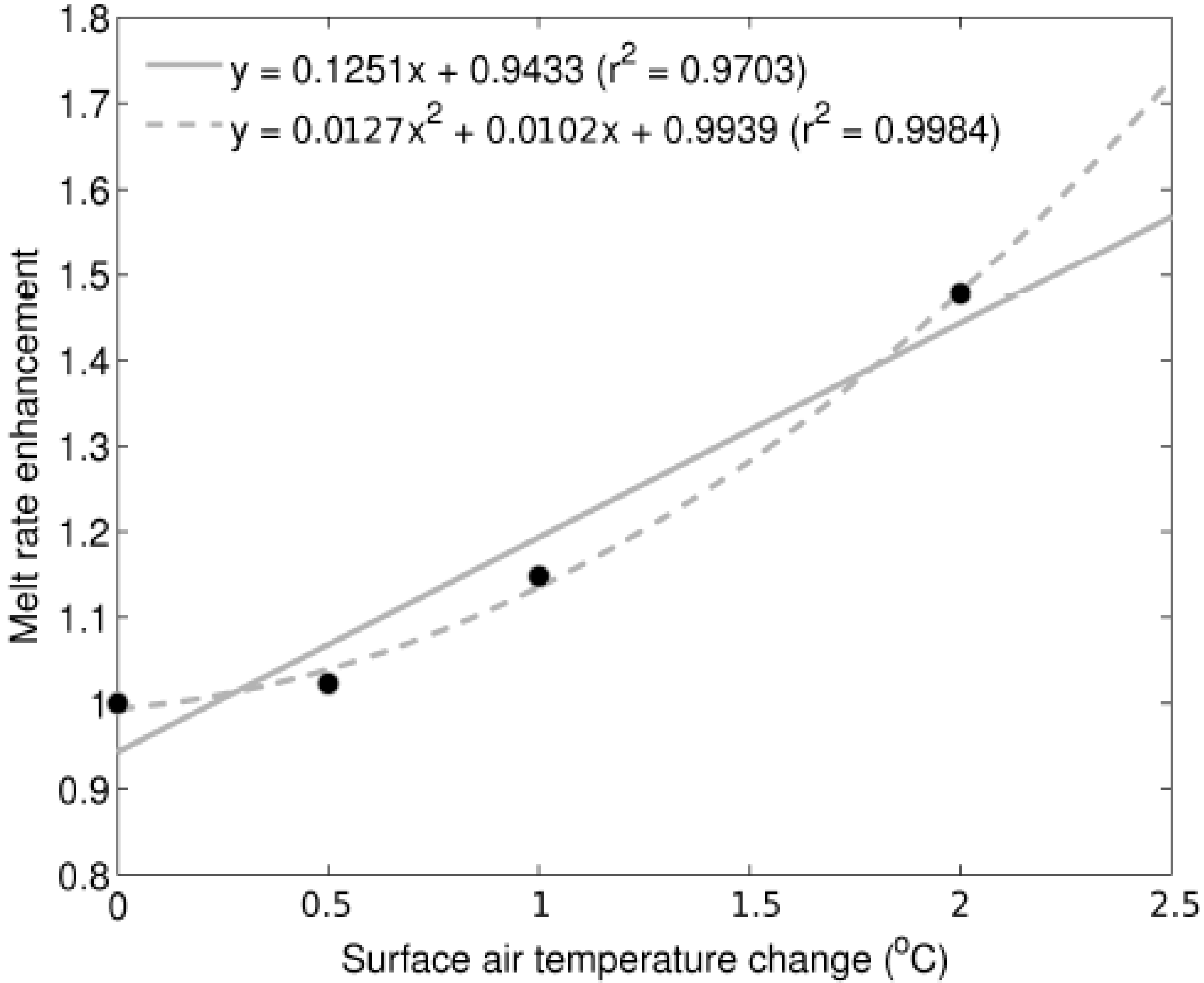
Air-Sea flux	Lateral warming (°C)			
change (%)	0	0.25	0.5	1
0	R	L1	L2	L3
-10	A1	+0.5		
-20	A2		+1	
-40	A3			+2

- 10 model runs and approximate predictions of changes in polynya activity, CDW warming and relationship with surface air-temperature in the Amery Ice Shelf region, based on linear trends from observations
- “+2” scenario is ~50-100 year projection based on A1B scenario



