Southern **O**cean **S**ea **I**ce and **C**onvection (SOSIC) in Global Ocean GCMs

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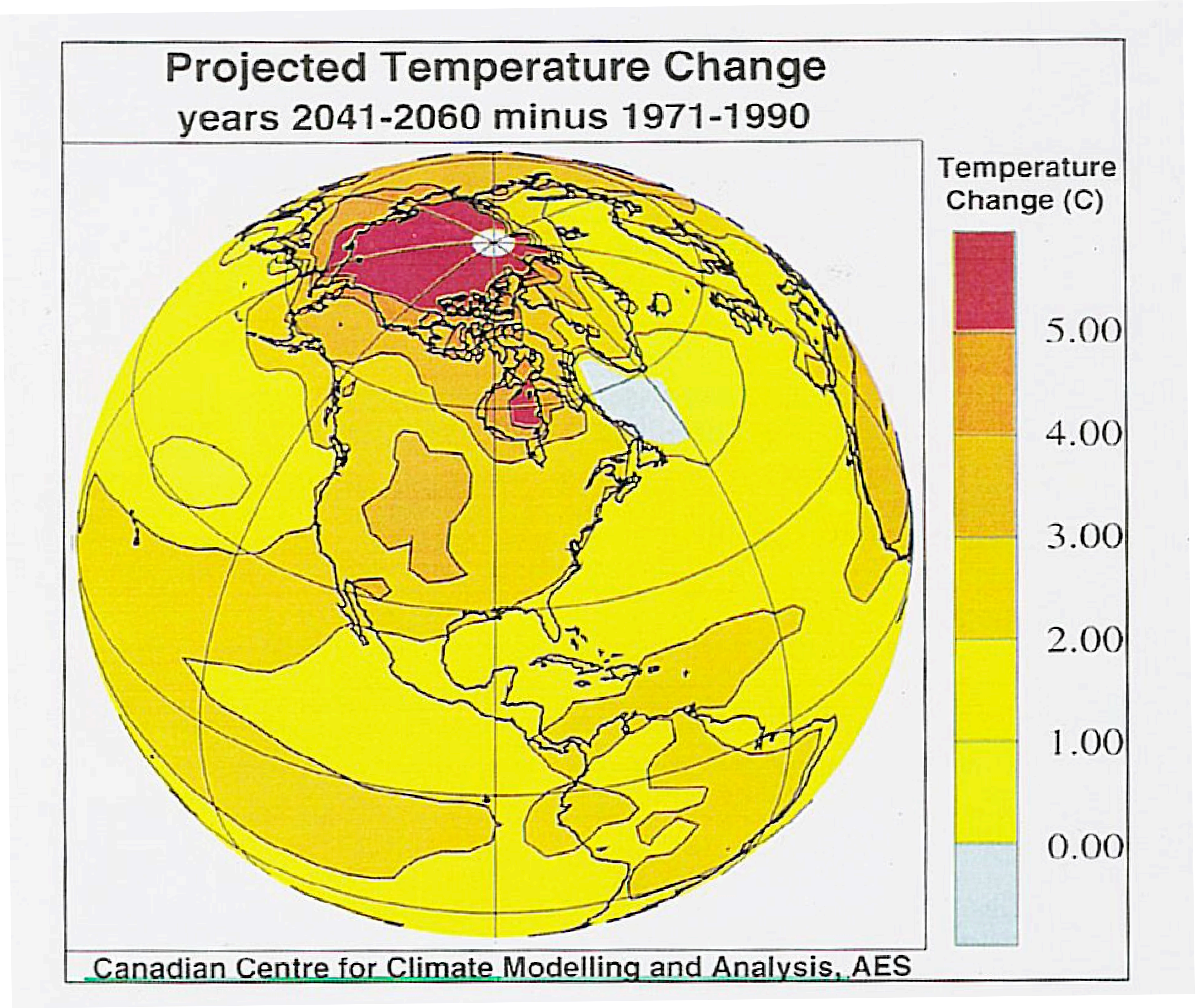
Sponsors: NASA, NSF, TAMU

Projected warming over Arctic Ocean



WCRP/WMO (2001)

Warming of Antarctic winter troposphere

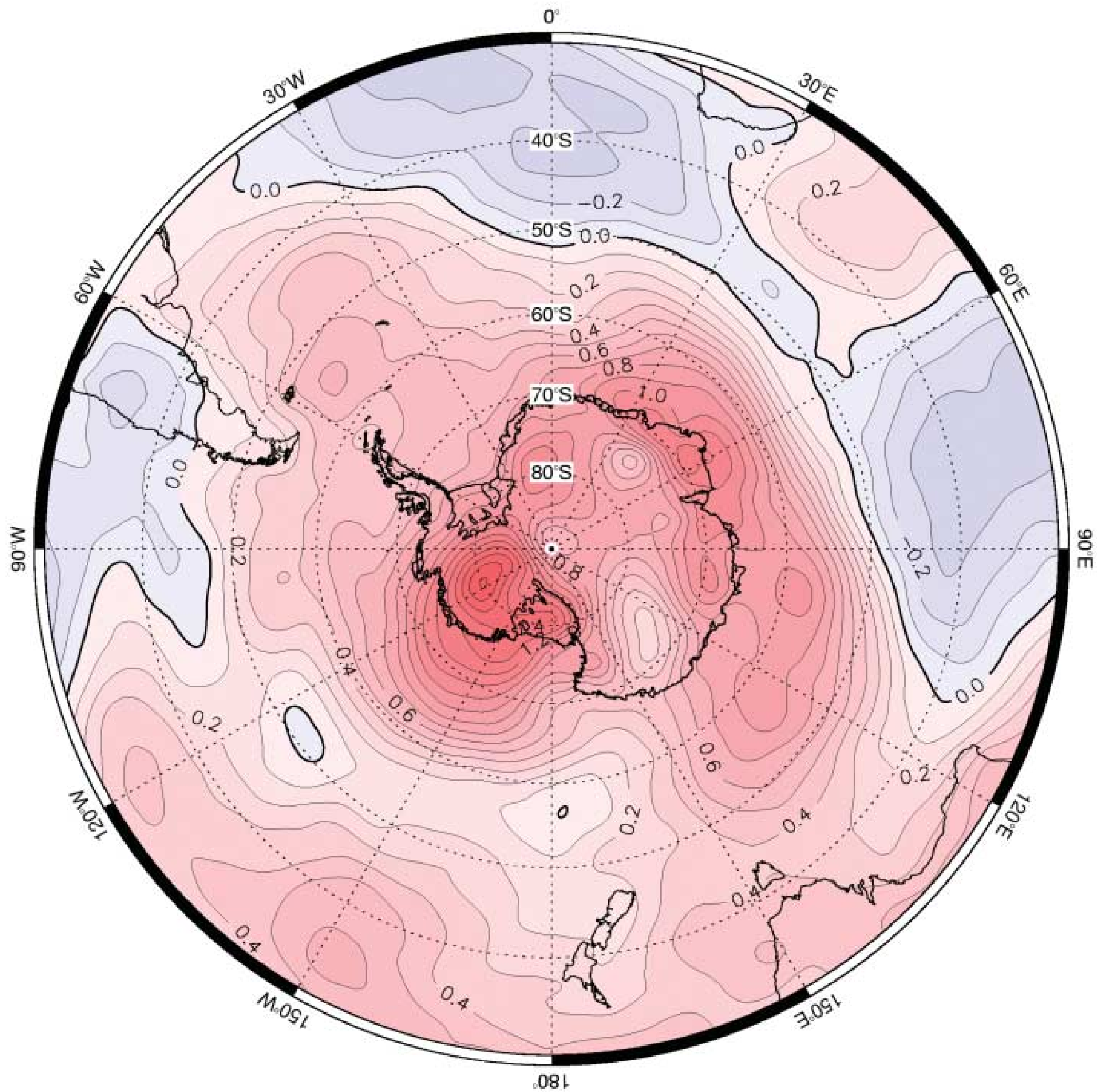
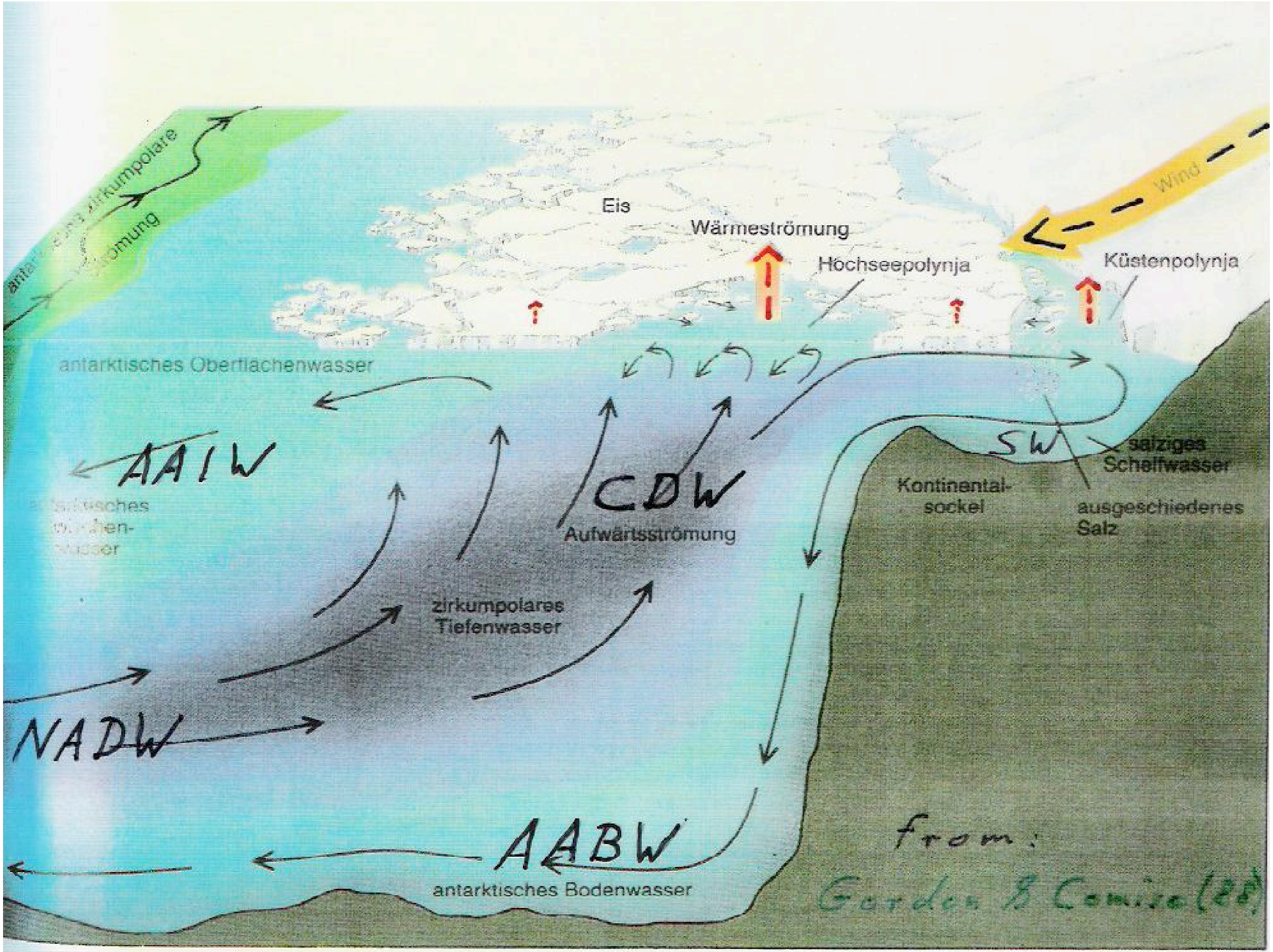


Fig. 2. Trends (°C per decade) in the winter season 500-hPa temperatures from 1979 to 2001 from the ECMWF reanalysis.

