Photo credit: Steve Nicholls

Ocean Interactions with the Antarctic Ice Shelves In East Antarctica

Laura Herraiz–Borreguero, National Oceanographic Centre-Southampton, UK

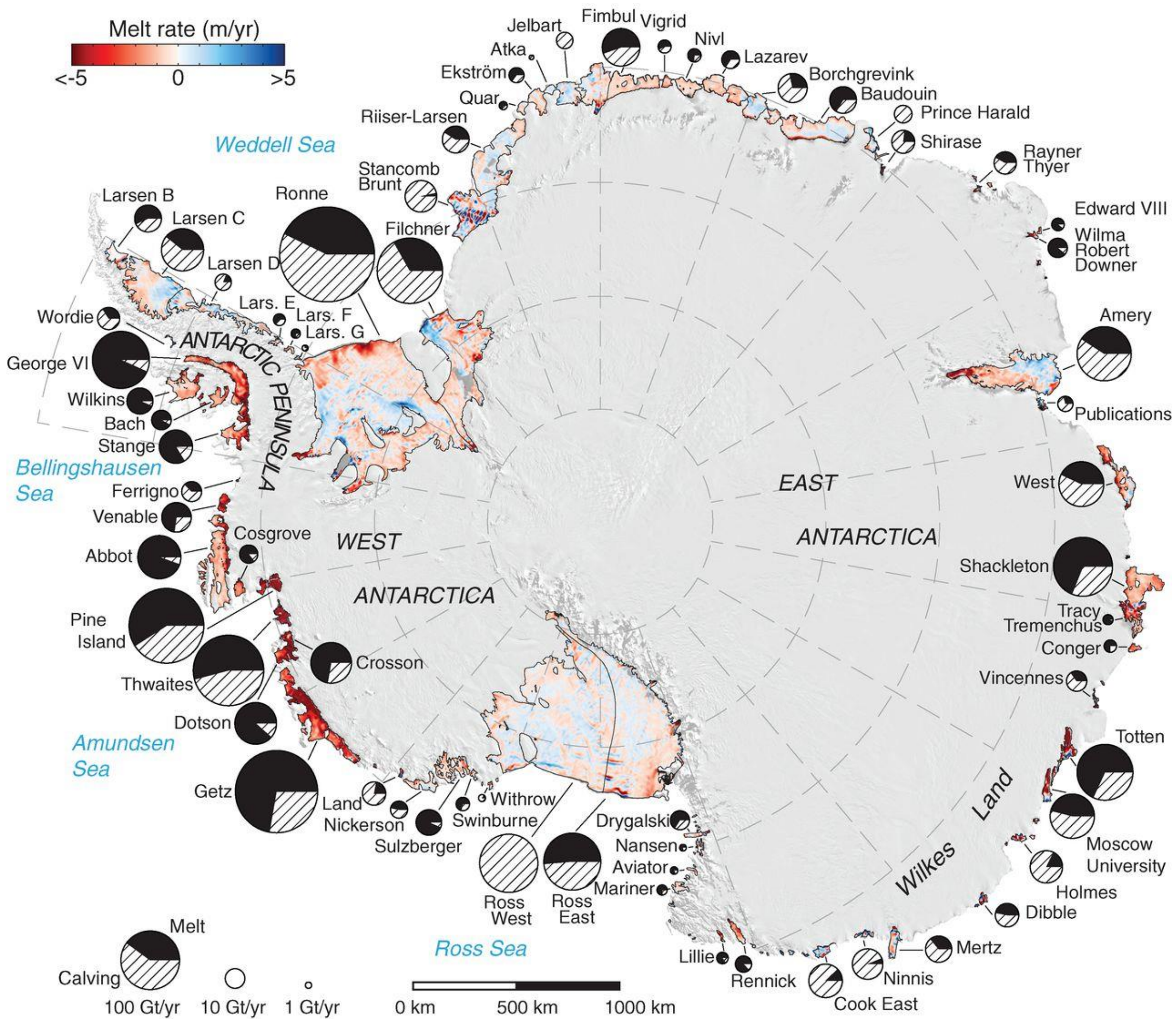
Peter Schlosser and Robert Newton, LDEO, USA

Steve Rintoul, Beatriz Peña-Molino, ACECRC, Australia

MARIE CURIE ACTIONS

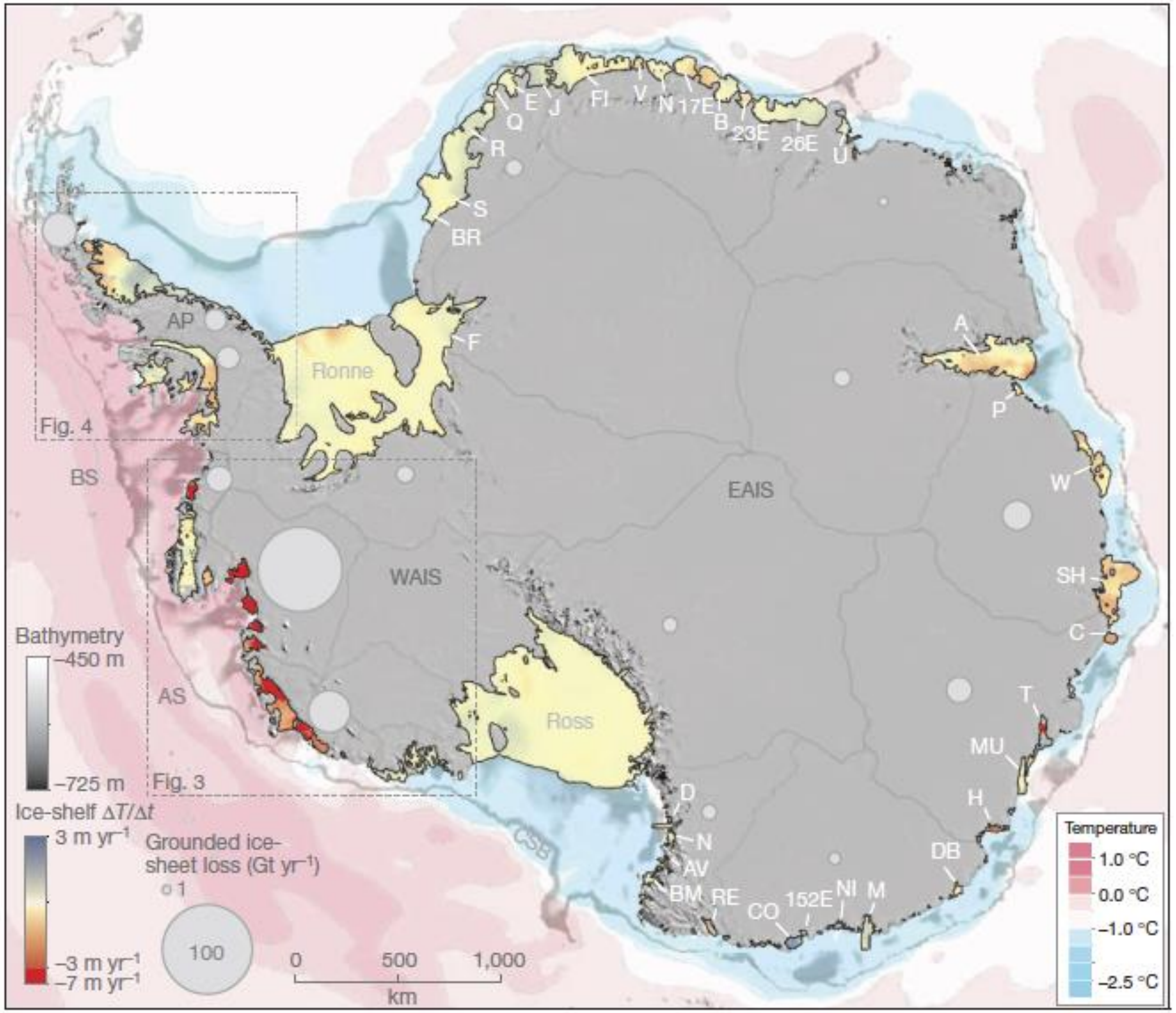
1. East Antarctic ice shelves
2. Amery ice shelf
3. Meltwater tracers: noble gases

Fig. 1 Basal melt rates of Antarctic ice shelves.Color coded from <–5 m/year (freezing) to >+5 m/year (melting) and overlaid on a 2009 Moderate Resolution Imaging Spectroradiometer mosaic of Antarctica.



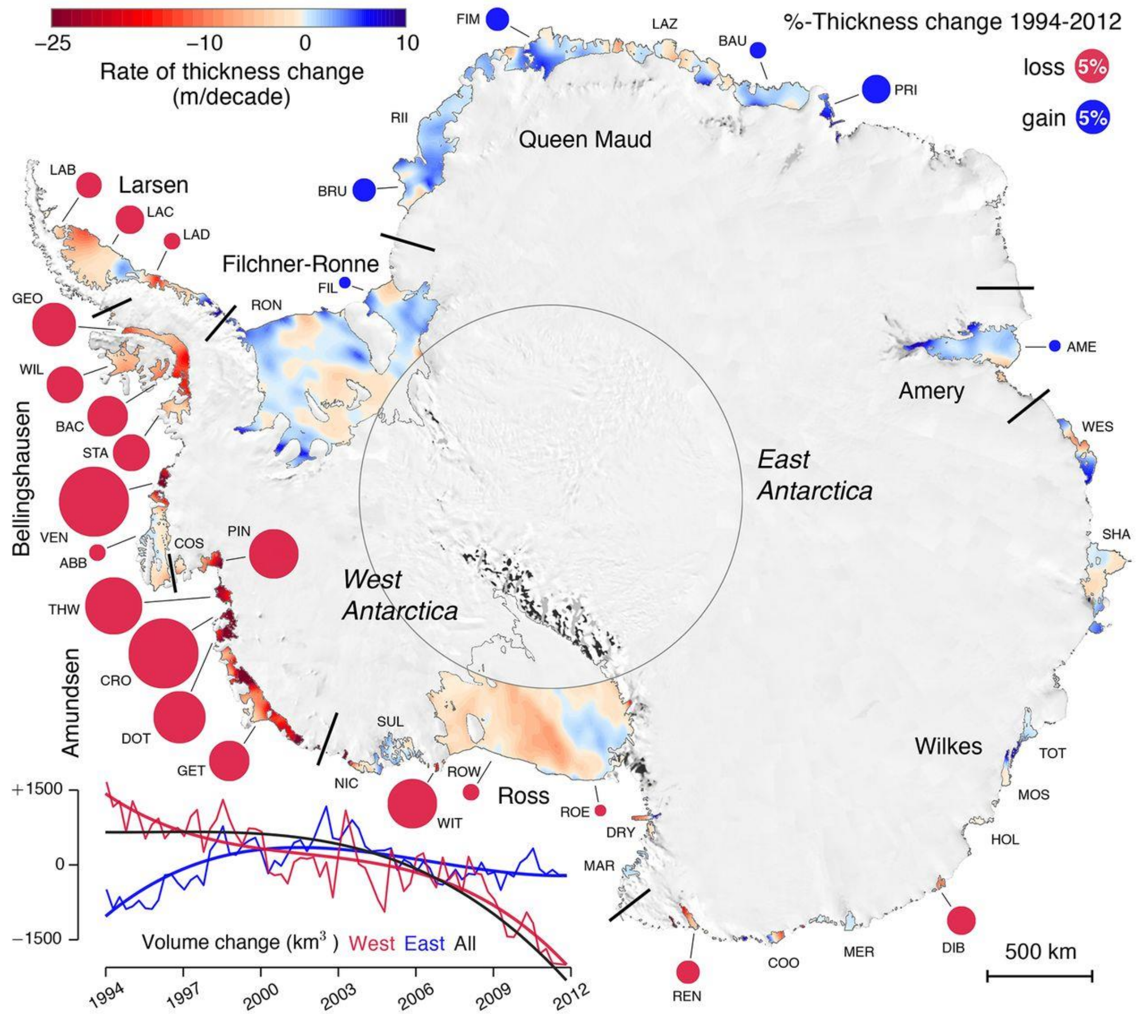
Rignot et al., 2013

Antarctic ice–shelf ice–thickness change rate ΔT/Δt, 2003–2008



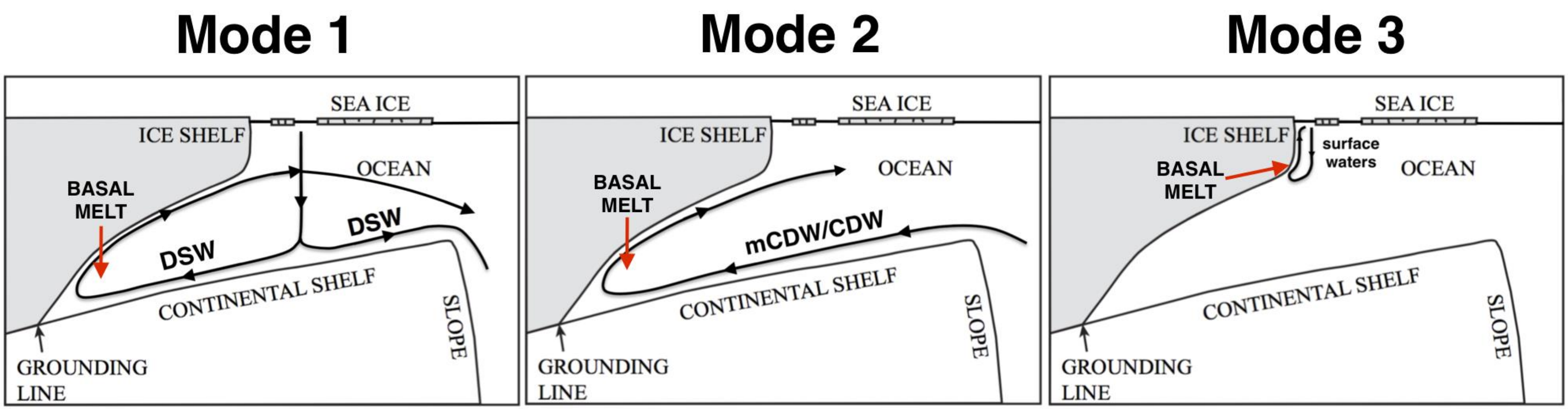
Pritchard et al., 2012

Fig. 1 Eighteen years of change in thickness and volume of Antarctic ice shelves.Rates of thickness change (m/decade) are color-coded from -25 (thinning) to +10 (thickening).



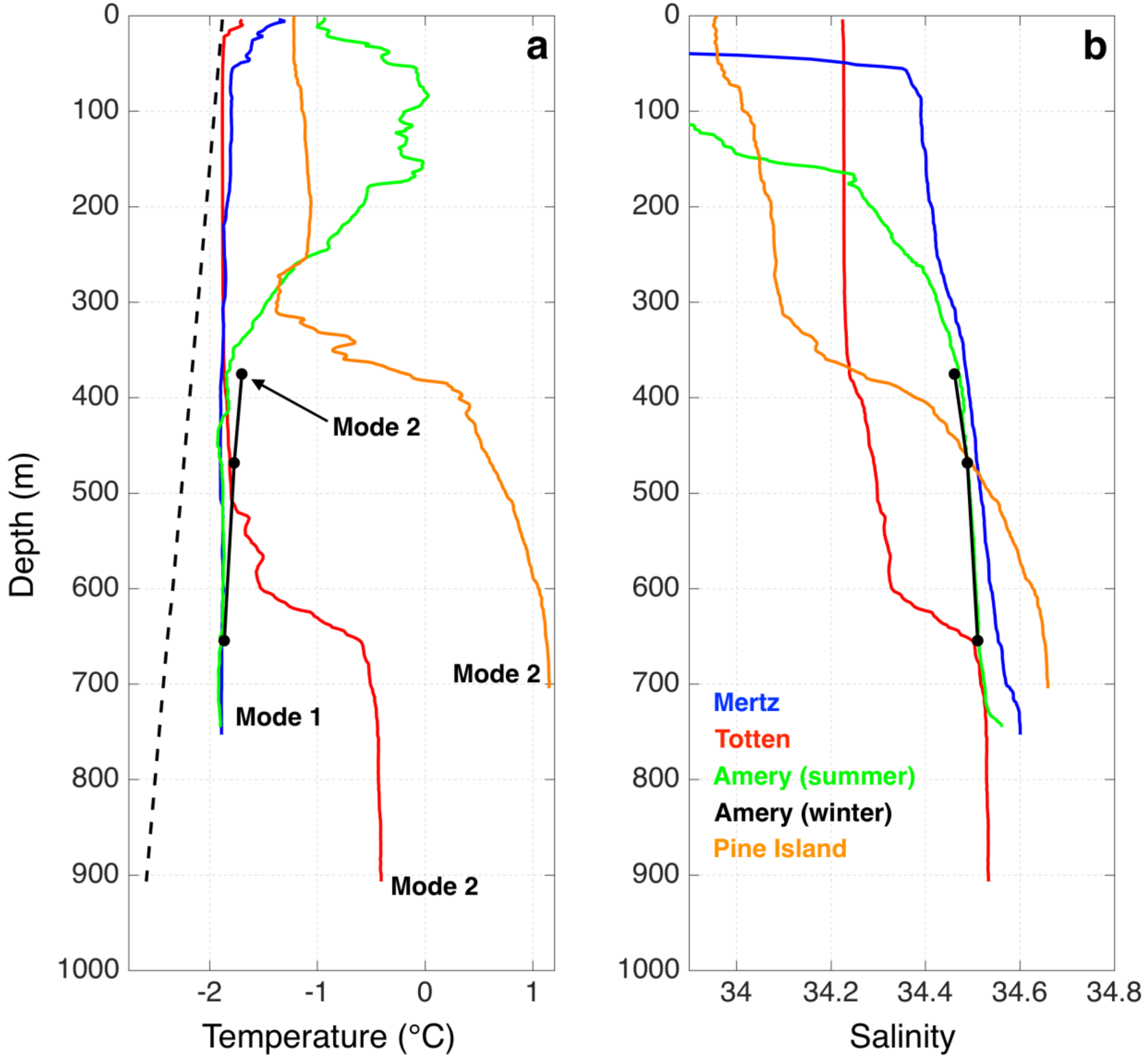
Paolo et al., 2015

Silvano, Rintoul and Herraiz-Borreguero
Oceanography 29(4):130–143,
https://doi.org/10.5670/oceanog.2016.105.

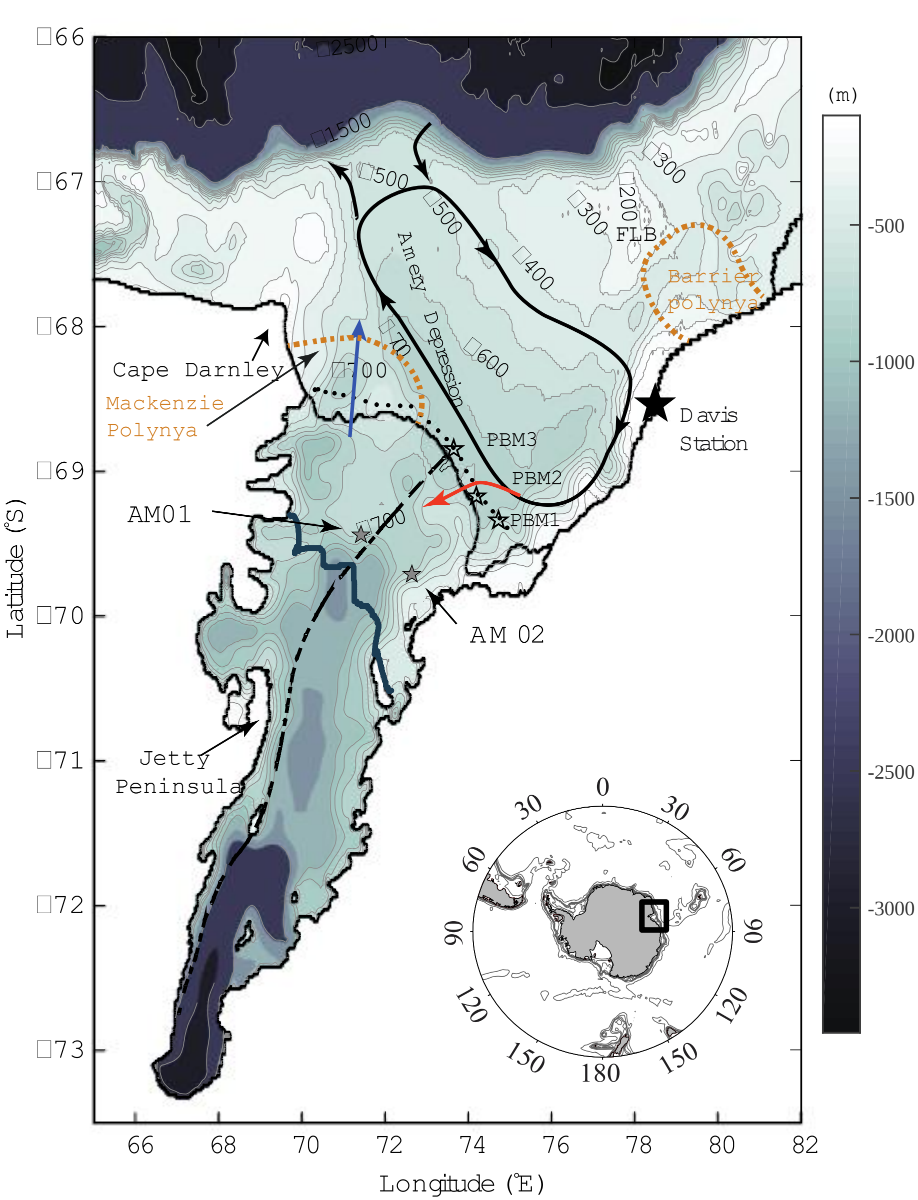


Mertz Glacial Tongue

Water properties of the strongest inflow to ice-shelf cavities in East and West Antarctica.