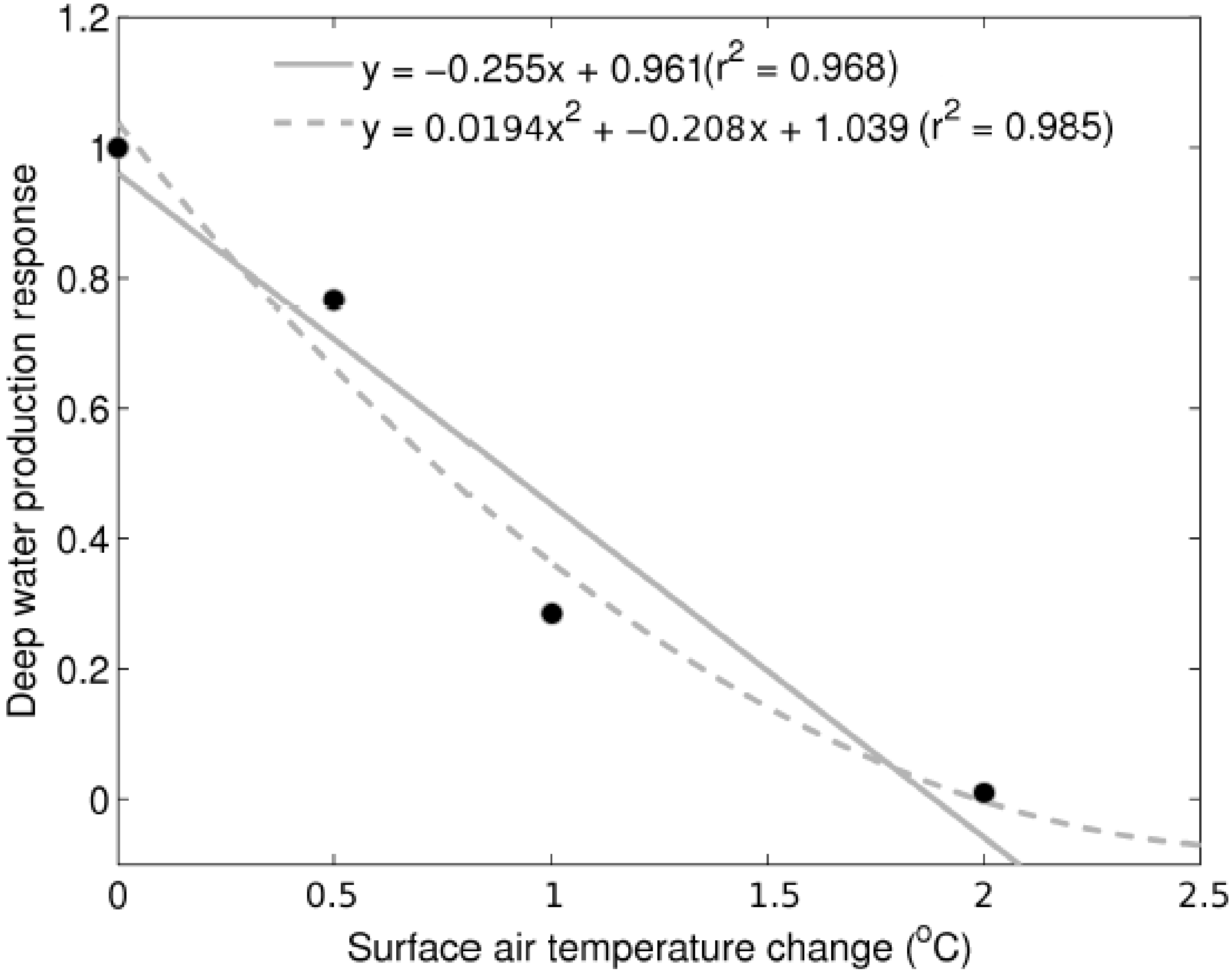
Melt rate enhancement
AABW production response
y = −0.0044x + 0.9949 (r2 = 0.986)
y = 0x2 + −0.0046x + 0.9937 (r2 = 0.986)
y = 0.3029x + 0.9847 (r2 = 0.9908)
y = 0.1356x2 + 0.1625x + 1.0016 (r2 = 0.9997)
y = 0.0195x + 0.9661 (r2 = 0.986)
y = 0x2 + 0.0215x + 0.9759 (r2 = 0.9895)
y = −0.8009x + 1.1852 (r2 = 0.8836)
y = −1.4088x2 + 0.6582x + 1.0091 (r2 = 0.9989)
Surface air-sea flux change (%)
CDW warming (oC)

Net melt rate response to combined forcing



- Enhancement due to both an increase in melt rate and a decrease in accretion (mostly frazil formation).
- “+2” increases melting at deepest parts of cavity by ~5 m year^{-1}
- 500 years to melt through thickest ice

AABW response to combined forcing



- Shutdown of AABW at +2 ^{o}C
- Combined effect of increased dilution by ISW and reduced HSSW production

Concluding remarks

- Frazil ice enhances marine ice accretion and limits supercooling with implications for ice shelf mass balance and dense water formation
- Net mass loss of the Amery Ice Shelf is 45.6 Gt year^{-1}
- AABW formation is ~1.2 Sv and is overestimated in models without ice shelf/ocean interaction by 2.8x
- Surface warming of +2” (40 % change in air-sea flux and a 1^{o}C warming of CDW):
  - Potentially remove the Amery Ice Shelf in 500 years
  - Shutdown of AABW production from Cape Darnley region
- Subgridscale icebergs influence AABW formation and melting of ice shelves
- Next step is to couple with a dynamic ice shelf/ice stream model