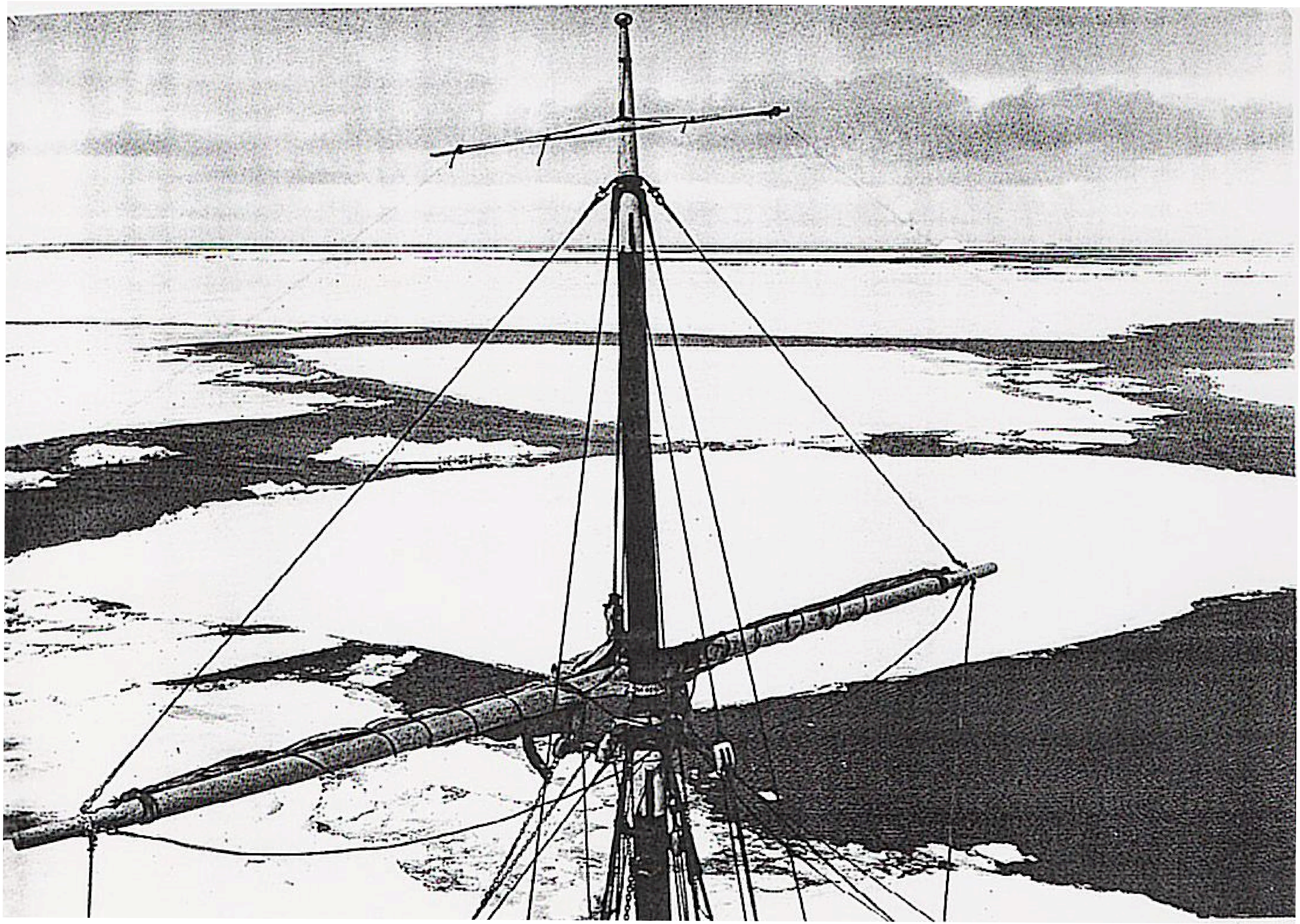
Turner et al.(2006)

Southern Ocean



Gordon and Comiso (1988)

Sea Ice

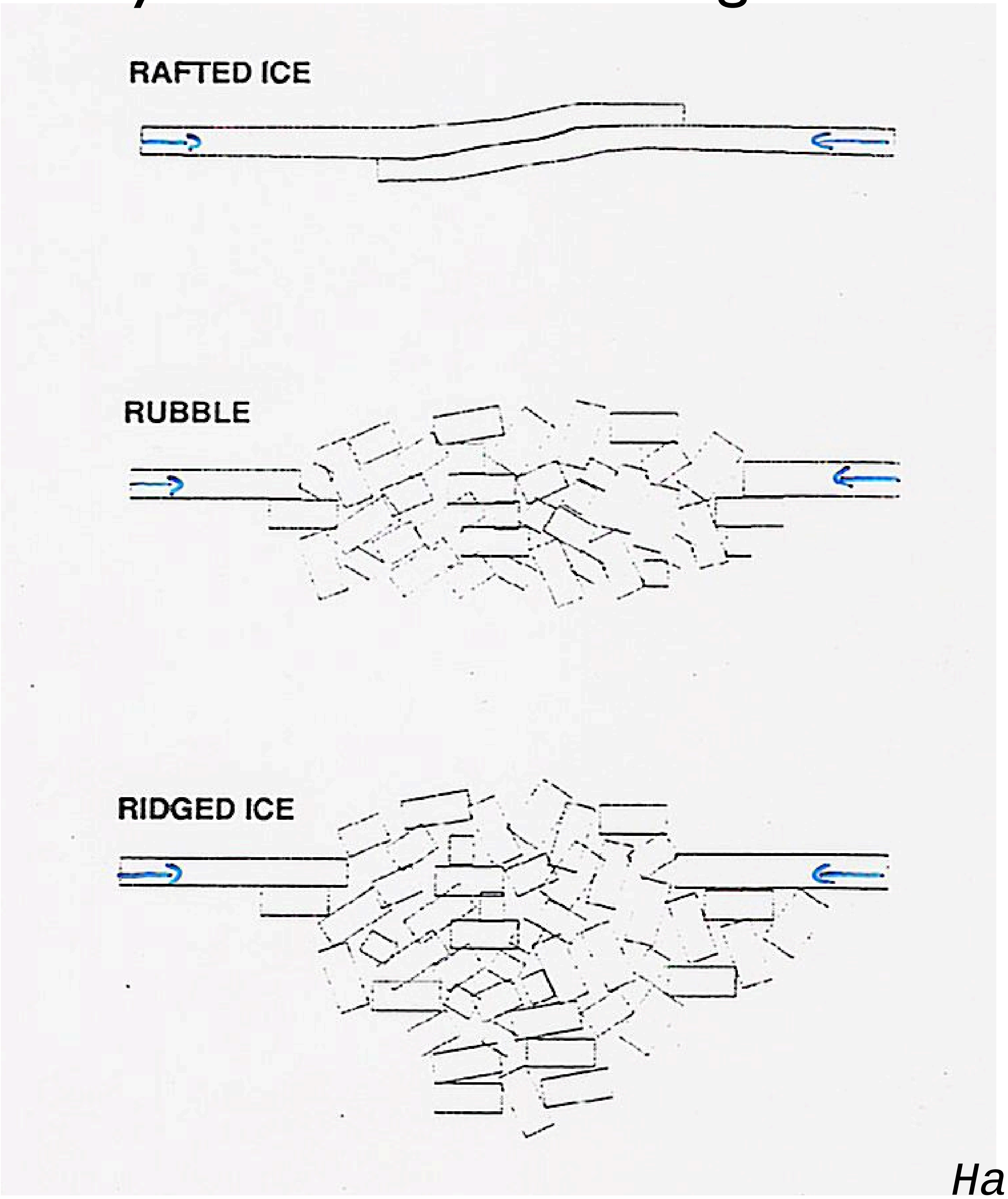


Shackleton Exp. (1915)

Sea Ice

Shackleton Exp. (1915)