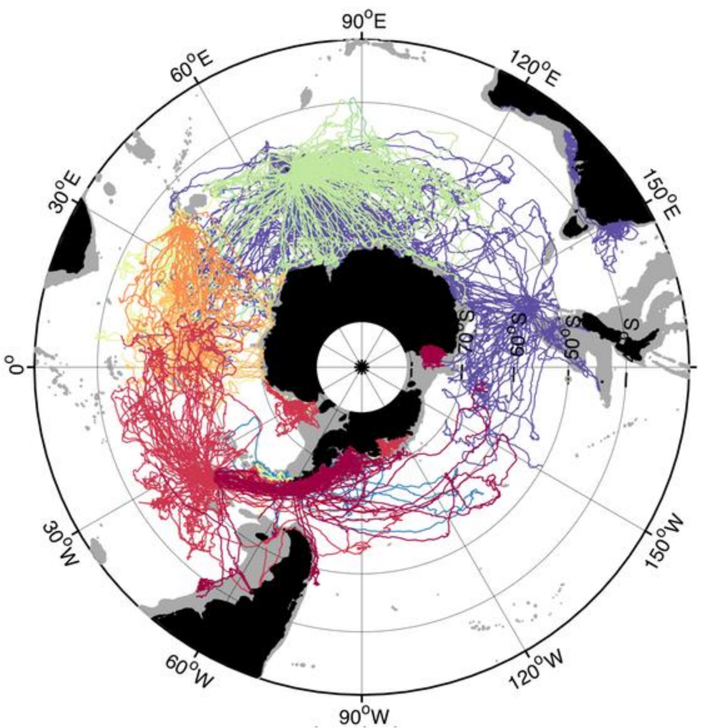
Prydz Bay-Amery ice shelf system: observational platforms

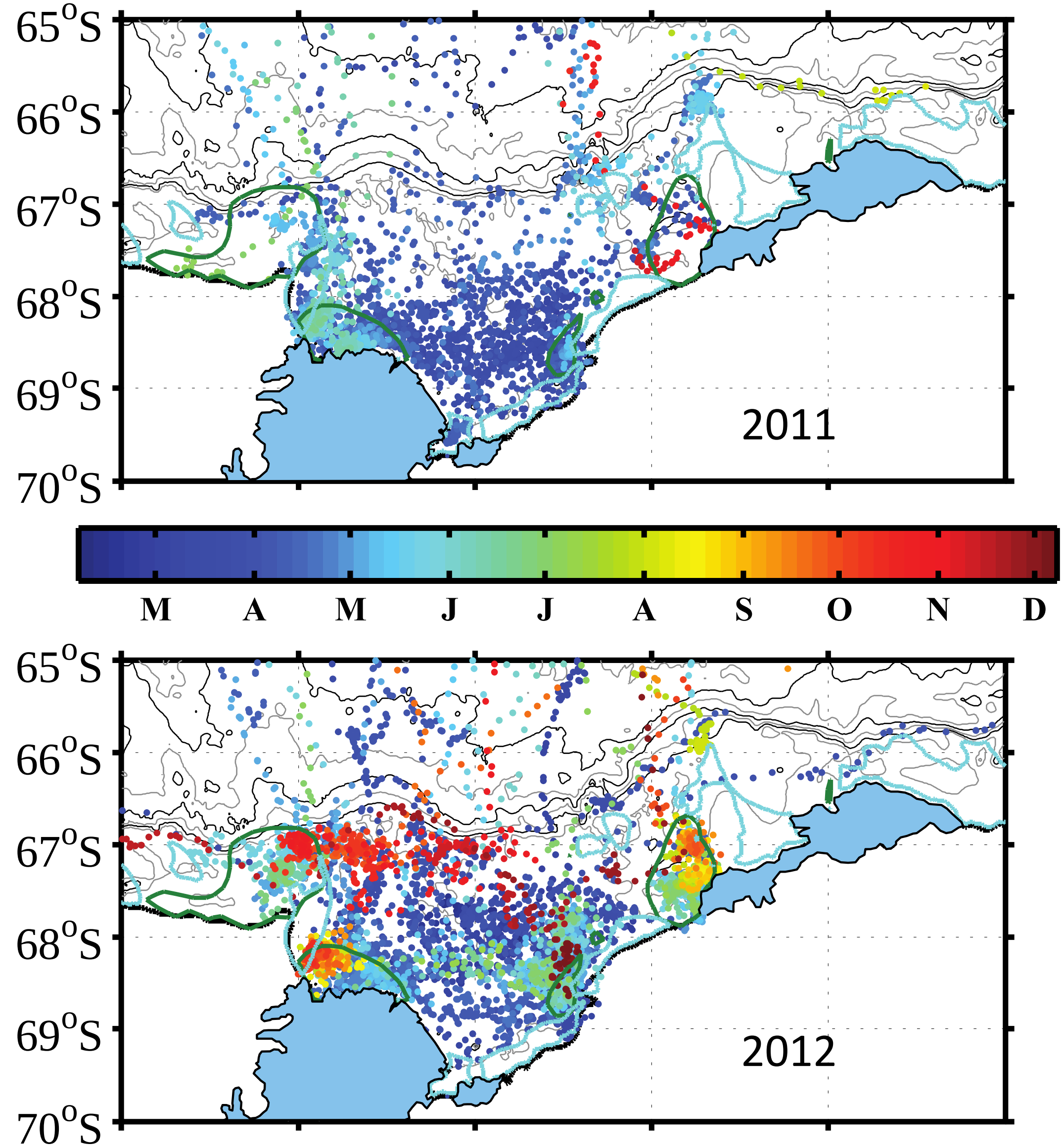


Instrumented marine mammals
(high spatial and temporal coverage)

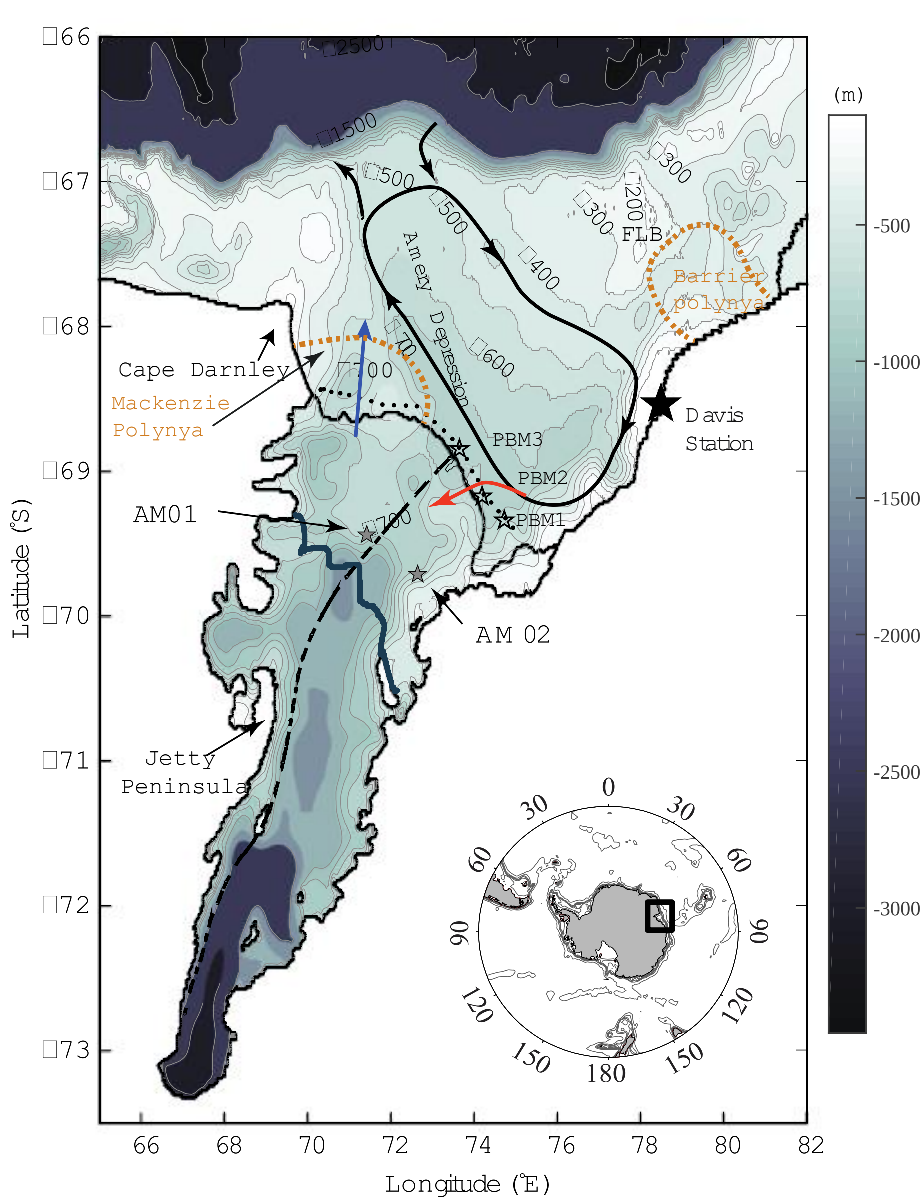
Herraiz-Borreguero et al., 2015; 2016

Prydz Bay-Amery ice shelf system: observational platforms



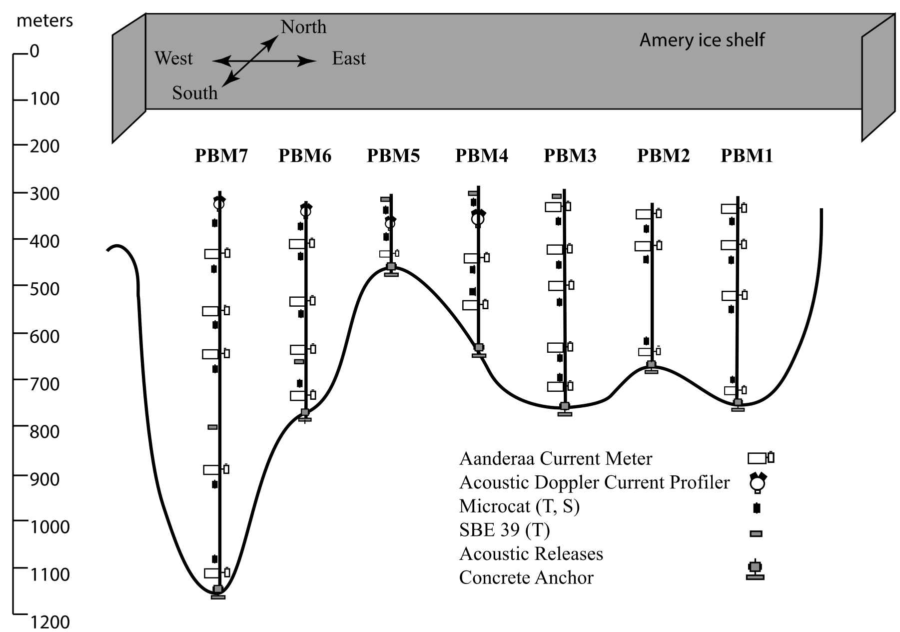


Prydz Bay-Amery ice shelf system: observational platforms



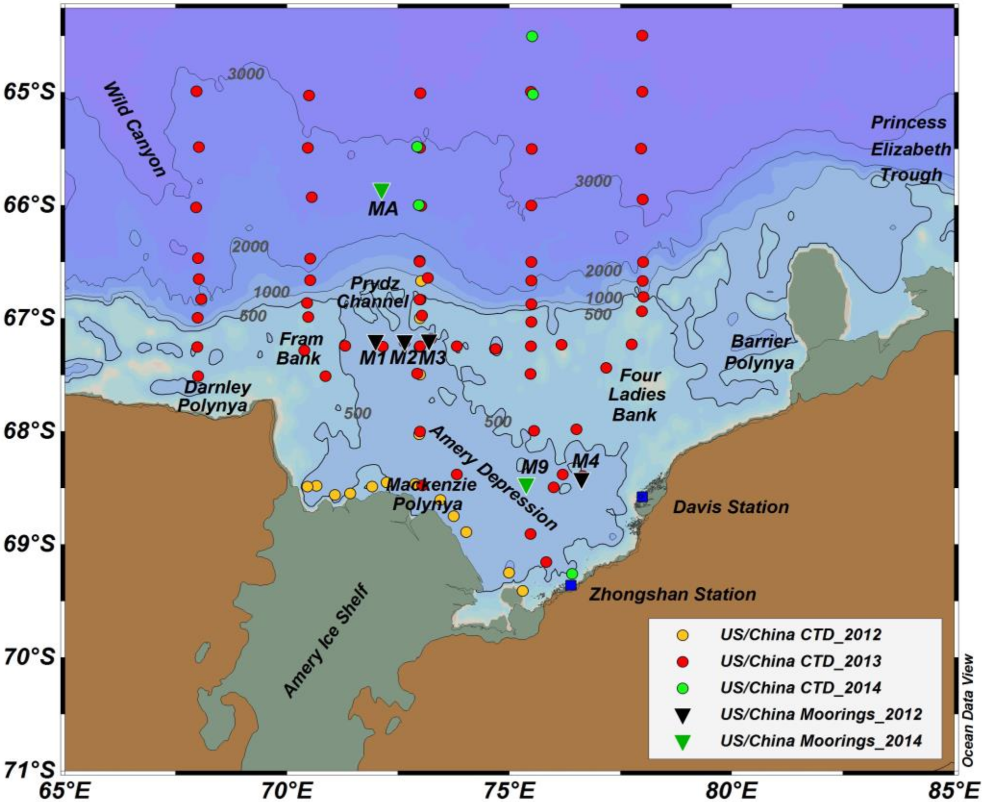
Open ocean instrumented moorings (temporal resolution)

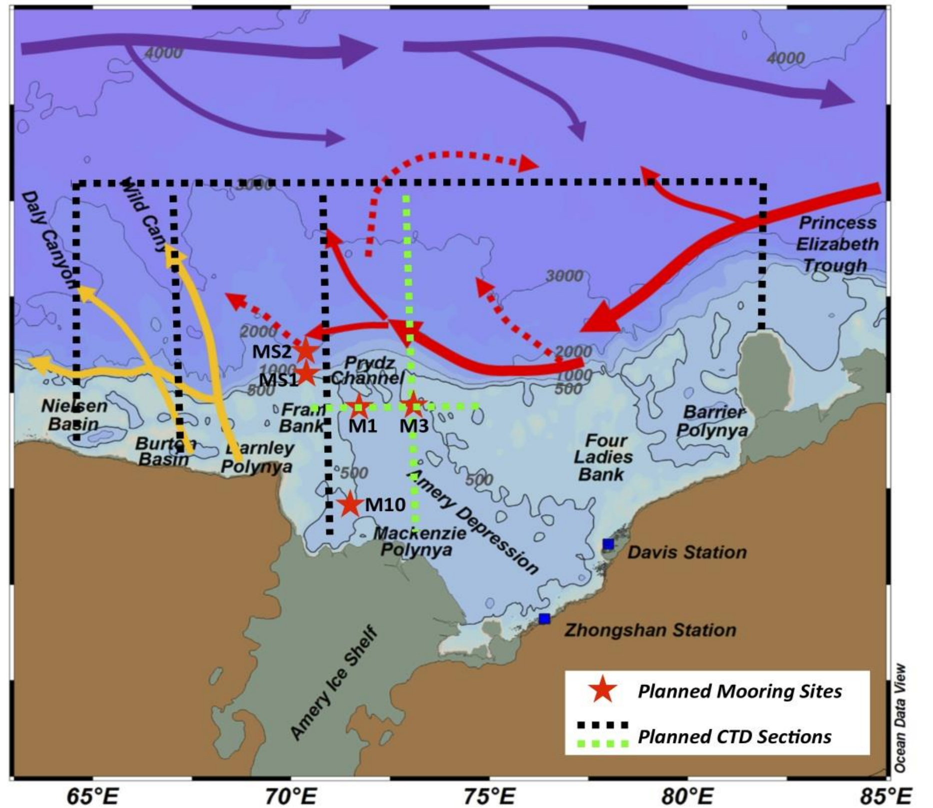
Ship-based CTD profiles (vertical resolution)



Herraiz-Borreguero et al., 2015; 2016

Prydz Bay-Amery ice shelf system: observational platforms



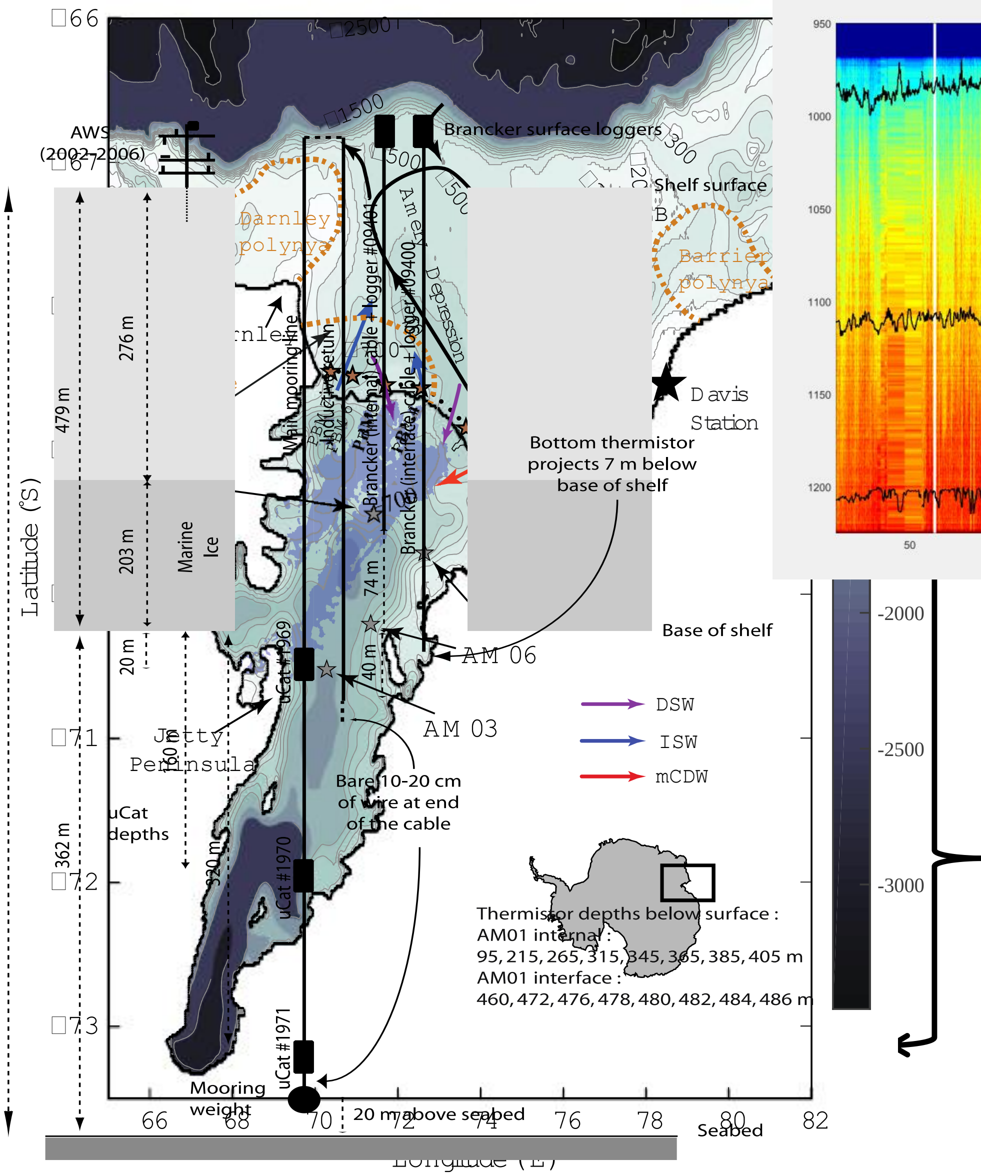


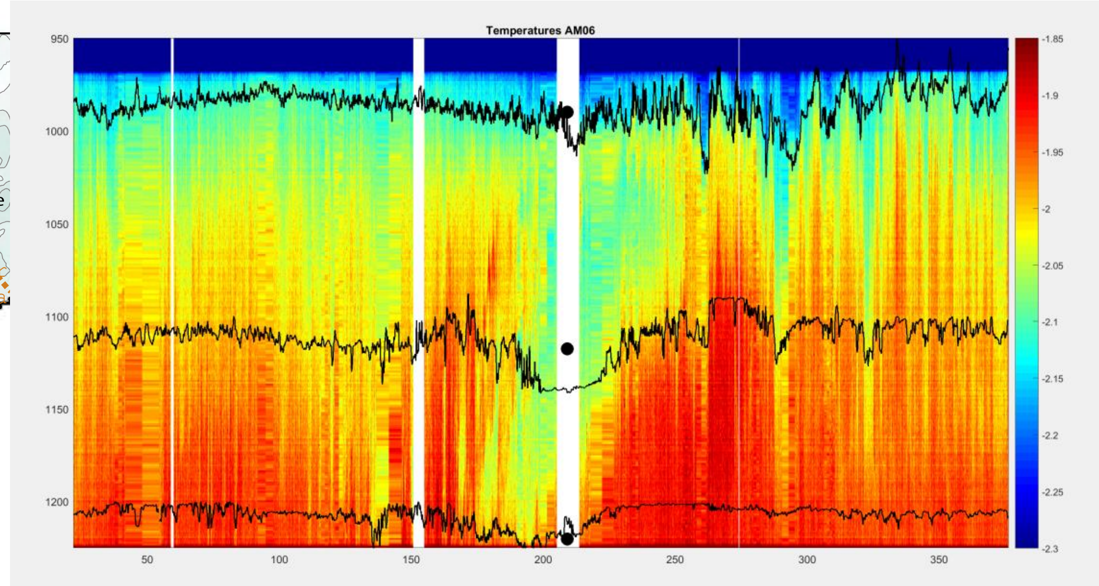
U.S./Chinese Collaborative Study: Investigation of Bottom Water Formation in Prydz Bay, Antarctica

www.soos.aq, Xiaojun Yuan (LDEO)

Prydz Bay-Amery ice shelf system: observational platforms ?

