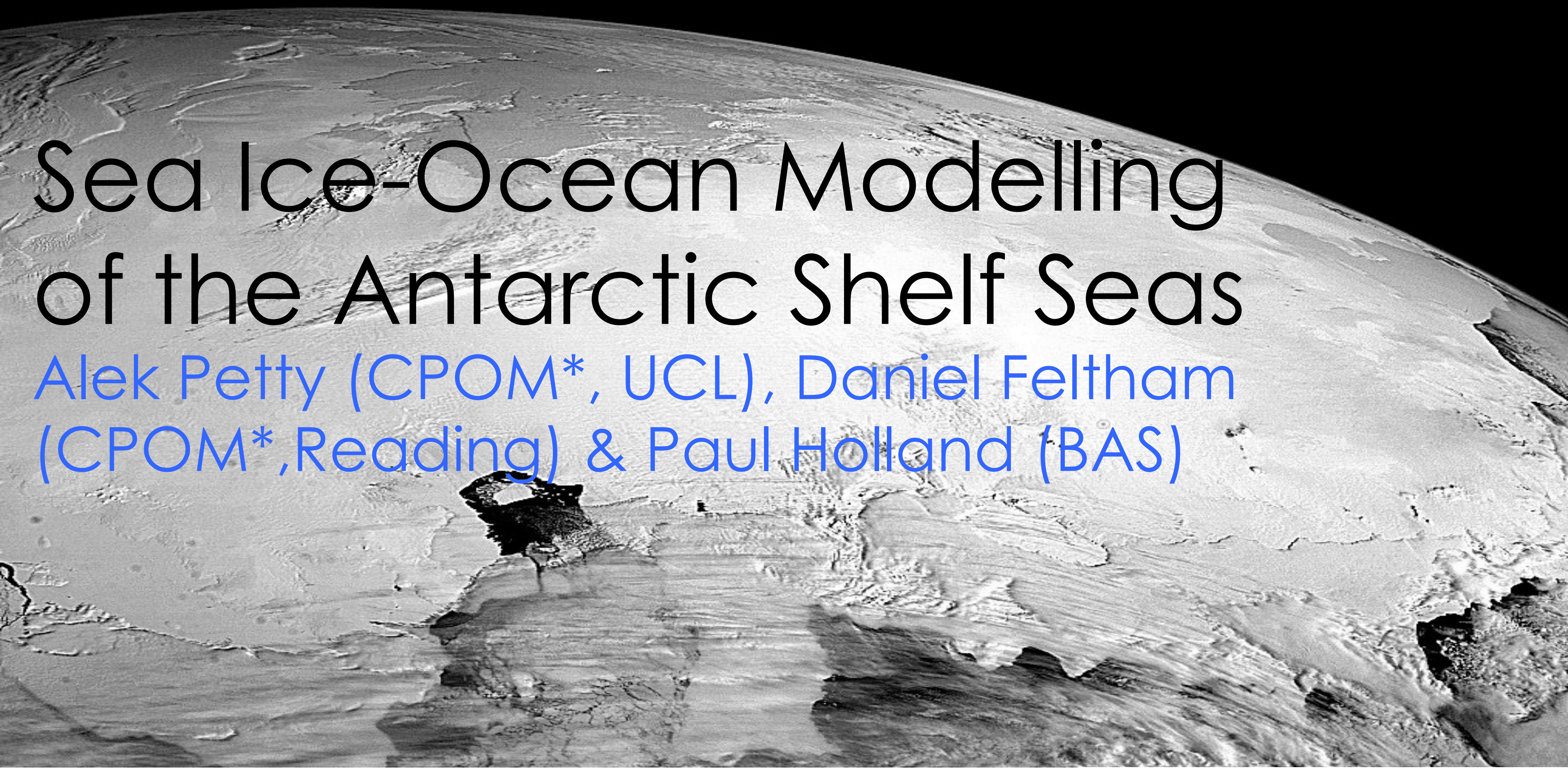

UCL

Sea Ice-Ocean Modelling of the Antarctic Shelf Seas

Alek Petty (CPOM*, UCL), Daniel Feltham (CPOM*,Reading) & Paul Holland (BAS)

cpom

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

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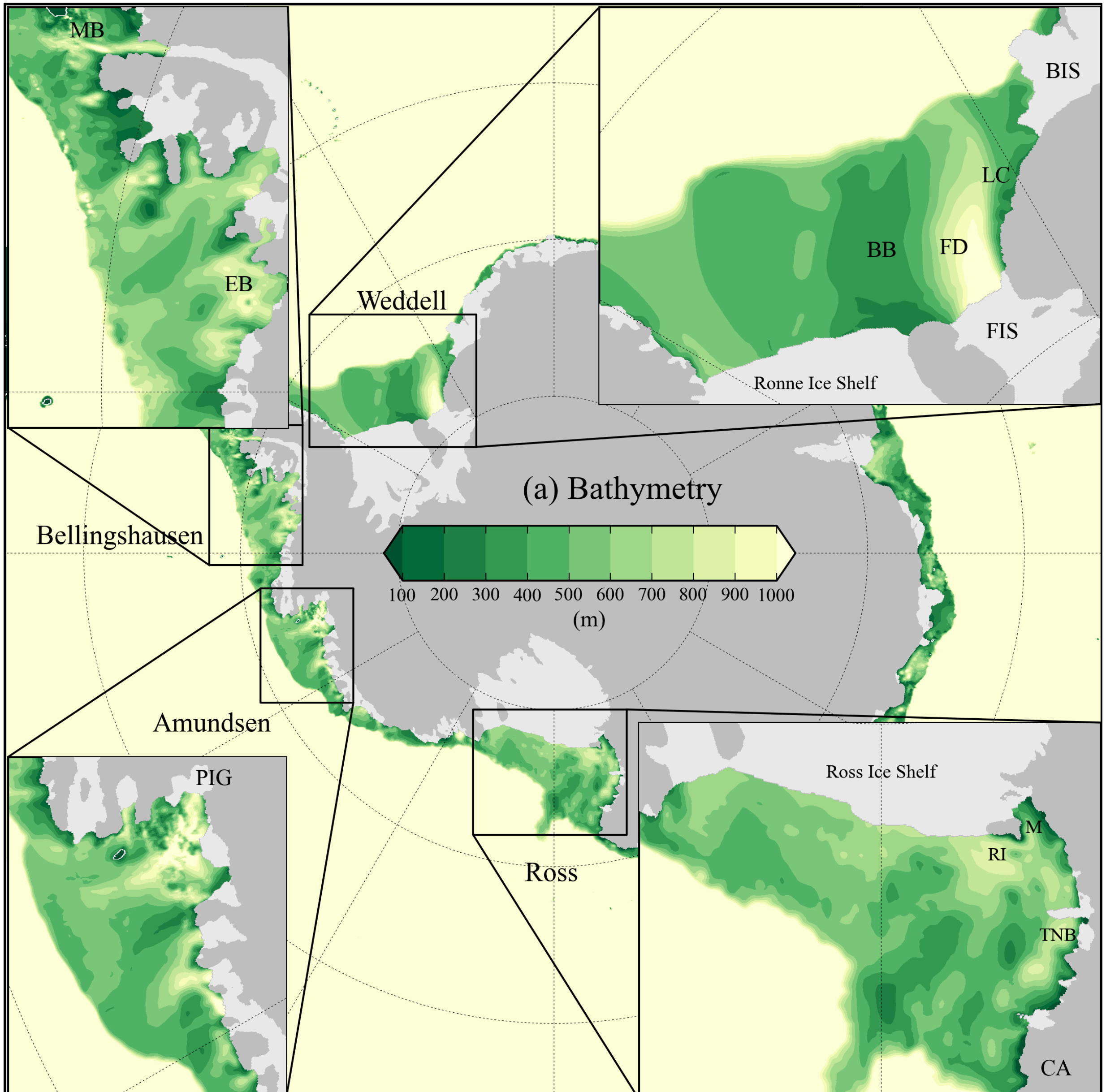
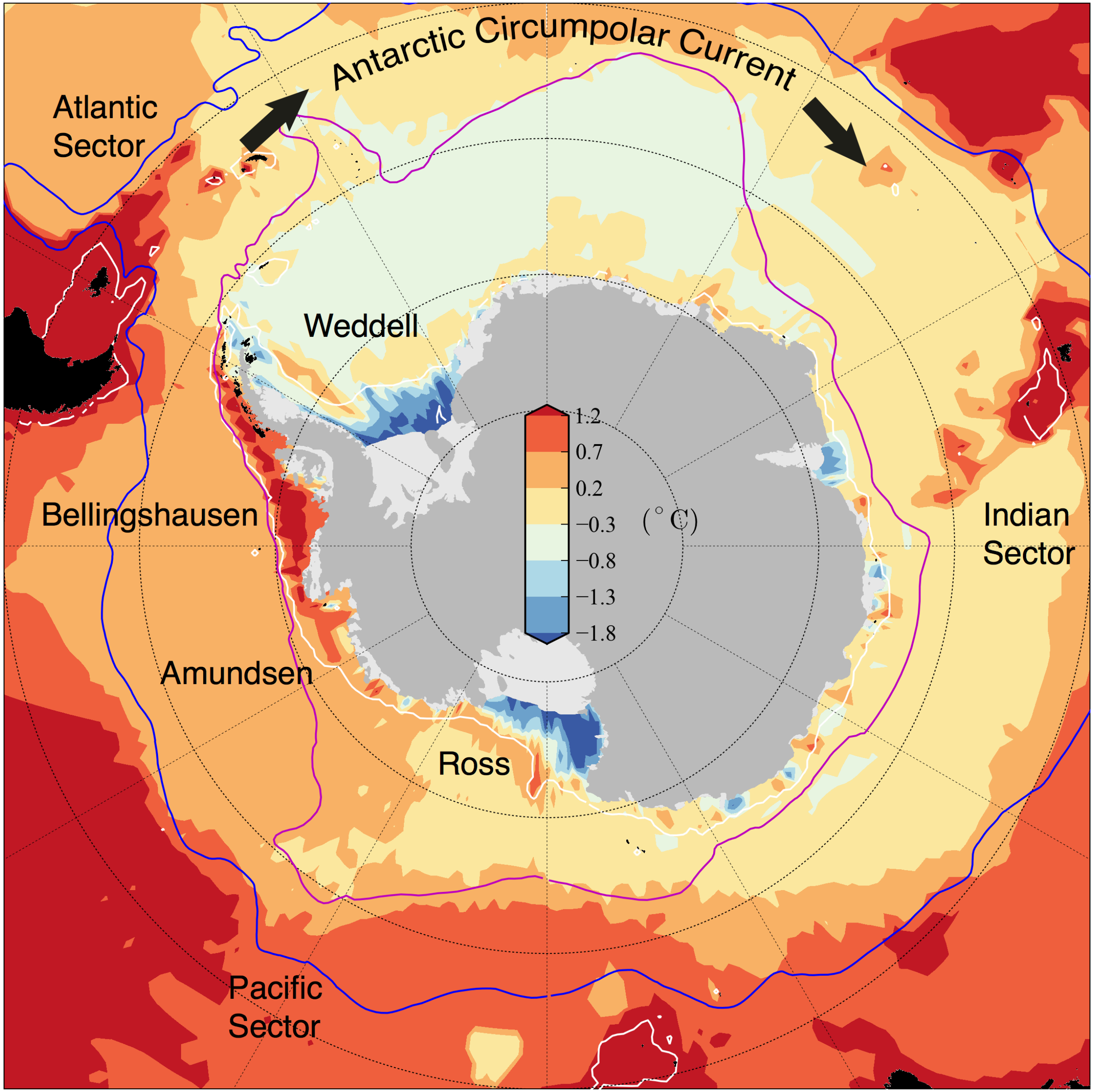
The Antarctic Shelf Seas



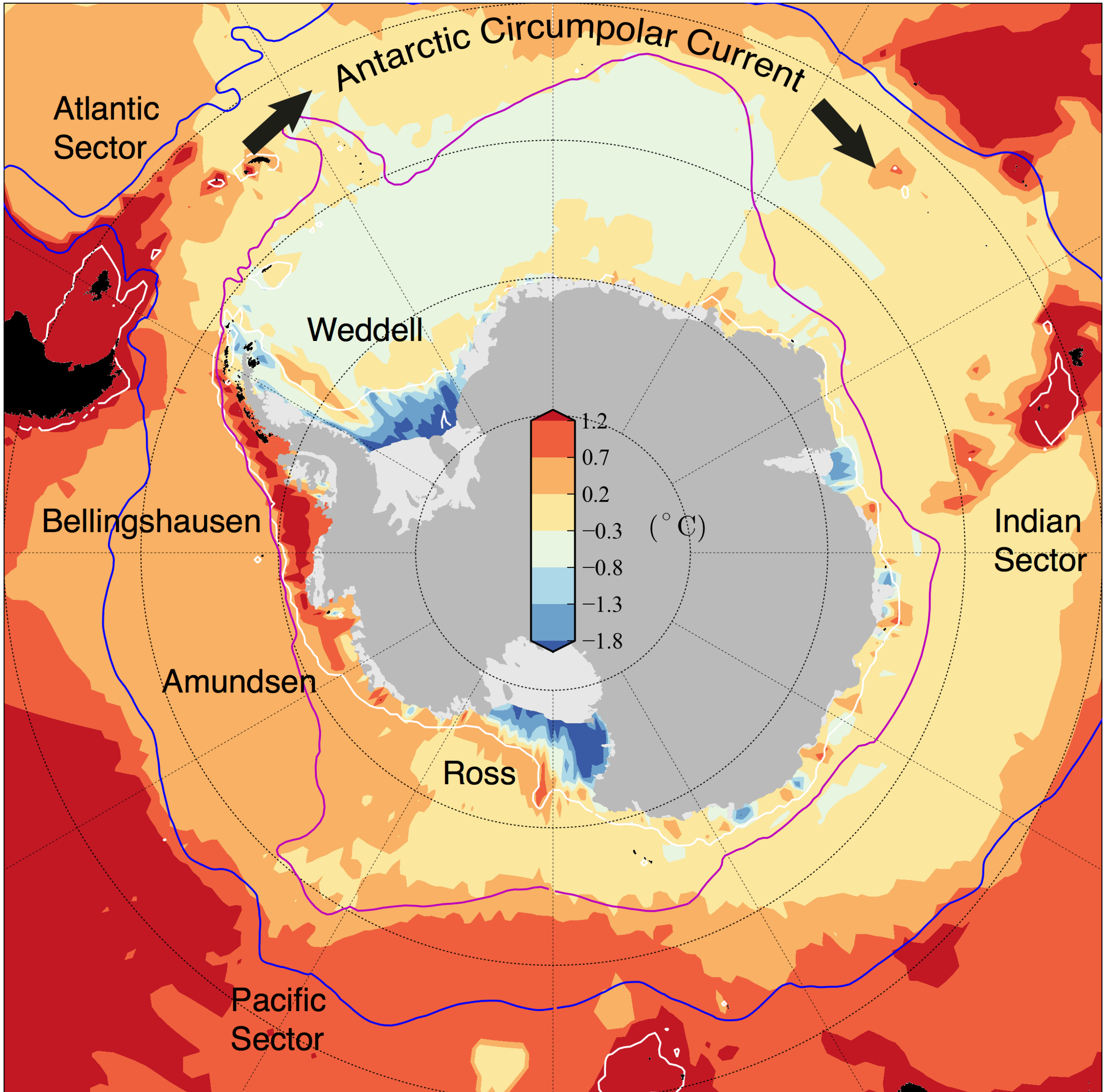
Bathymetry from RTOPO (Timmermann et al. 2010)

Bottom Temperature



Ocean Climatology from the World Ocean Atlas 09 (WOA09)

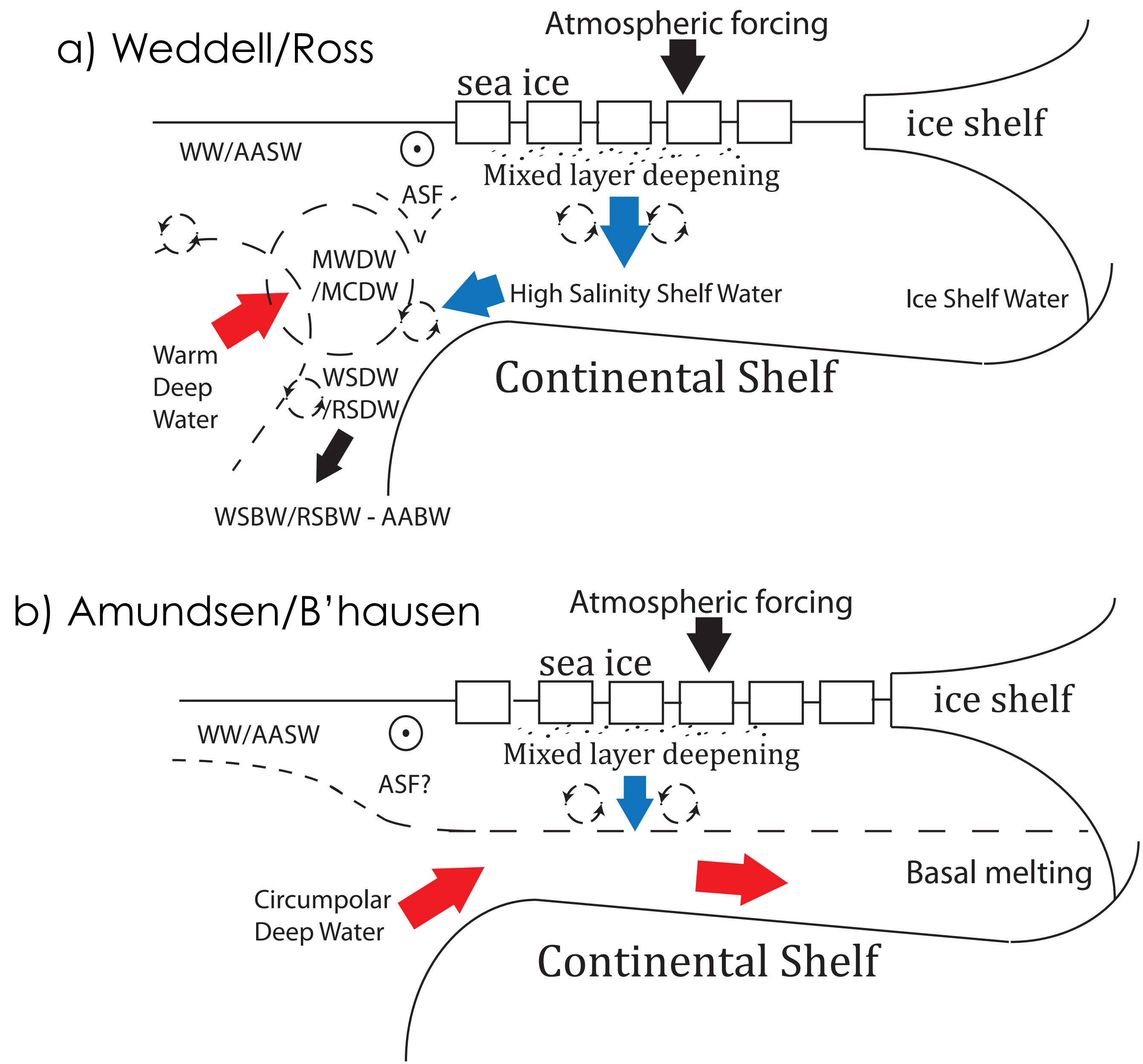
Temperature at 1000 m North of the Shelf



Ocean Climatology from the World Ocean Atlas 09 (WOA09)

What’s going on?