Dynamic ice-thickness growth

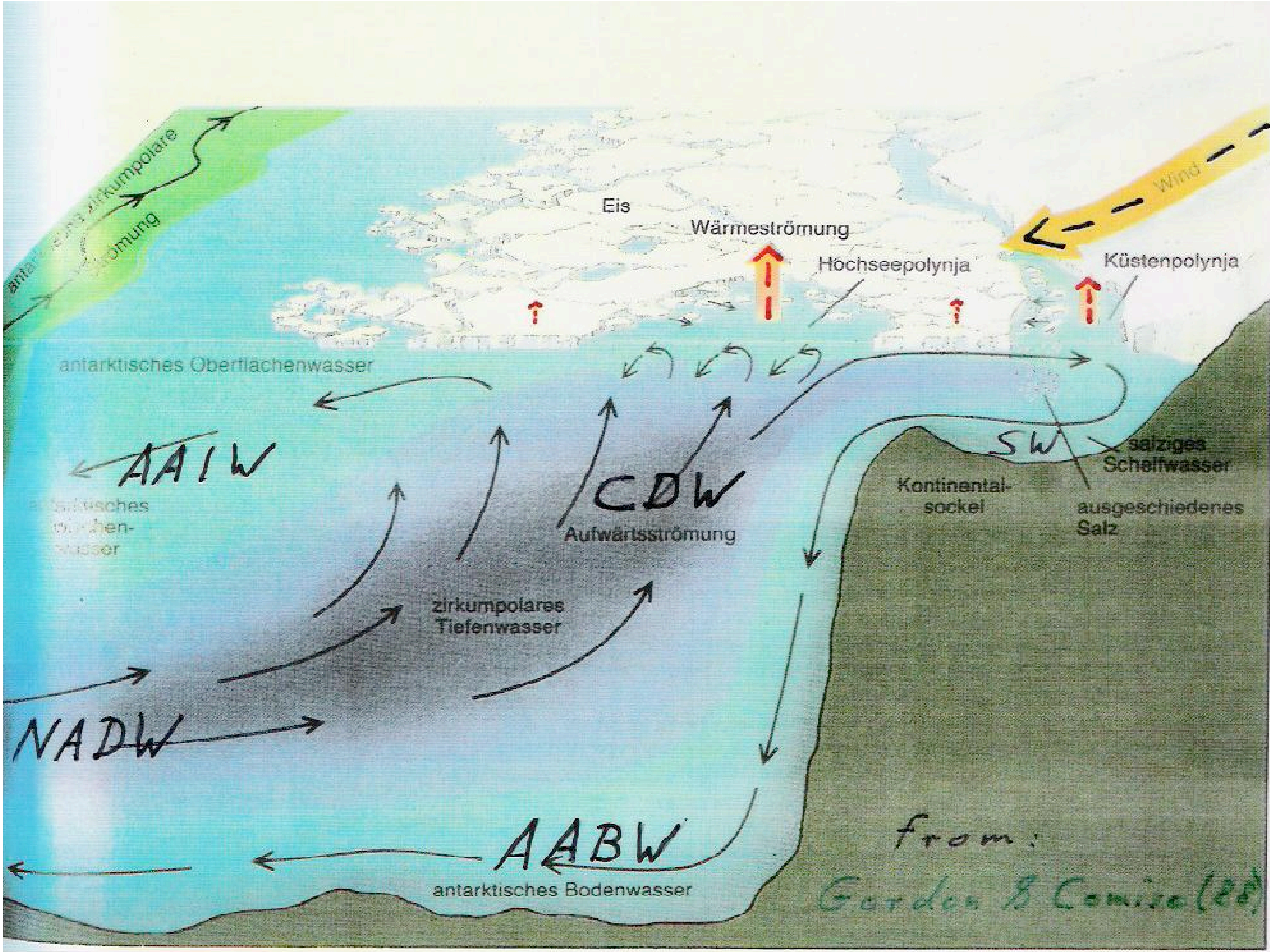


Haapala (2000)

Western Weddell Sea

Shackleton Exp. (1915)

Southern Ocean



Gordon and Comiso (1988)

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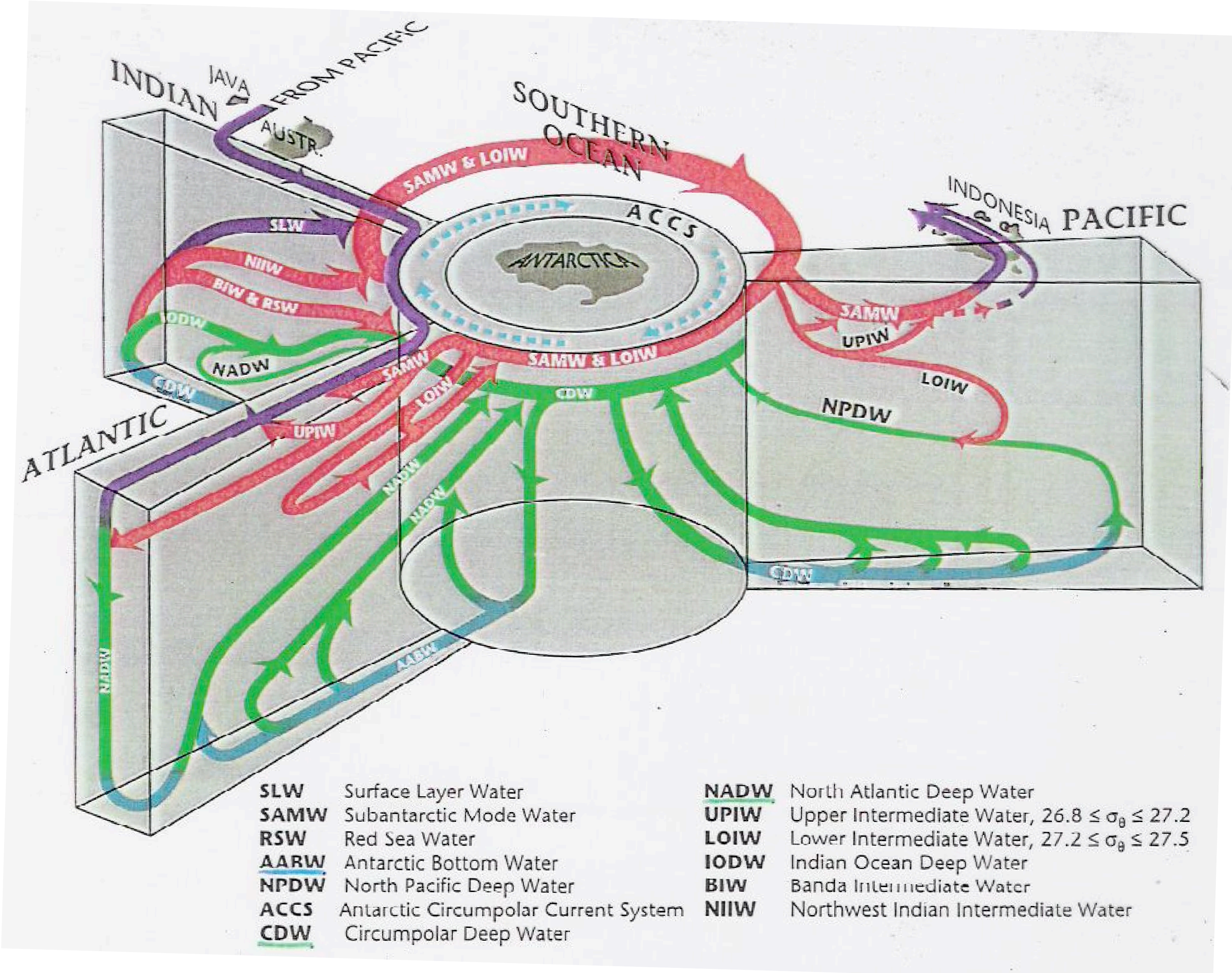
Schematic of thermohaline circulation

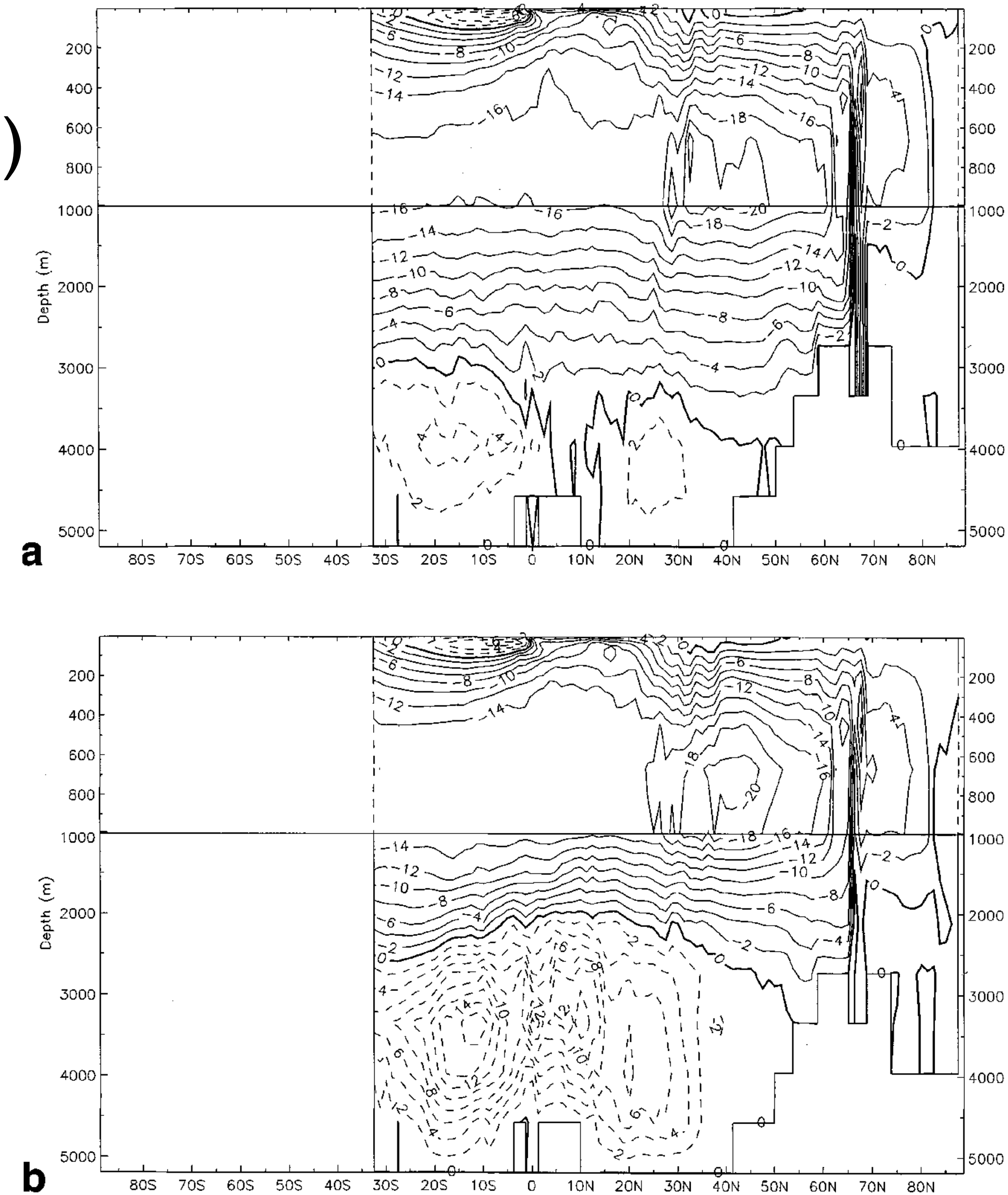


Schmitz (1996)