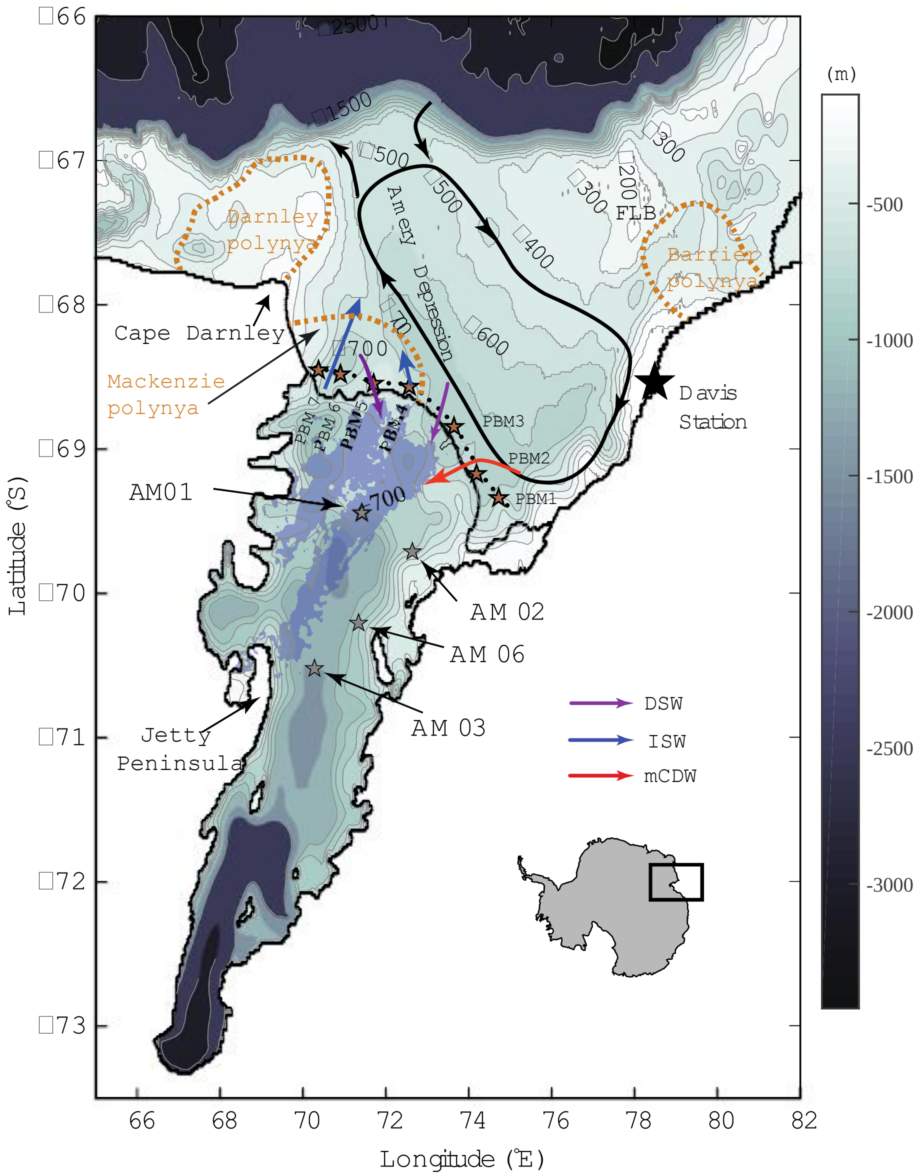
Warner et al., IGS 2016



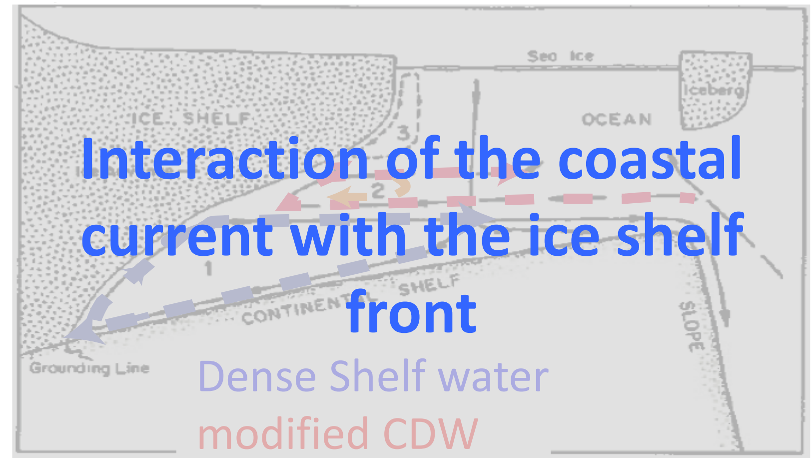


Oceanographic moorings and optic fiber deployed through the ice shelf

Prydz Bay-Amery ice shelf system: what do we know ?



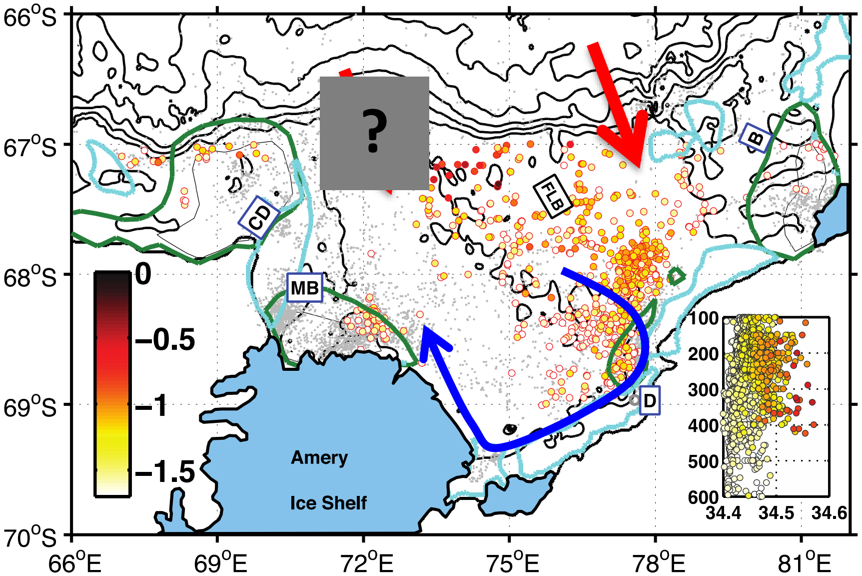
Eastern Side: Mode 1 and 2 overlap during the autumn-winter months



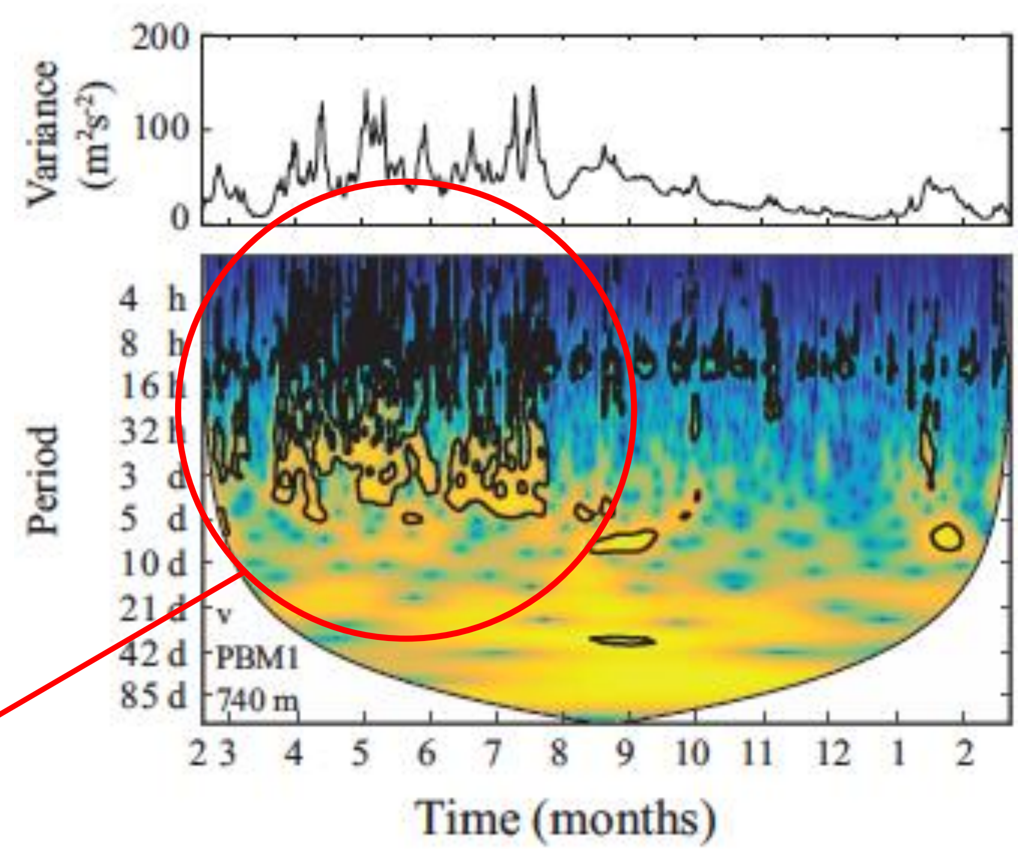
Western side: Mode 1 dominates the circulation beneath the AIS

Herraiz-Borreguero et al., 2015; 2016

Prydz Bay-Amery ice shelf system: mCDW inflow and coastal current



Wavelet analyses of PBM1, at 740 m

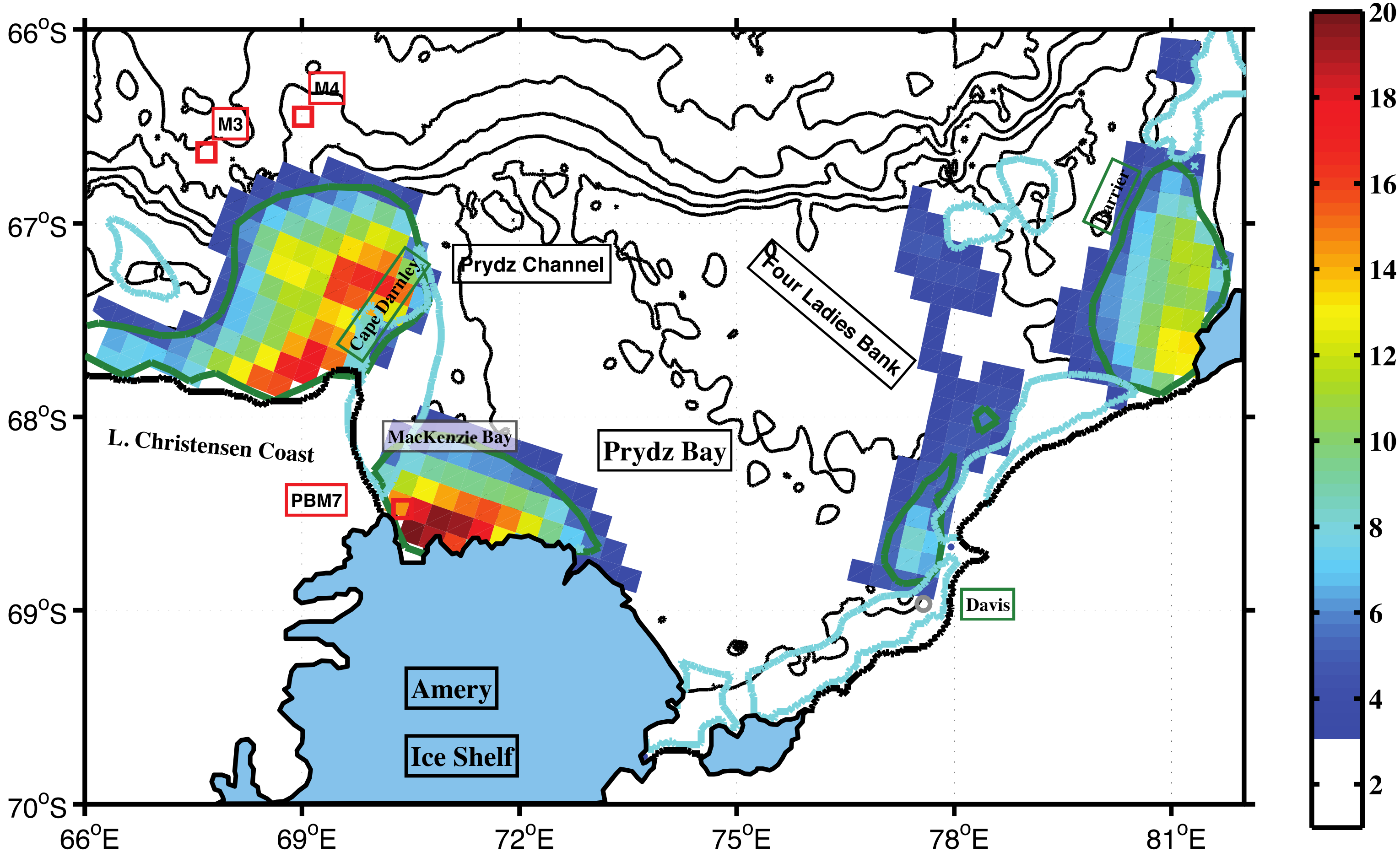


In regional scales, conservation of potential vorticity causes the flow to follow contours of constant depth. Thus, the ice shelf constitutes a barrier for the flow to enter the ice shelf cavity.

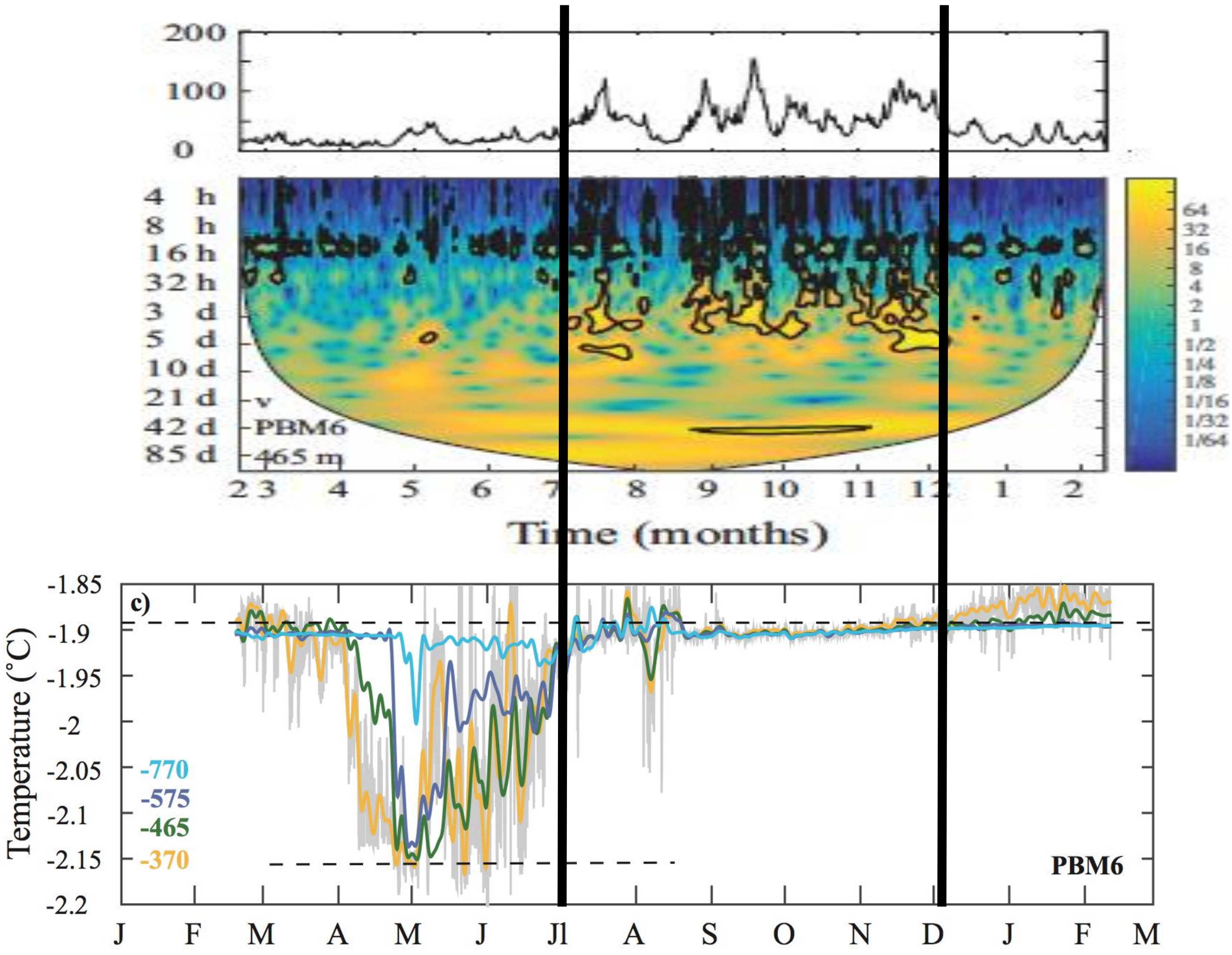
Eddies and coastally-trapped waves

Herraiz-Borreguero et al., 2015; 2016

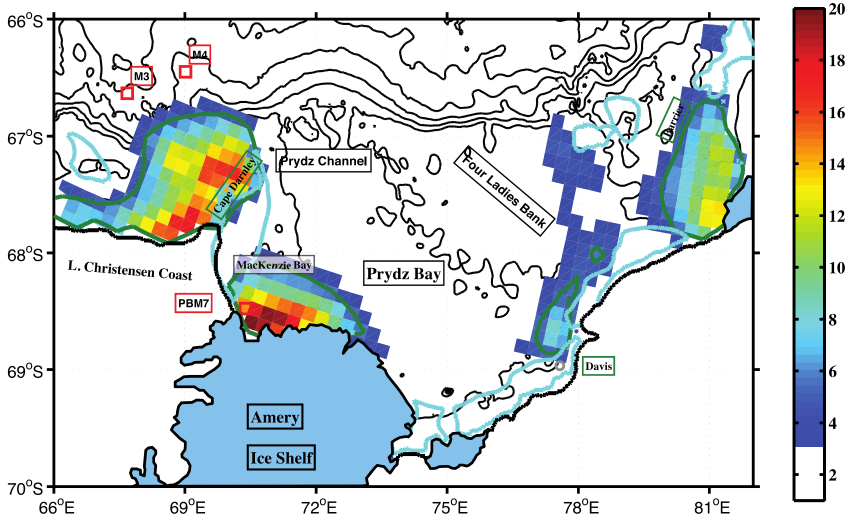
Prydz Bay-Amery ice shelf system: Mackensie Polynya and ocean circulation variability