Acknowledgments

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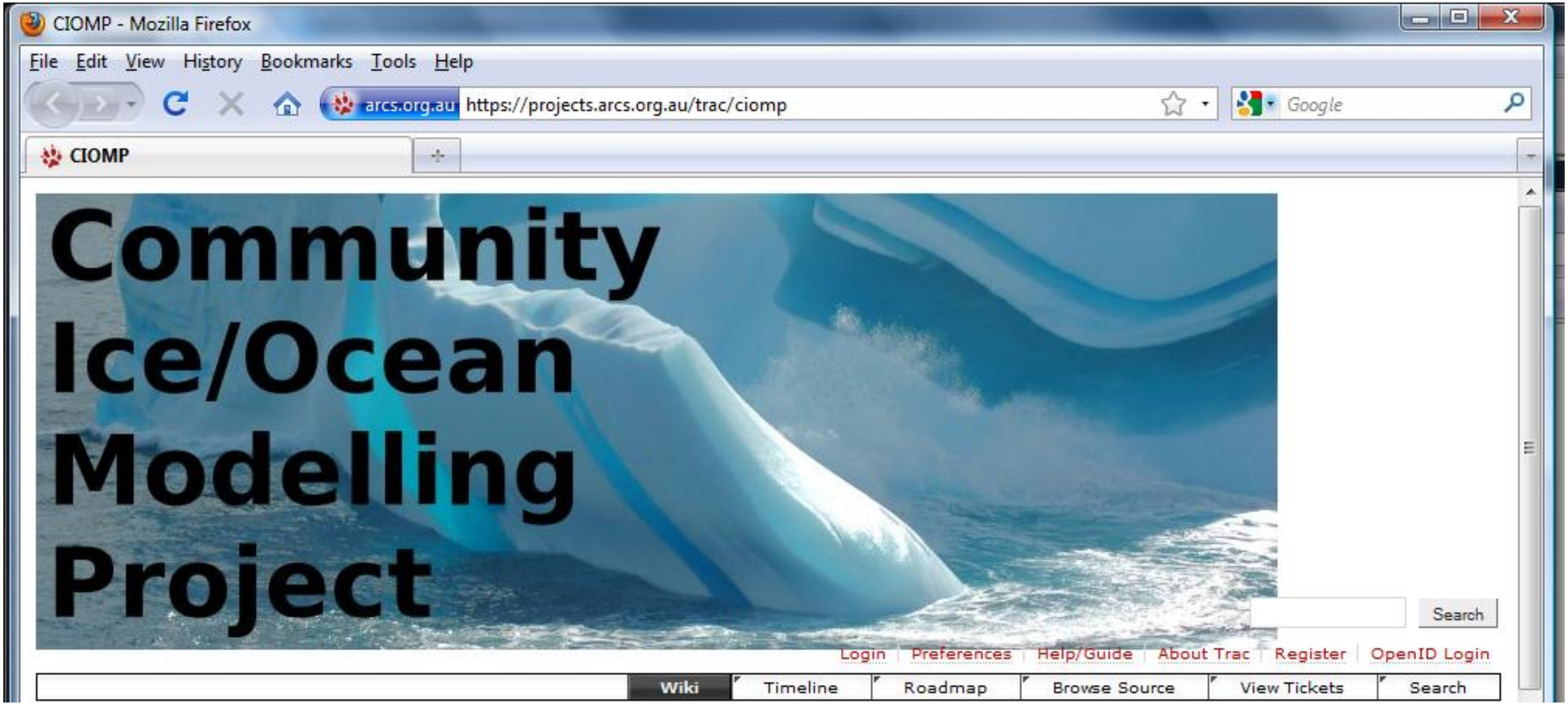
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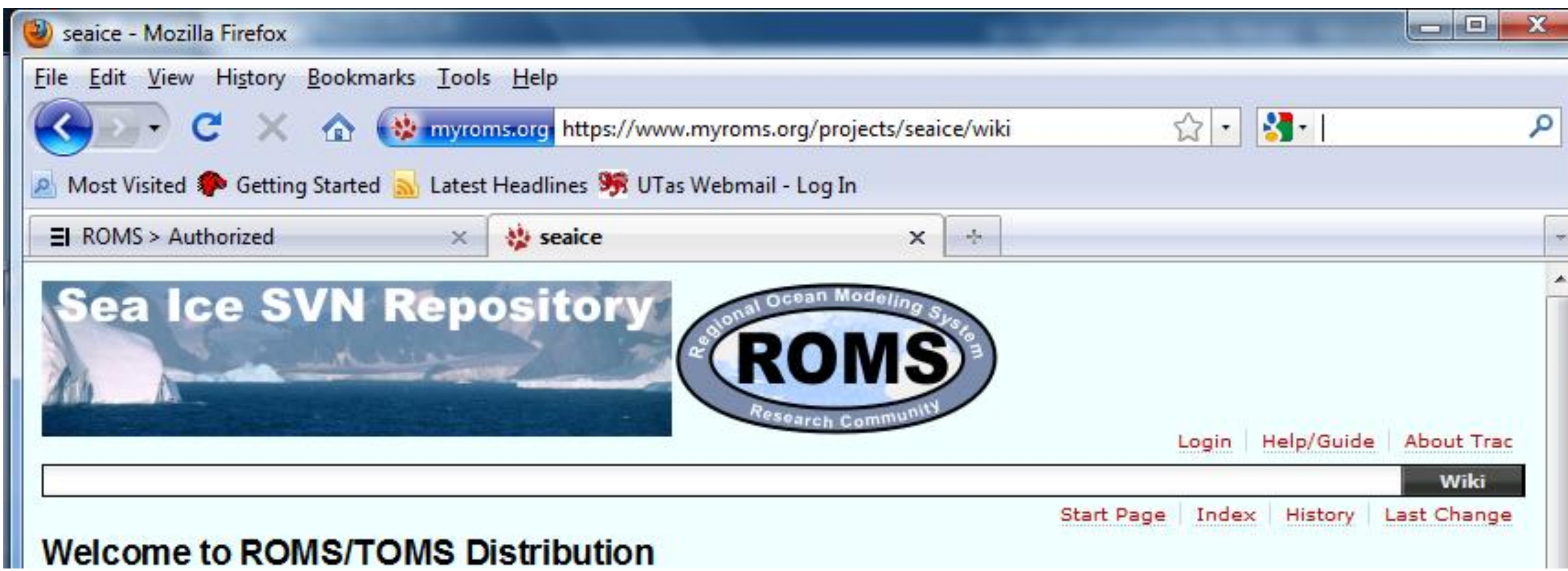
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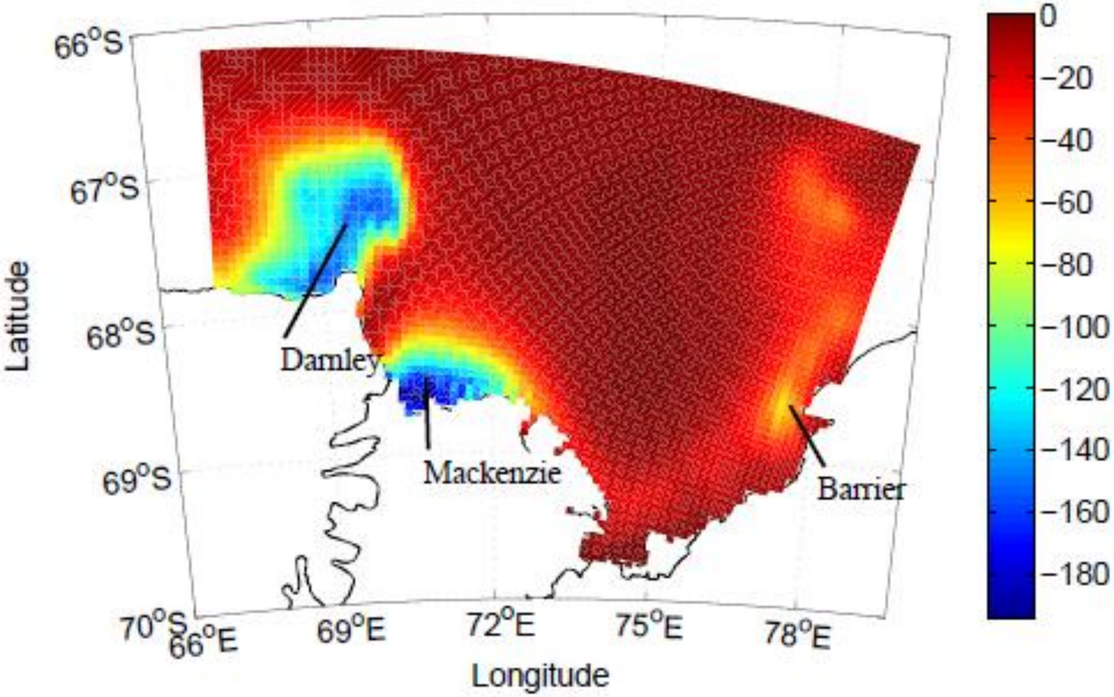
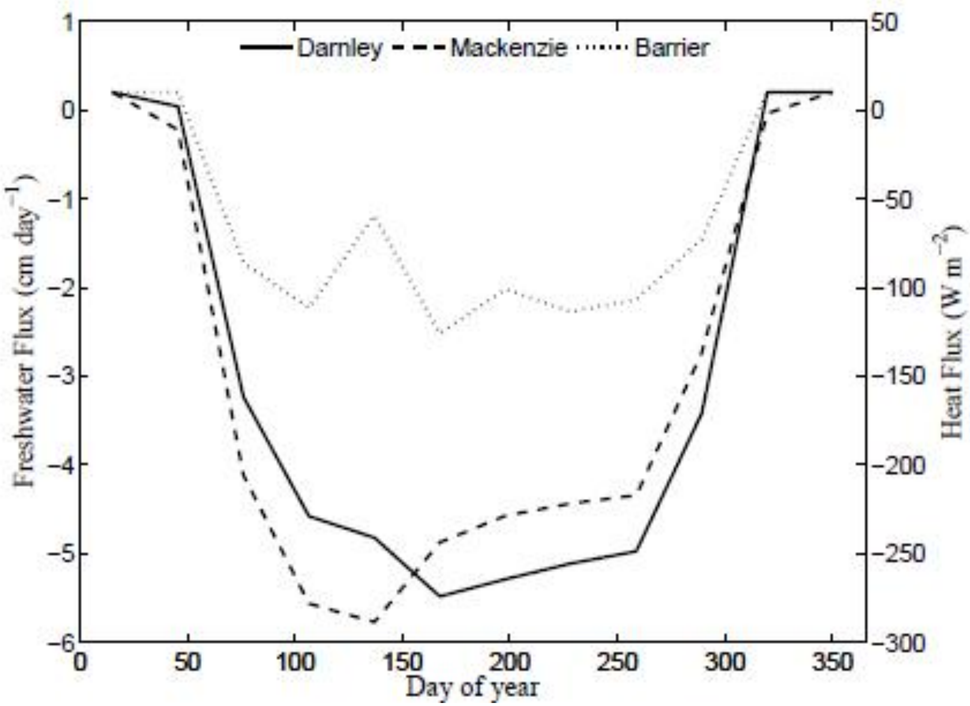
Welcome to ROMS/TOMS Distribution