Coupled atmosphere - ice - ocean GCM (HAD)

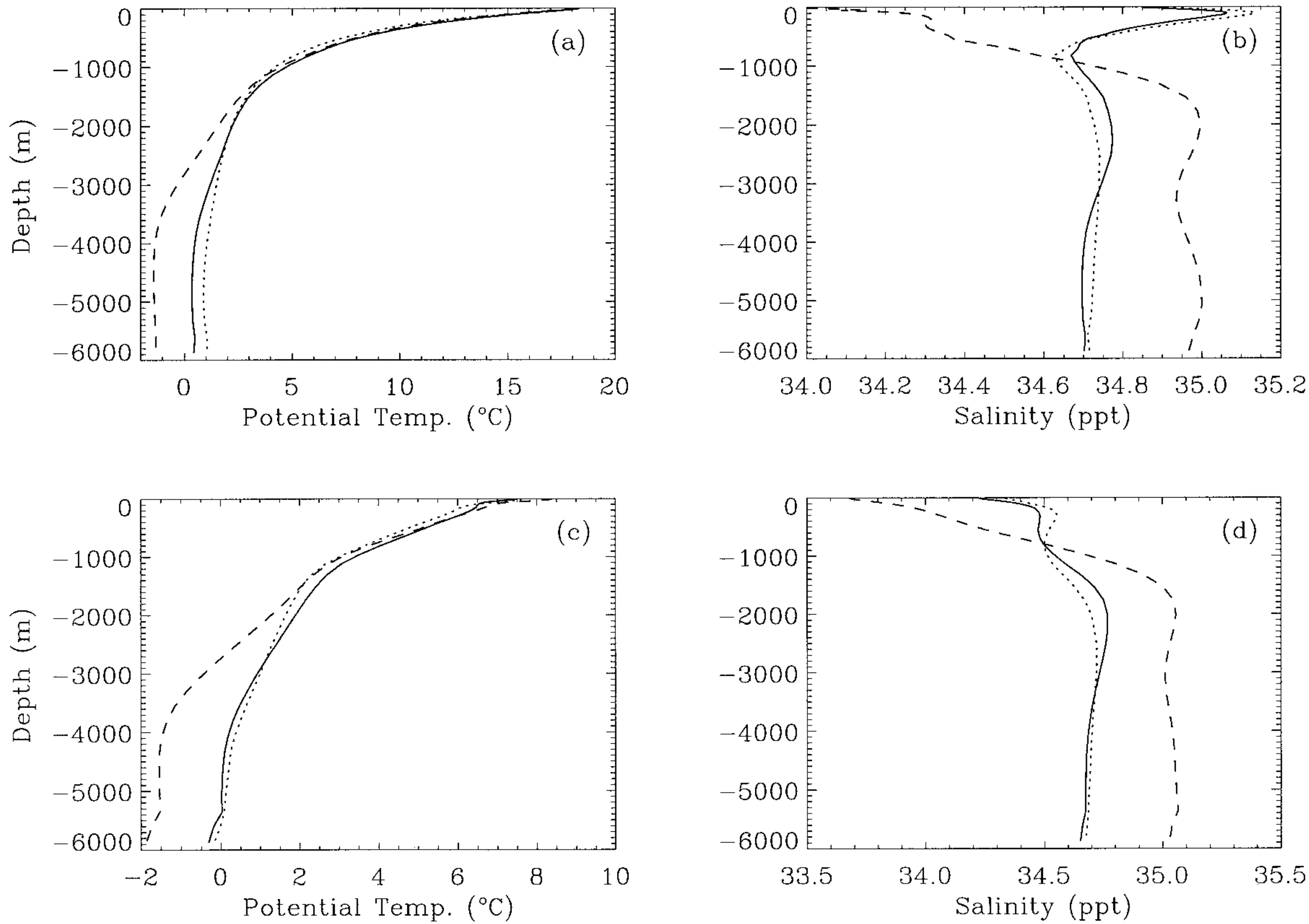
Years 81 to 120

Years 361 to 400



Gordon et al.(2000)

Coupled atmosphere - ice - ocean GCM (NCAR)



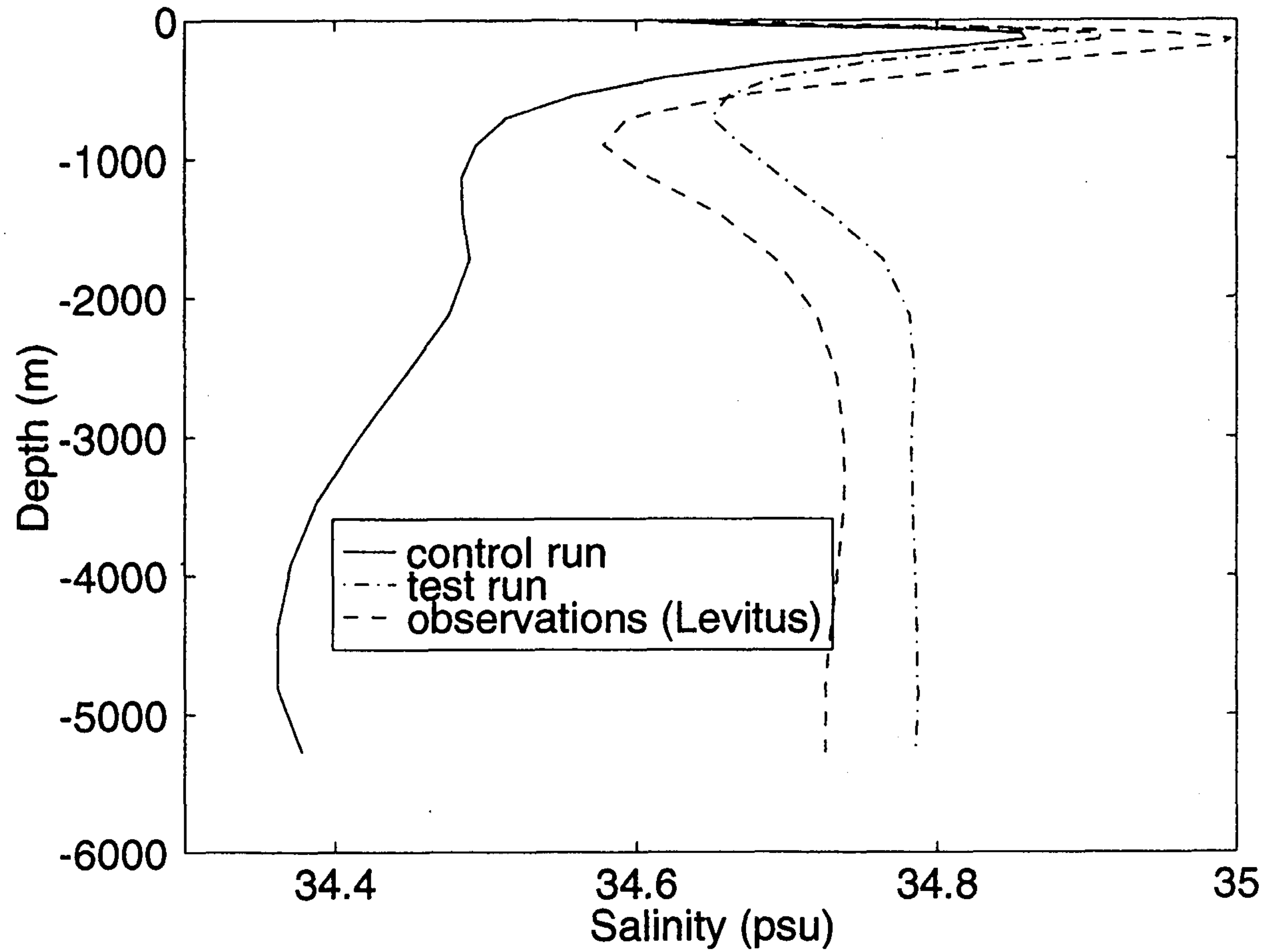
Global

Southern Ocean

dotted: observed
solid: uncoupled
dashed: coupled

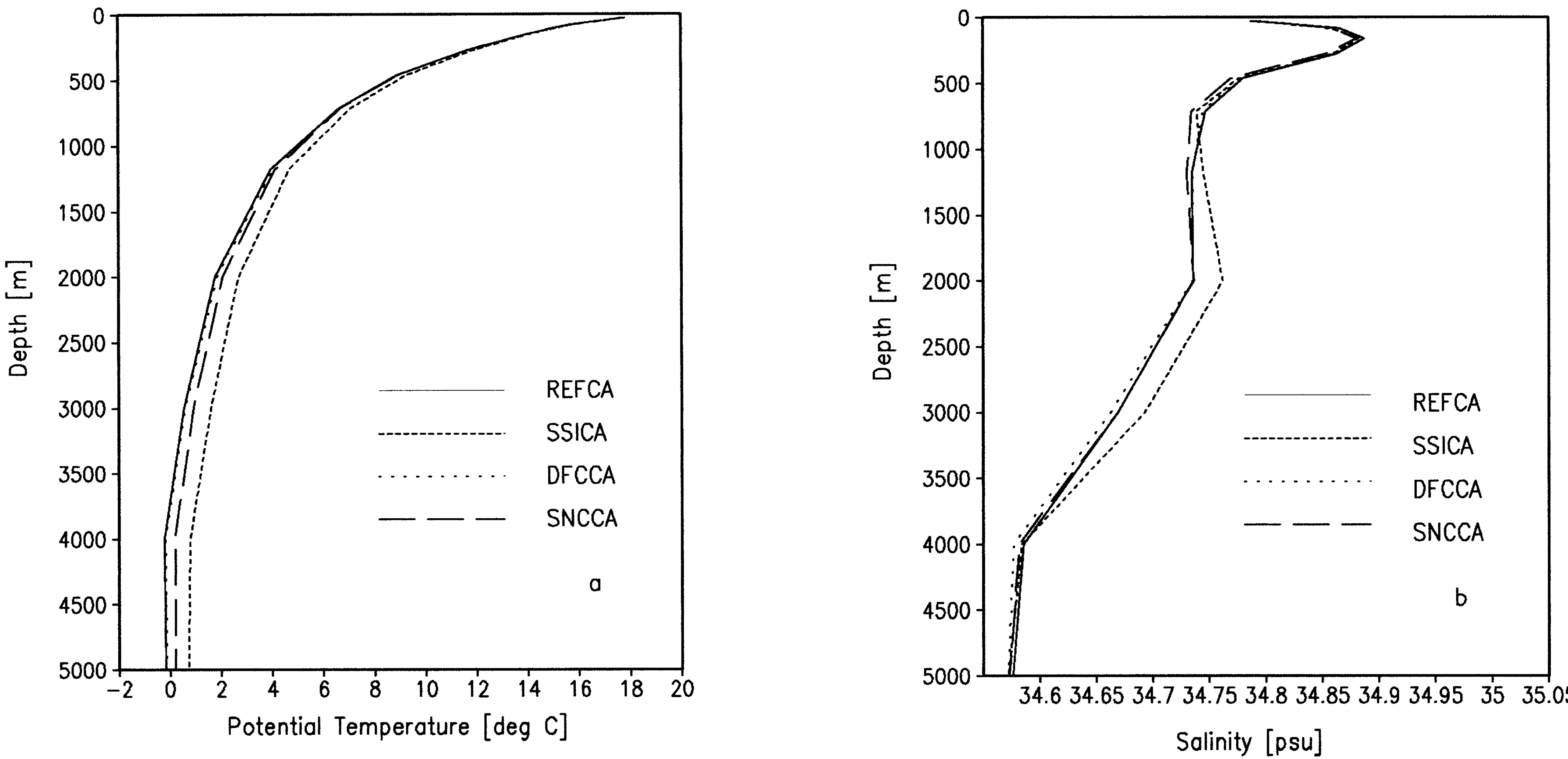
Bryan (1998)