Bimodal Shelf Sea Schematic



Why the bimodal distribution?

Possible Reasons

DIRECT MECHANISMS

1. Regionally varying SURFACE FLUXES
   - atmosphere results in more/less sea ice production (and thus brine release).

2. Regionally varying OCEAN DYNAMICS
   - rate/properties of warm waters being transported on-shelf.

FEEDBACK MECHANISMS

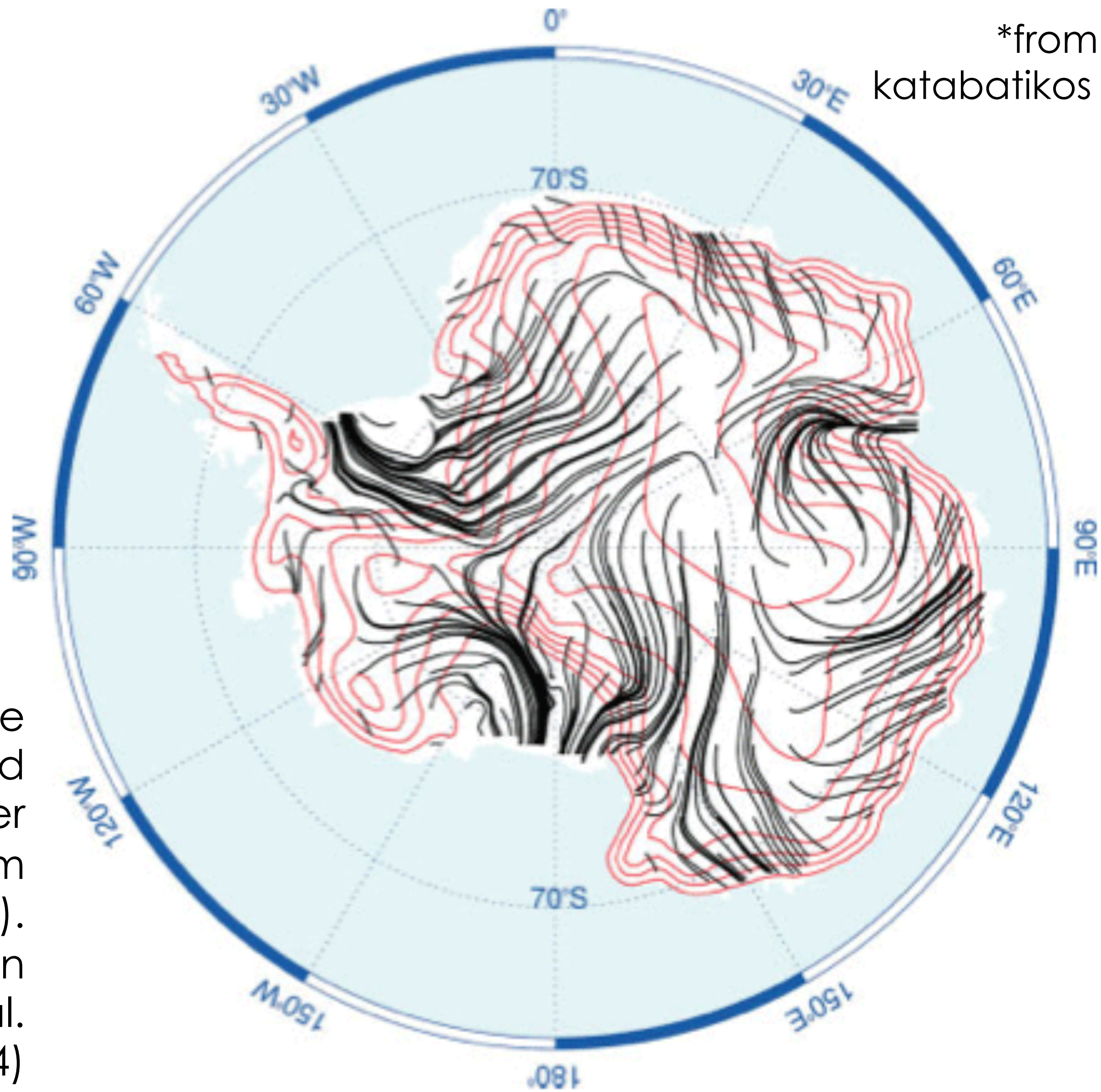
3. Impact of ocean dynamics on sea ice production
   - e.g. mixing with warm shelf waters reducing sea ice production.

4. Impact of sea ice production on-shelf transport.
   - e.g. dense waters preventing on-shelf transport of warm waters.

5. Warmer waters induce ice-shelf melt, suppressing mixing.

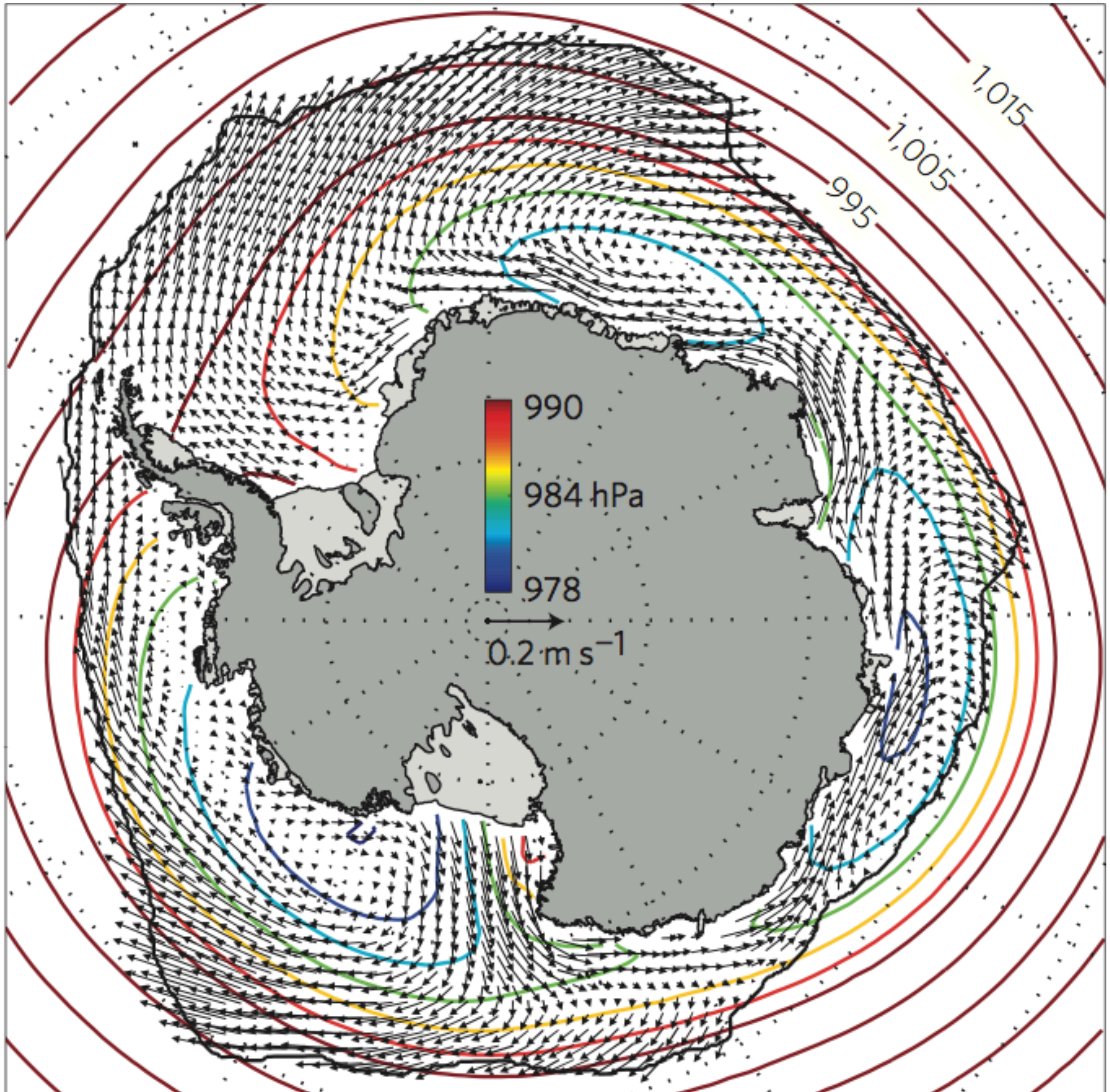
Katabatic* Winds

*from the Greek word katabatikos meaning "going downhill"



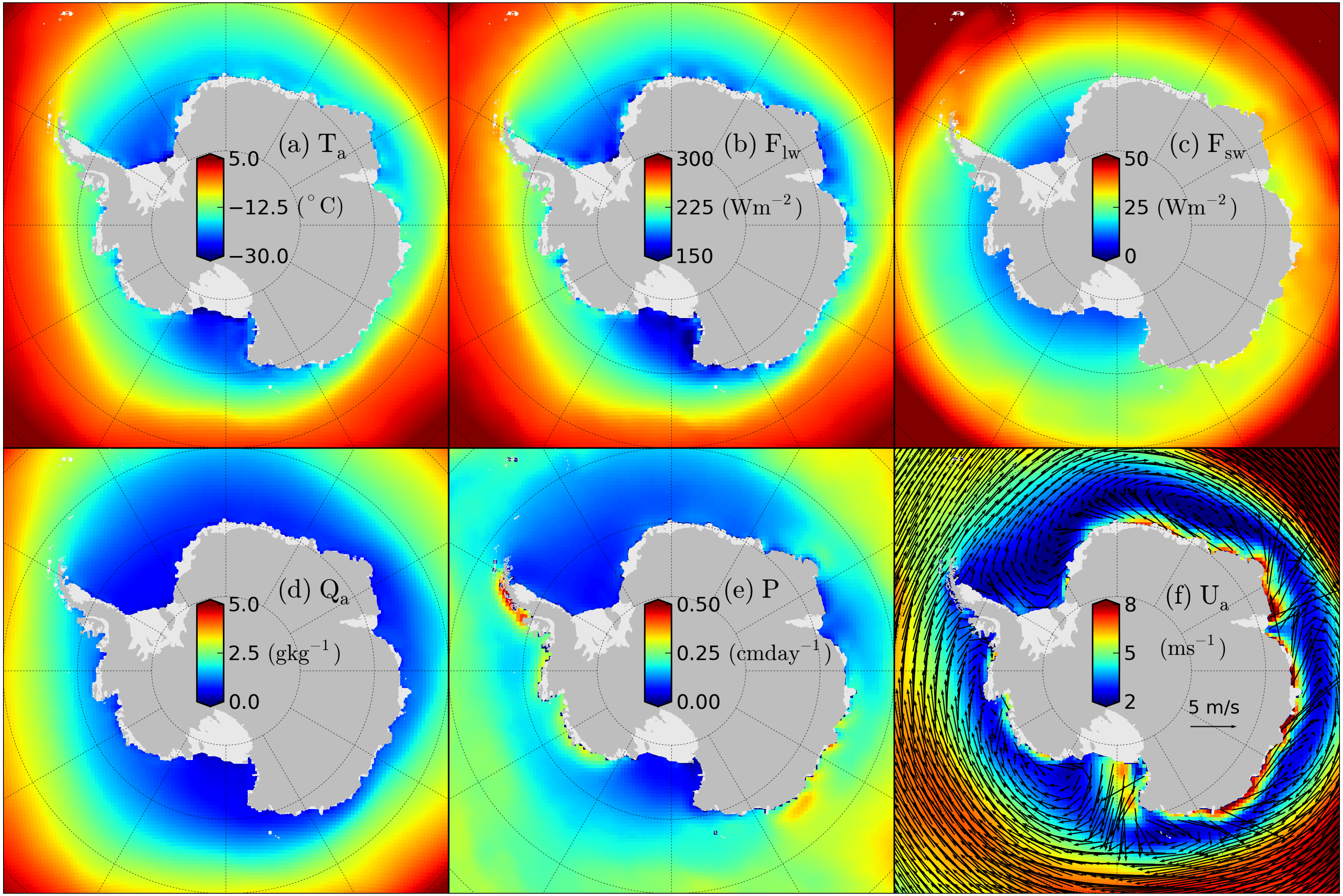
Near-surface wind streamlines over Antarctica from (RACMO). Taken from van Lipzig et al. (2004)

Prevailing Winds



Near-surface wind vectors overlaid on sea-level pressure from ERA-I. Taken from Holland & Kwok (2012)

ERA-I Mean (1980-2011) Winter Forcing



Possible Reasons

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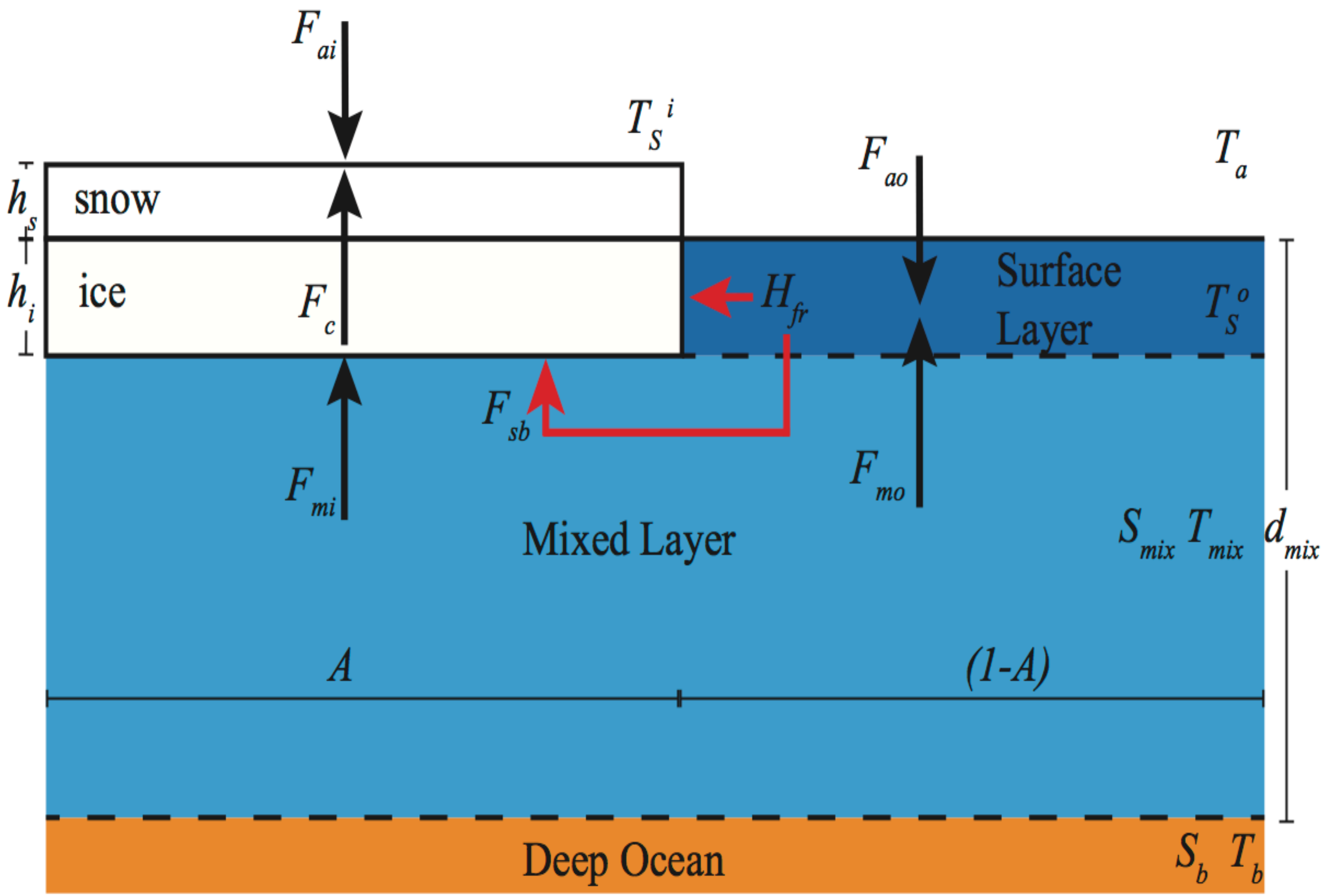
How can we investigate this?

Idealised Sea Ice-Mixed Layer Modelling



The Petty-Holland-Feltham (PHF) Model..