Air-Sea fluxes



(a)



•Top panel: Wintertime snapshot of surface heat flux (W/m^2)

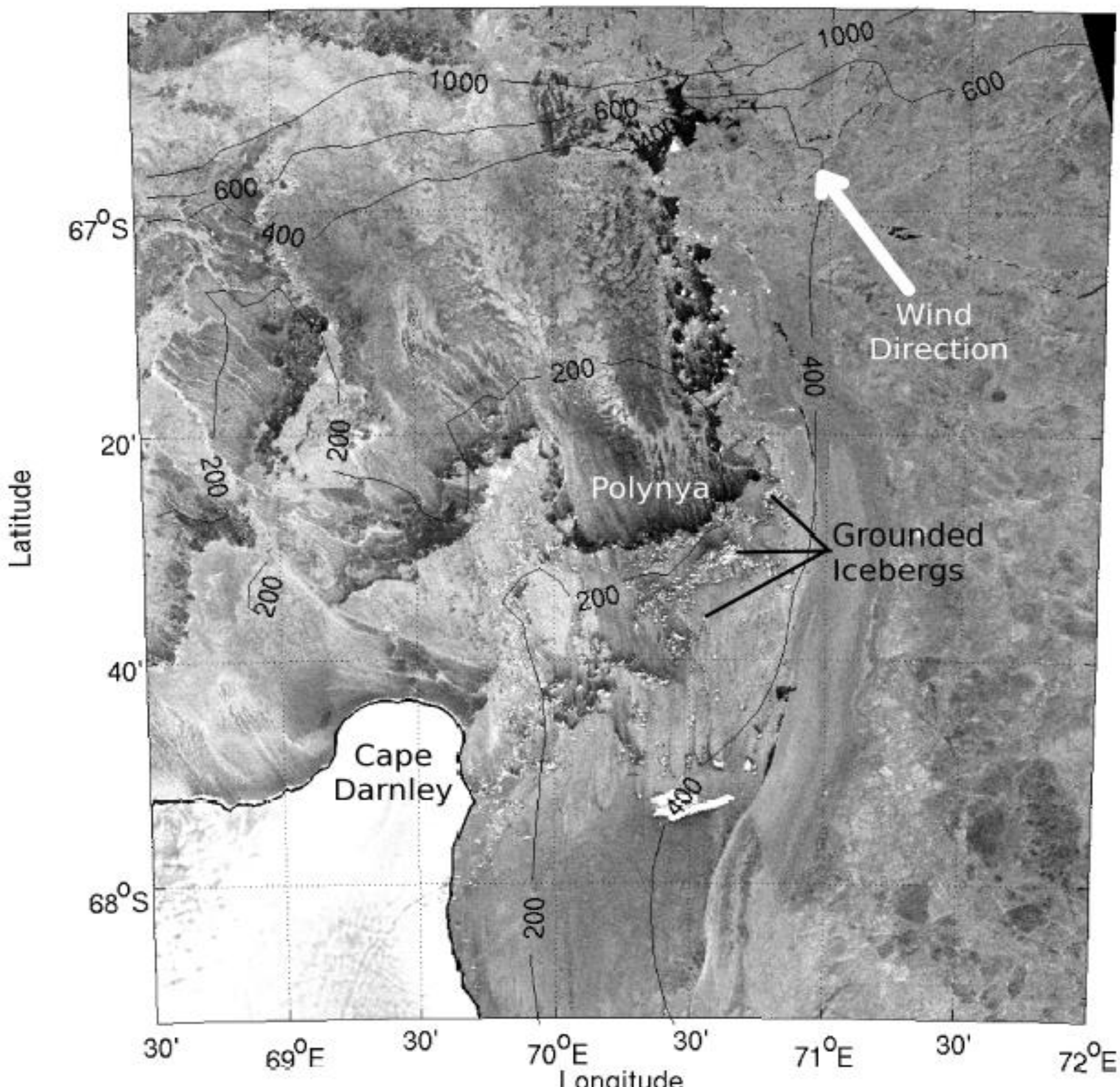
•Bottom panel: time series of surface fluxes from 3 main polynyas