Global ice - ocean GCM: experiments with modified brine distribution



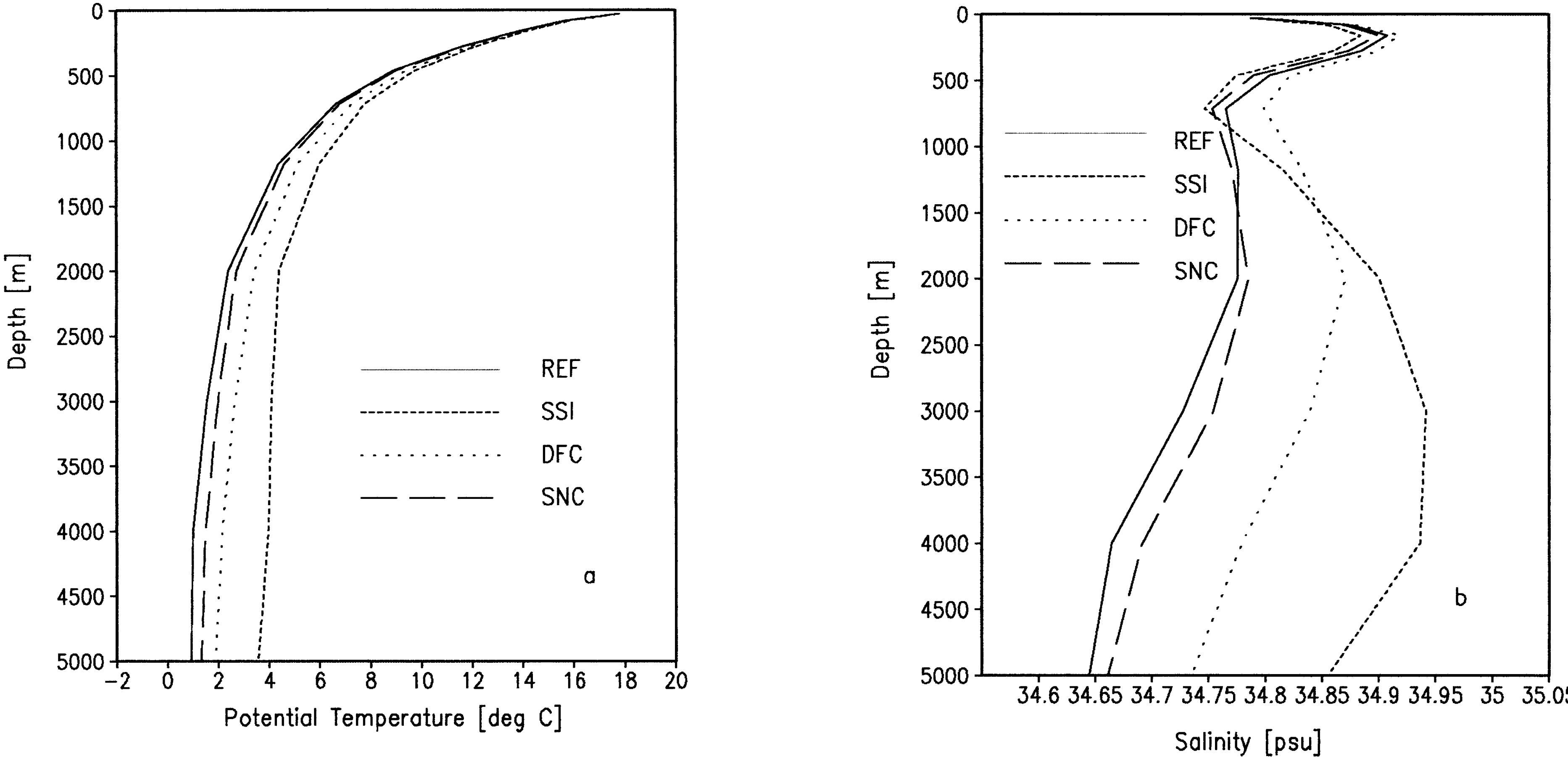
Duffy and Caldeira (1997)

Global ice - ocean GCM: experiments with convective adjustment



Stössel, Yang, and SJKim (2002)

Global ice - ocean GCM: experiments with plume convection

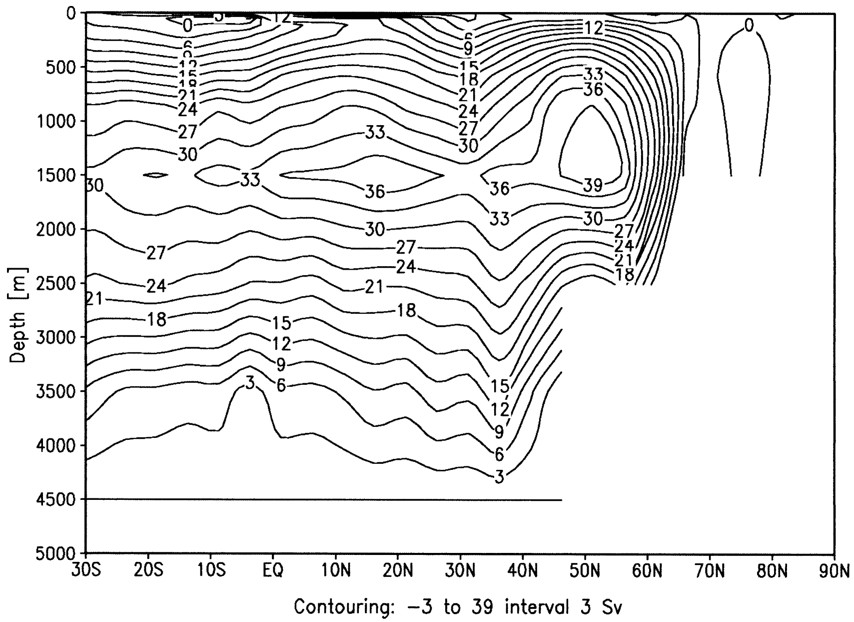


Stössel, Yang, and SJKim (2002)

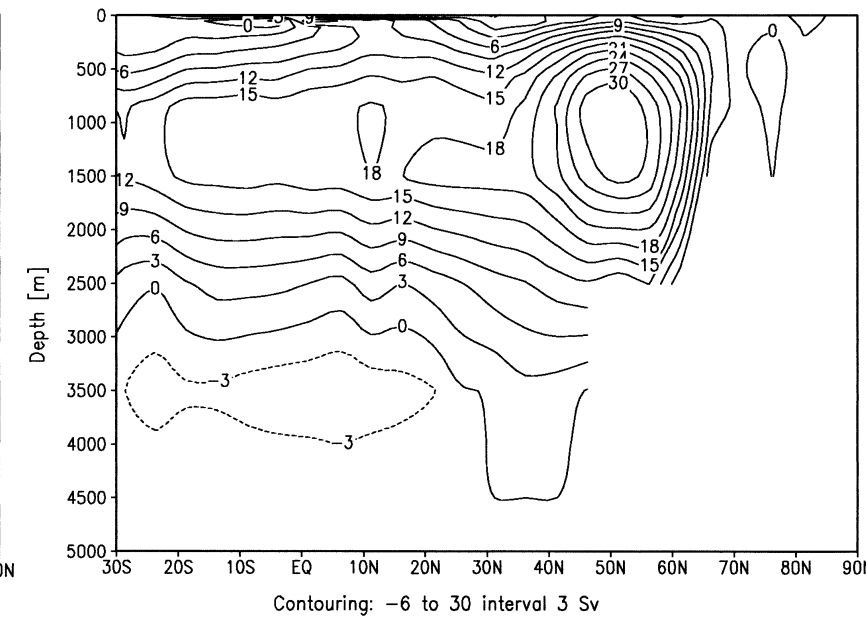
Global ice - ocean GCM: salty sea-ice experiments