Mixed Layer Energy Balance

ENERGY REQUIRED TO ENTRAIN DENSE WATER FROM BELOW

ENERGY SINK FROM MIXED LAYER TURBULENCE

$$P_E = P_w + P_B - P_m$$

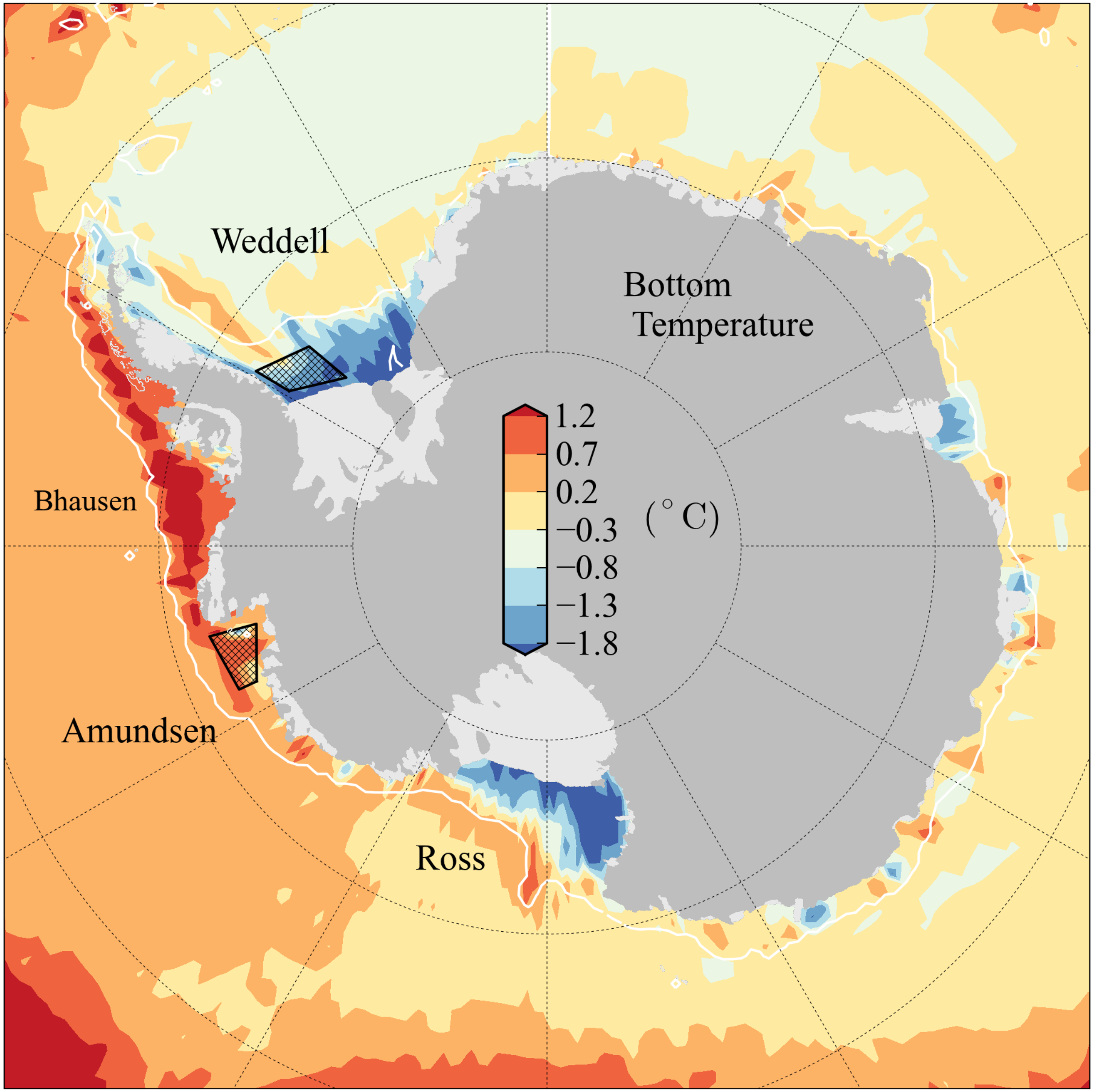
ENERGY INPUT TO THE MIXED LAYER FROM WIND STIRRING

ENERGY INPUT TO THE MIXED LAYER FROM BUOYANCY FLUXES

Rearranging the above gives the mixed layer entrainment rate…

$$w = \frac{dd_{mix}}{dt} = \frac{1}{d_{mix}\Delta b + c_m^2}[c_1 u_\star^3 + c_2 d_{mix} B_0]$$

Idealised Study Regions



Force with NCEP-CFS Atmospheric data

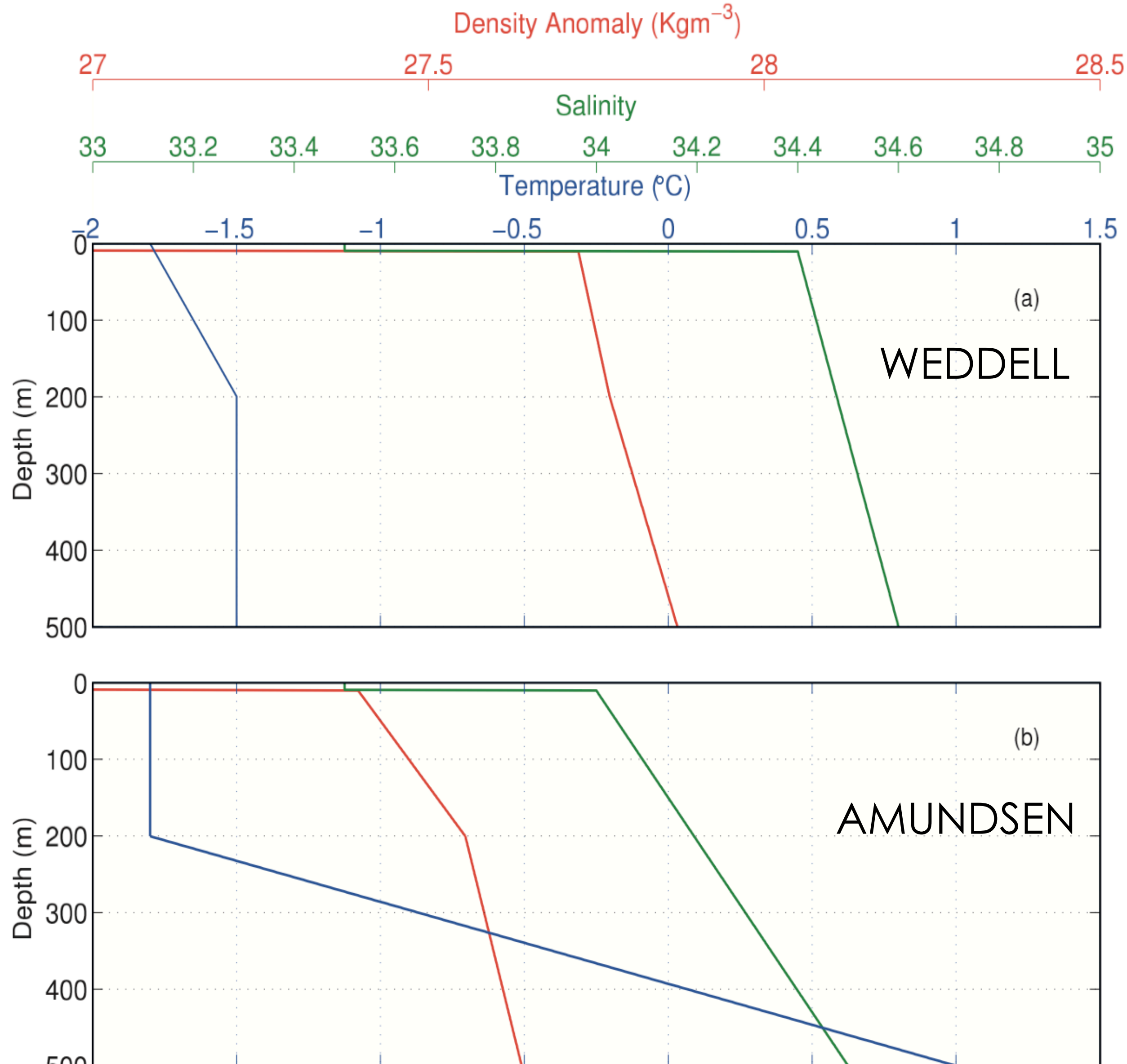
Idealised Ocean Profiles

Initialise with SUMMER (Jan) ocean profiles

Use profile resembling the ocean properties around the shelf break.

Weddell Sea
- MWDW (~ -1.5°C) intrusions.
- Not HSSW

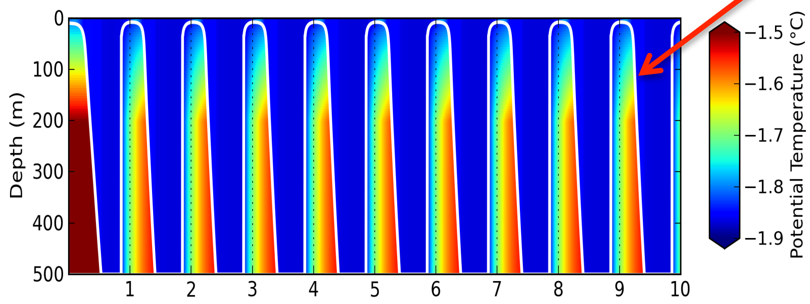
AMUNDSEN SEA
- CDW (~1°C) below Winter Water



Shelf Sea Temperature – Model Results

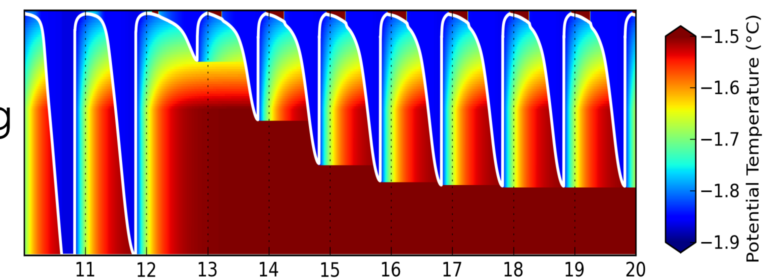
Mixed Layer Depth

Weddell Reference Simulation

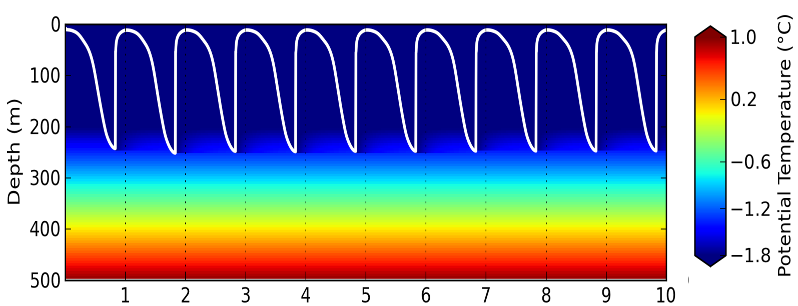


Switch Forcing

Apply Amundsen Forcing

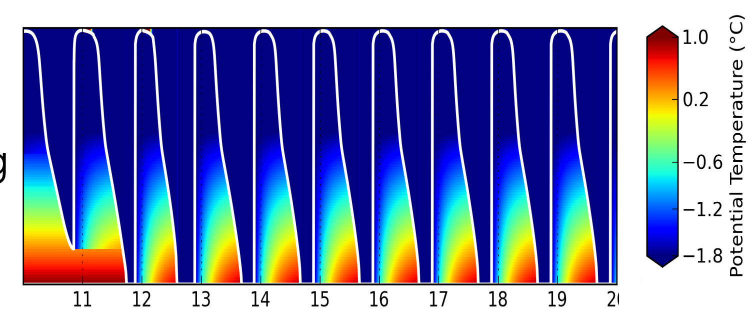


Amundsen Reference Simulation



Switch Forcing

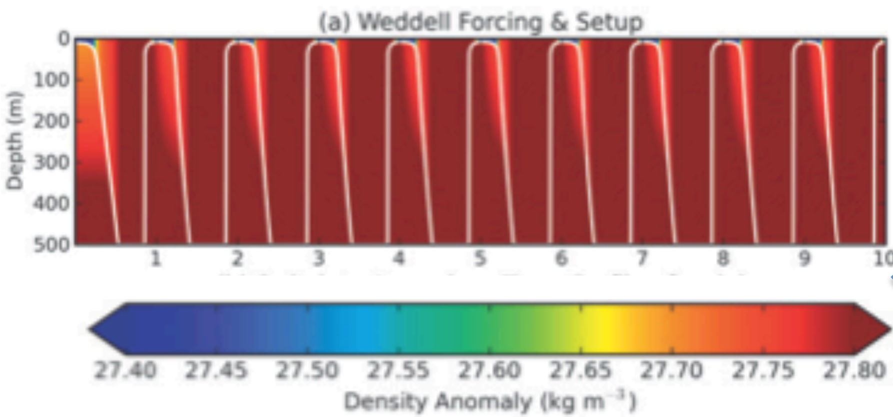
Apply Weddell Forcing

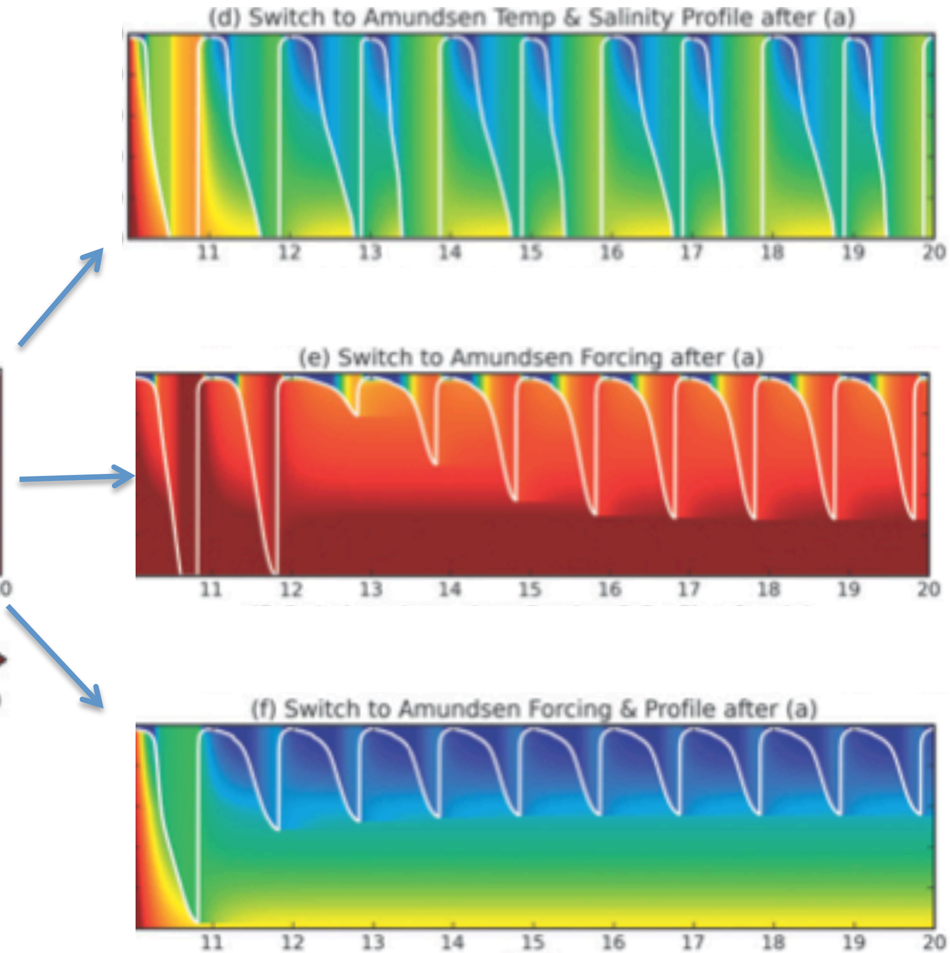


[Petty et al., Impact of atmospheric forcing over the Antarctic continental shelf, JPO, 2013]

Switching Ocean Profile/Atmosphere

Reference Weddell Simulation





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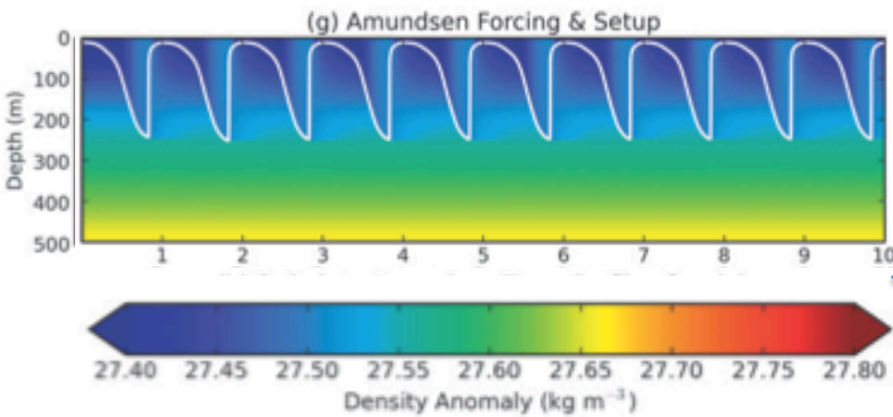