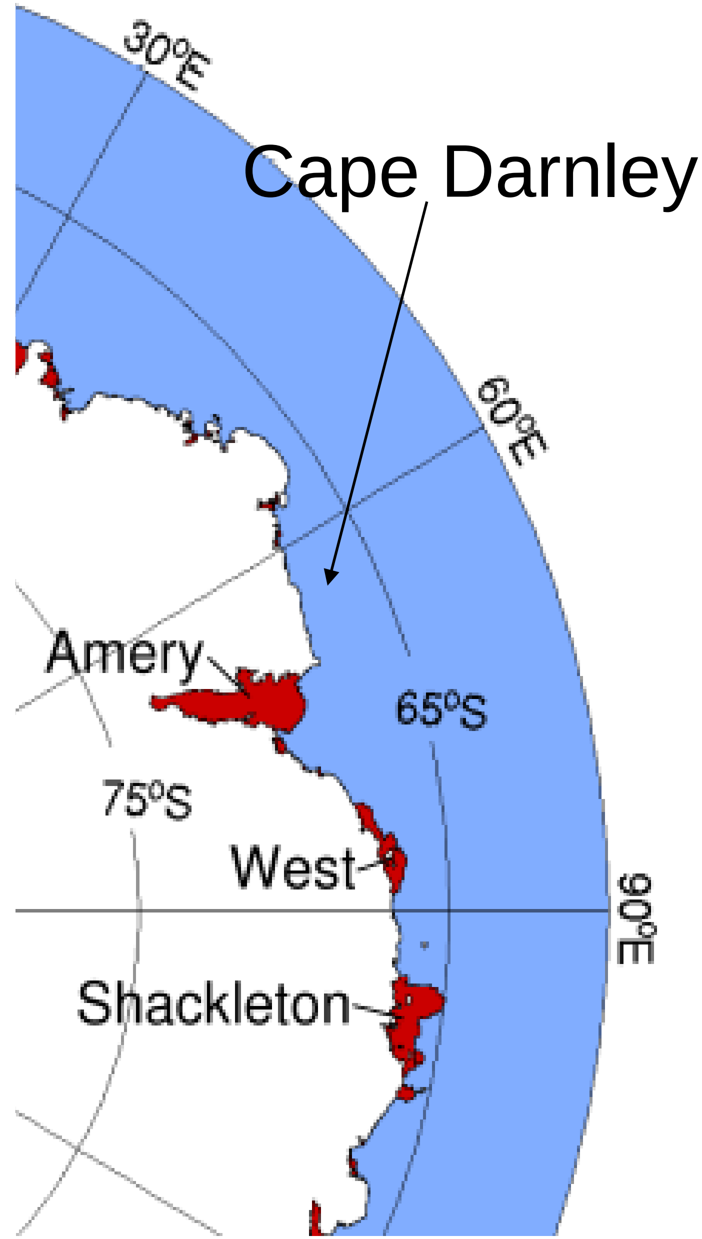
•Polynyas in the region:

Cape Darnley
Mackenzie
Barrier

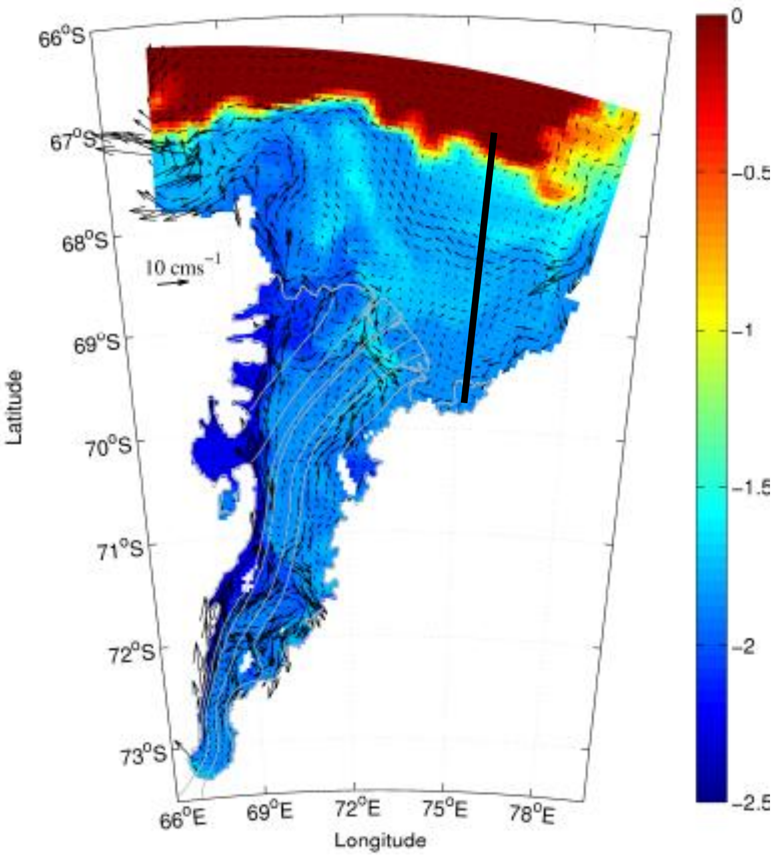
• Is the Amery Ice Shelf/ Prydz bay system a region Of AABW production?