plume convection

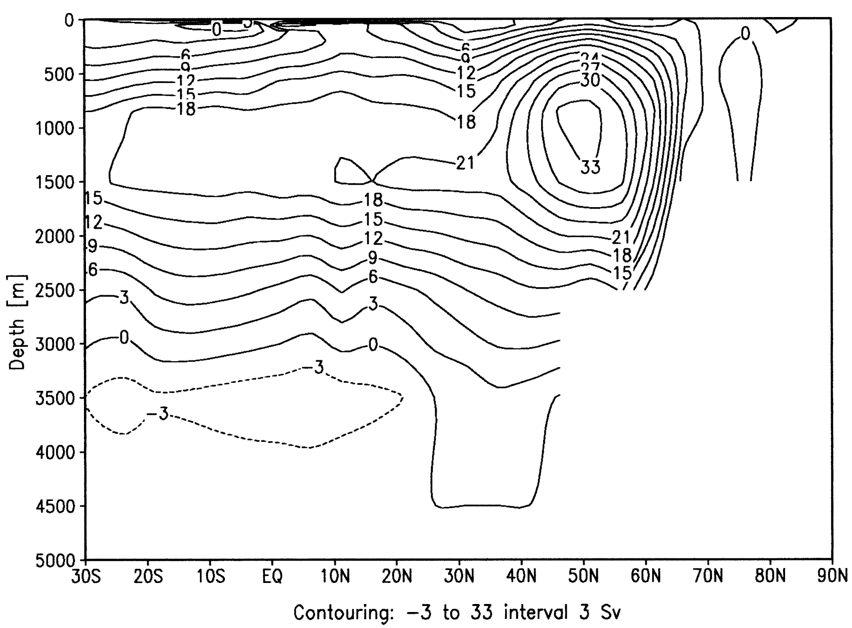
salty sea ice



reference

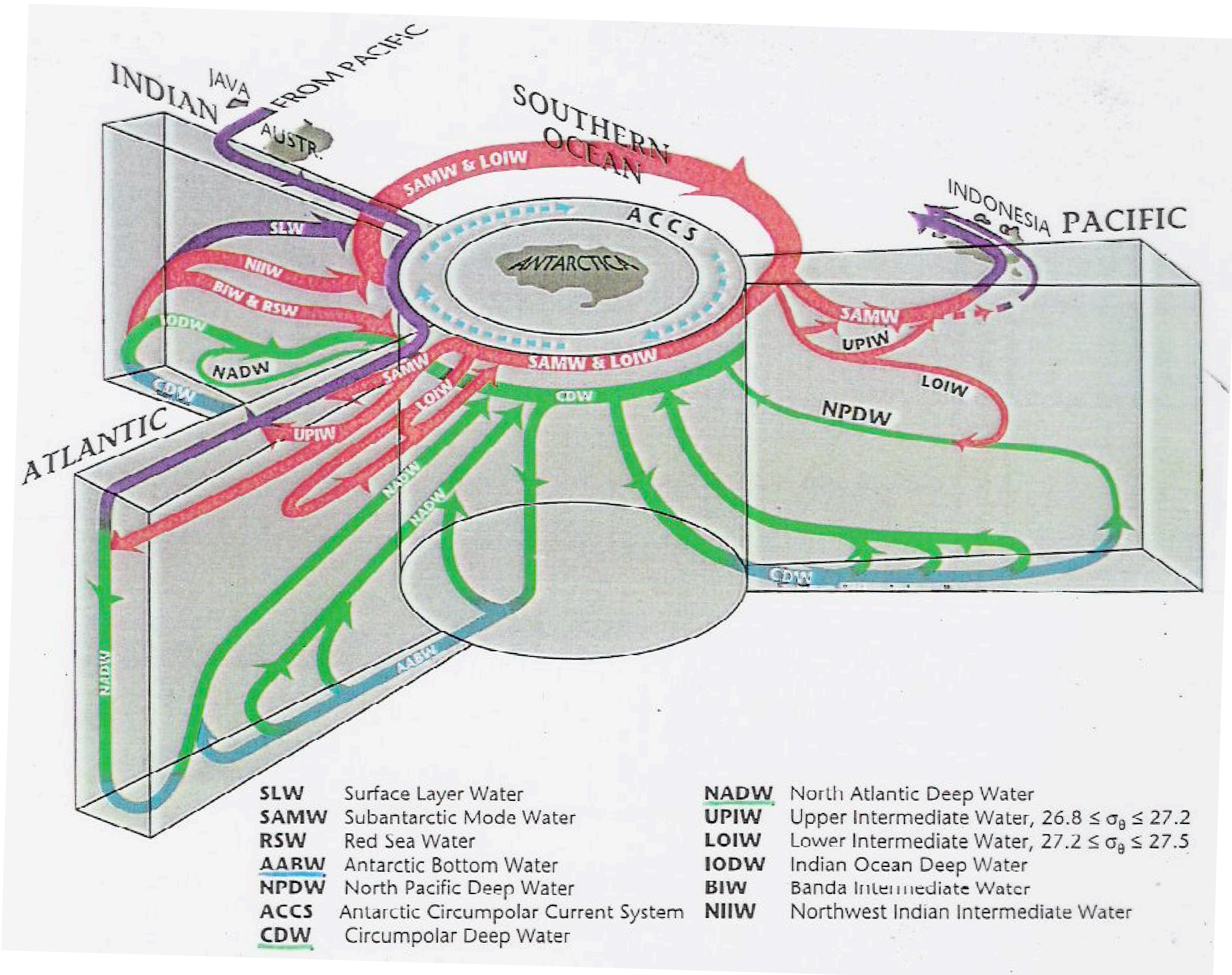


convective adjustment



Stössel, Yang, and SJKim (2002)

Schematic of thermohaline circulation



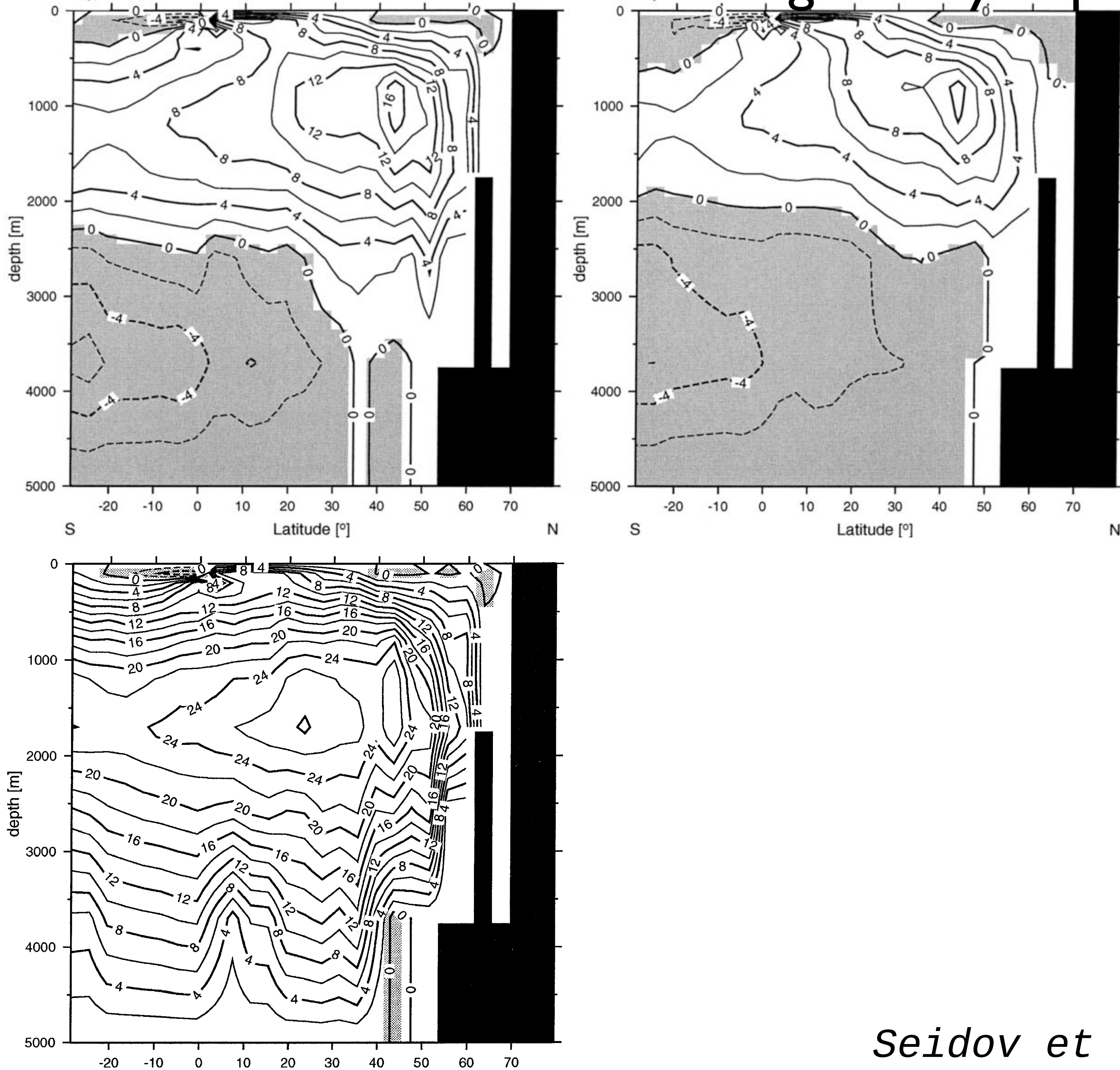
Schmitz (1996)

Global ocean GCM: modified restoring salinity experiments

Ref. exp.