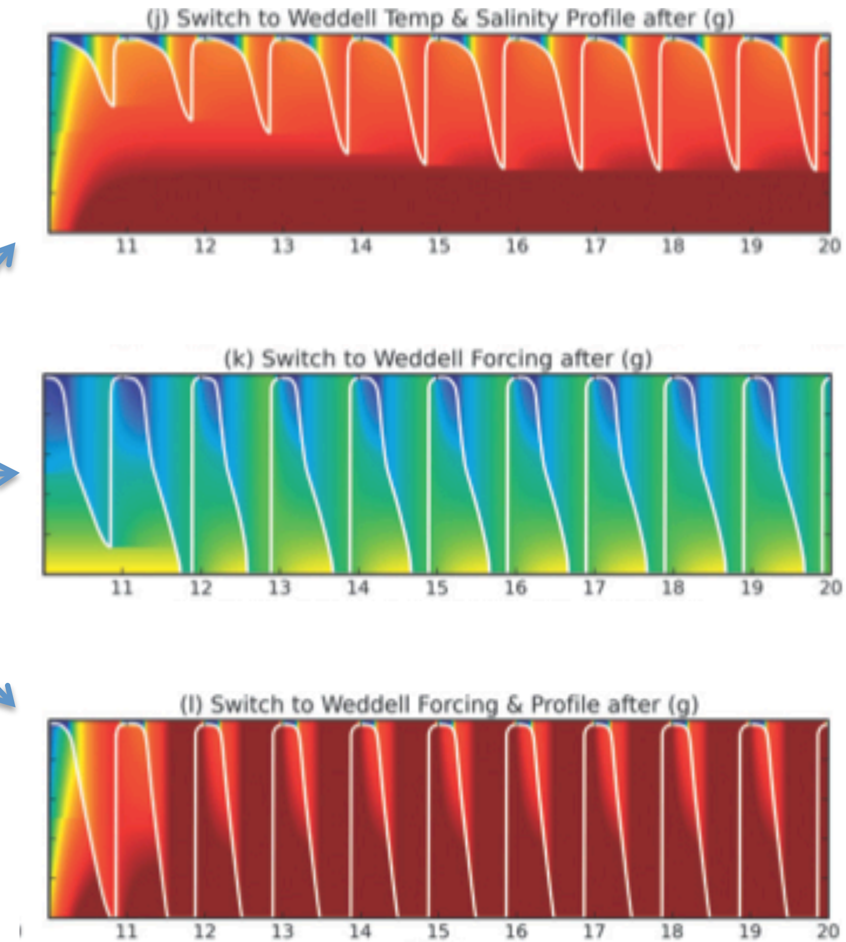

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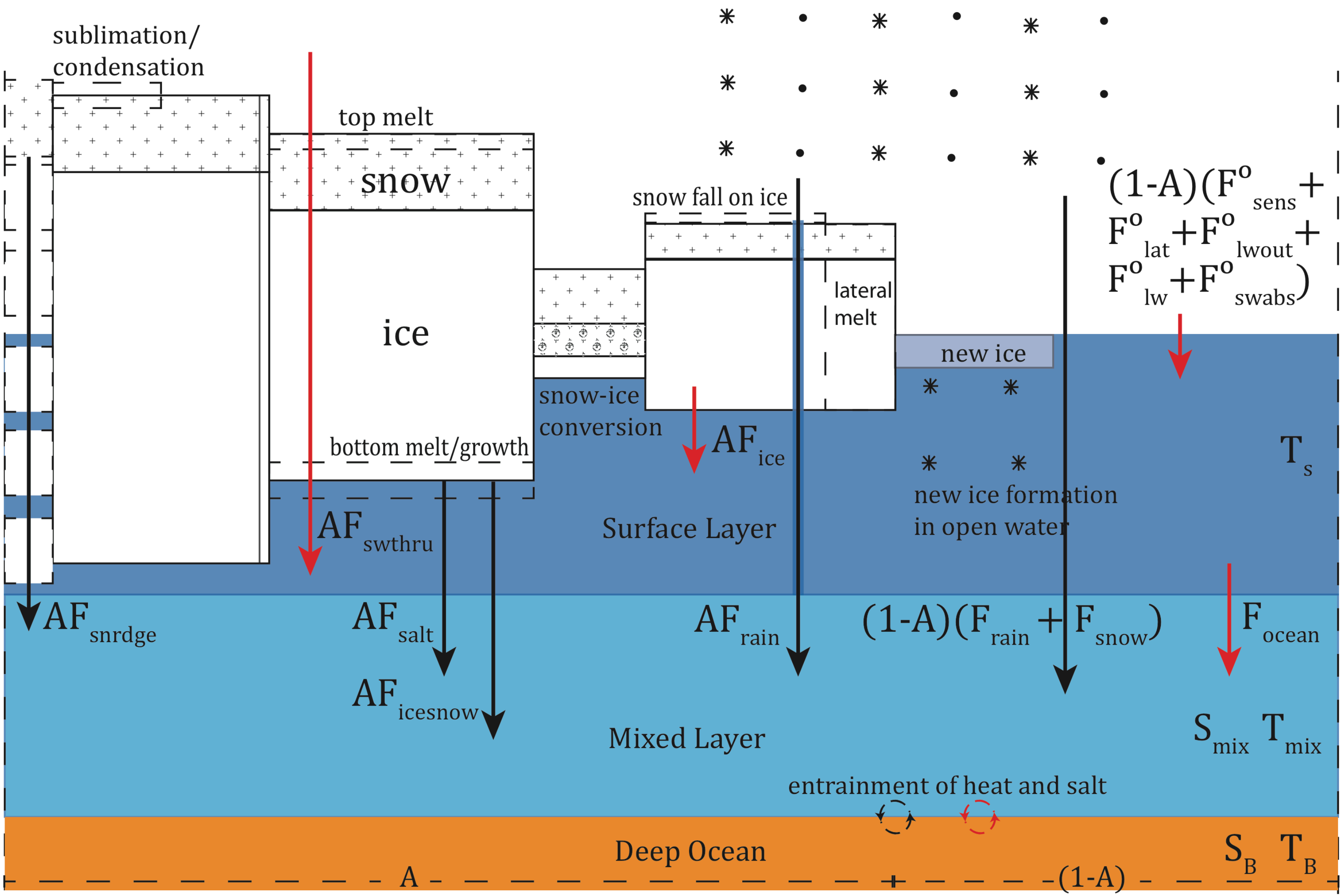
5. Warmer waters induce ice-shelf melt, suppressing mixing.

Result – Atmosphere is important

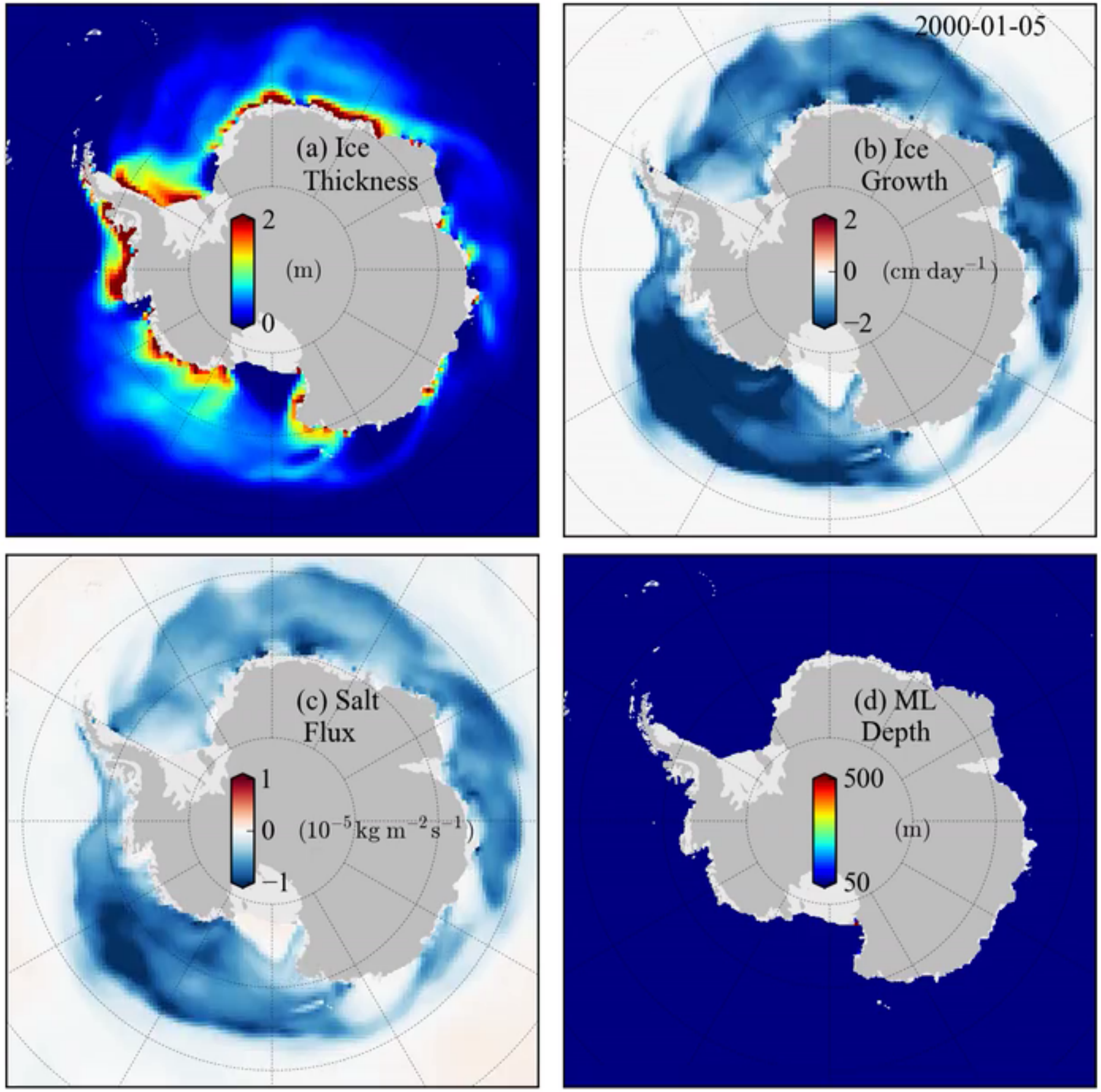
What next?

Let’s use a more sophisticated sea ice model!

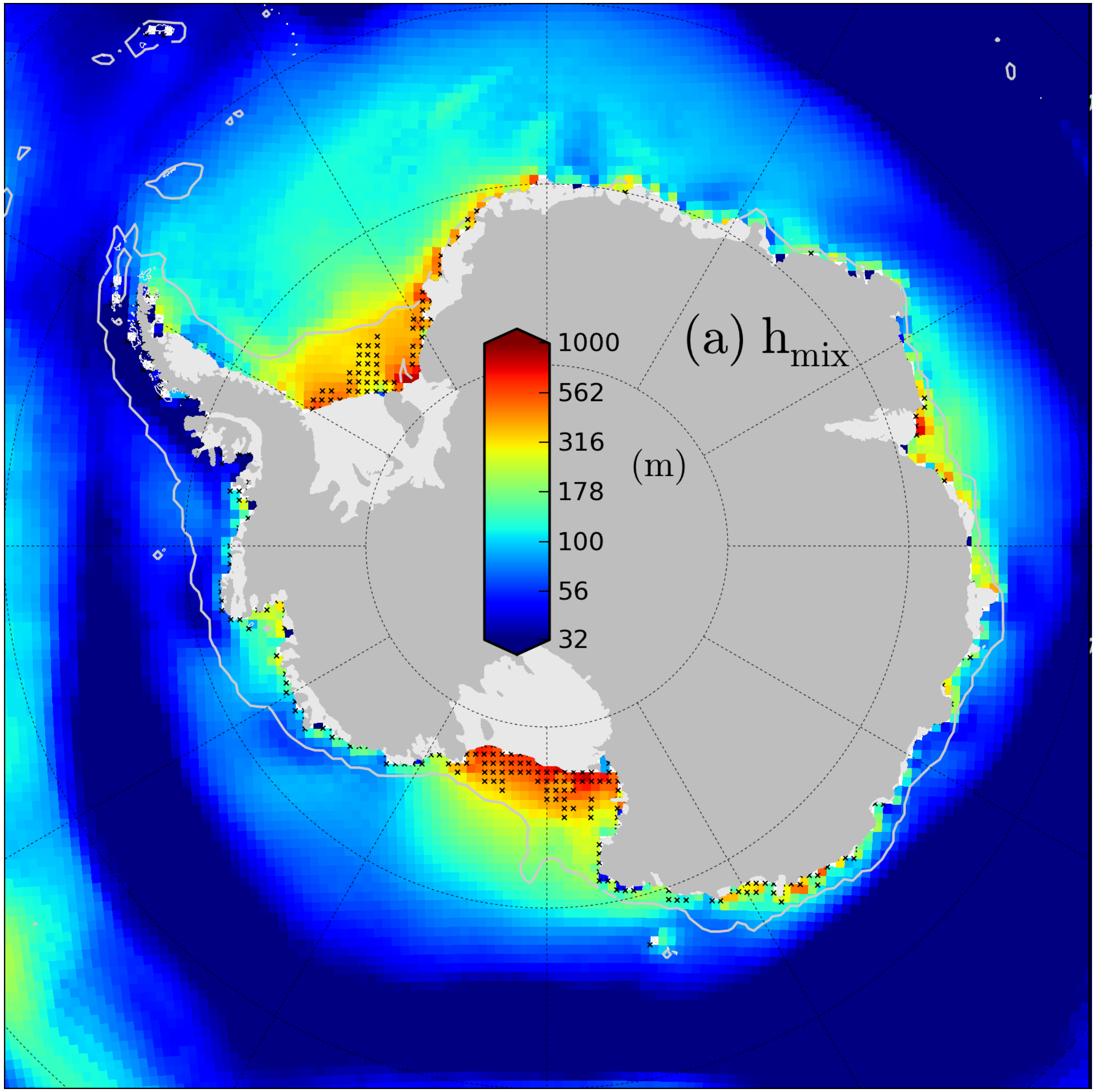
CICE Modelling Study



The Model in Action..



Mean (1985-2011) Maximum ML Depth



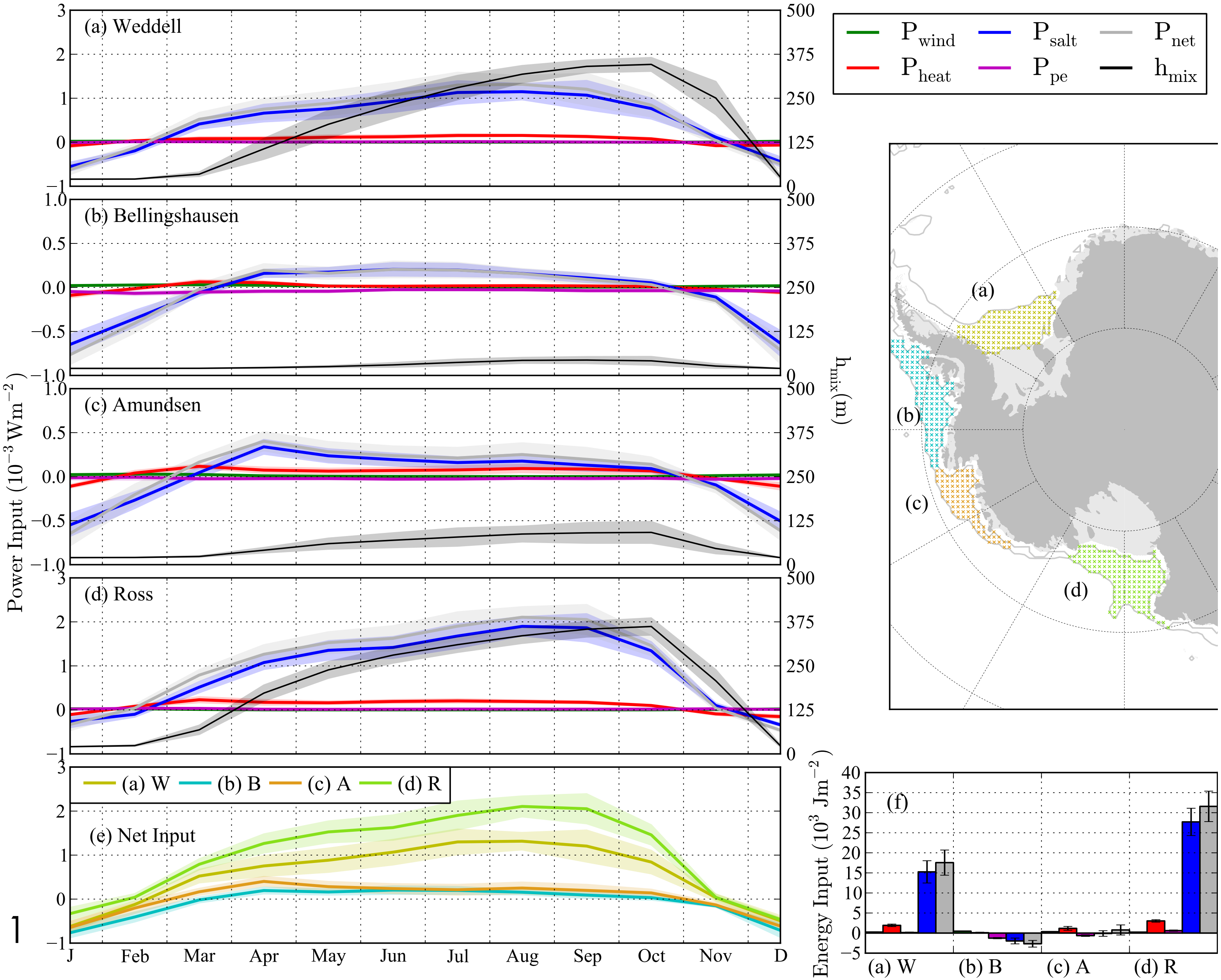
[Petty et al., Sea ice and the ocean mixed layer over the Antarctic shelf seas, The Cryosphere, 2013]