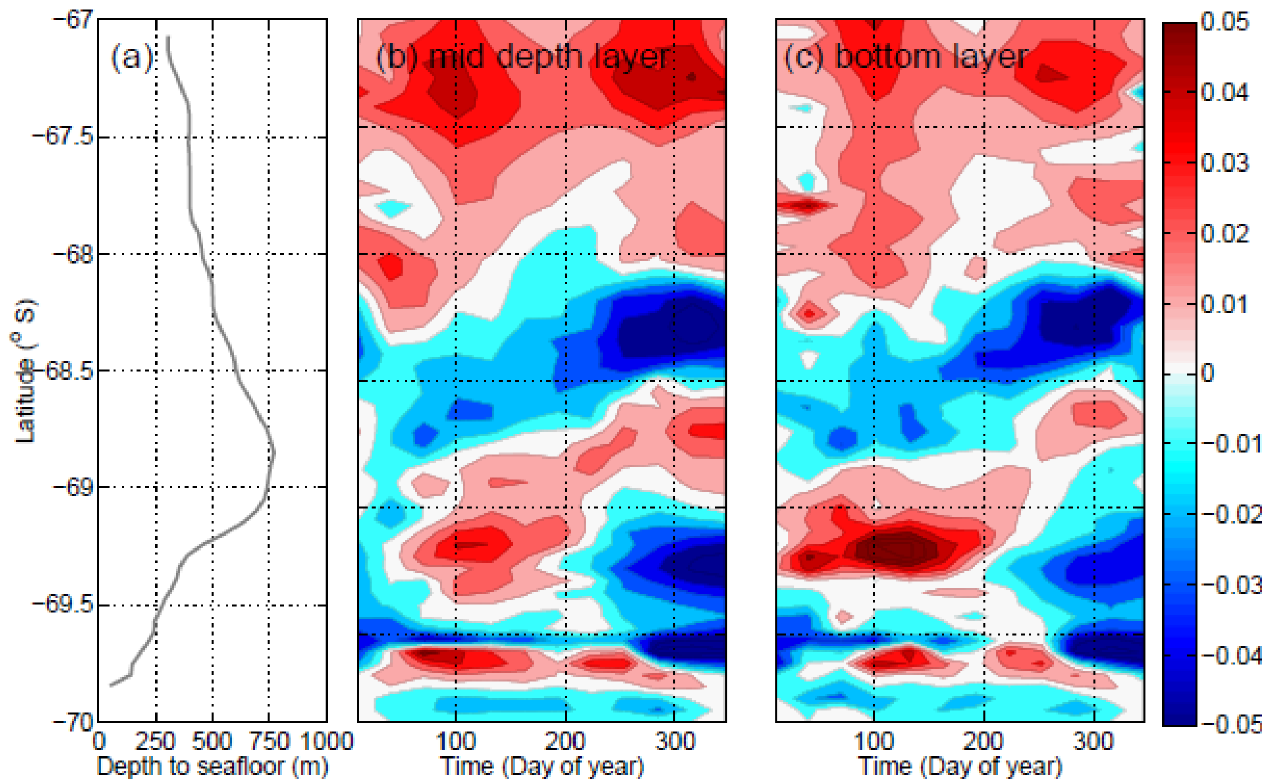
Imposed air-sea fluxes captures subgridscale features