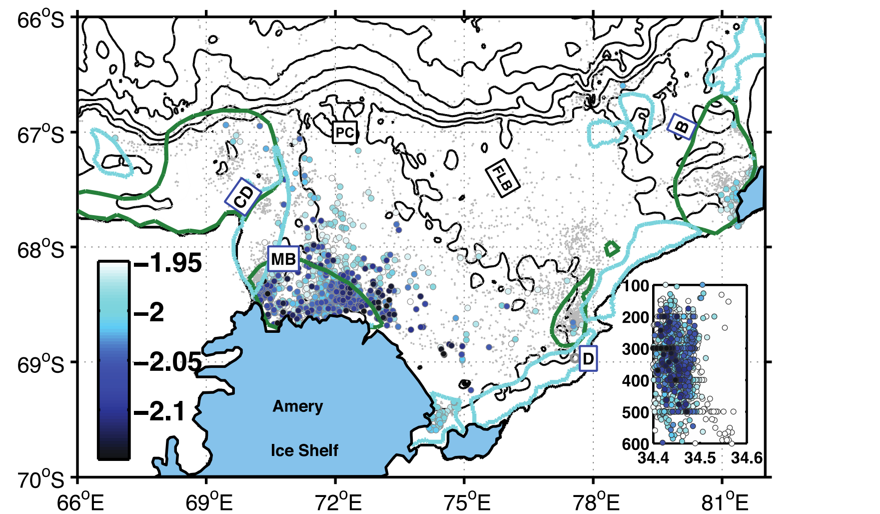


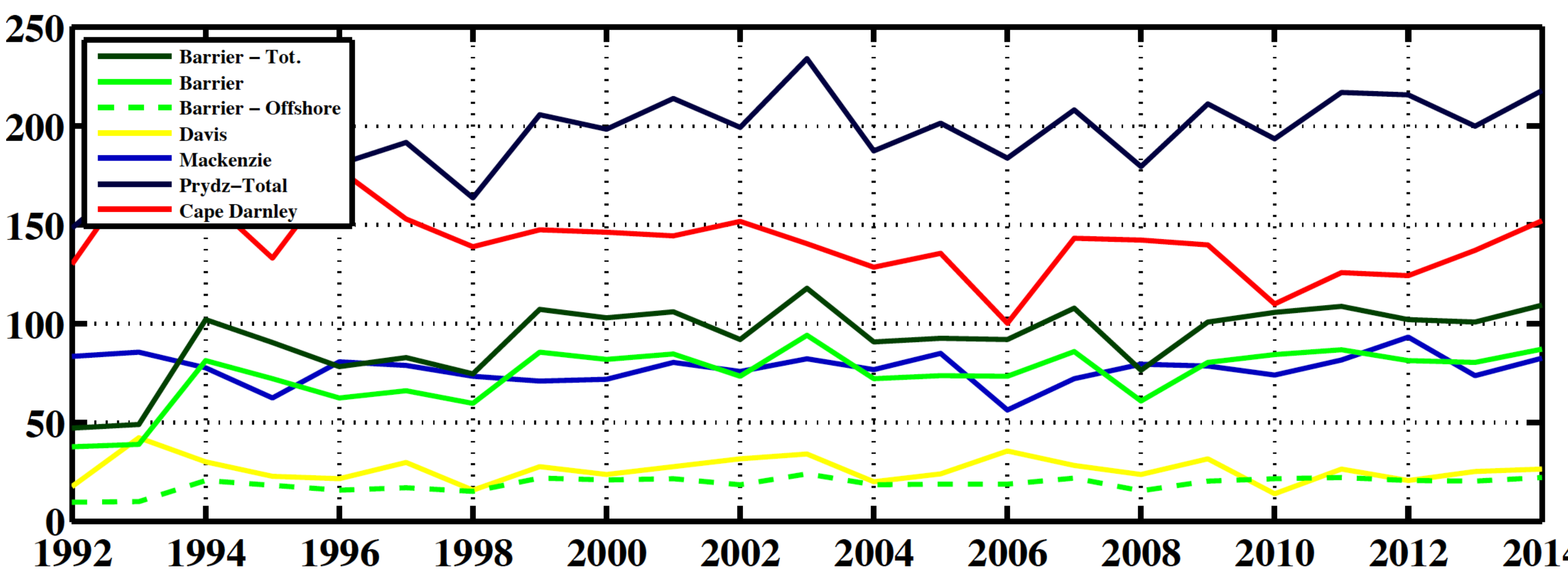
Prydz Bay-Amery ice shelf system: Mackensie Polynya and ocean circulation variability



Prydz Bay-Amery ice shelf system: Mackensie Polynya and ocean circulation variability

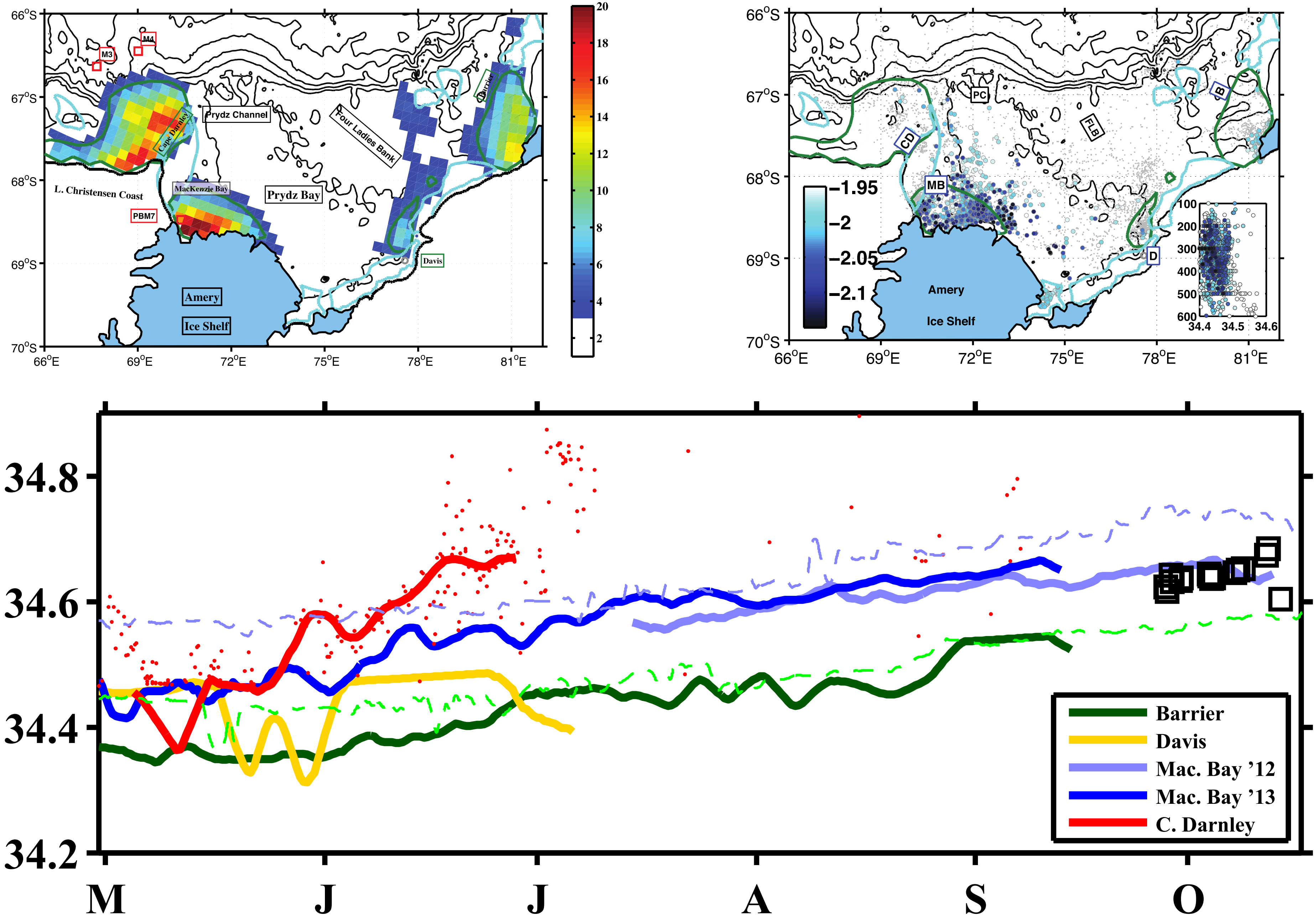






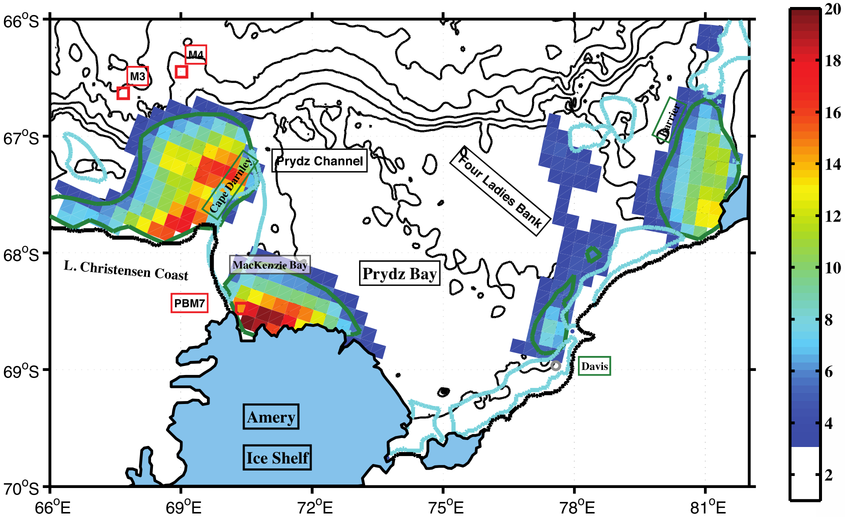
Williams et al., 2016

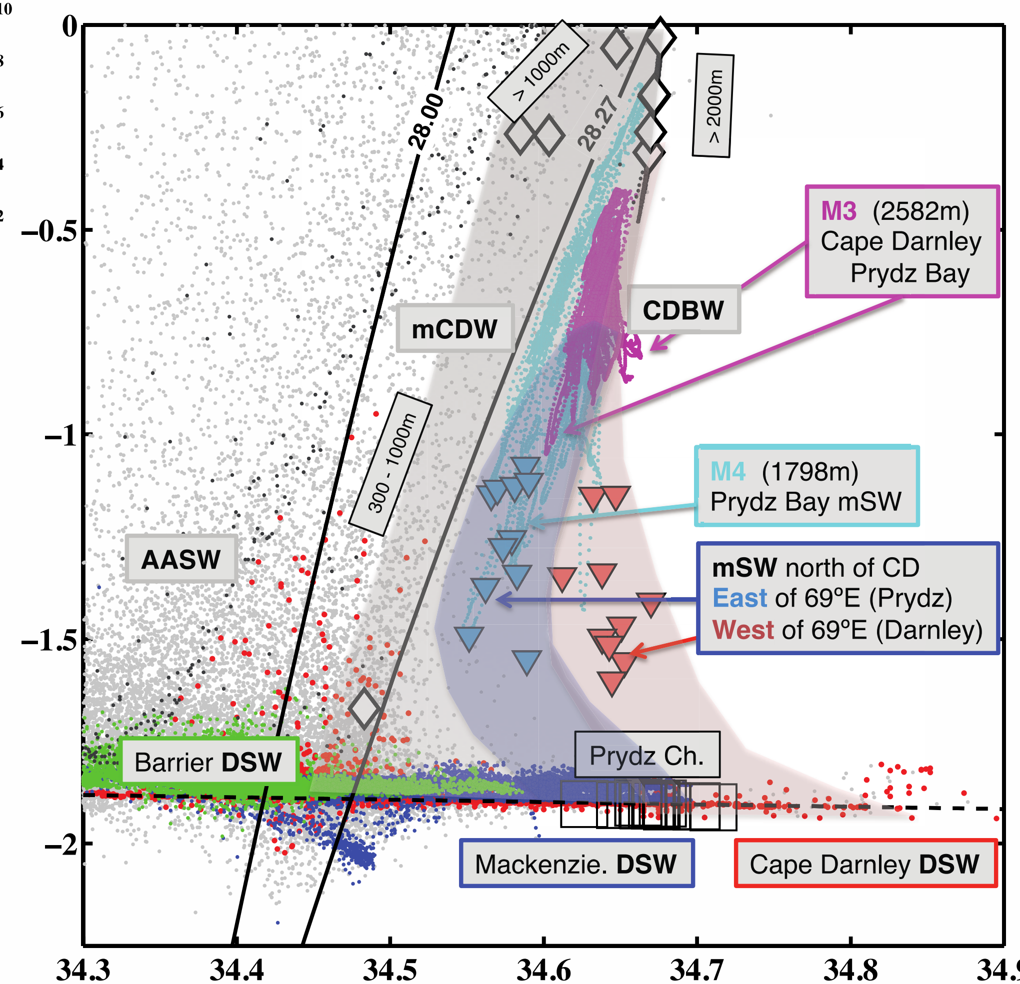
Prydz Bay-Amery ice shelf system: Mackensie Polynya and ocean circulation variability



Williams et al., 2016

Prydz Bay-Amery ice shelf system: Mackensie Polynya and ocean circulation variability

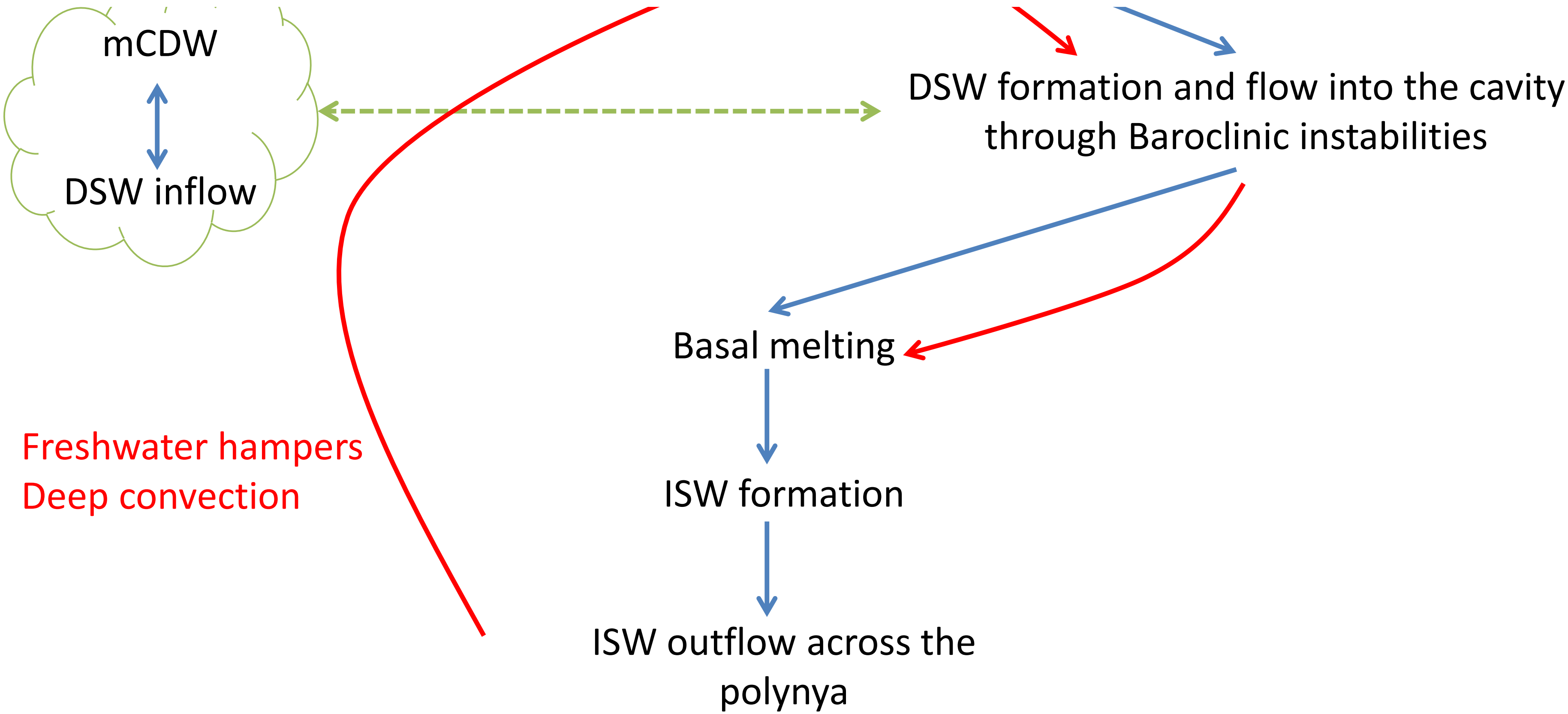


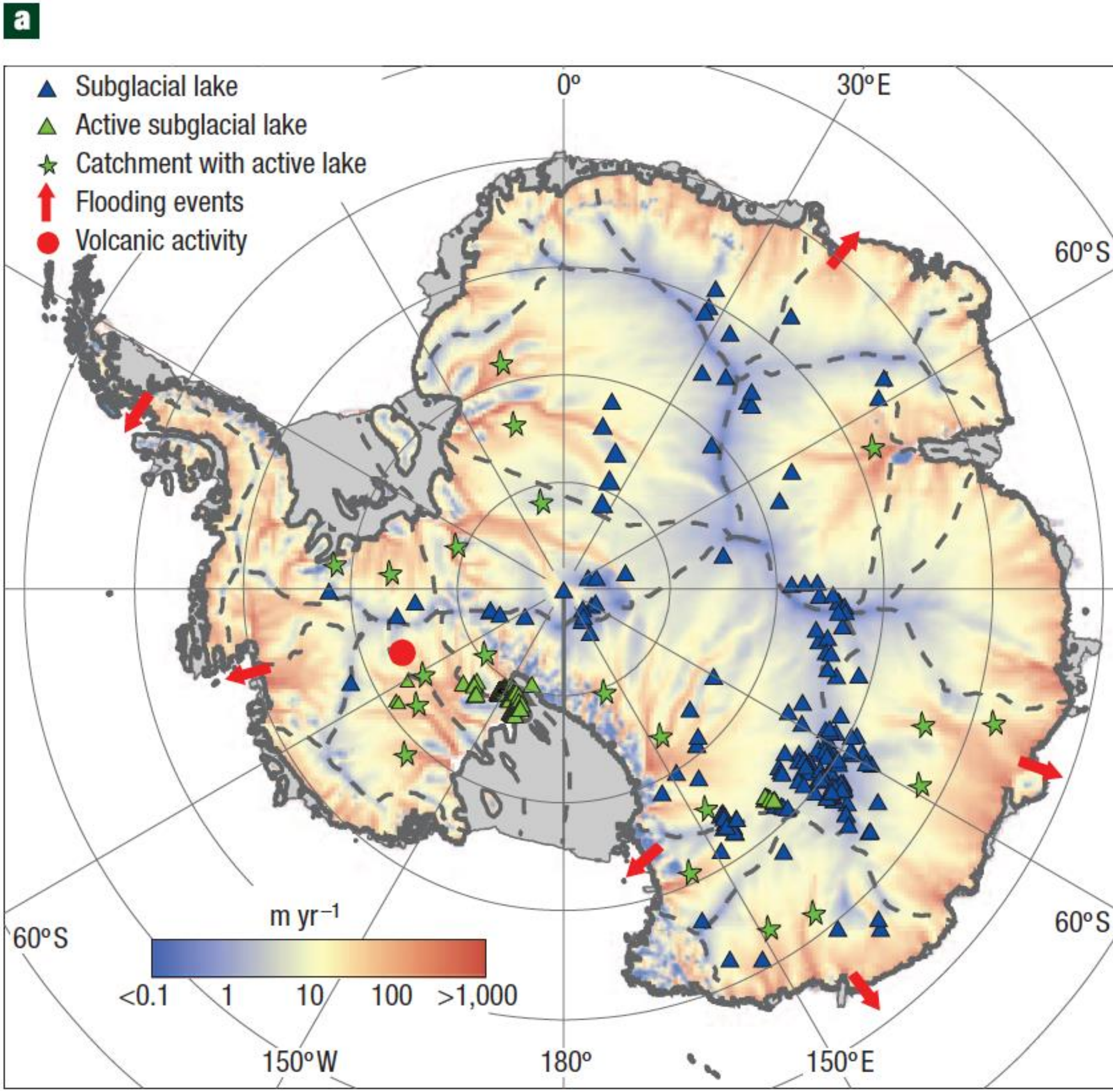


Williams et al., 2016

Large flux of iron from the Amery Ice Shelf marine ice to Prydz Bay, East Antarctica