Mixed Layer Energy Balance

$$P_E = P_{wind} + P_{salt} + P_{heat} + P_{pe} - P_m$$

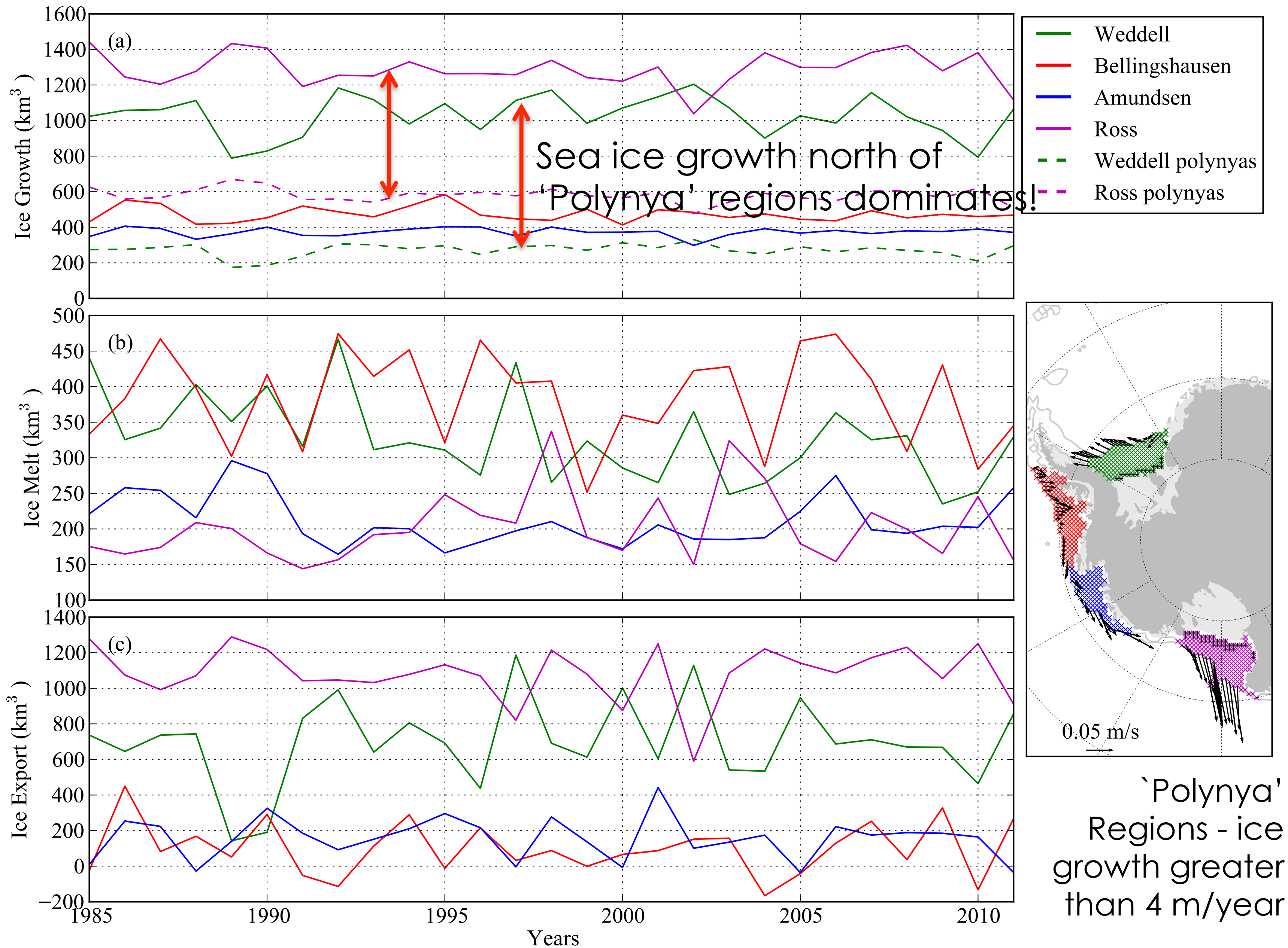
- P_E: ENERGY REQUIRED TO ENTRAIN DENSE WATER FROM BELOW
- P_{wind}: ENERGY INPUT TO THE MIXED LAYER FROM WIND STIRRING (DIRECT)
- P_{salt}: ENERGY INPUT TO THE MIXED LAYER FROM ICE/SNOW SALT FLUX (BUOYANCY)
- P_{heat}: ENERGY INPUT TO THE MIXED LAYER FROM SURFACE HEAT FLUX (BUOYANCY)
- P_{pe}: ENERGY INPUT FROM NET PRECIPITATION (BUOYANCY)

Surface-Mixed Layer Energy Input



2000-2011

Regional Sea Ice Mass Balance



`Polynya' Regions - ice growth greater than 4 m/year

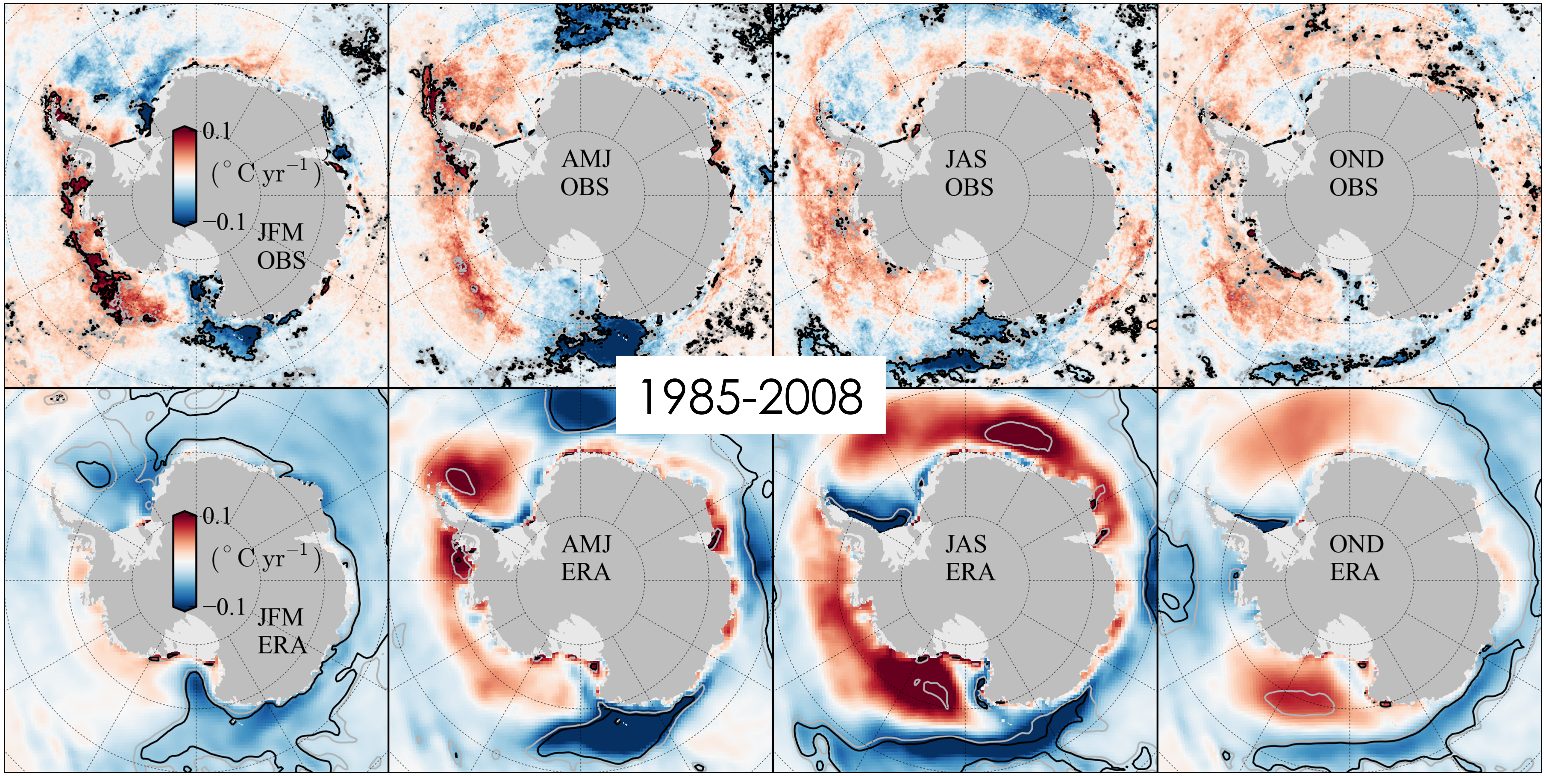
Result – Sea ice is important

Trends – The Final Chapter (literally)

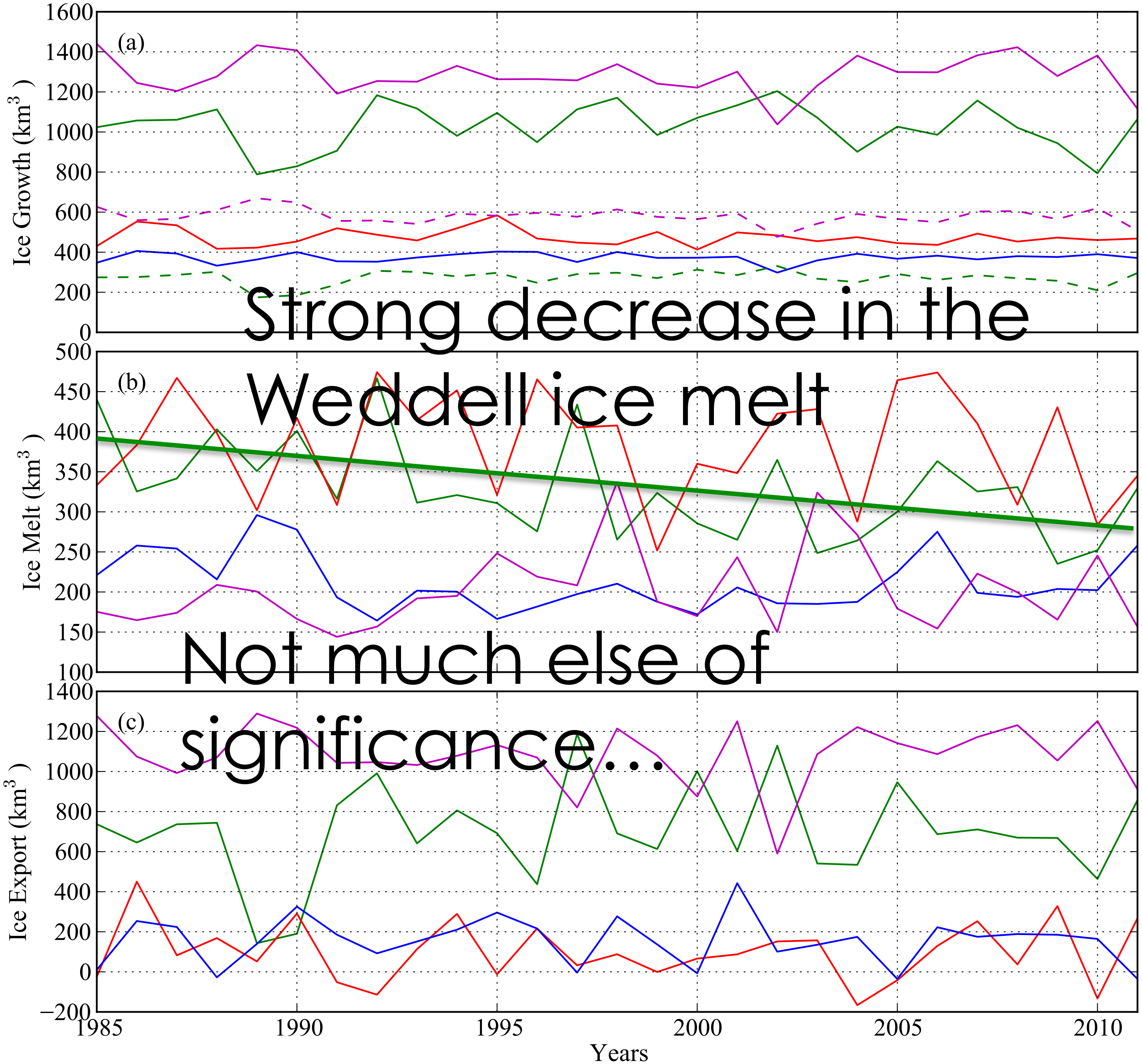
Temperature Trends

Comiso satellite (infra-red) 'skin' temperature trends

ERA-I 2 m air temperature trends

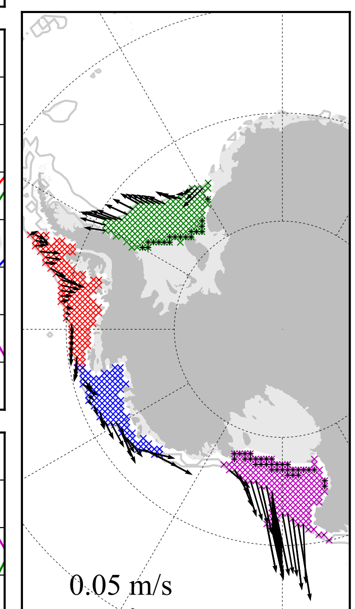


Regional Sea Ice Mass Balance



Strong decrease in the Weddell ice melt

Not much else of significance…



'Polynya' Regions - ice growth greater than 4 m/year

What does this do to the sea ice and mixed layer?

Not much that's significant..

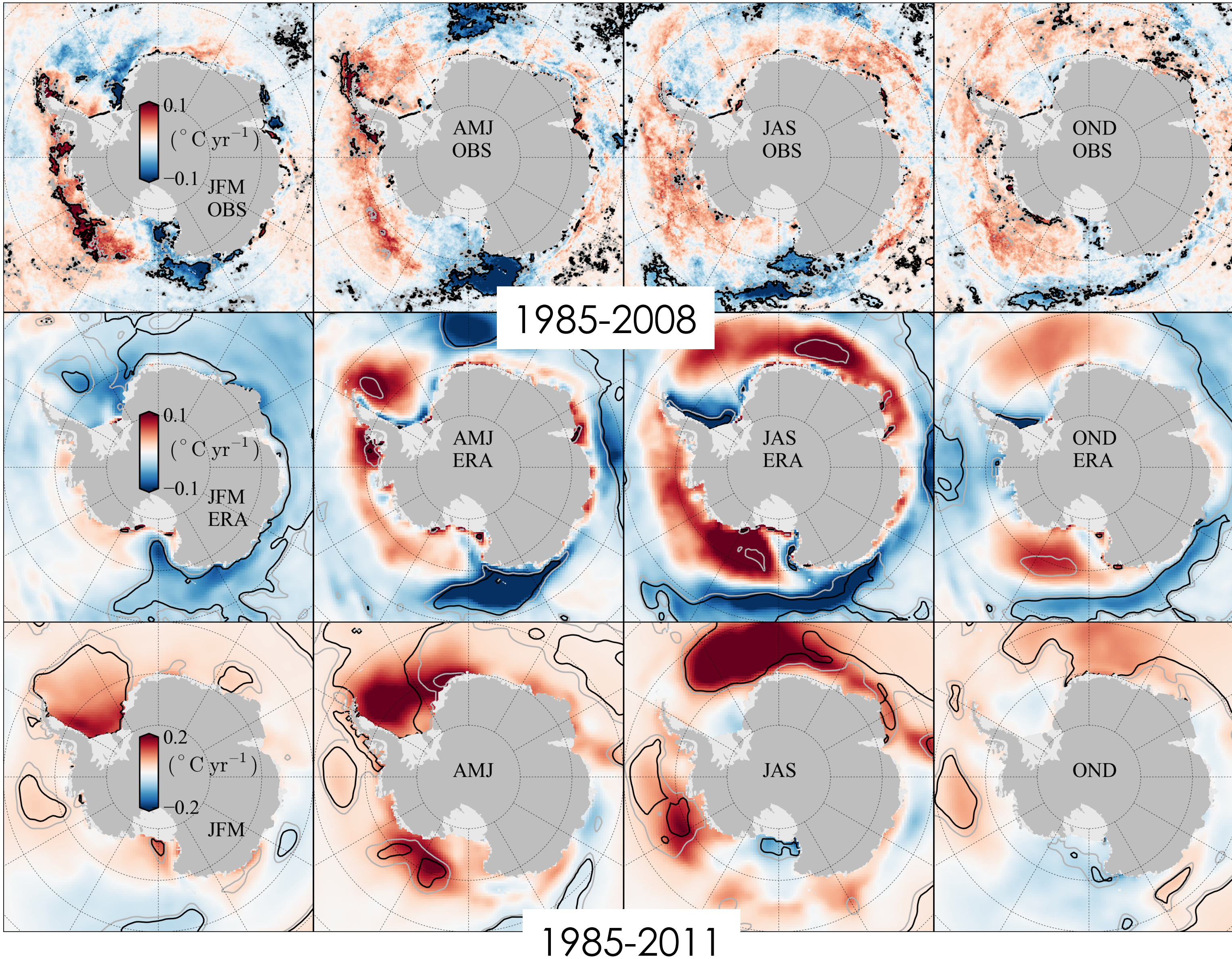
Use CMIP5 model output to extend into the coming century..