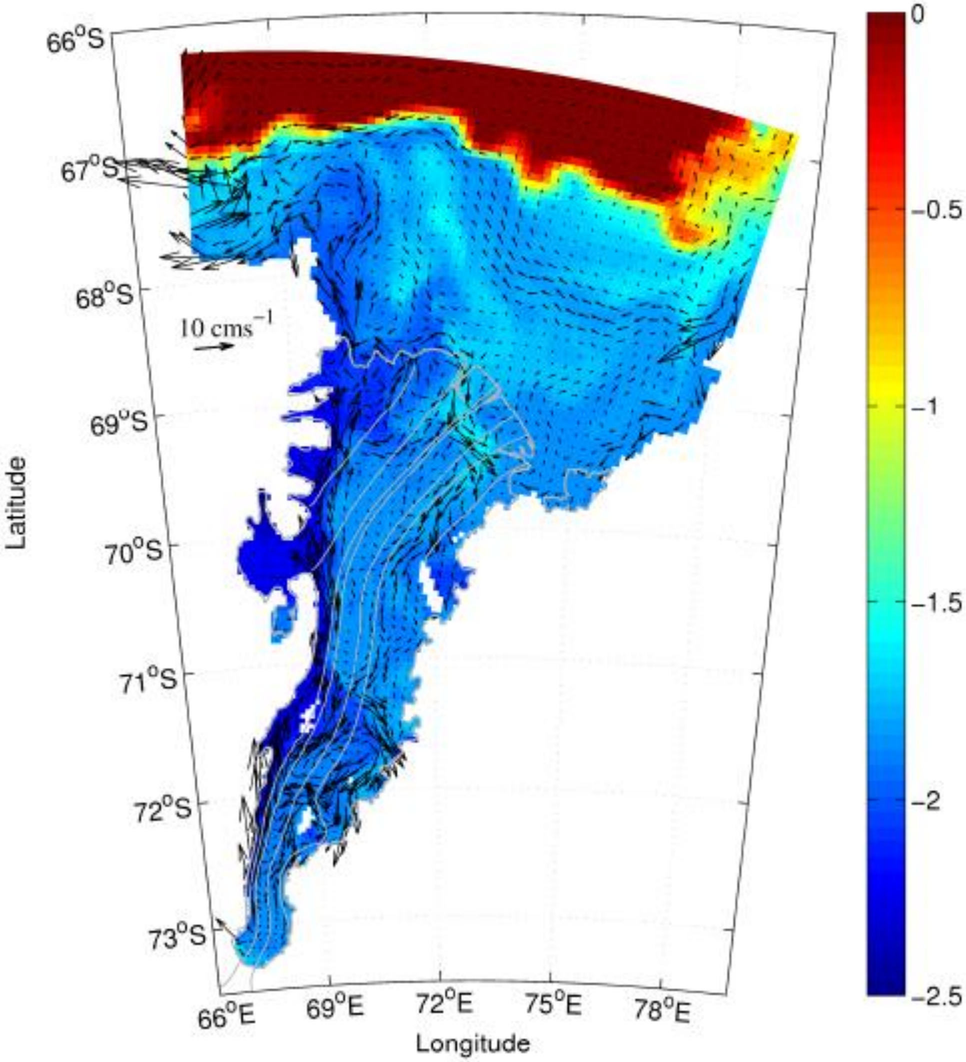


Winter Circulation

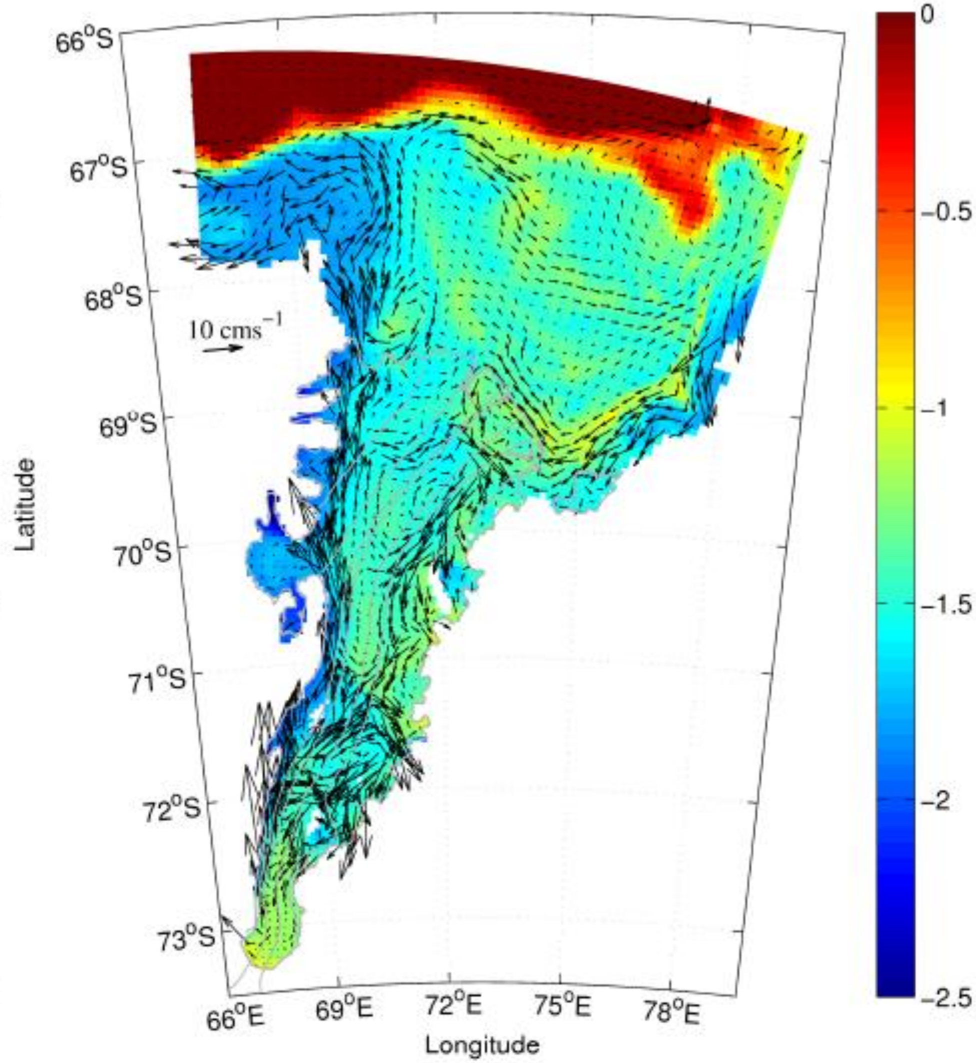




Polynyas control circulation and melt/freeze

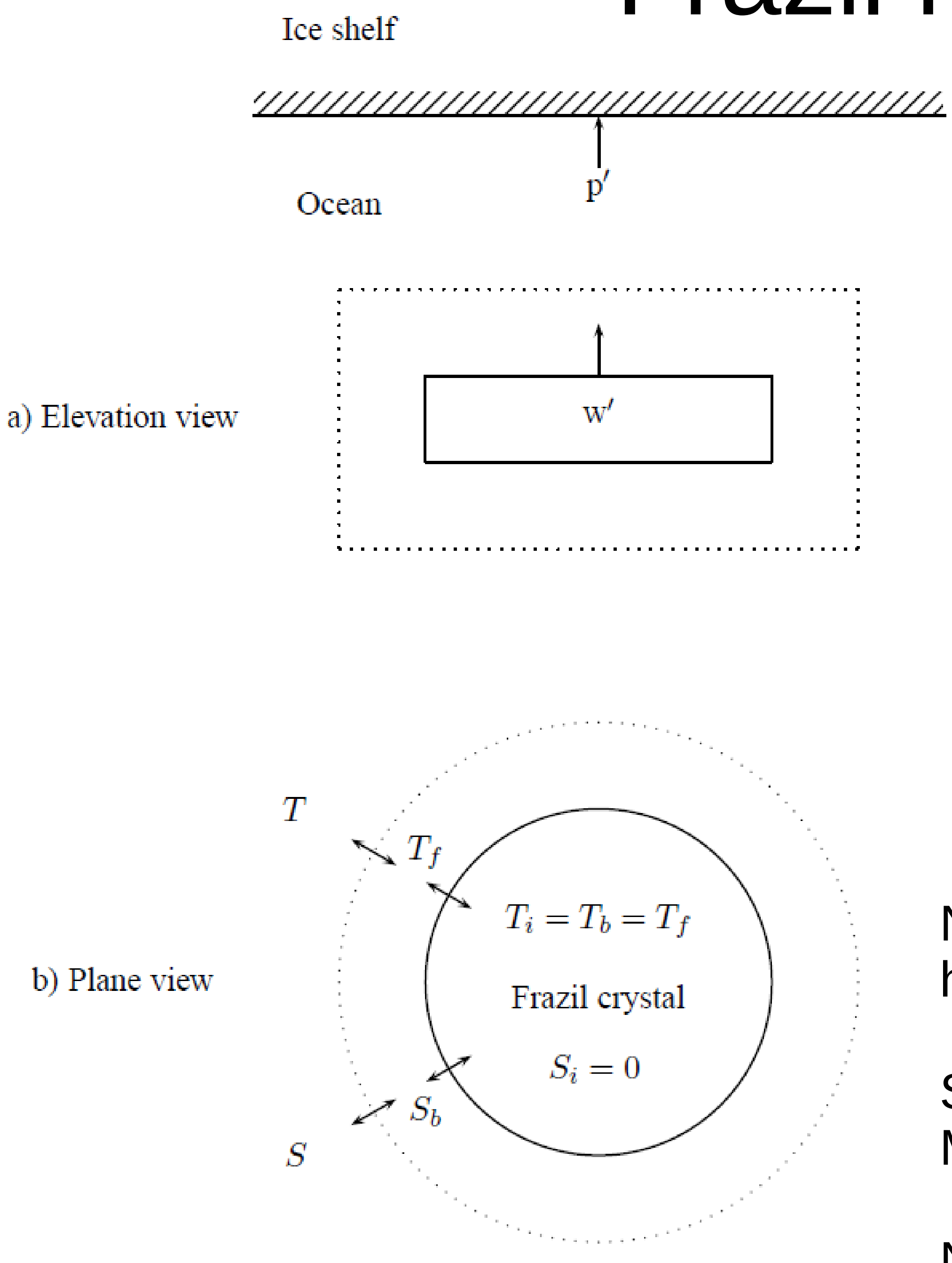


(a) Reference simulation



(b) Reference without Barrier polynya

Frazil modelling



Analogous to basal conditions.
Conservation of heat and salt:

$$\rho_i L f' = \rho c_w \gamma'_T \mathcal{A}(T_b - T)$$

$$\rho_i S_b f' = \rho \gamma'_S \mathcal{A}(S_b - S)$$