Exp.: -2 psu in NA

Exp.: -1 psu in SO



Seidov et al.(2001)

Summary

I: Response of modelled THC is highly sensitive to parameterization of SOSIC

III: Detailed verification of Southern Ocean sea ice in global (atmosphere –) ice – ocean GCMs may lead to improved parameterizations

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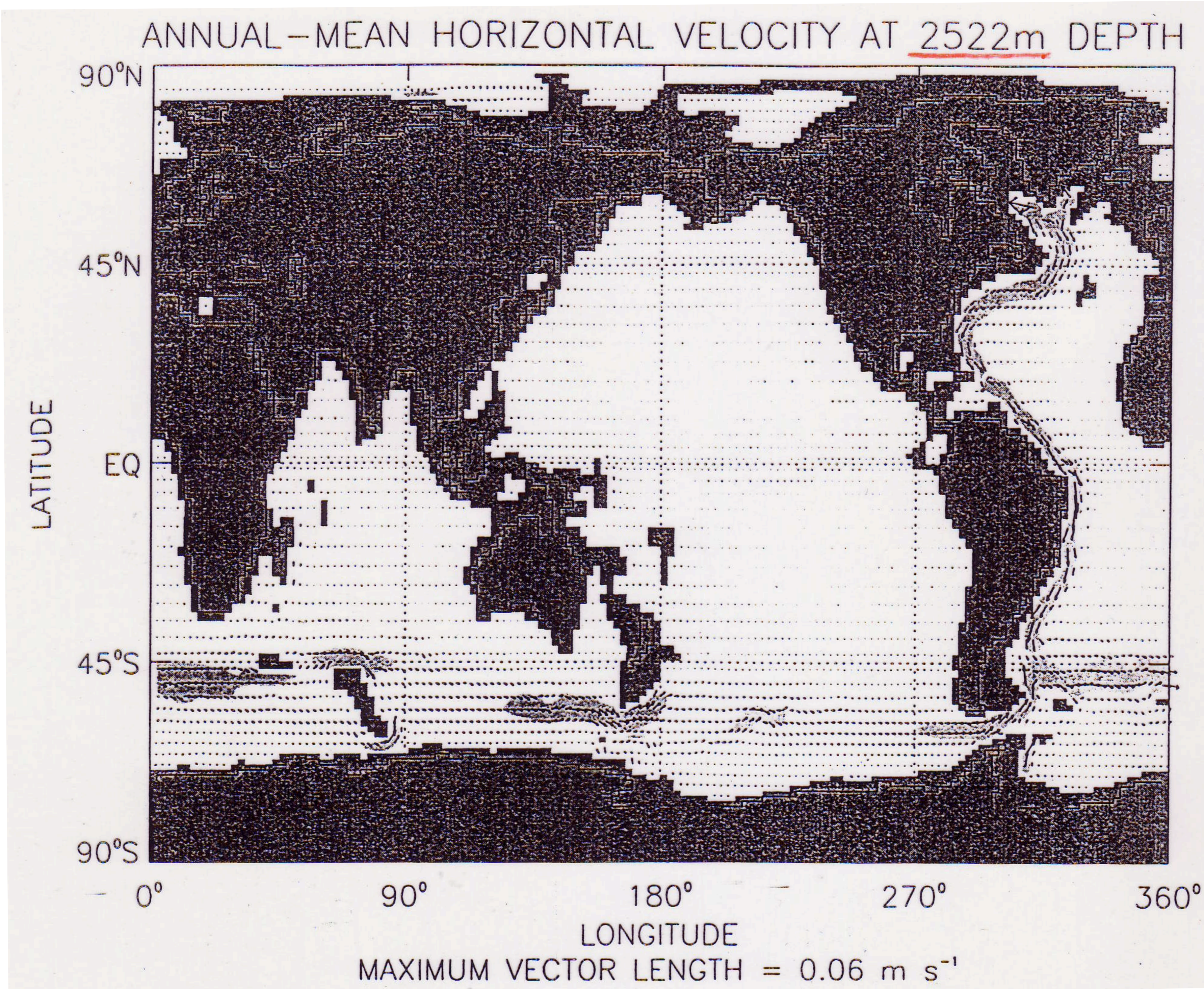
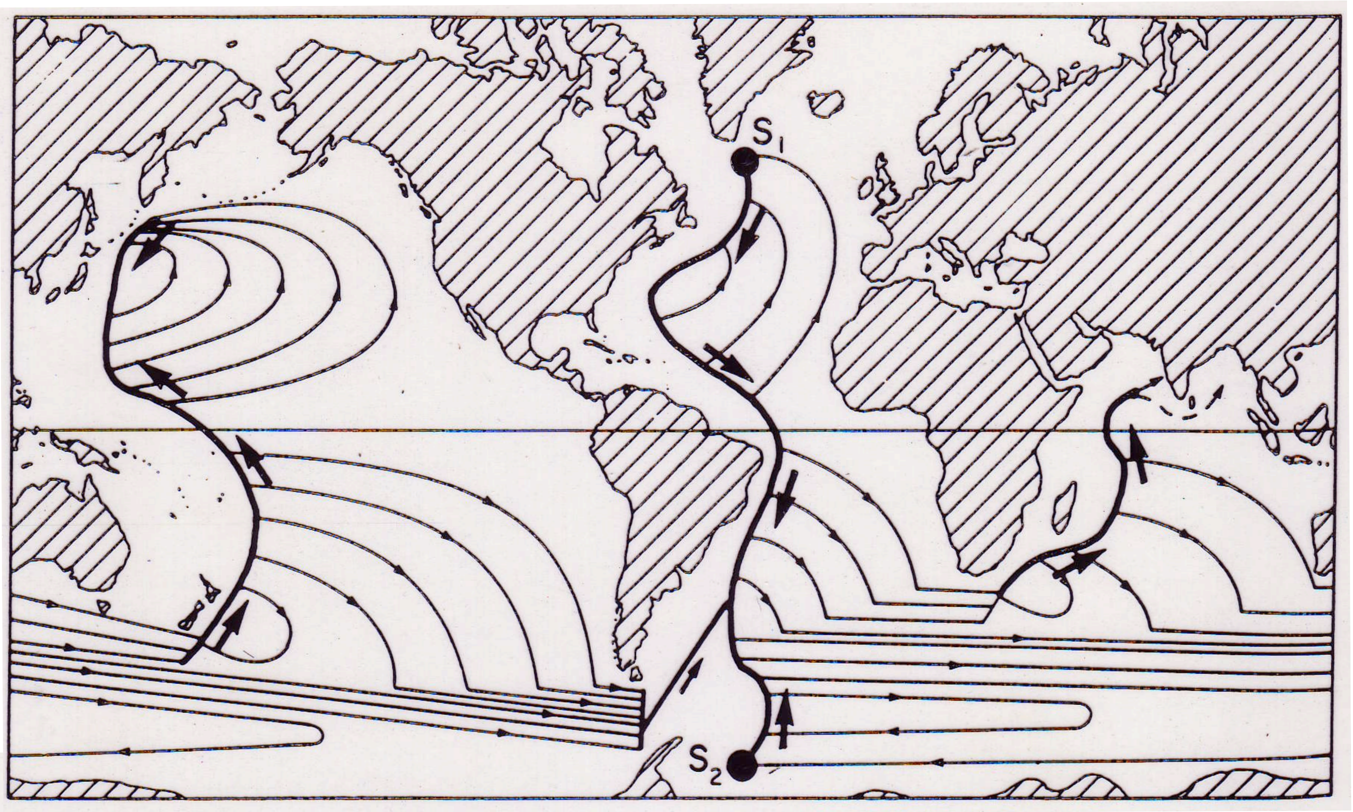


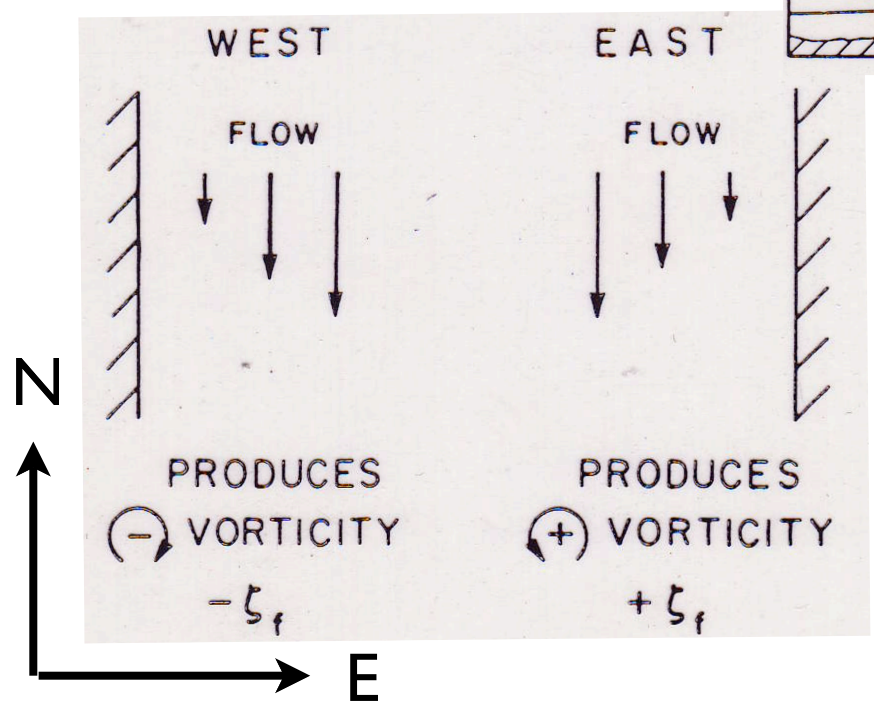
Gent et al.(1998)