Temperature Trends

Comiso satellite (infra-red) 'skin' temperature trends

ERA-I 2 m air temperature trends

HadGEM2-ES 2 m air temperature trends



Temperature Trends

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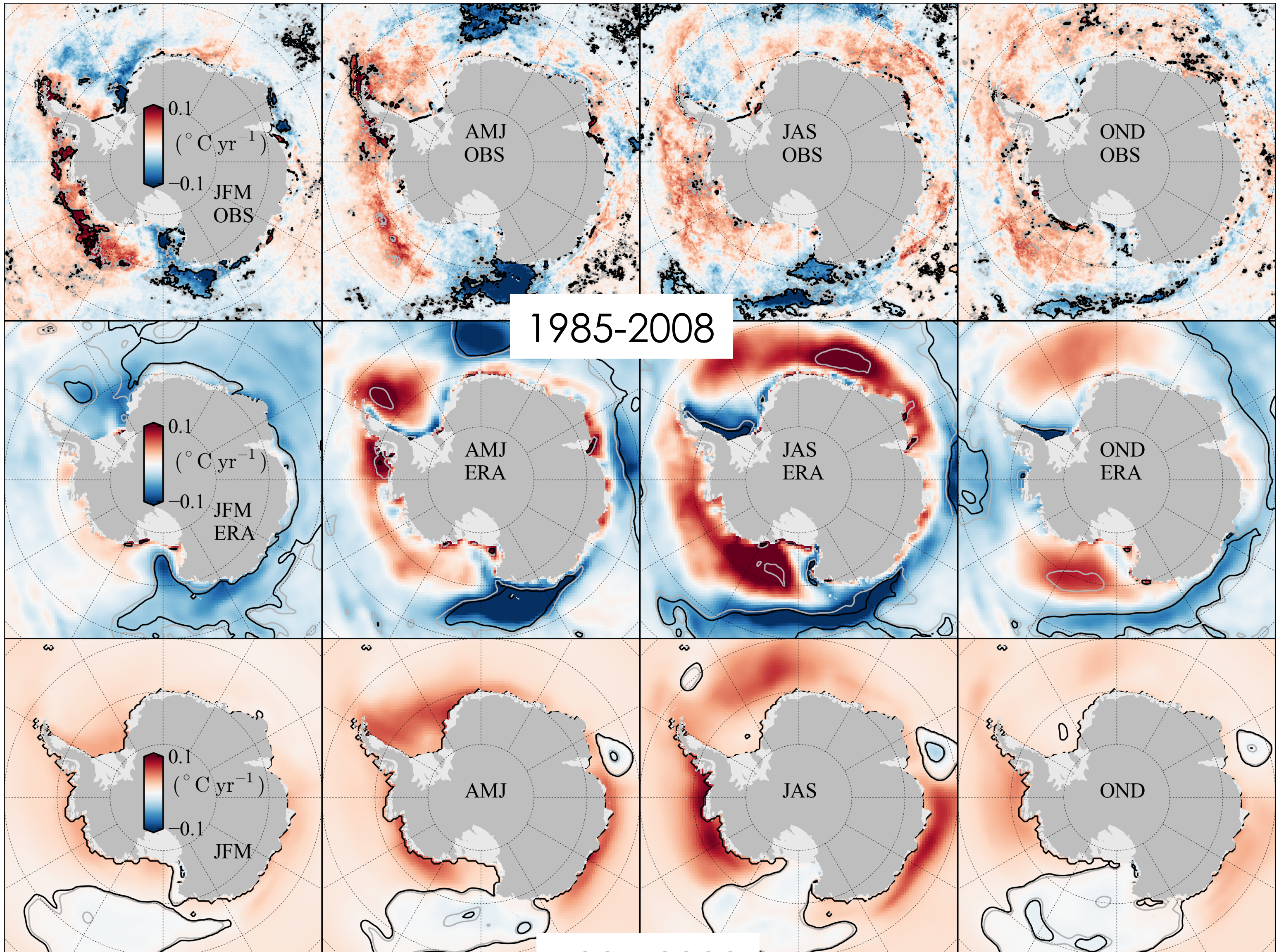
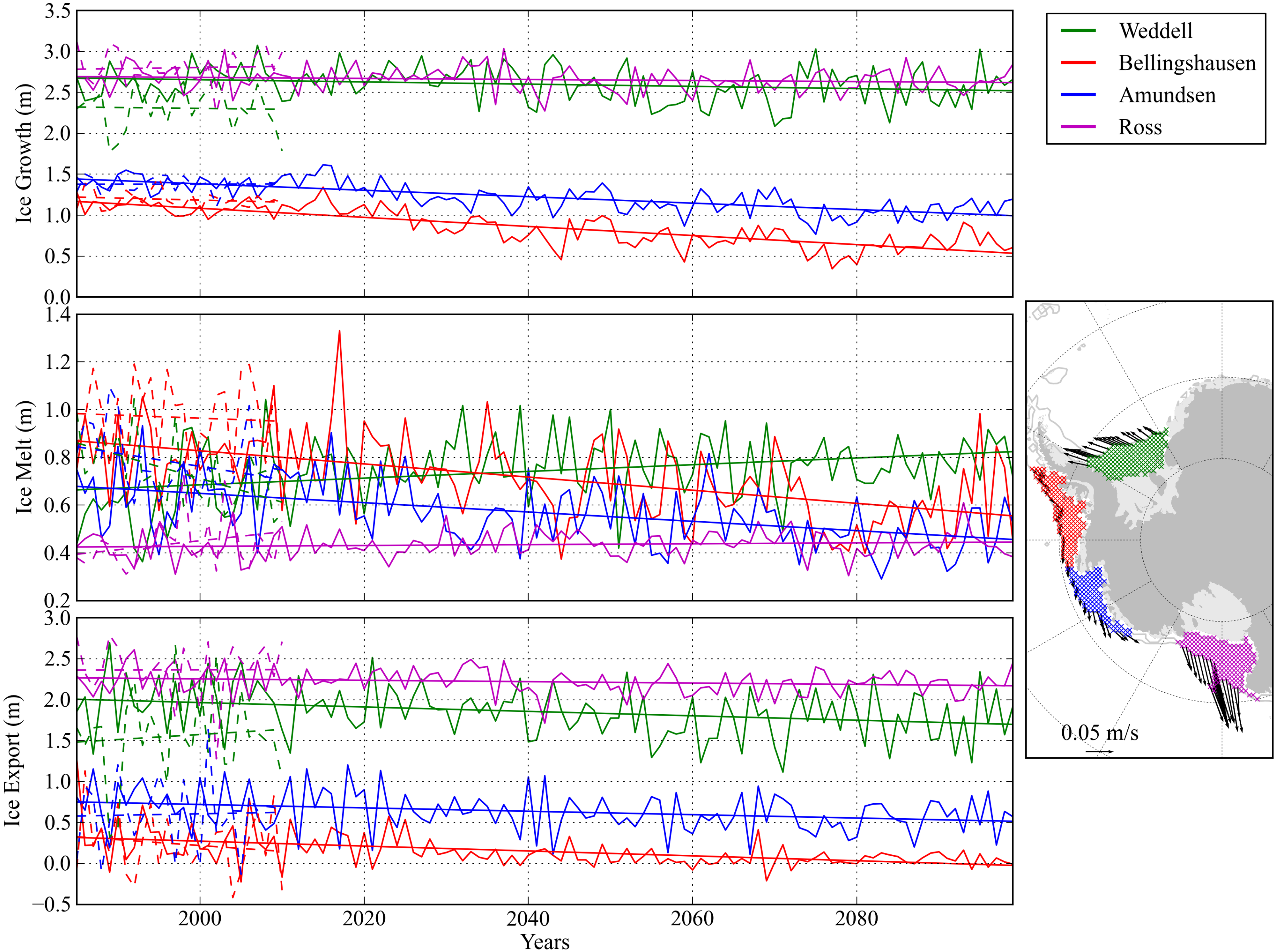
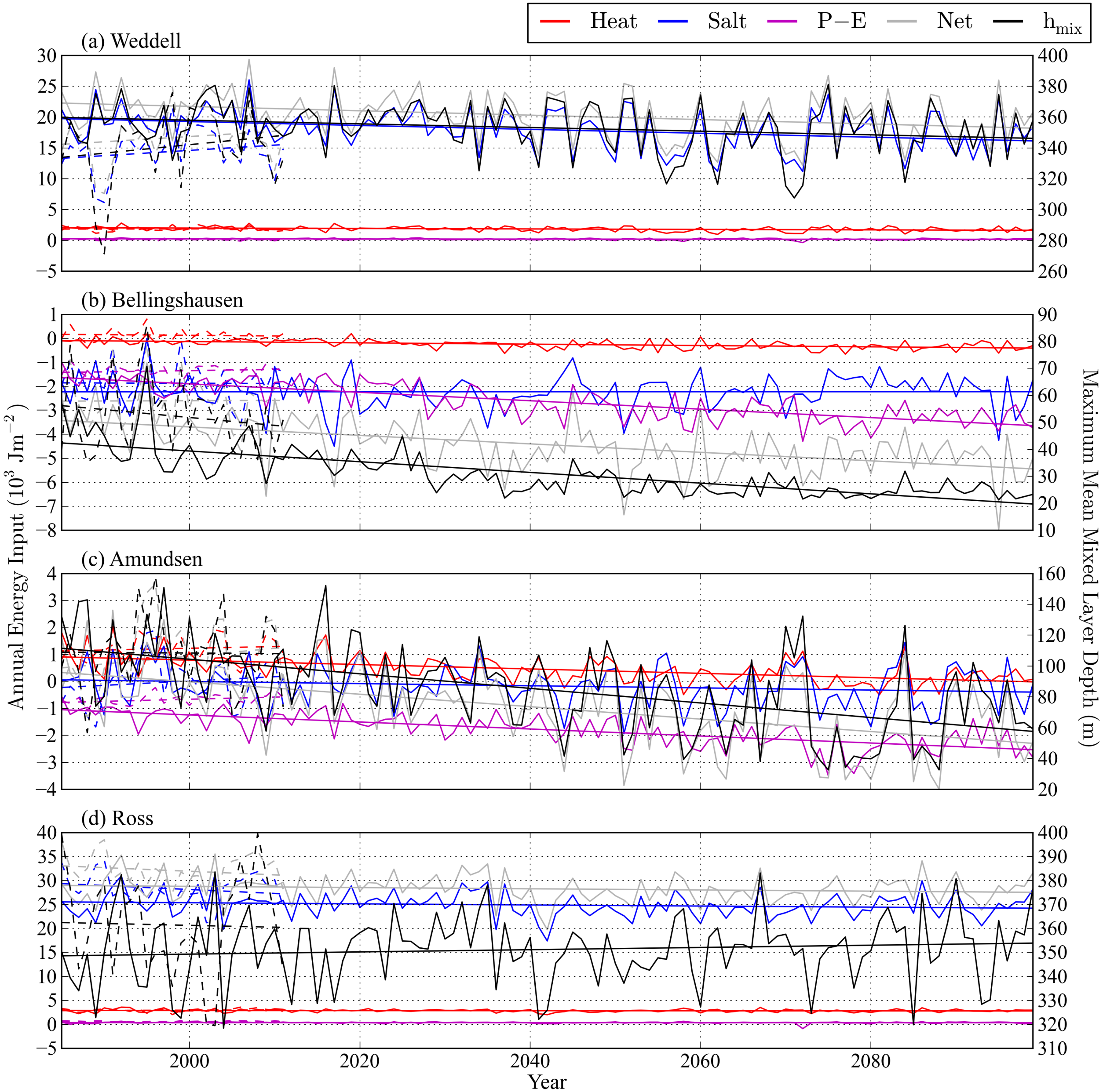


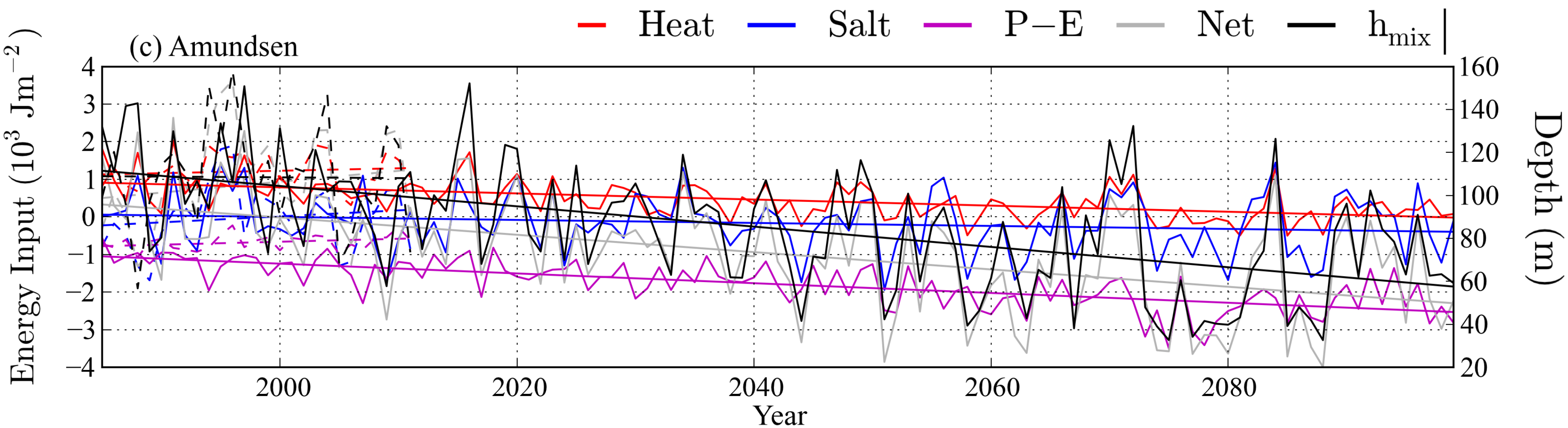
Sea Ice Mass Balance Trends

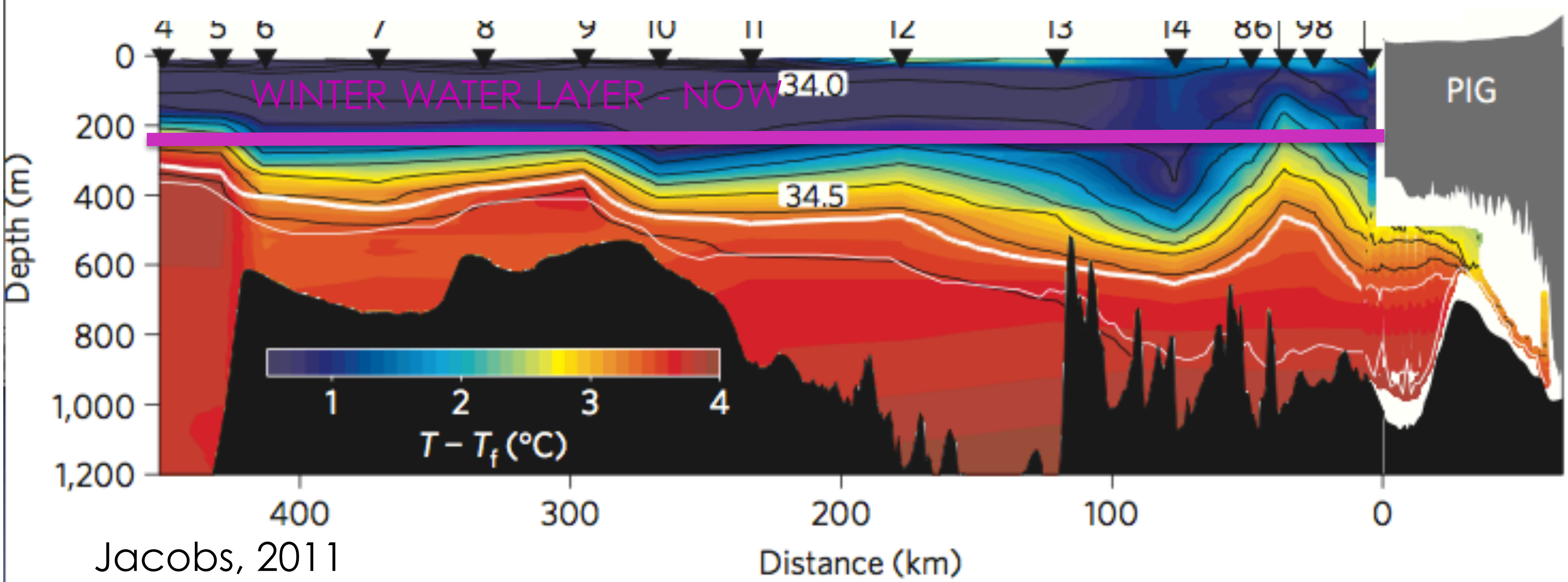


Mixed Layer Trends



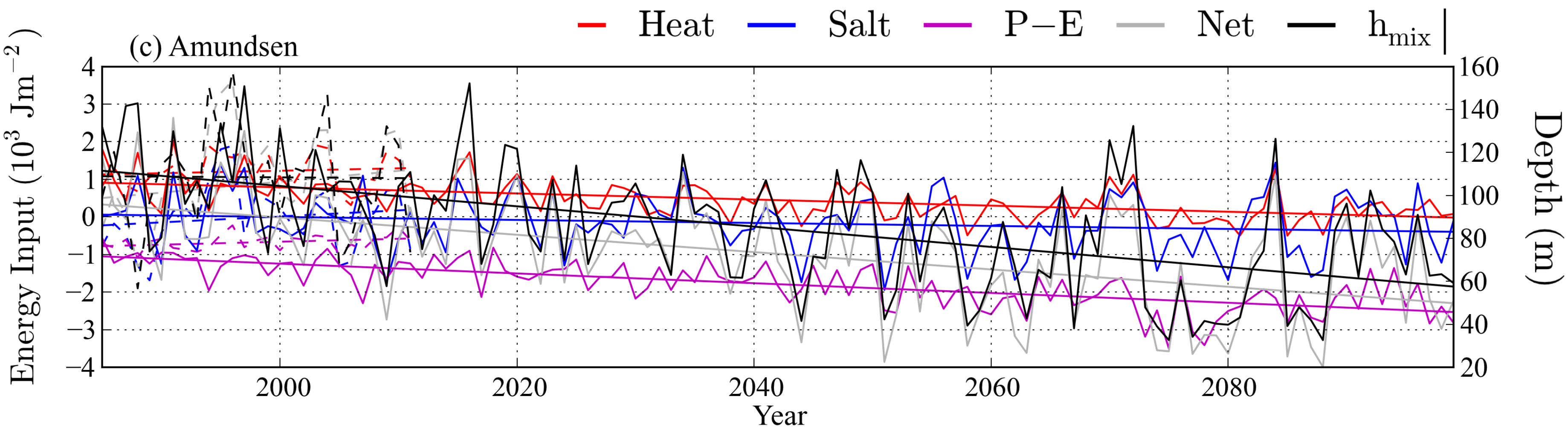
Maximum ML-Depth Trend (1985-2099)

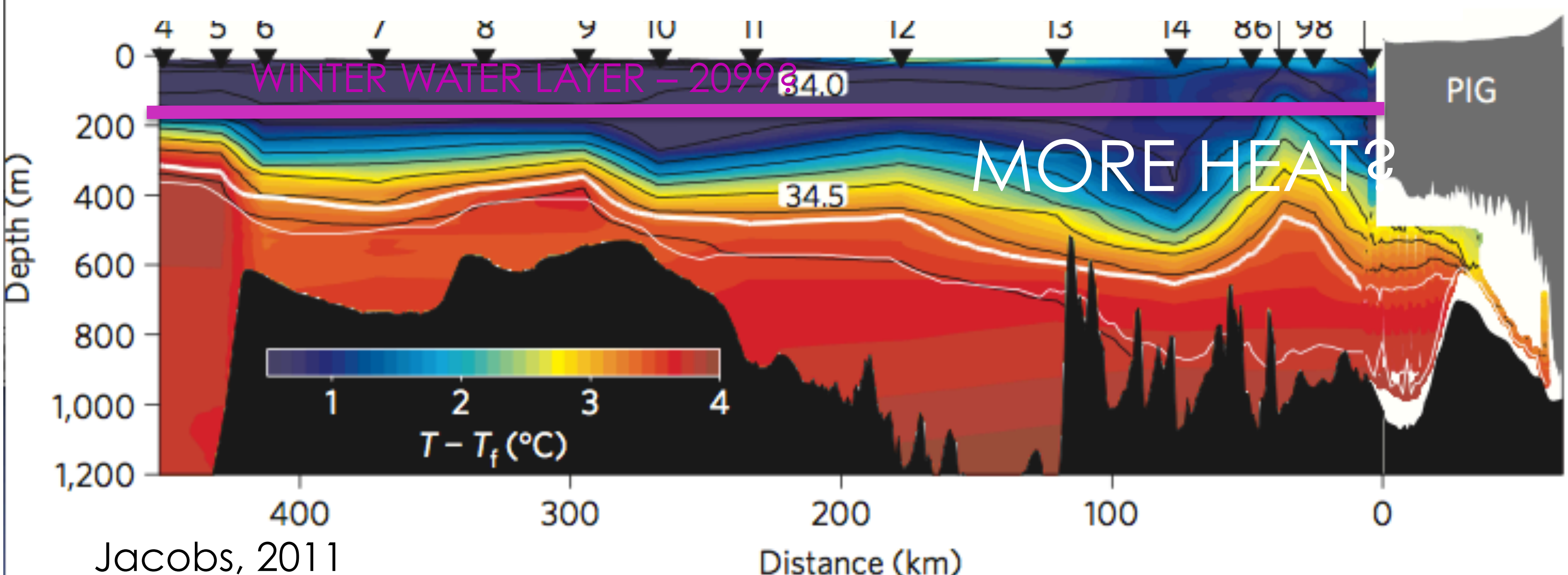




Jacobs, 2011

Maximum ML-Depth Trend (1985-2099)





Jacobs, 2011

Surface Salt Input Trends

No significant trends in the ERA-I simulation!