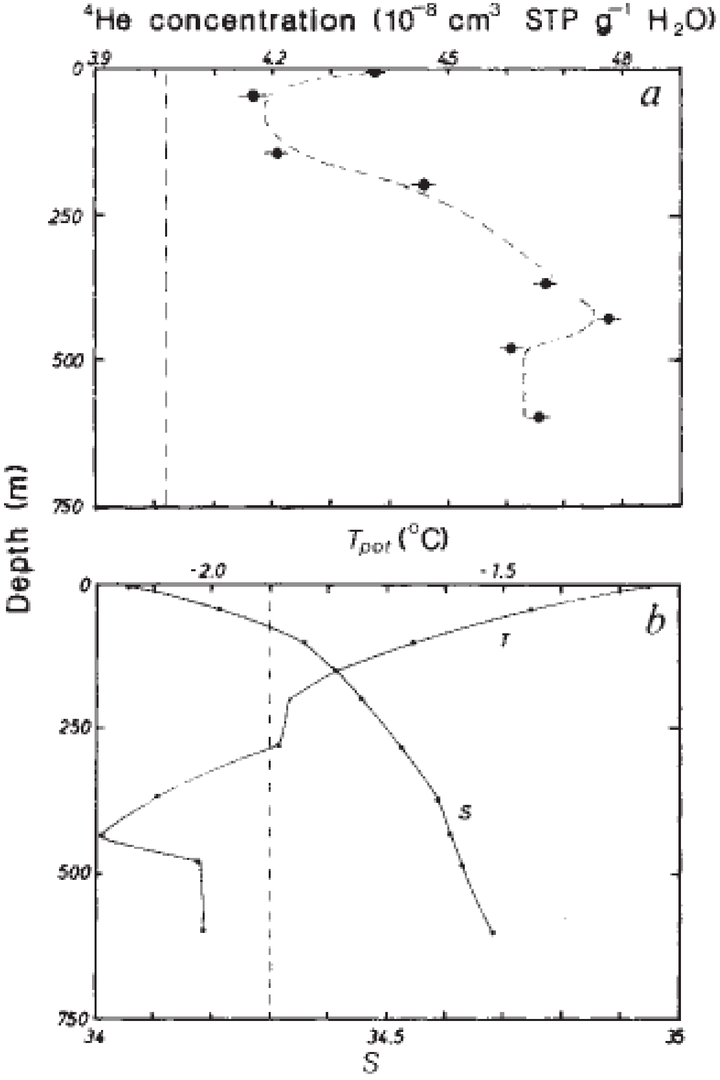
L. Herraiz-Borreguero[1,2], D. Lannuzel[3,4], P. van der Merwe[3], A. Treverrow[3], and J. B. Pedro[1]




a
Subglacial lake
Active subglacial lake
Catchment with active lake
Flooding events
Volcanic activity
0°
30° E
60° S
60° S
60° S
150° W
180°
150° E
m yr⁻¹
<0.1
1
10
100
>1,000

Bell, 2008

Helium (^{3,4}He), a good tracer of glacial melt water

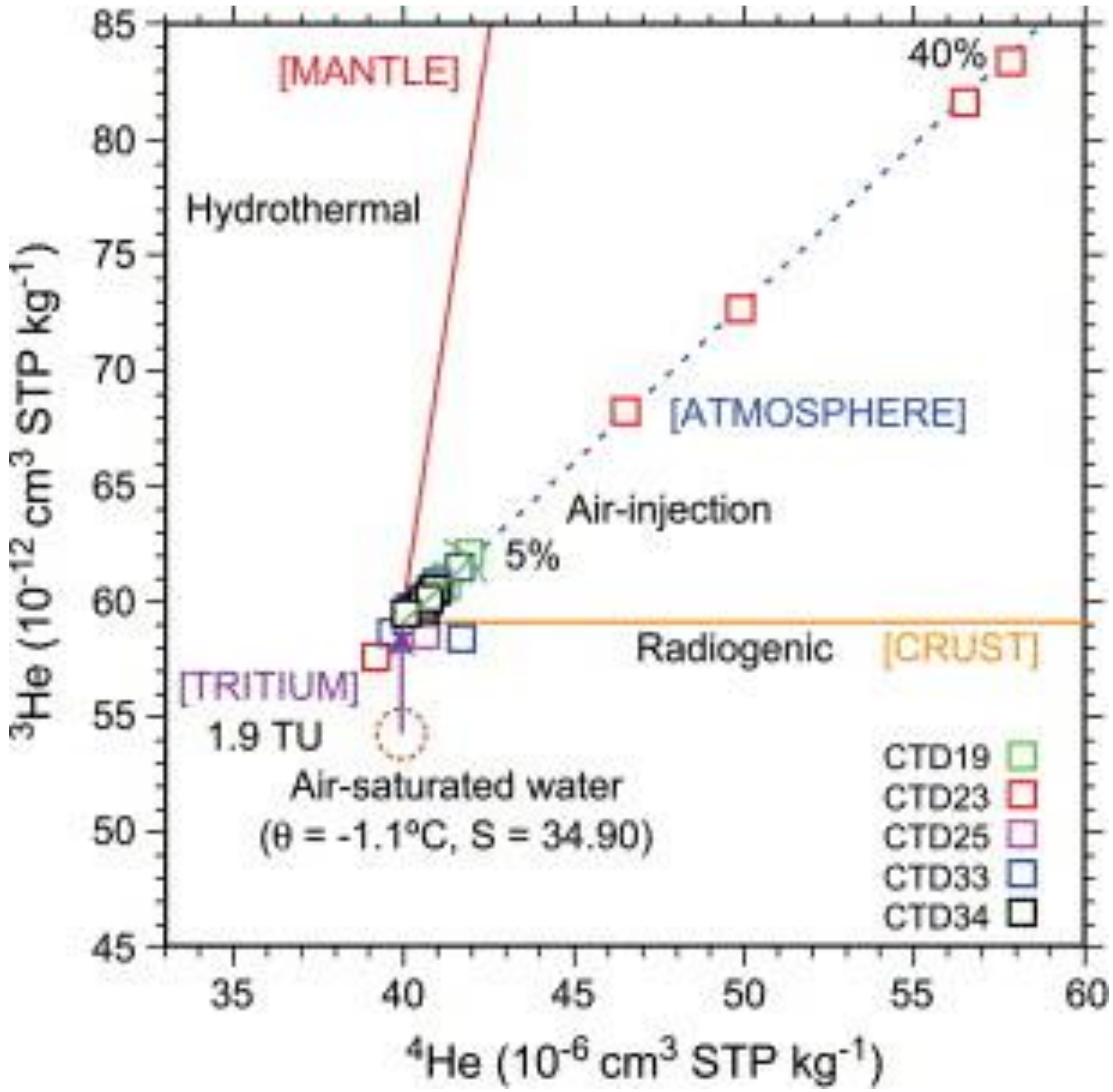


Schlosser, 1986

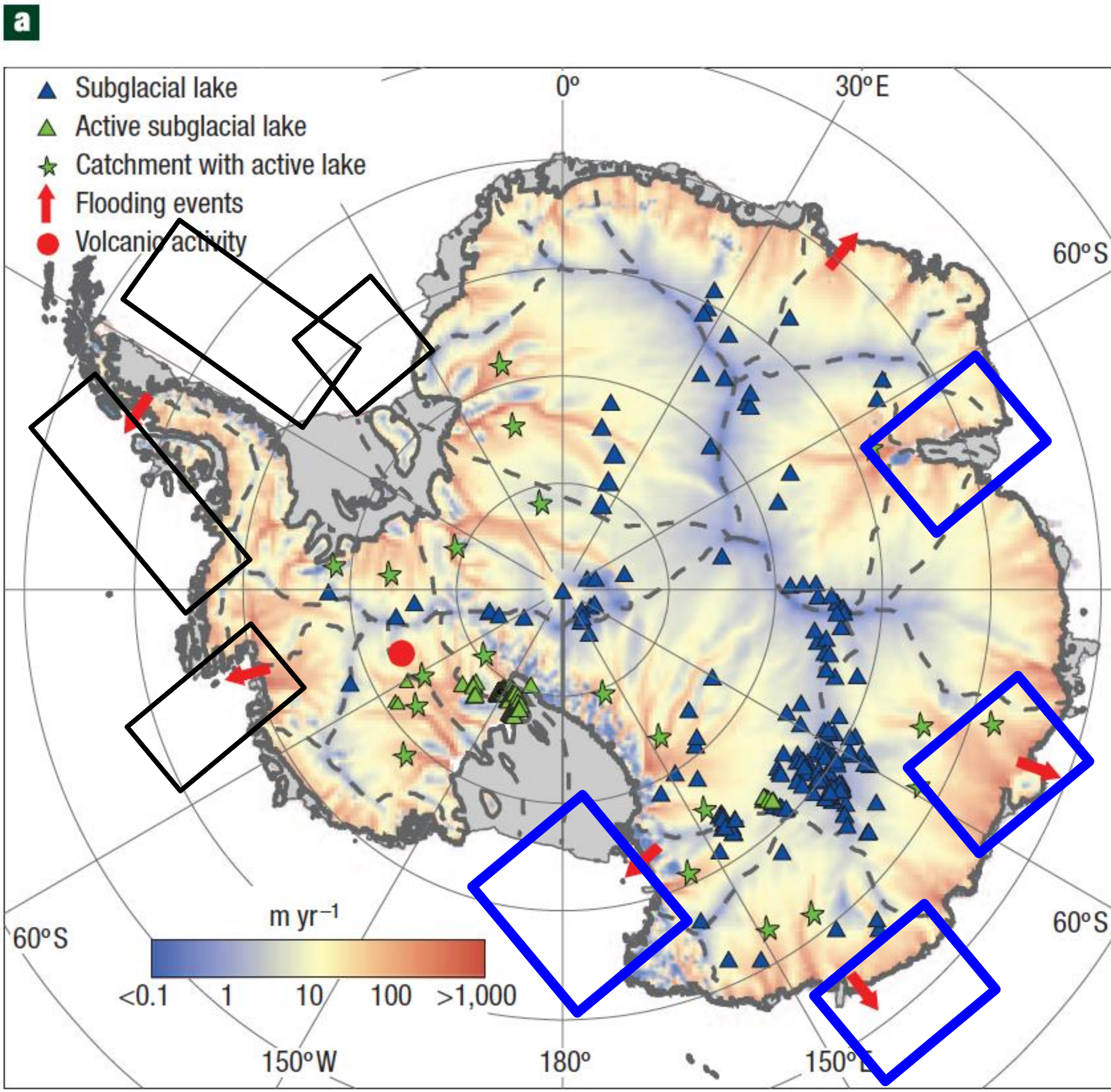
The low solubility of helium and neon in seawater results in **concentrations well above solubility equilibrium with the atmosphere** (the primary source of helium and neon in the ocean), producing a glacial melt signal which can be traced from an ice front, across the continental shelf and into the abyssal ocean.

^{4}He: Nuclear reactions in rocks and sediments From the decay of U and Th, geothermal Activity, volcanic eruptions (e.g**. high [^{4}He] are common in deep ground water discharge)**

^{3}He: Radioactive decay of atmospheric tritium



Hahm et al., 2004


a
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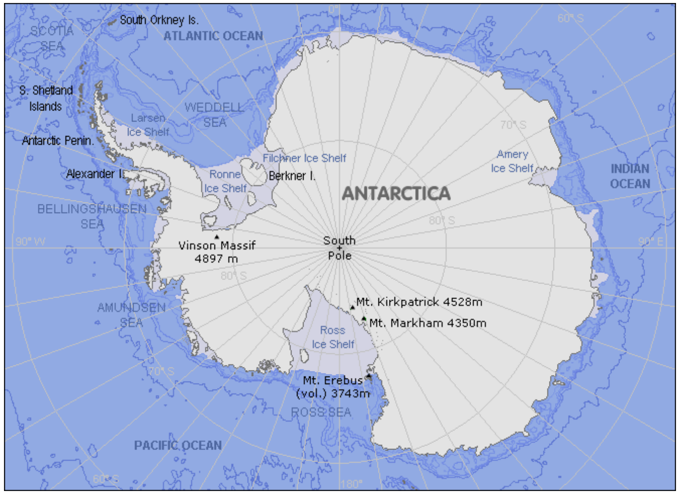
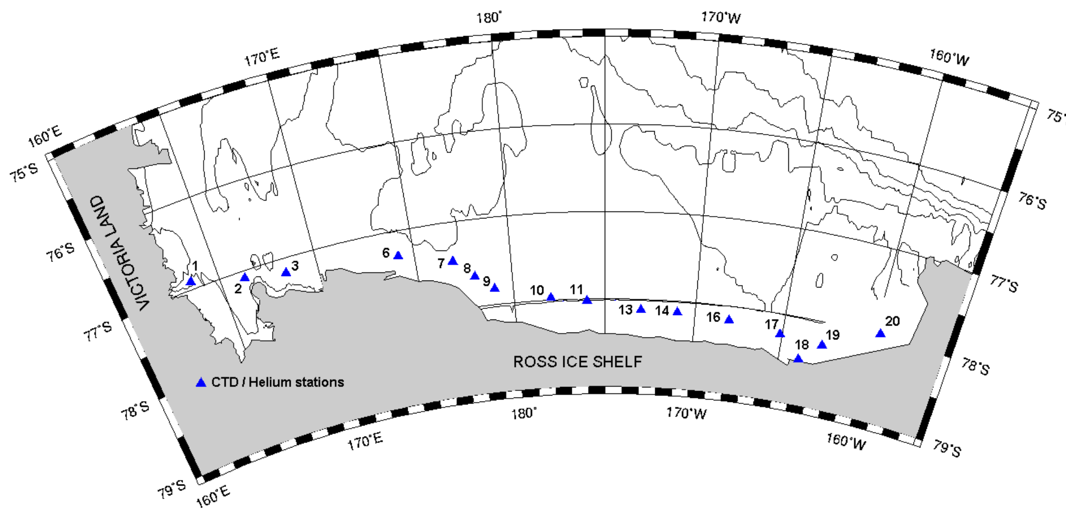
150°W
180°
150°E
m yr⁻¹
<0.1
1
10
100
>1,000

Bell, 2008

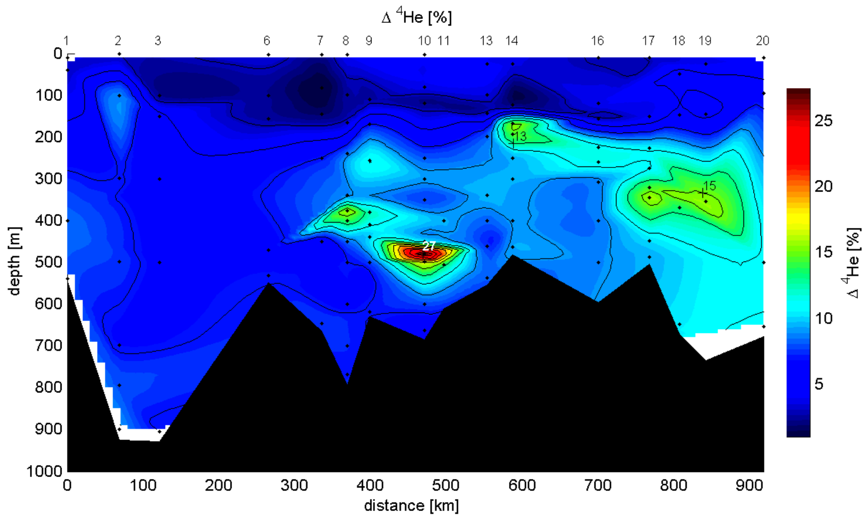
RIS: Palmer 2000 section





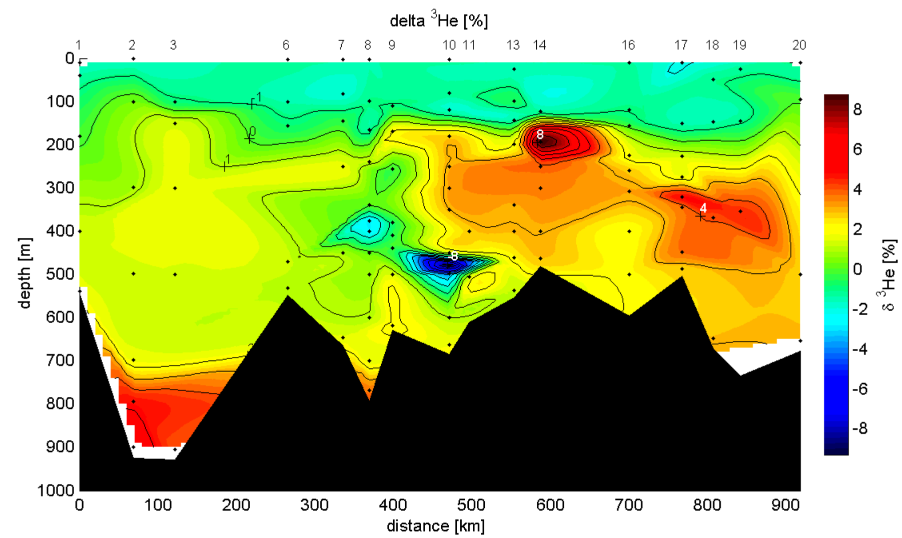
Schlosser et al., in prep.