where:

$$\gamma'_T = \frac{Nu k_T}{r a_r}$$

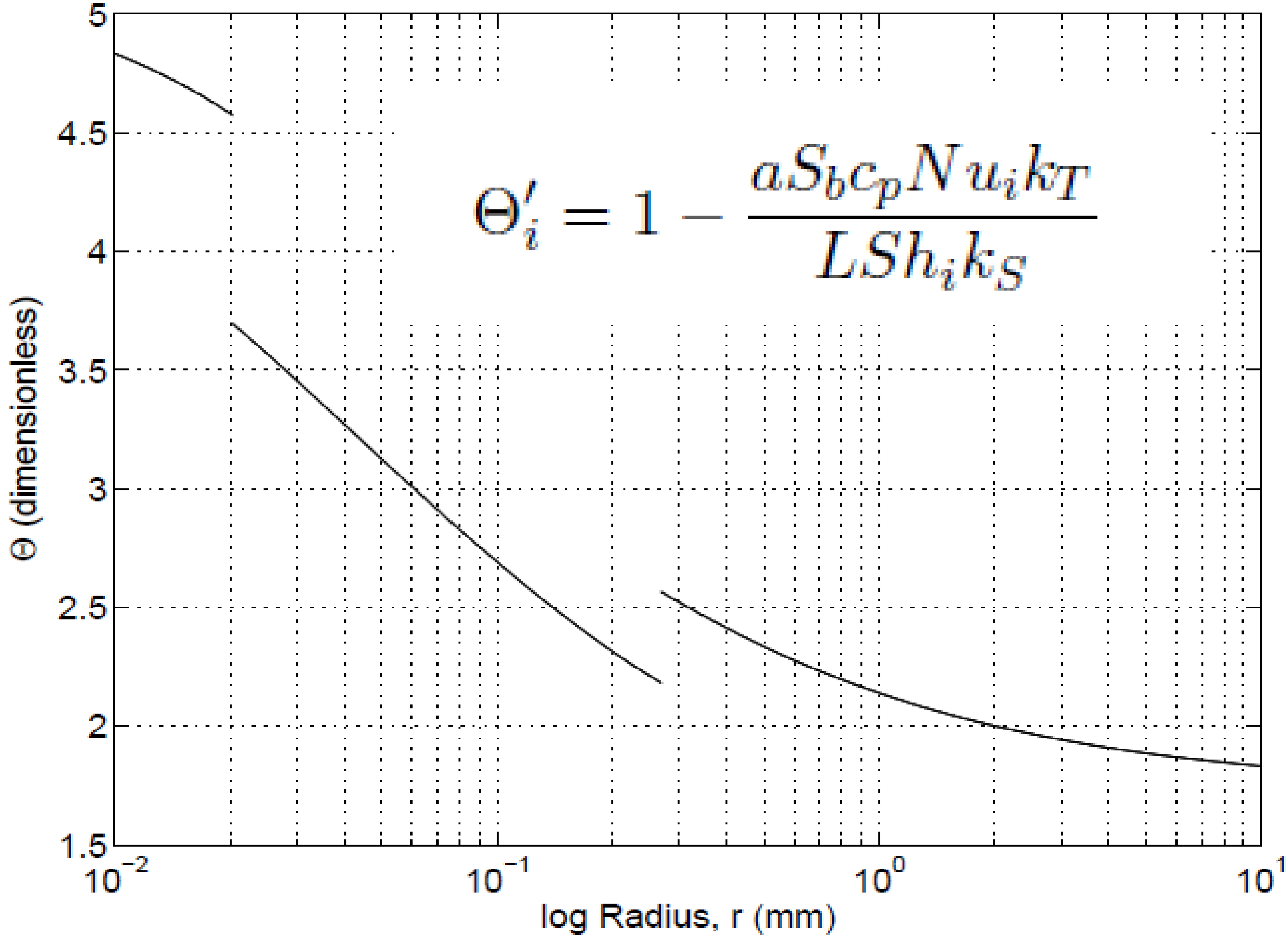
$$\gamma'_S = \frac{Sh k_S}{r a_r}$$

Nu = Nusselt number. Ratio of convective heat transfer to total heat transfer

Sh = Sherwood number.
Mass transfer analogy of Nu

Nu and Sh both scale with crystal size

Scaling Factor Θ’



- The effect of salt is more important for smaller crystals and can be included by utilising a scaling factor