NB PIG currently thinning by ~30 Gt/yr!
BUT – where does this extra melt water go?

More significant trends in the HadGEM2-ES simulation

ERA-I	**Weddell**	**B'hausen**	**Amundsen**	**Ross**
Shelf sea area (10^3 km^2)	433	398	261	459
$\overline{h}_{max}$ (m)	340	50	110	360
S_{ice} (kg m^{-2}dec^{-1})	3.60 (95)	0.33	2.16	-0.61
S_{pe} (kg m^{-2}dec^{-1})	-0.16	0.36	0.63 (93)	-0.03
S_{net} (kg m^{-2}dec^{-1})	3.50 (92)	0.70	2.78 (92)	-0.63
FWE_{net} (Gt dec^{-1})	-43.1 (92)	-7.91	-20.6 (92)	8.20
$\widehat{S}_{net}$ (dec^{-1})	0.01 (92)	0.01	0.02 (92)	-0.002
Shelf sea salinity (dec^{-1})	2e-4 (97)	-1e-4 (92)	1e-4	2e-5
'Polynya' area (10^3 km^2)	55.1	-	-	96.9
$\overline{h}^p_{max}$ (m)	520	-	-	590
S^p_{net} (kg m^{-2}dec^{-1})	4.75	-	-	-5.70 (91)
FWE^p_{net} (Gt dec^{-1})	-7.46	-	-	15.7 (91)
$\widehat{S}^p_{net}$ (dec^{-1})	0.01	-	-	-0.01 (91)
HadGEM2-ES				
$\overline{h}_{max}$ (m)	350	30	90	350
S_{ice} (kg m^{-2}dec^{-1})	**-1.14**	-0.32 (96)	**-0.43**	-0.010
S_{pe} (kg m^{-2}dec^{-1})	-0.04 (93)	**-1.29**	**-0.93**	-0.020
S_{net} (kg m^{-2}dec^{-1})	**-1.18**	**-1.60**	**-1.37**	-0.040
FWE_{net} (Gt dec^{-1})	**14.5**	**18.1**	**10.1**	0.48
$\widehat{S}_{net}$ (dec^{-1})	**-0.003**	**-0.05**	**-0.01**	-1e-4
Shelf sea salinity (dec^{-1})	**-4e-5**	**5e-5**	**-5e-5**	6e-6
'Polynya' area (10^3 km^2)	76.5	-	-	93.9
$\overline{h}^p_{max}$ (m)	550	-	-	590
S^p_{net} (kg m^{-2}dec^{-1})	**-1.79**	-	-	-0.69 (98)
FWE^p_{net} (Gt dec^{-1})	**3.88**	-	-	1.84 (98)
$\widehat{S}^p_{net}$ (dec^{-1})	**-0.003**	-	-	-0.001 (98)

Result – Sea ice isn't important?*

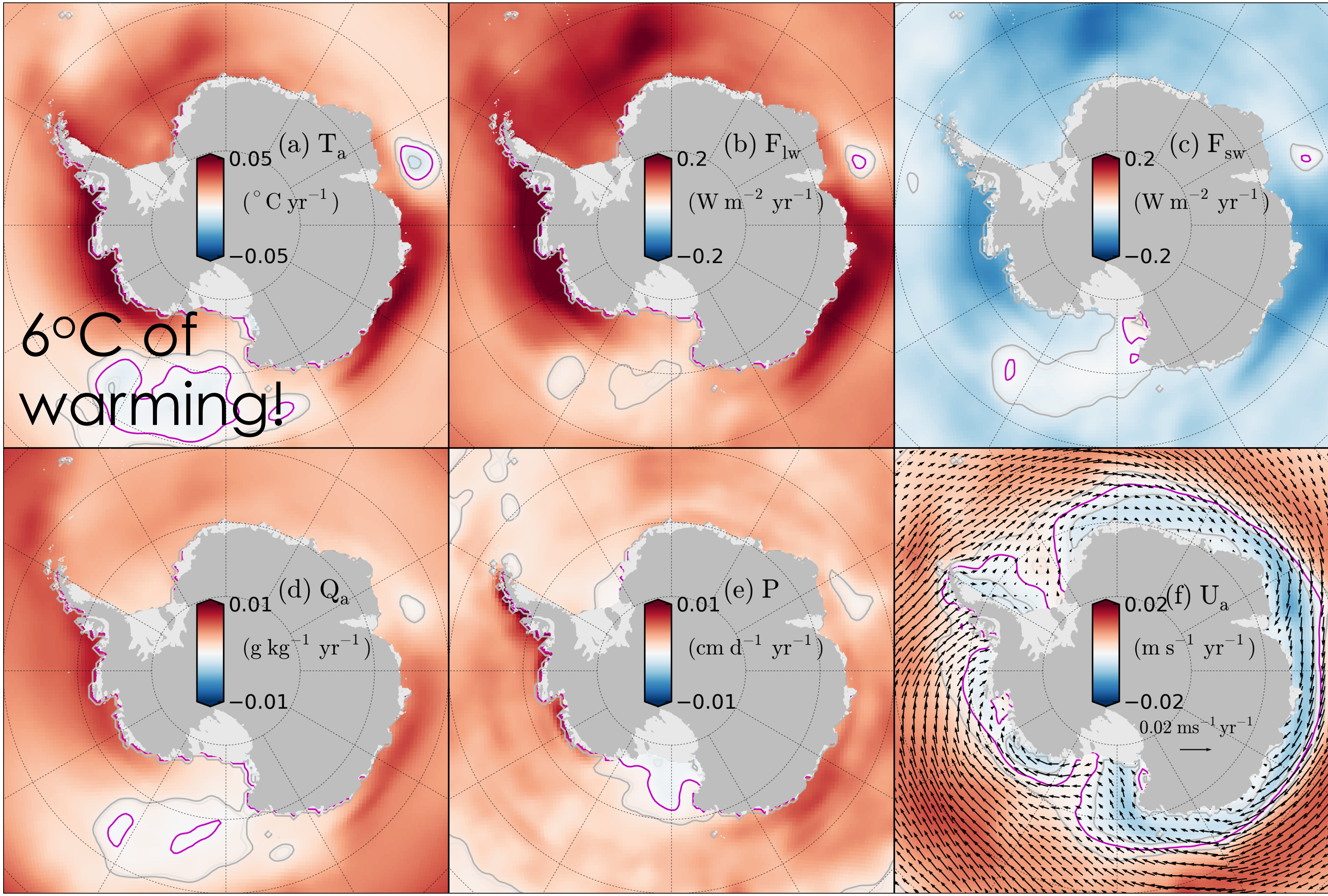
*more work needed..

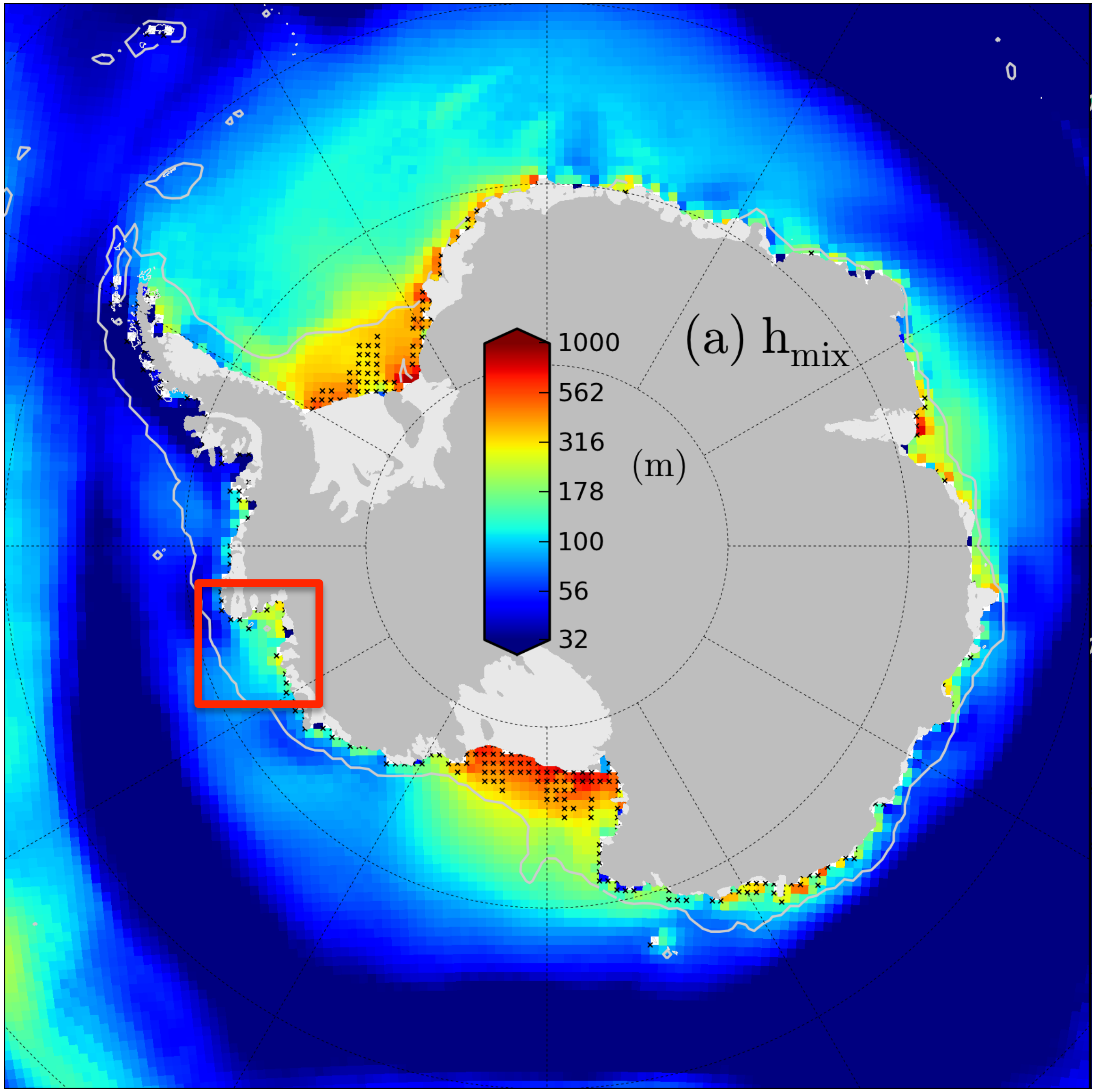
Summary

1. Atmosphere can explain bimodal distribution in seabed temp.
2. Sea ice dominates mixed layer depth evolution.
3. Shows strong regional variability
4. Likely that ice shelf trends will dominate over the coming decades?!

Questions?

hadGEM2-ES 1980-2099 Annual Trend

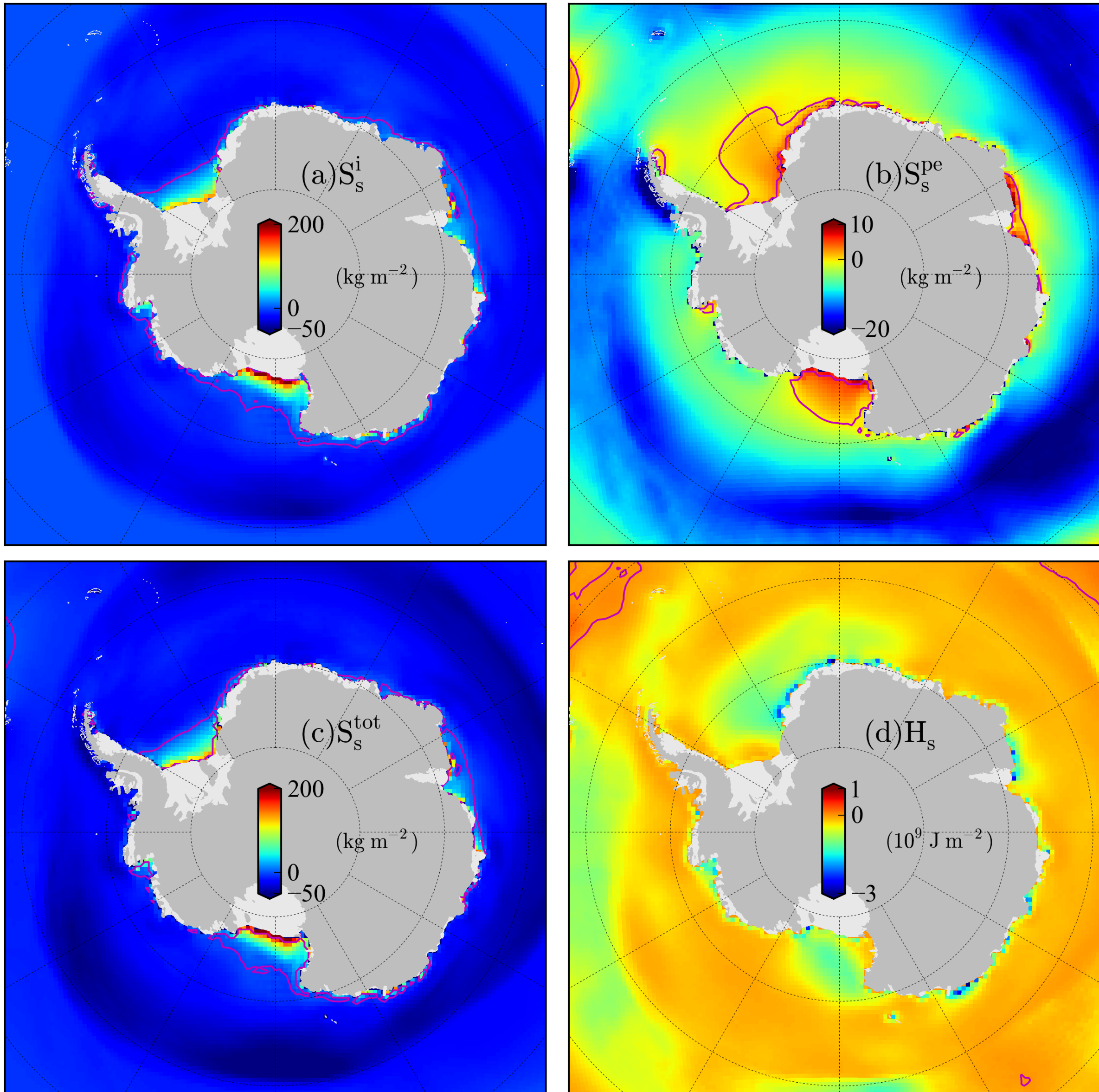



1000
562
316
178
100
56
32
(m)
(a) h_{mix}

Mean (1985-2011) Annual Buoyancy Input

Salt (ice)