Helium isotope sections



AS2K section from Station 1 (77 S 163 E) to 20 (78S 160W)

Distinct ^4He excesses in ISW cores; larger than Ne excesses

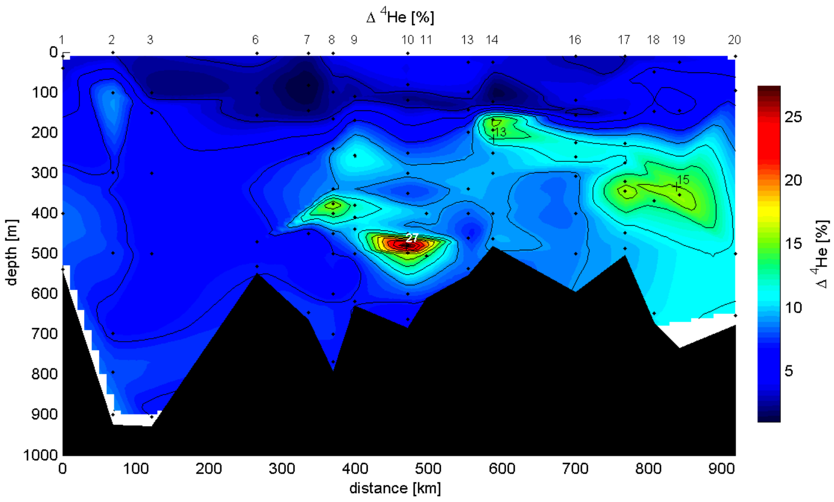


AS2K section from Station 1 (77 S 163 E) to 20 (78S 160W)

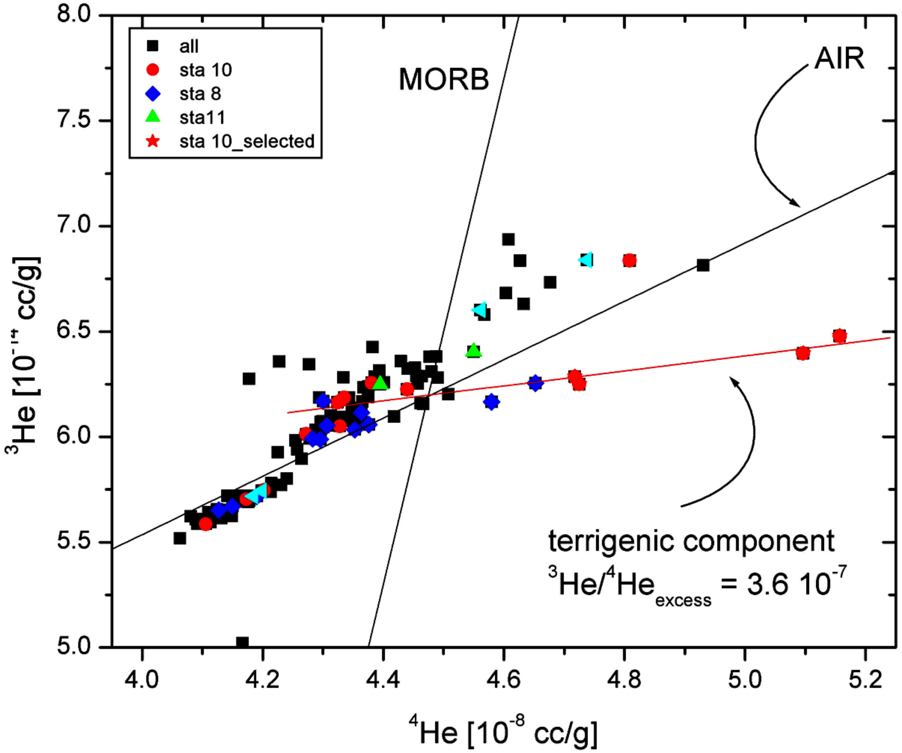
δ^3He signals related to ^4He excesses in ISW cores indicate addition of terrigenic helium of crustal origin

Schlosser et al., in prep.

Terrigenic helium signal



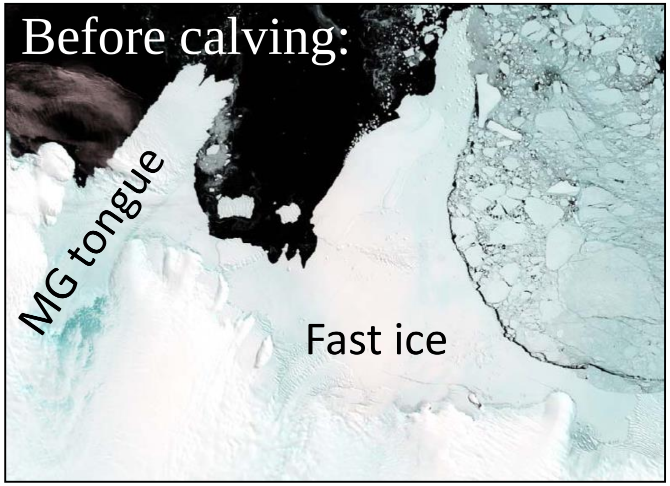
AS2K section from Station 1 (77 S 163 E) to 20 (78S 160W)

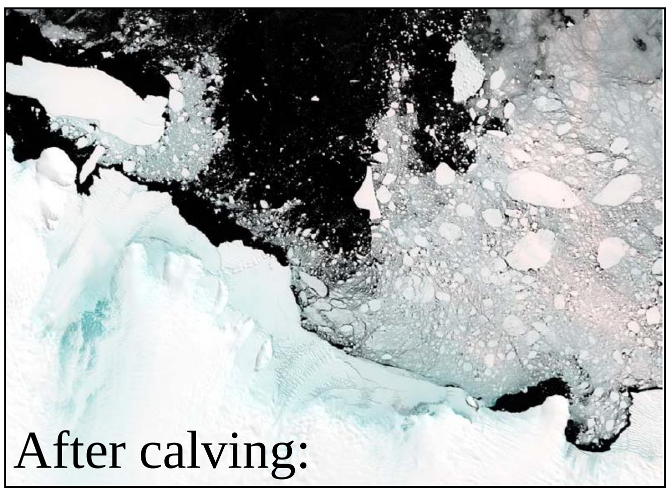


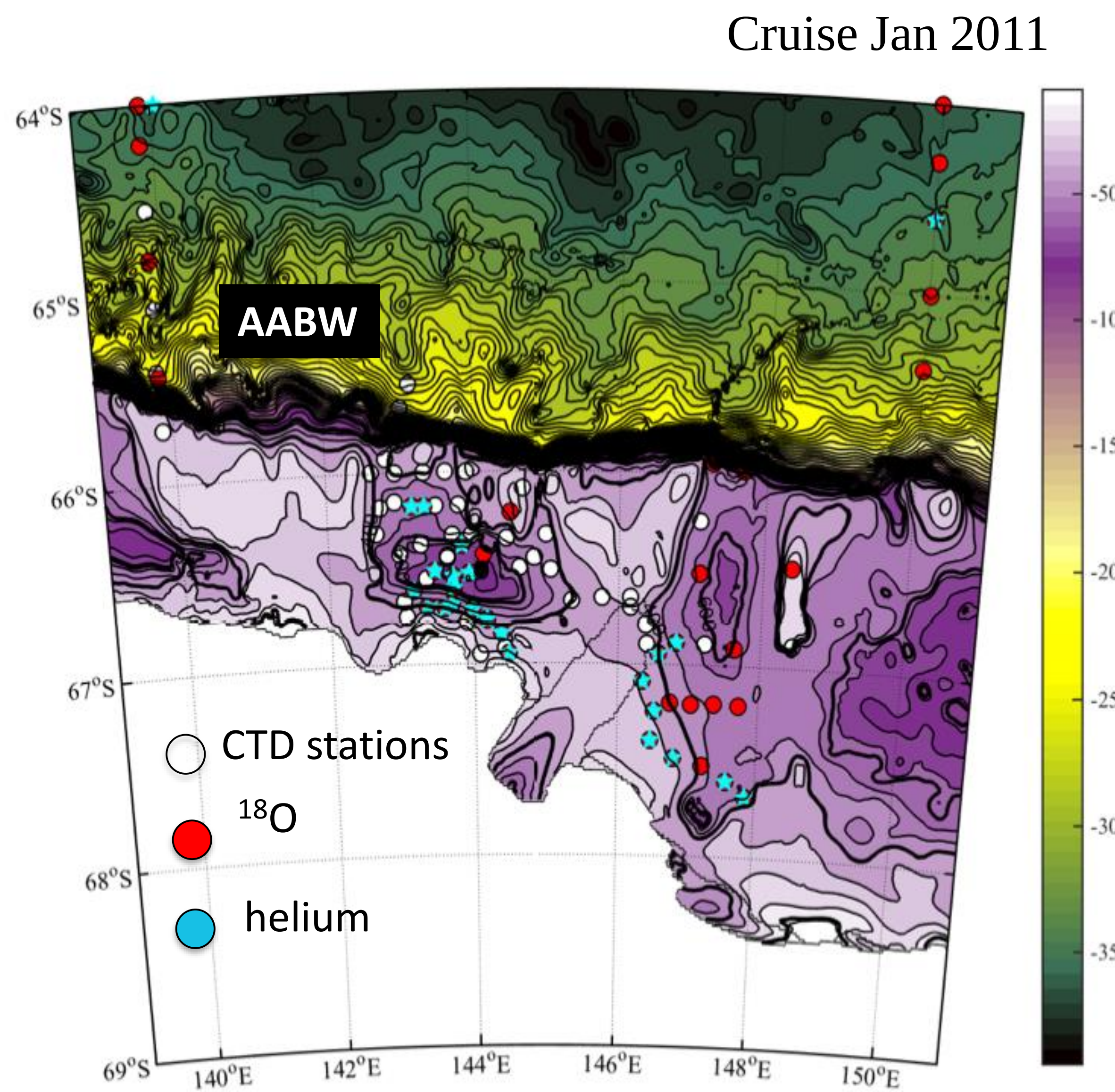
We can use this data to quantify the contribution of the subglacial freshwater contribution to the observed meltwater plume exiting the ice shelves cavities

Schlosser et al., in prep.

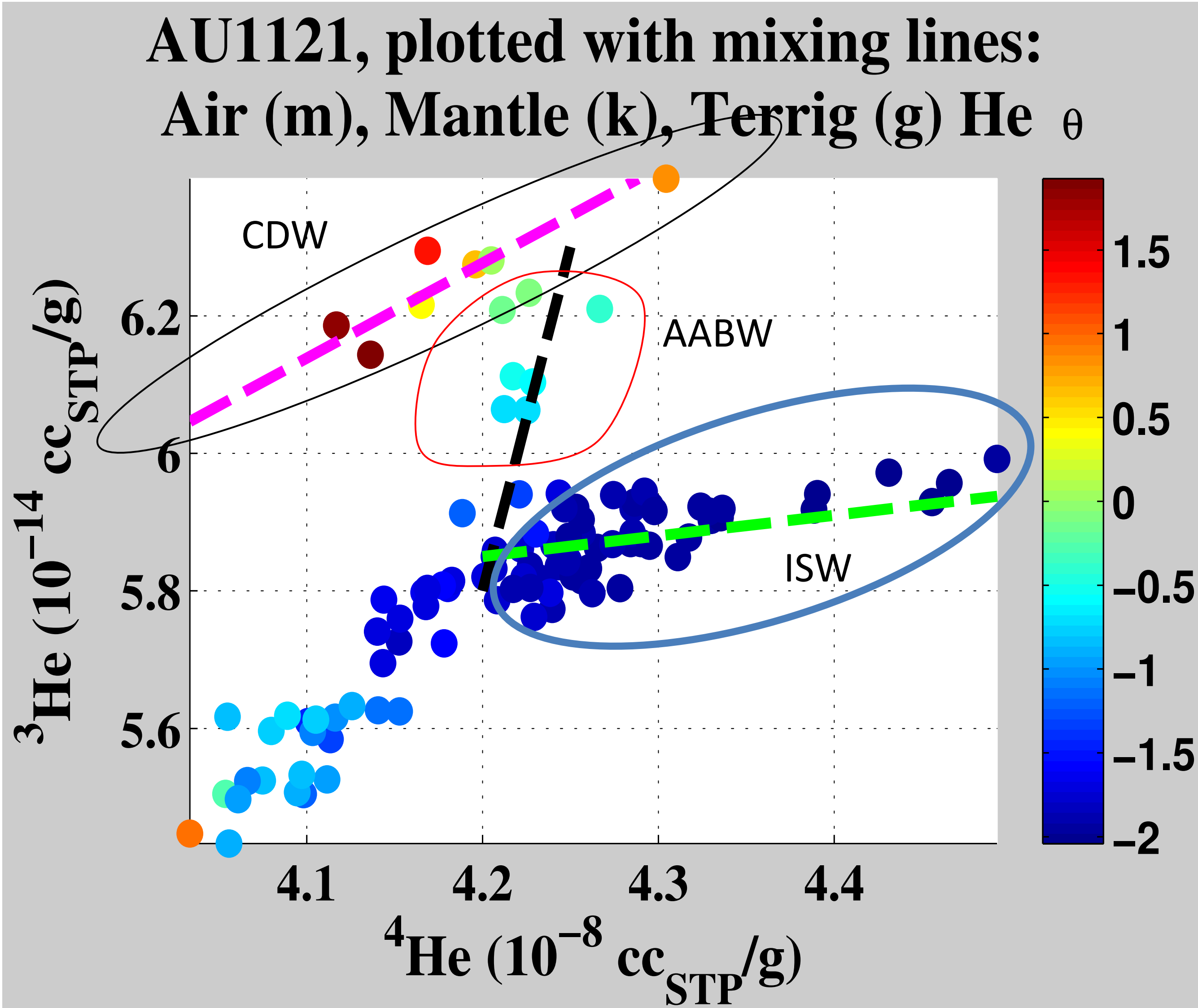
Mertz Glacial Tongue



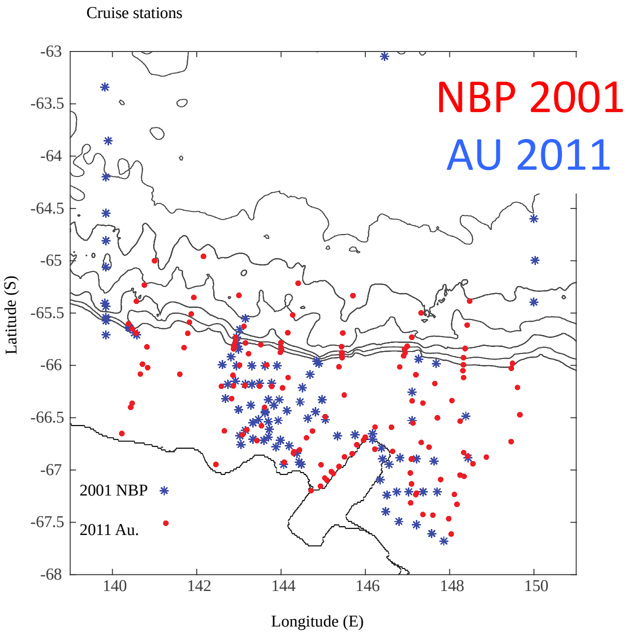


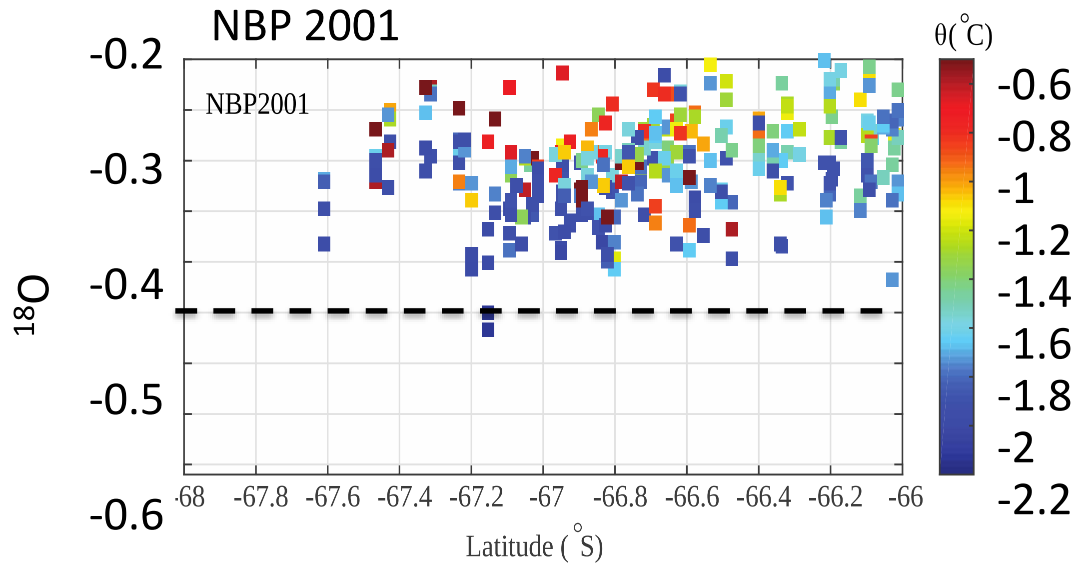


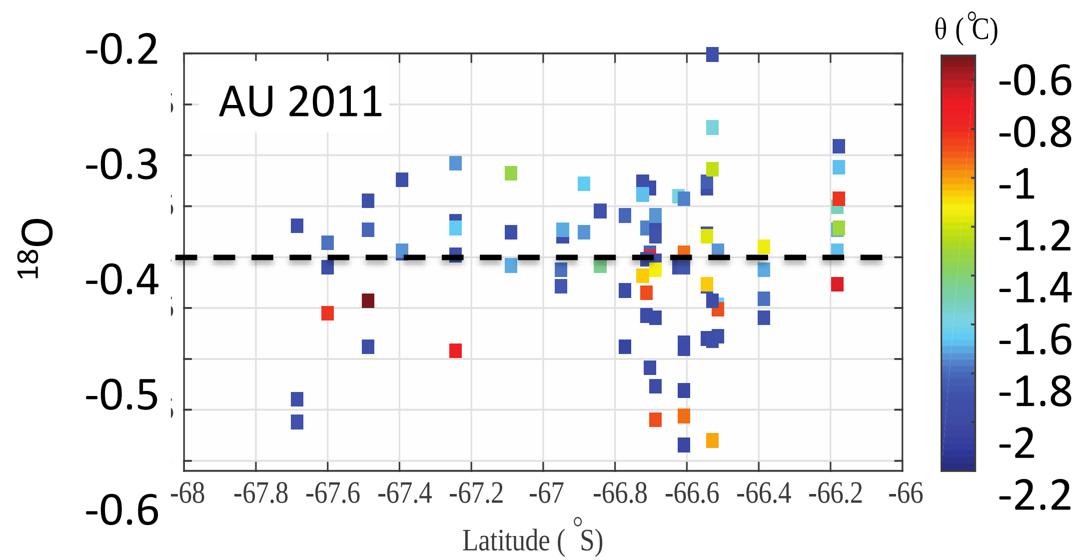
Herraiz-Borreguero et al., in prep.



Circumpolar Deep Water (**CDW**)   Antarctic Bottom Water (**AABW**)   Ice Shelf Water (**ISW**)

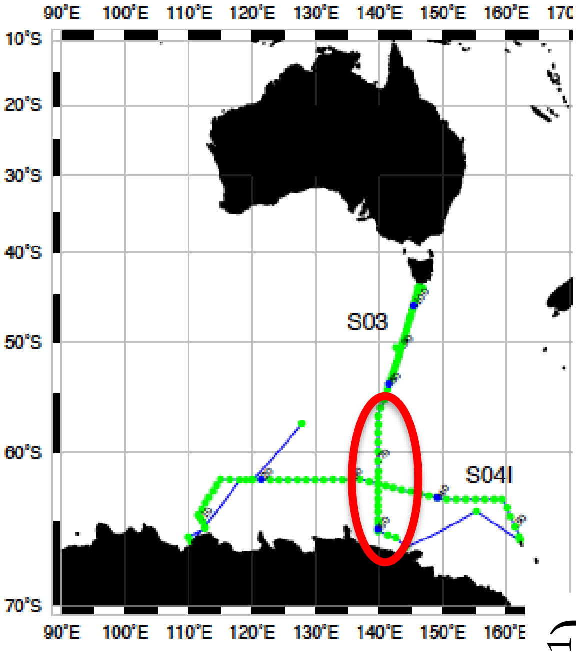






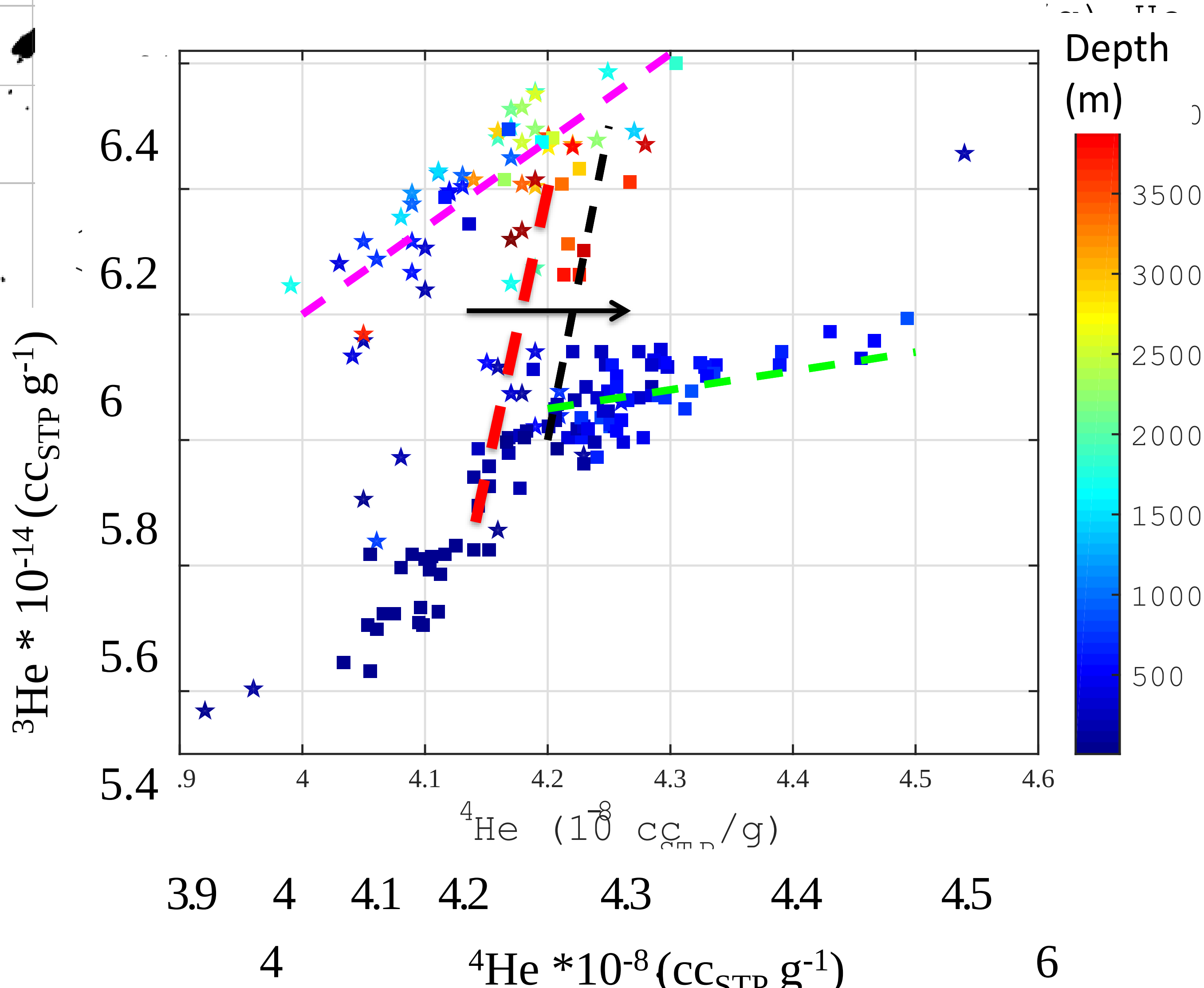
Para-meter	Mean f_{MGW} (±1std) per mil	Max f_{MGW} Per mil	AABW f_{MGW} Per mil
2011 MC, θ, S, ^{18}O	1.88 ± 1.73	6.57	1.56
2001 MC, θ, S, ^{18}O	0.88 ± 0.72	4.00	0.6

Herraiz-Borreguero et al., in prep.