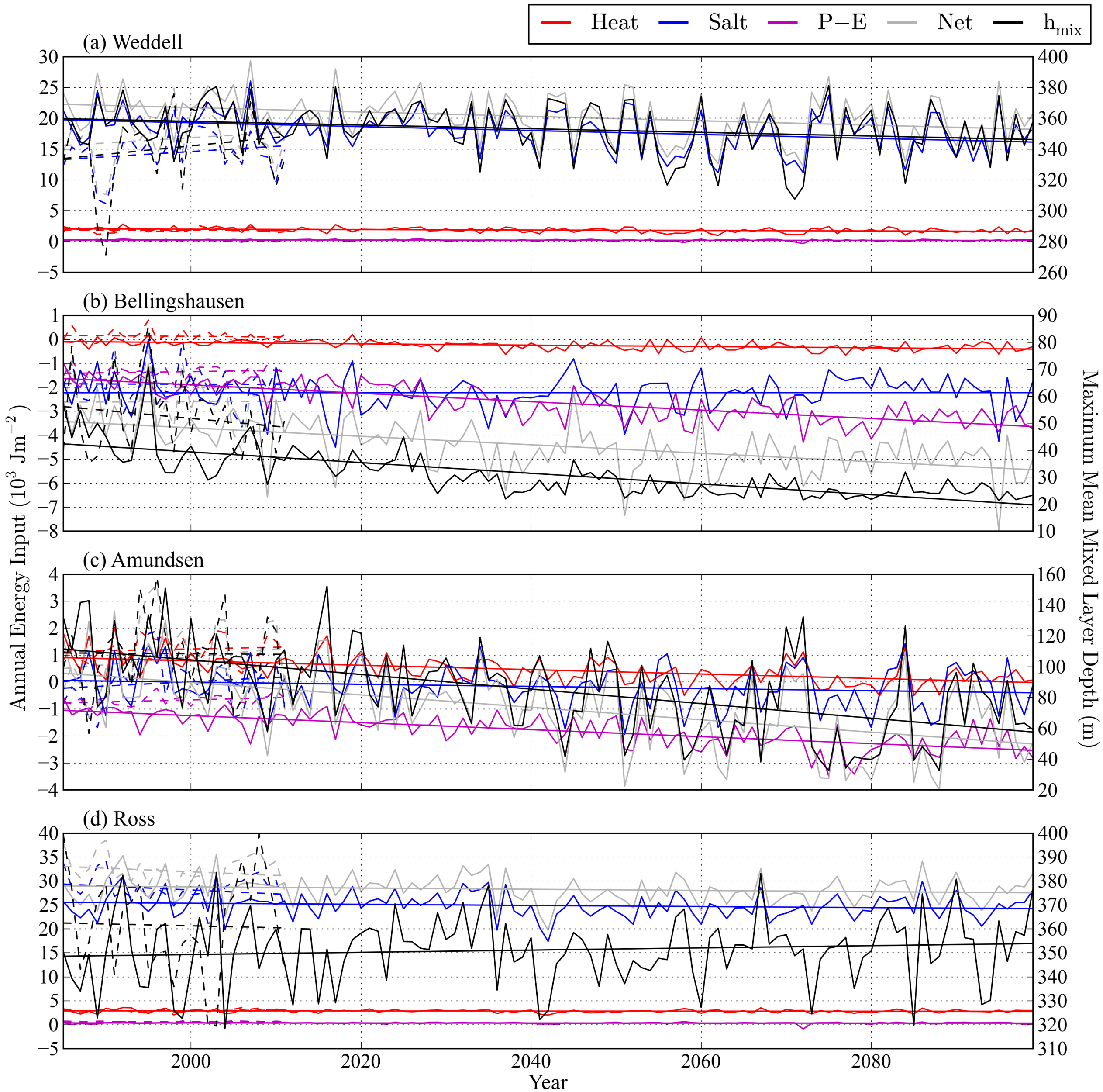
Salt (P-E)



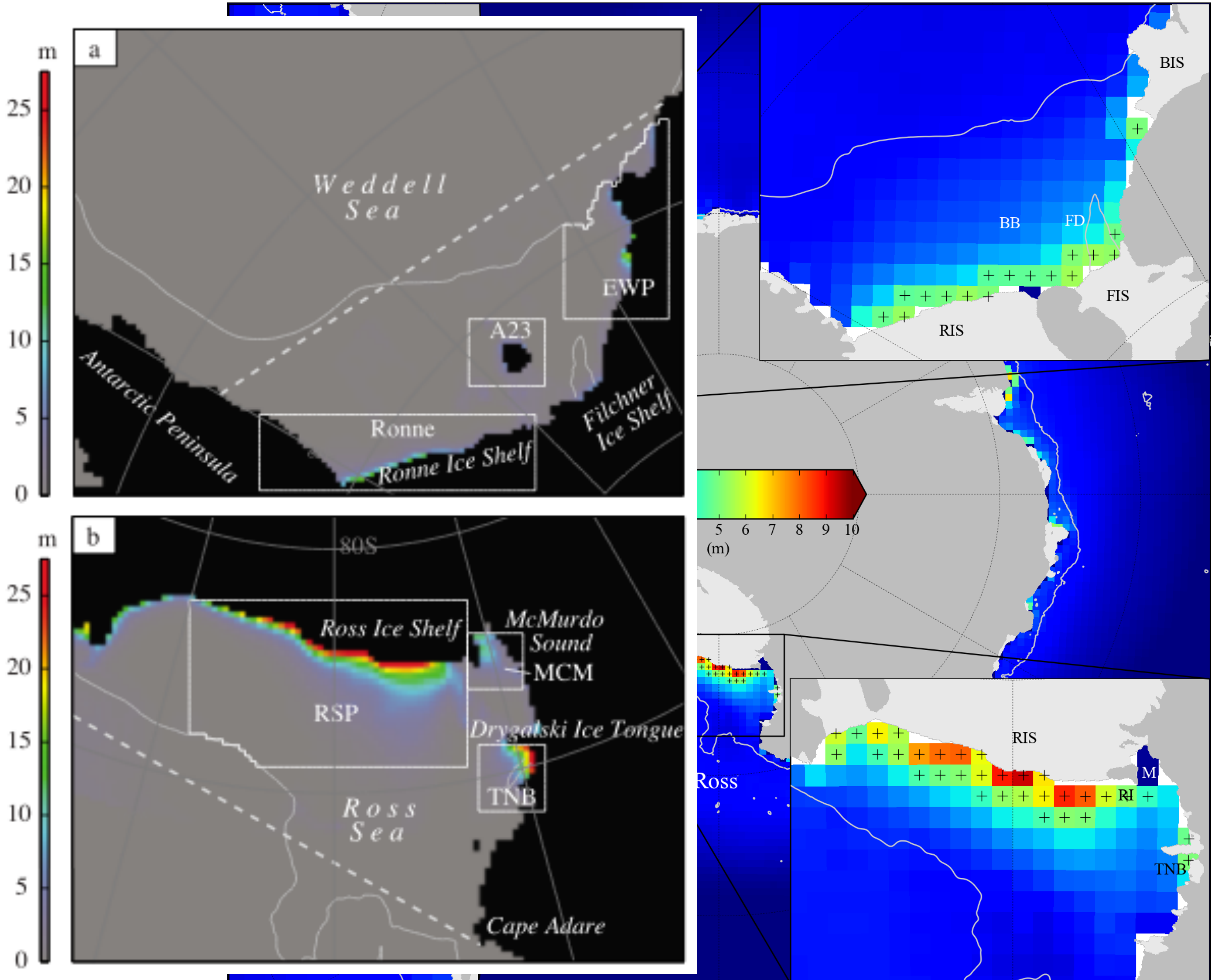
Salt (total)

Heat (surface)

Maximum ML-Depth Trend (1985-2099)

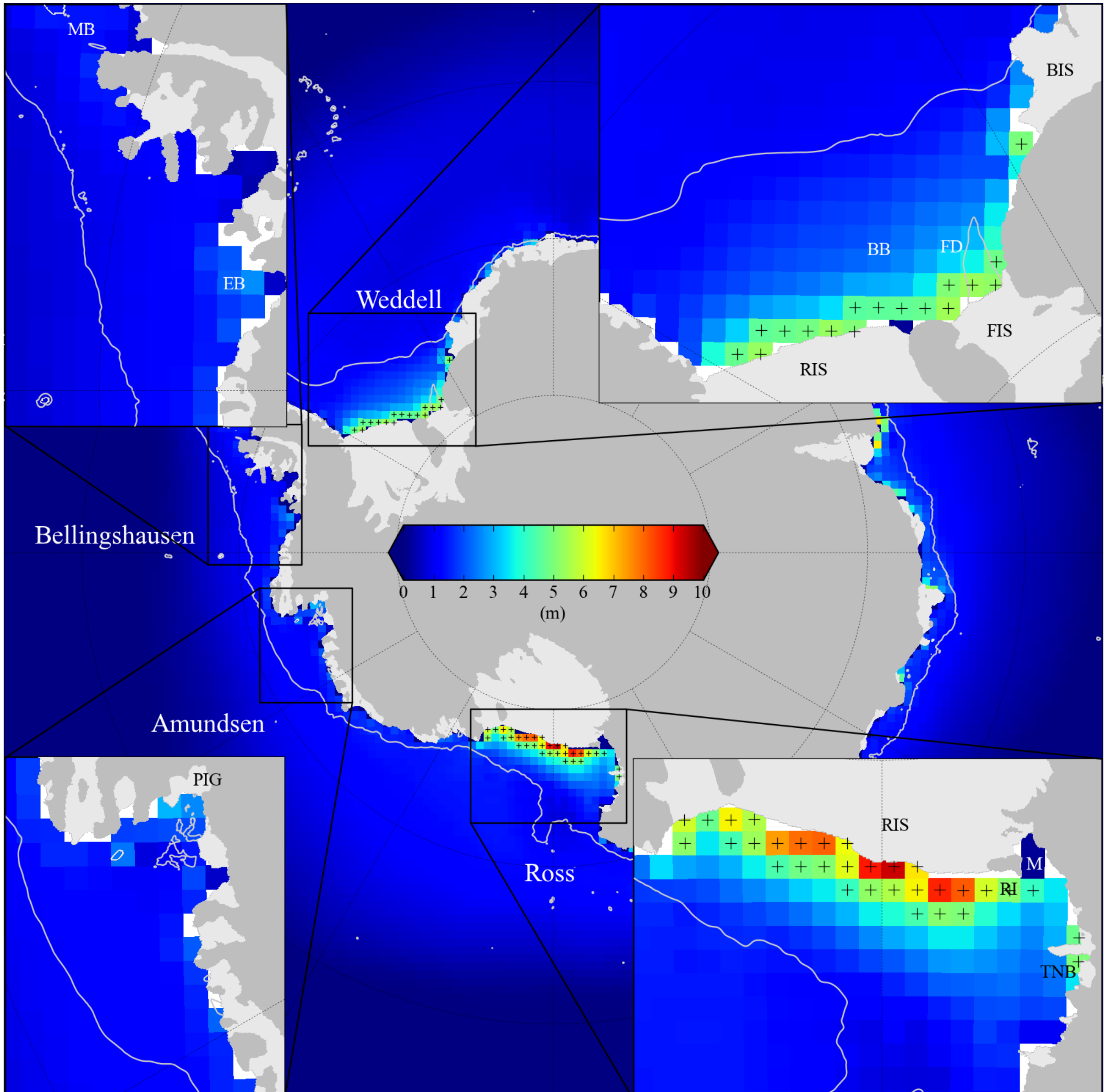


Mean (1985-2011) Annual Sea Ice Growth

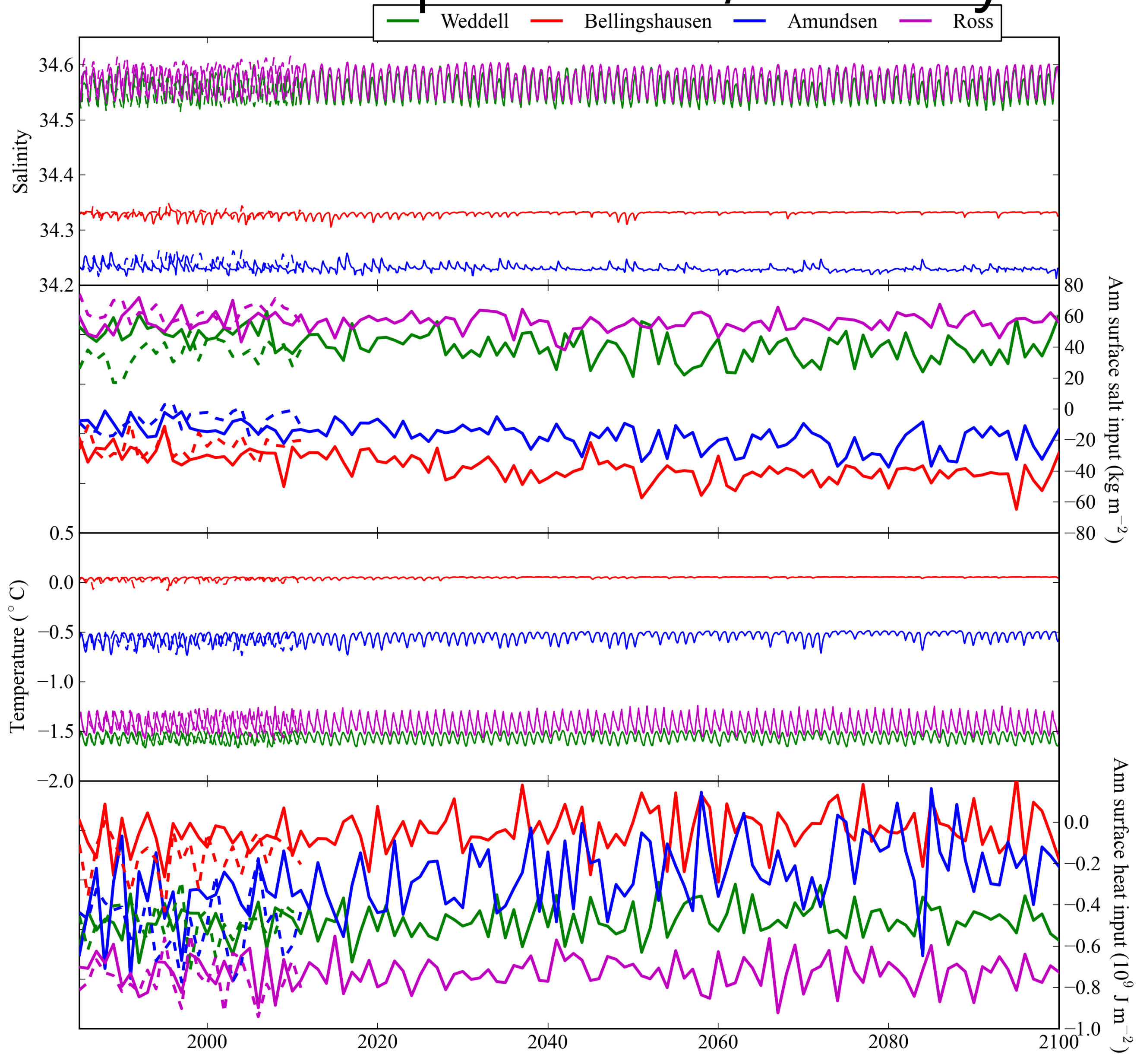


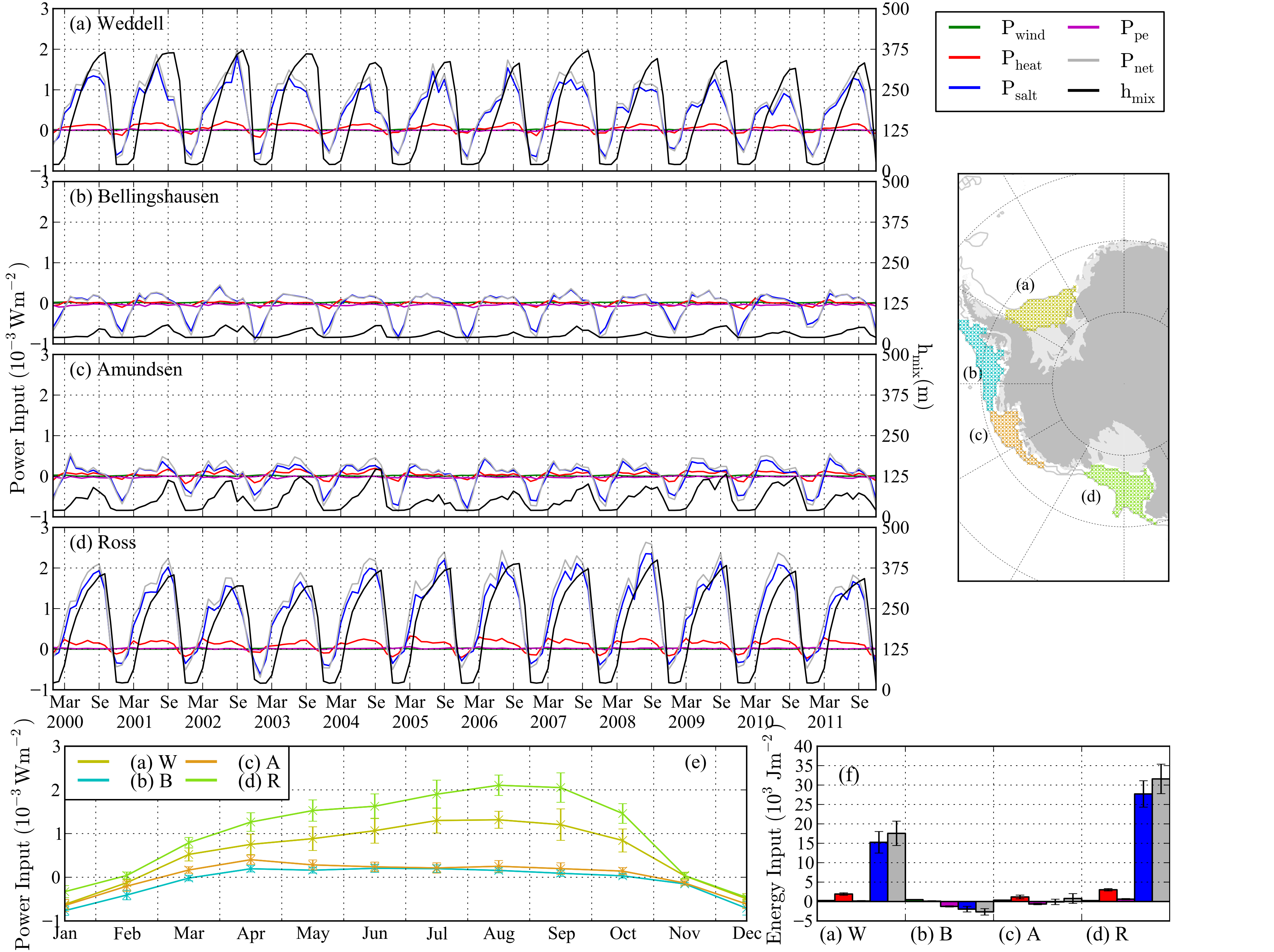
Drucker, 2011

Mean (1985-2011) Annual Sea Ice Growth



Shelf Sea Temperature/Salinity Trends





(a) Weddell
(b) Bellingshausen
(c) Amundsen
(d) Ross
Power Input (10^{-3} W m^{-2})
h_{mix} (m)
P_{wind}
P_{heat}
P_{salt}
P_{pe}
P_{net}
h_{mix}
Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se Mar Se
2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011
(a)
(b)
(c)
(d)
(e)
(a) W
(b) B
(c) A
(d) R
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
(f)
Energy Input (10^3 J m^{-2})
(a) W (b) B (c) A (d) R