☆ 1994

□ 2011



Herraiz-Borreguero et al., in prep.

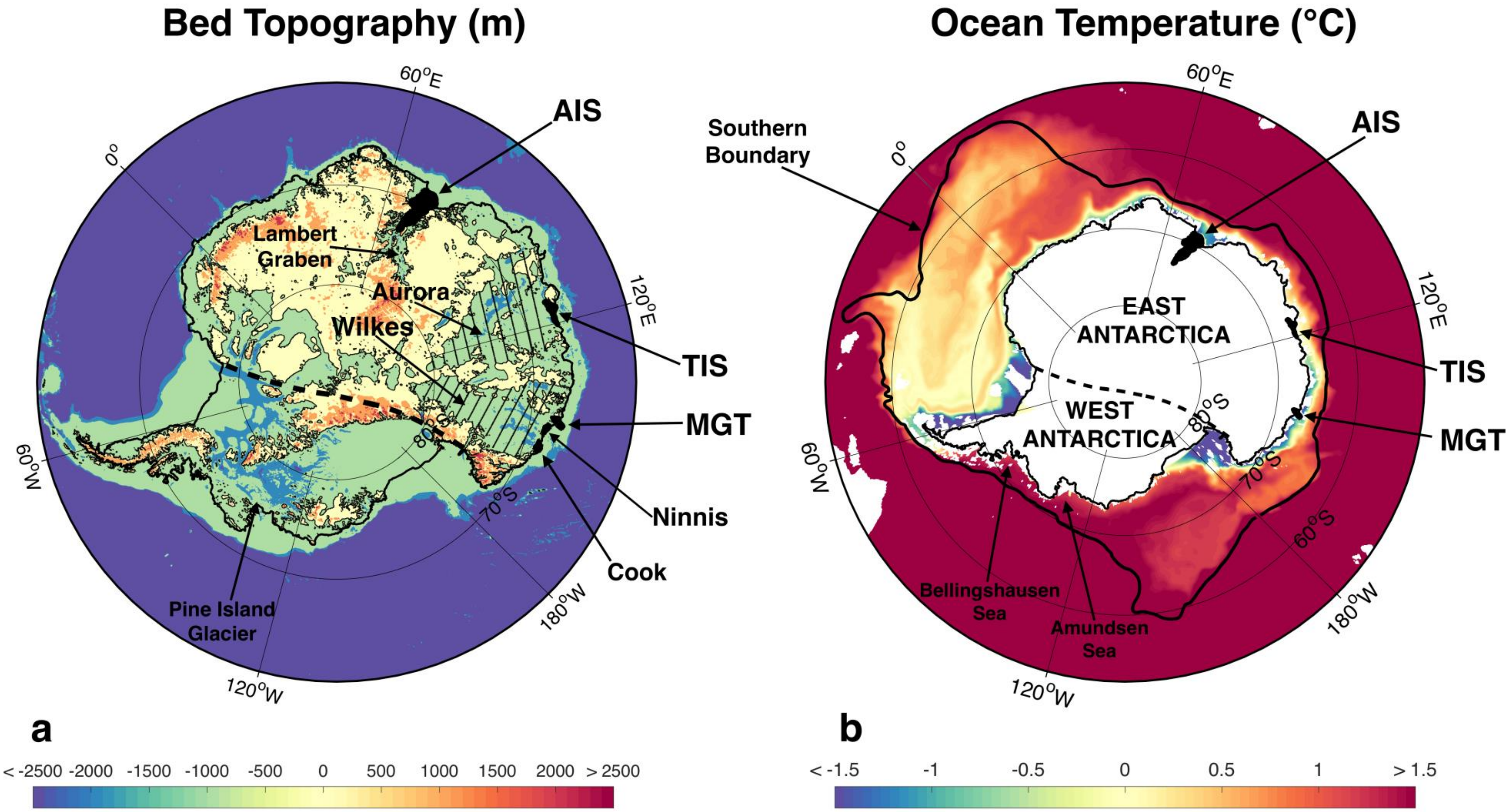
Conclusions

1. Need more work on how currents interact with ice shelves fronts and what it means for the inflow of waters

2. Polynyas:
   1. ocean stratification matters
   2. Freshwater can actually hamper the formation of dense shelf waters

3. Noble gases gives us information on the source of the glacial freshwater and how this freshwater is exported

4. It can inform models

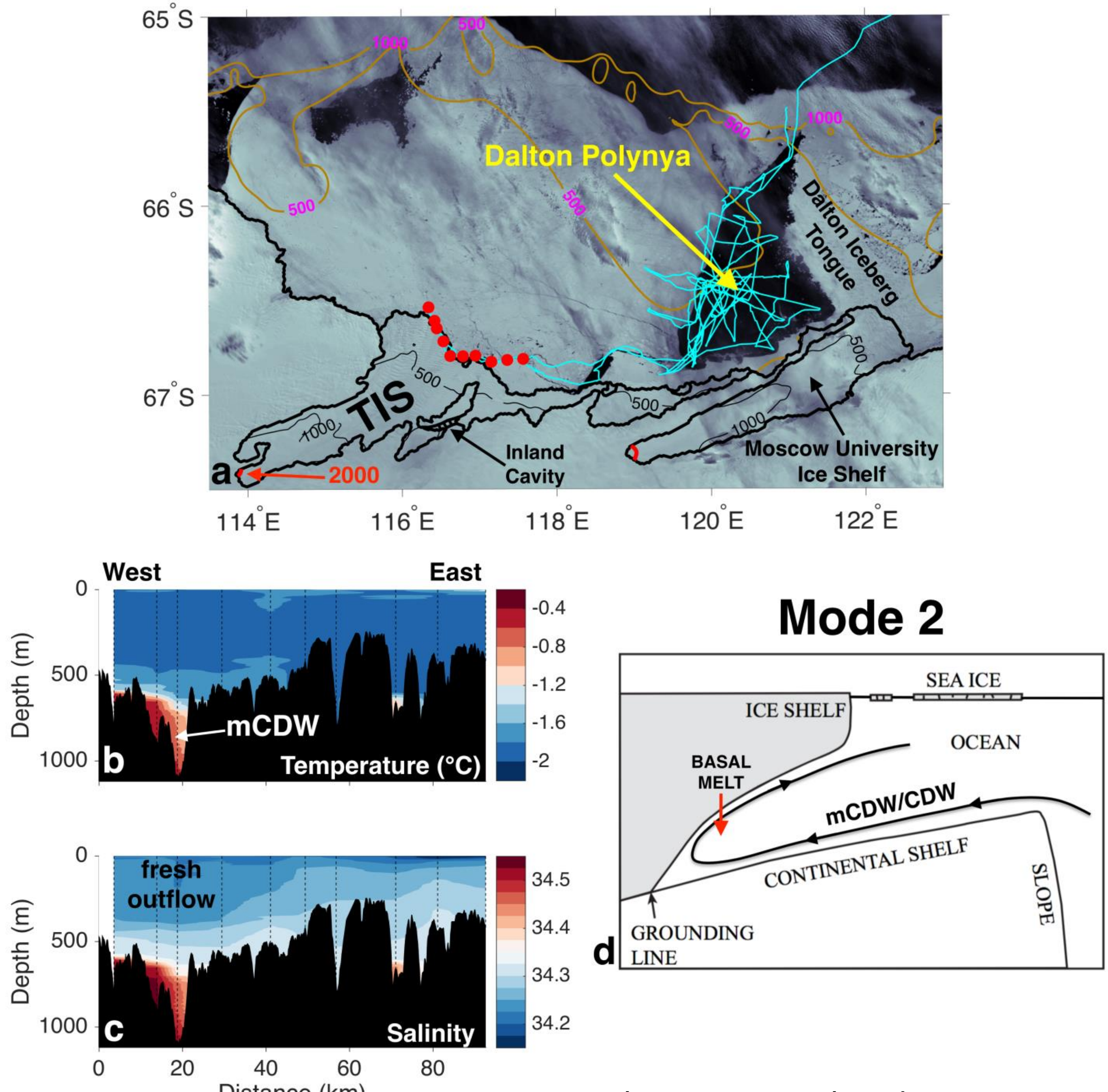


AIS: Amery ice shelf

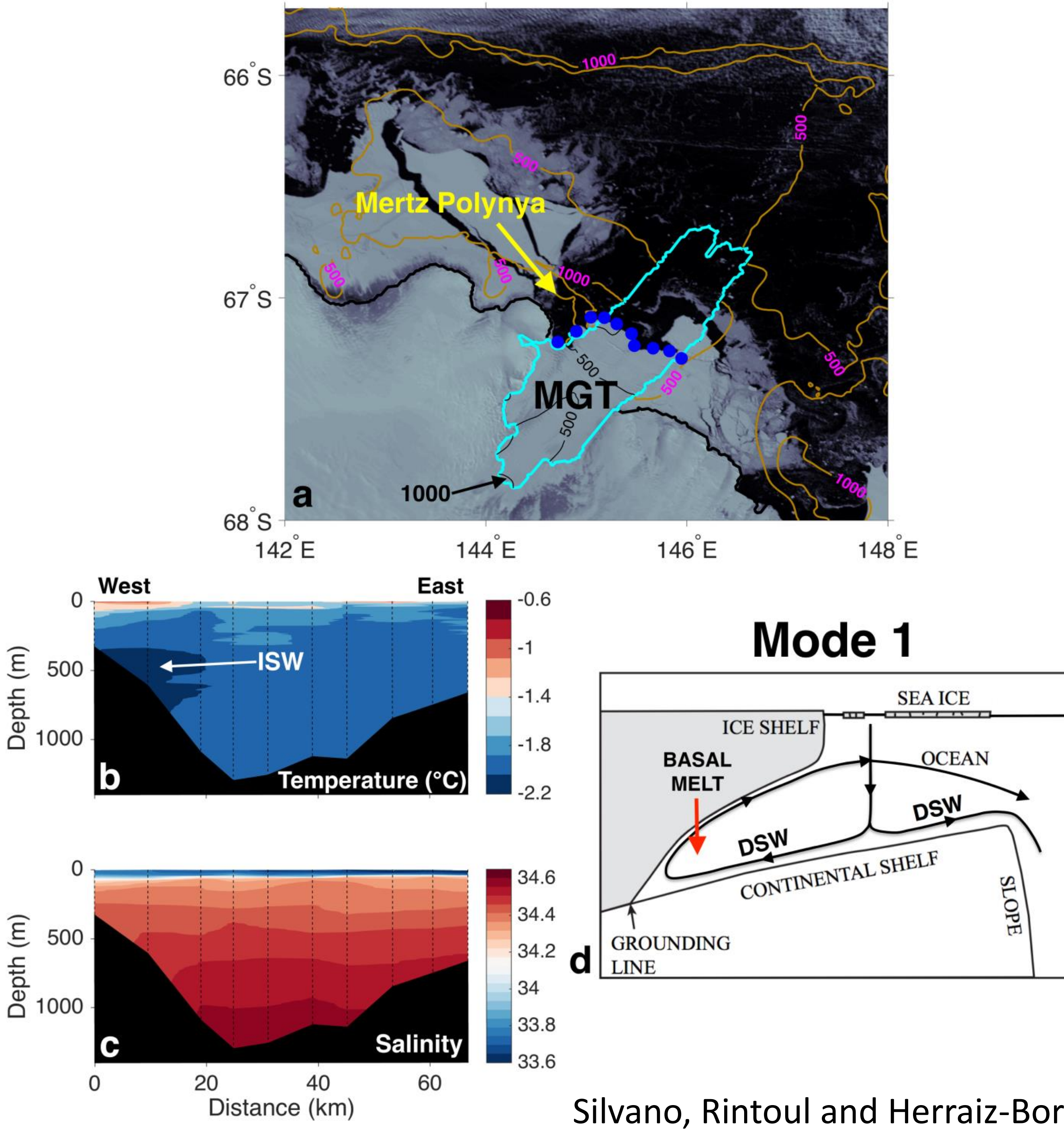
TIS: Totten ice shelf

MGT: Mertz Glacial Tongue

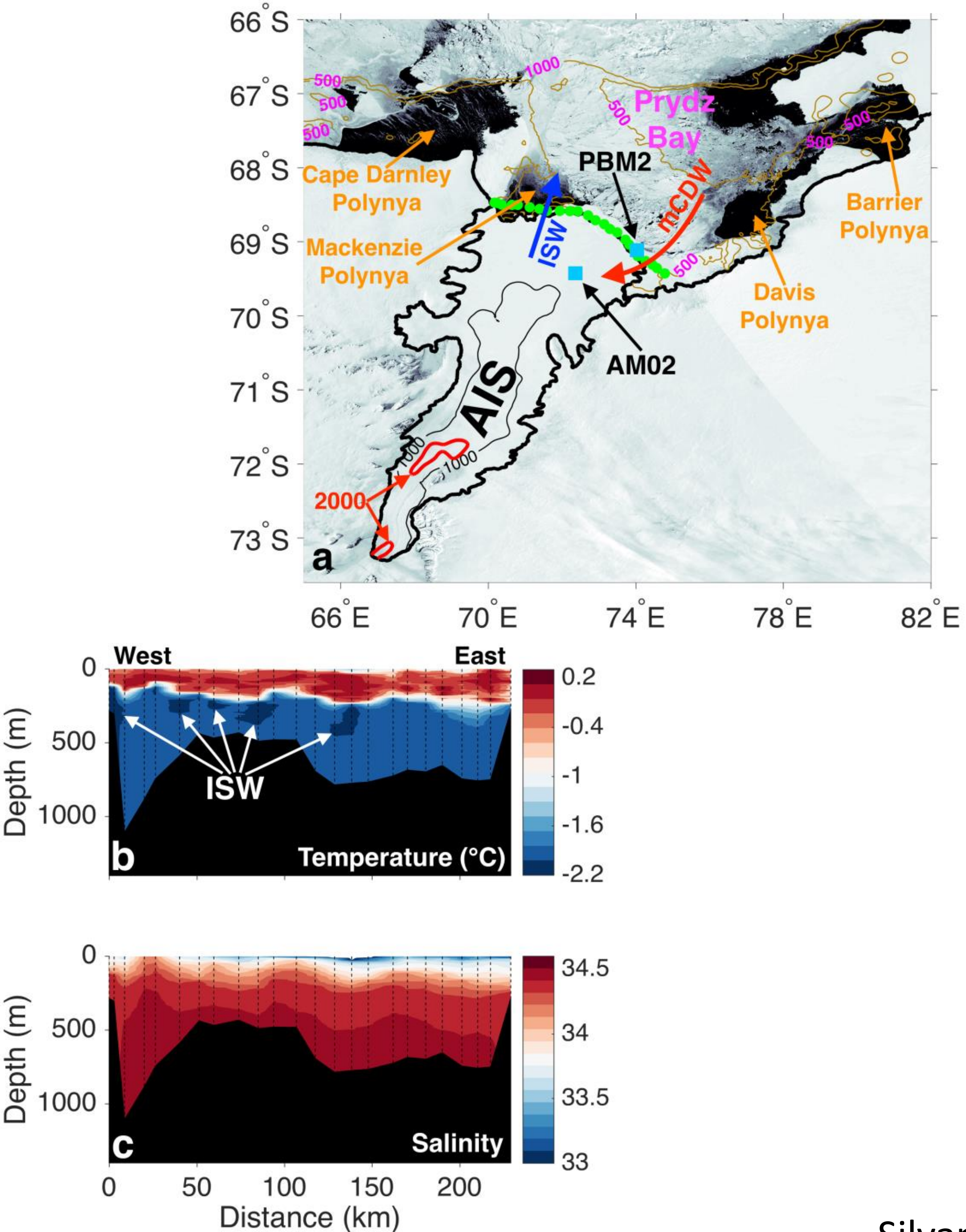
Silvano, Rintoul and Herraiz-Borreguero, 2016

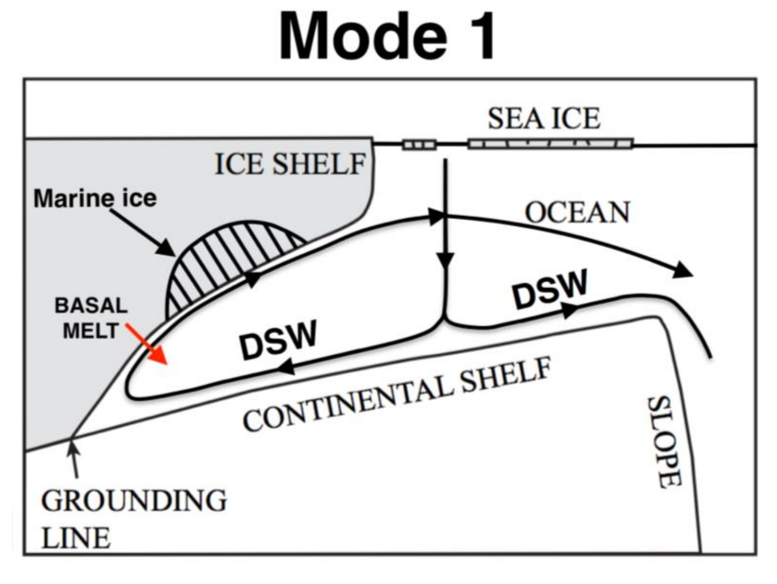


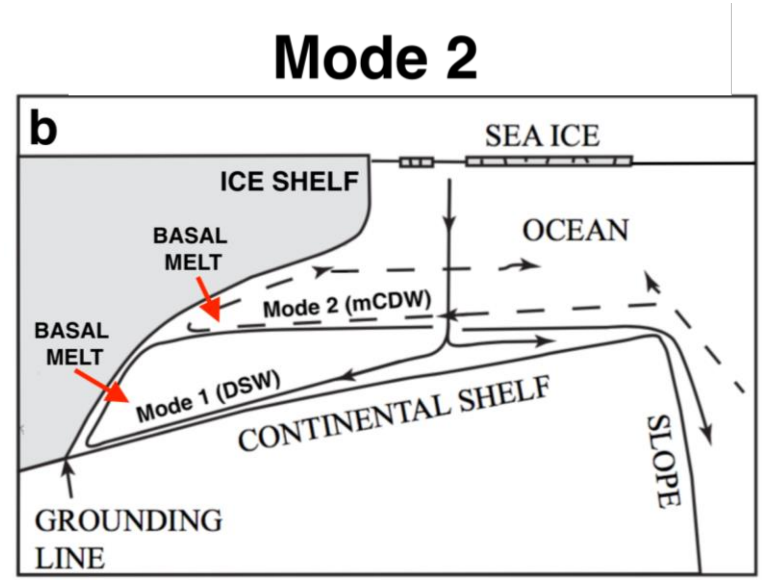
Silvano, Rintoul and Herraiz-Borreguero, 2016



Silvano, Rintoul and Herraiz-Borreguero, 2016

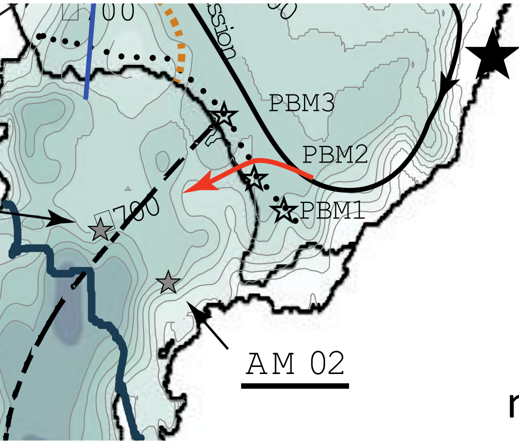


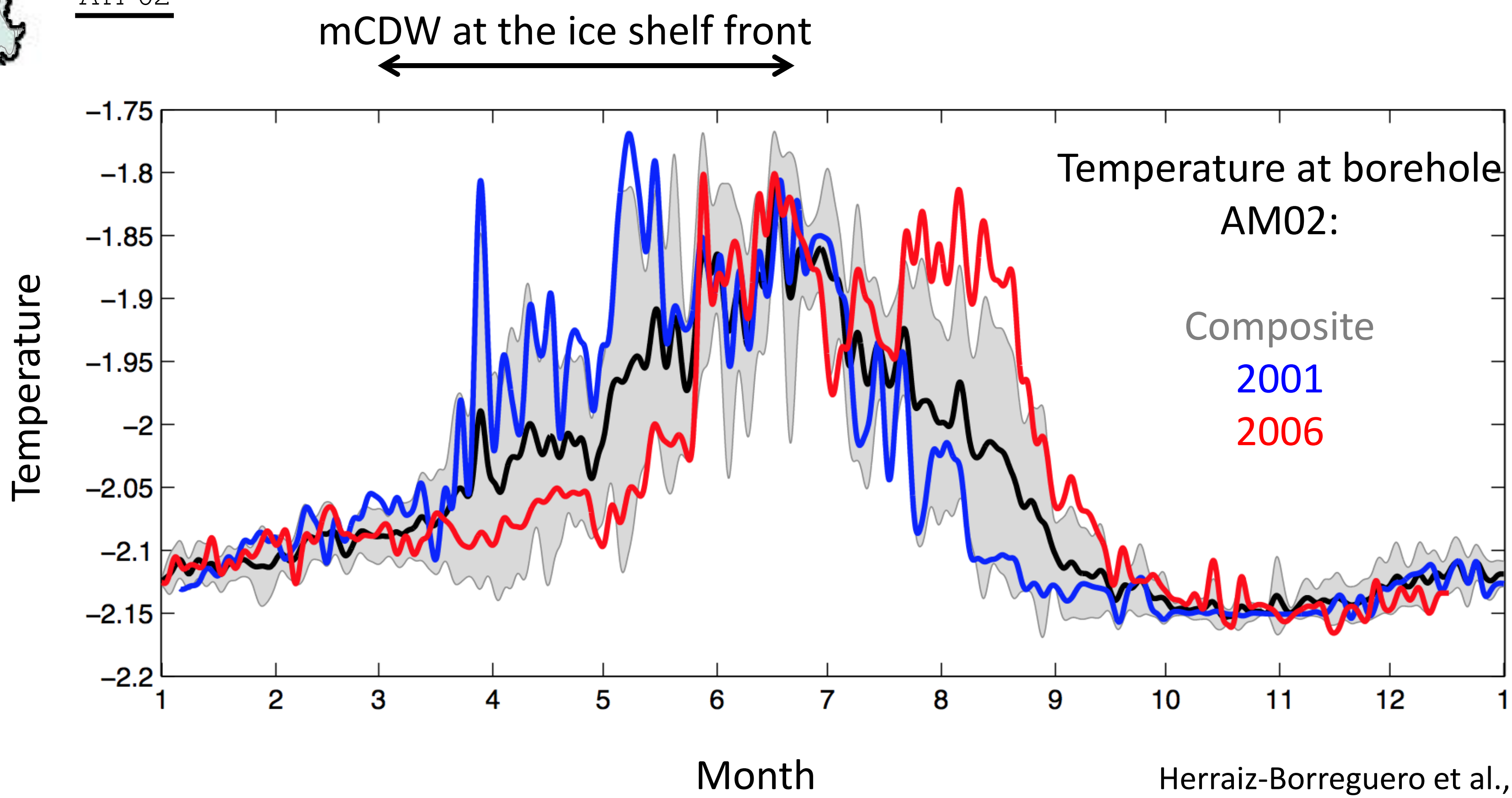




Silvano, Rintoul and Herraiz-Borreguero, 2016

mCDW is responsible for up to 2 ± 0.5 m yr^{-1} during 2001 (23.9 ±6.52 Gt yr^{-1}). However, heat content flux by mCDW at AM02 shows high intra-annual variability (up to ± 40%)





Herraiz-Borreguero et al., 2015

Prydz Bay-Amery ice shelf system: what do we know ?

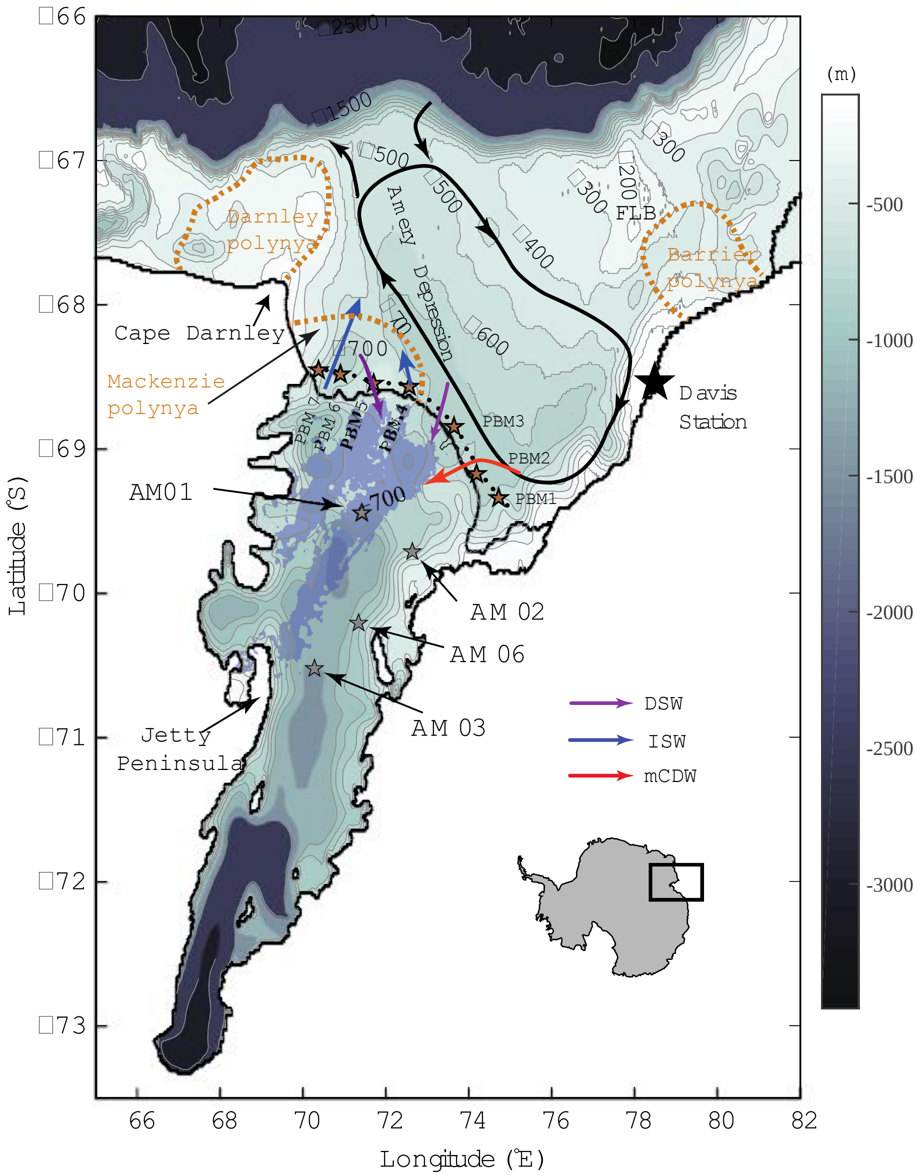


Table 2. Summary of the Most Recent Estimates of Net Basal Melt Beneath the Amery Ice Shelf

Study	Net Basal Melt (m yr^{-1})	Net Basal Mass Loss (Gt yr^{-1})
This study + *Herraiz-Borreguero et al.* [2015][a,b]	1.0 ± 0.4	57.4 ± 25.3
Depoorter et al. [2013][c]	0.65 ± 0.35	39 ± 21
Rignot et al. [2013][c]	0.58 ± 0.4	35.5 ± 22
Galton-Fenzi et al. [2012][d]	0.74	45.6
Yu et al. [2010][c]	0.5 ± 0.12	27 ± 7
Wen et al. [2010][c]	0.84 ± 0.12	46.4 ± 6.9

[a]Oceanographic study.
[b]Has been adjusted to give a net basal melt estimate in m/yr over the whole ice shelf area.
[c]Glaciological study.
[d]Modeling study.

Glacial Melt Water composition: Optimal MultiParameter (OMP) analysis

$$\left.\begin{array}{lllll}
f_{CDW} & + f_{AASW} & + f_{DSW} & + f_{MGW} & = 1 \\
f_{CDW}*\theta_{CDW} & + f_{AASW}*\theta_{AASW} & + f_{DSW}*\theta_{DSW} & + f_{MGW}*\theta_{MGW} & = \theta_{obs} \\
f_{CDW}*S_{CDW} & + f_{AASW}*S_{AASW} & + f_{DSW}*S_{DSW} & + f_{MGW}*S_{MGW} & = S_{obs} \\
f_{CDW}*{}^{18}O_{CDW} & + f_{AASW}*{}^{18}O_{AASW} & + f_{DSW}*{}^{18}O_{DSW} & + f_{MGW}*{}^{18}O_{MGW} & = {}^{18}O_{obs} \\
f_{CDW}*{}^{4}He_{CDW} & + f_{AASW}*{}^{4}He_{AASW} & + f_{DSW}*{}^{4}He_{DSW} & + f_{MGW}*{}^{4}He_{MGW} & = {}^{4}He_{obs}
\end{array}\right\} \mathbf{E * x = y}$$

E: matrix of end-members properties
x: vector of unkowns (**f**)
y: observations

least square method to resolve our system.

4 water masses used (or end-members):

1. Circumpolar Deep Water (CDW)
2. Antarctic Surface Water (AASW)
3. Dense Shelf Water (DSW)
4. Glacial Melt Water (GMW)

4-5 parameters: Mass conservation, Potential temperature (θ), salinity (S), ^{18}O & ^{4}He conc.
contribution of the 4 water masses; f1, f2, f3 and f4

We are not using the data at the top 200 m of the water column

Glacial Melt Water composition:

Cruise 2011

Parameters	Mean fG_{MW} (±1std) per mil	Maximum f_{GMW} Per mil
MC, θ, S, ^{18}O, ^{4}He	1.22 ± 1.04	4.46
MC, θ, S, ^{18}O	1.88 ± 1.73	6.57
MC, θ, S, ^{4}He	1.21 ± 1.07	4.91
MC, θ, ^{18}O, ^{4}He	2.20 ± 1.74	6.69
MC, S, ^{18}O, ^{4}He	1.46 ± 1.04	4.78

ISW f_{MGW} = 6.57 per mil

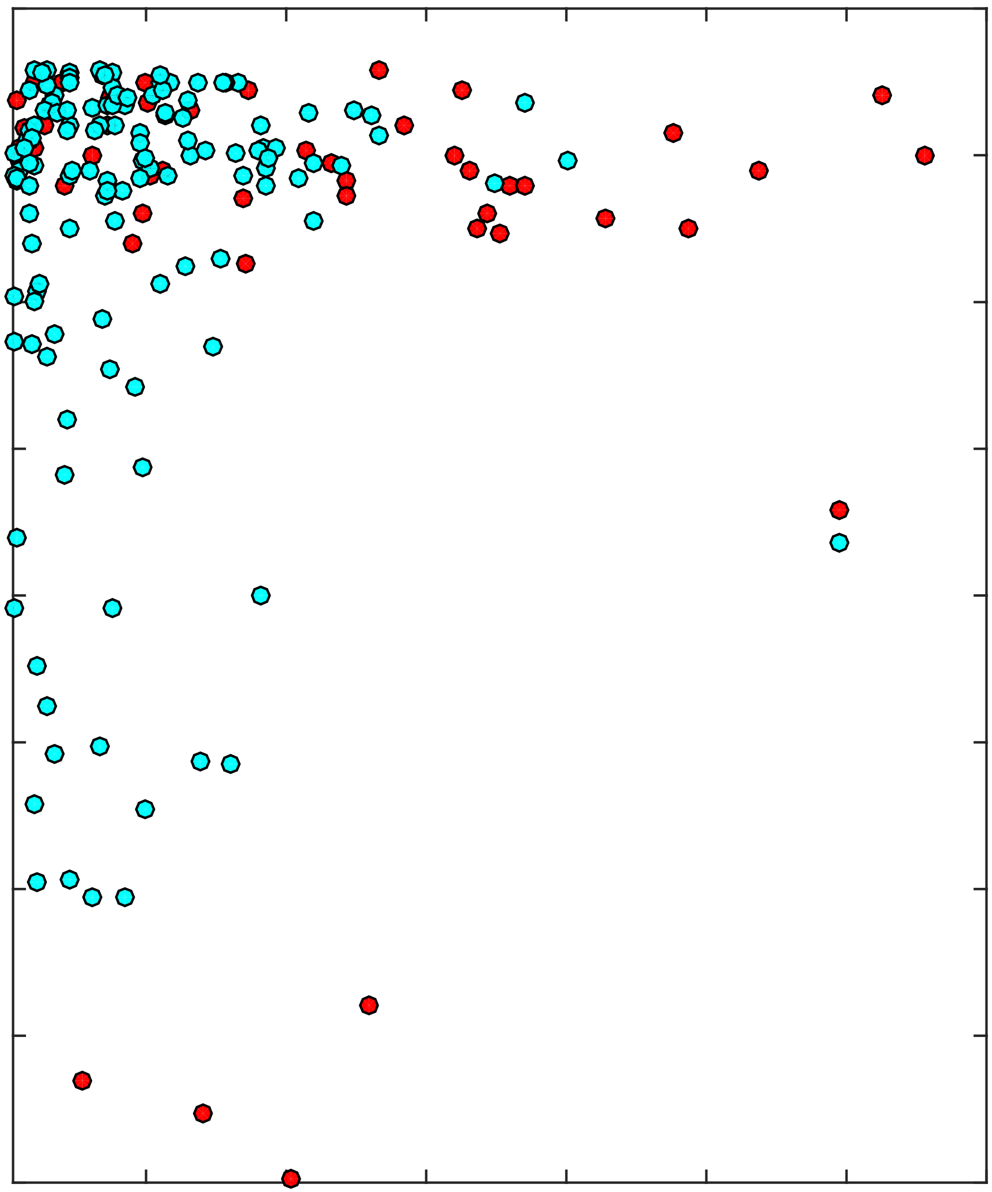
AABW f_{MGW} = 1.56 per mil

GMW fractions, fluxes and melt rates

	Ross Sea		Weddell Sea
	Deep ISW core	Shallow ISW core	Deep ISW (WSW/ISW)
Salinity	4.3 ‰	4.8 ‰	2.9 ‰
Neon	3.9 ‰	4.9 ‰	3.8 – 7 ‰ (^4He)
$\delta^{18}O$	3.9 ‰	4.6 ‰	2.8 - 6 ‰

No sign for re-freezing underneath the RIS

Mean residence time: ca. 3.5 years (Bill Smethie)
Deep core: ISW flux: ca. 0.1 Sv
GMW flux: 0.4 mSv
Melt rate for 100 km wide pathway: 0.1 m year^{-1}



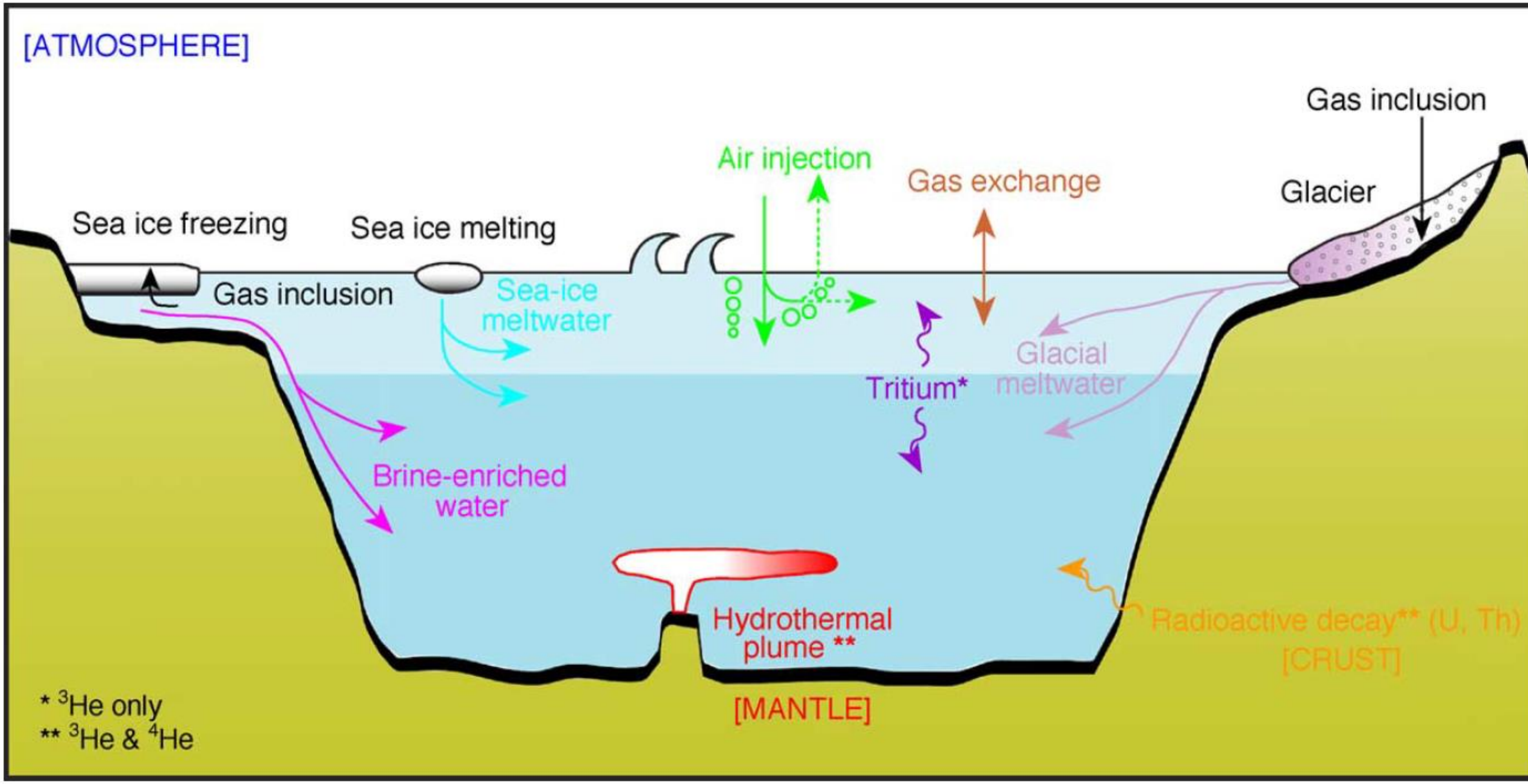


Fig. 1. Mechanisms controlling the distribution of helium and neon in the arctic seas. Helium isotopes have four sources: the atmosphere, mantle, crust and decay of tritium; however, neon has only one, the atmosphere. Helium and neon can be applied to explore the processes which can change the concentration of atmospheric gases, such as air injection, brine injection, sea-ice melting and glacier melting.