Deep-western boundary currents

$(\zeta + f)/D = \text{const.}$

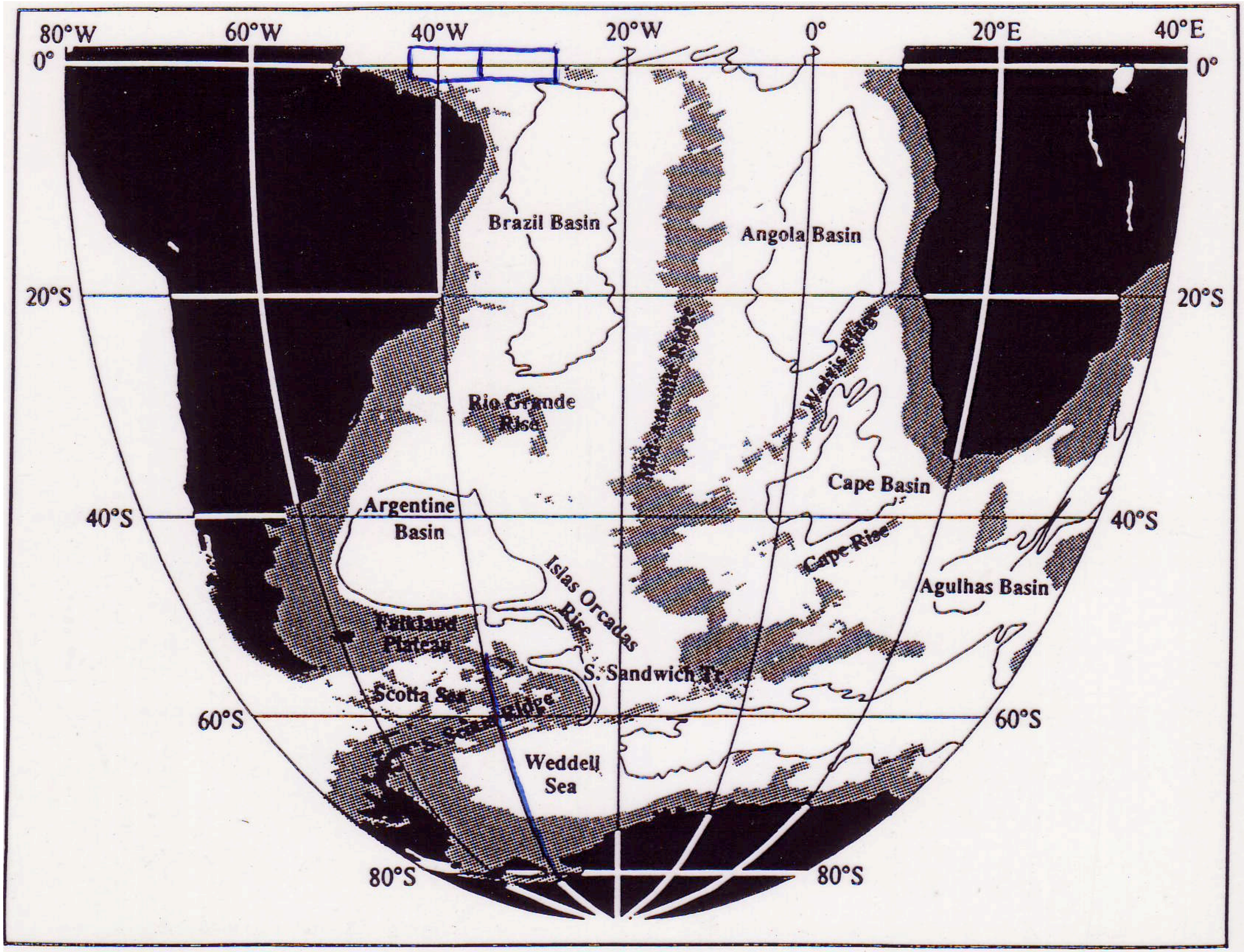


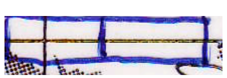
Stommel (1958)



Pond and Pickard (1990)

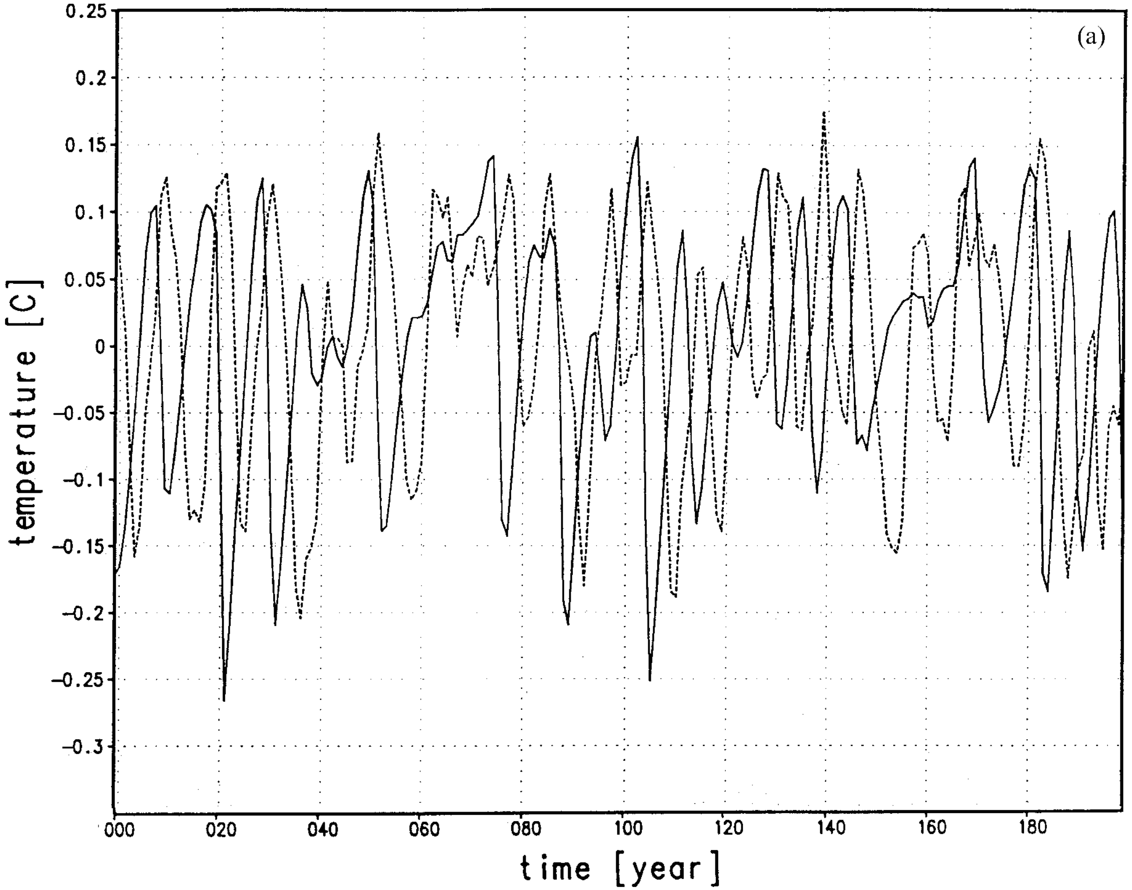
South Atlantic bathymetry

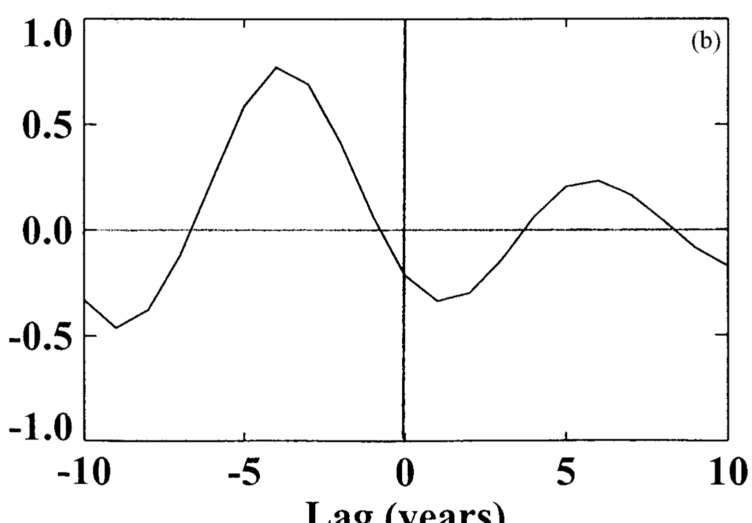


 box of *Hall et al. (1997)*

Reid (1989)

Decadal variability in global ice - ocean GCM



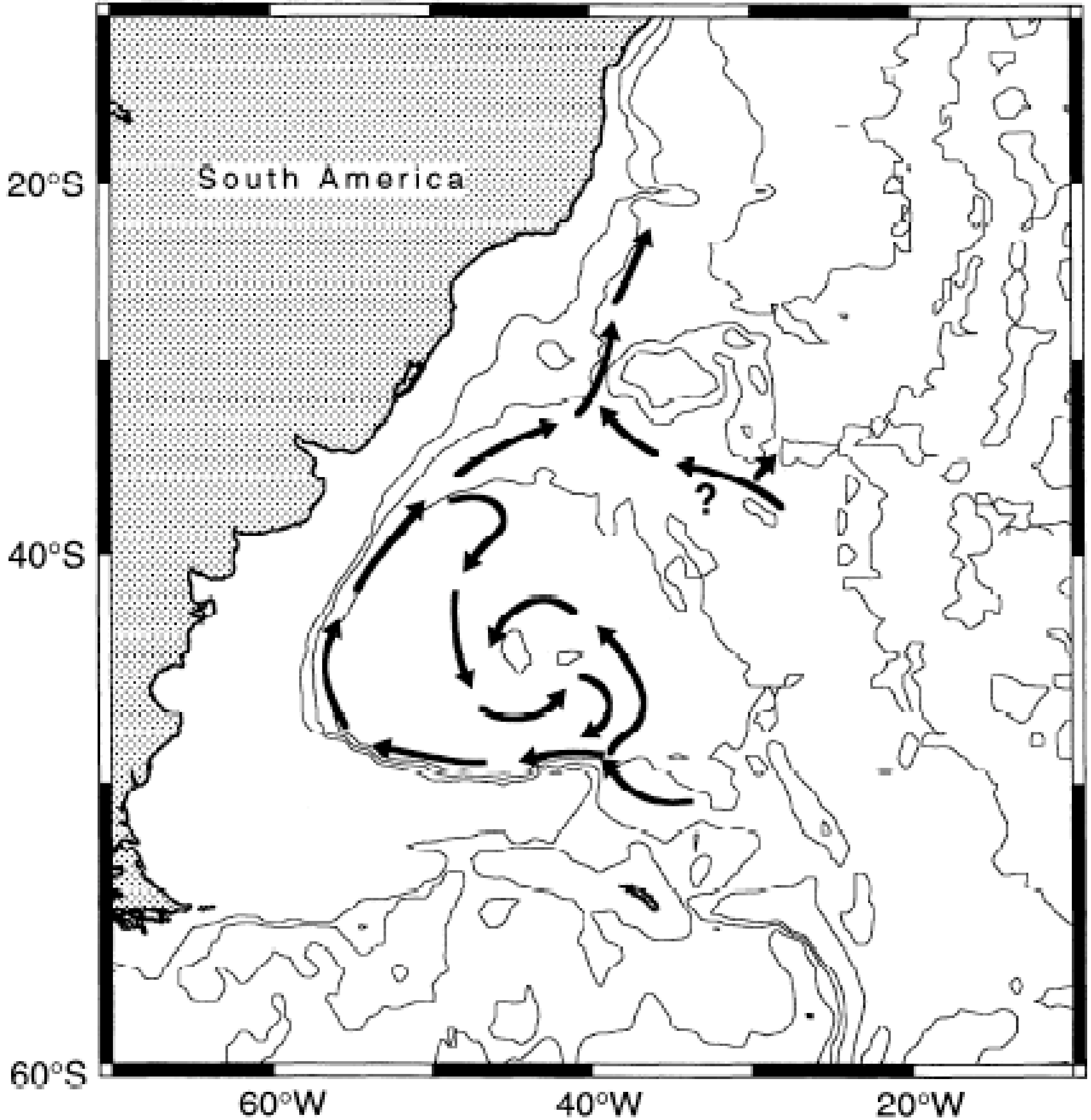


solid:
T at 3000m
at 70S, 50W

dashed:
Tx5 at 4000m
at 30S, 35W

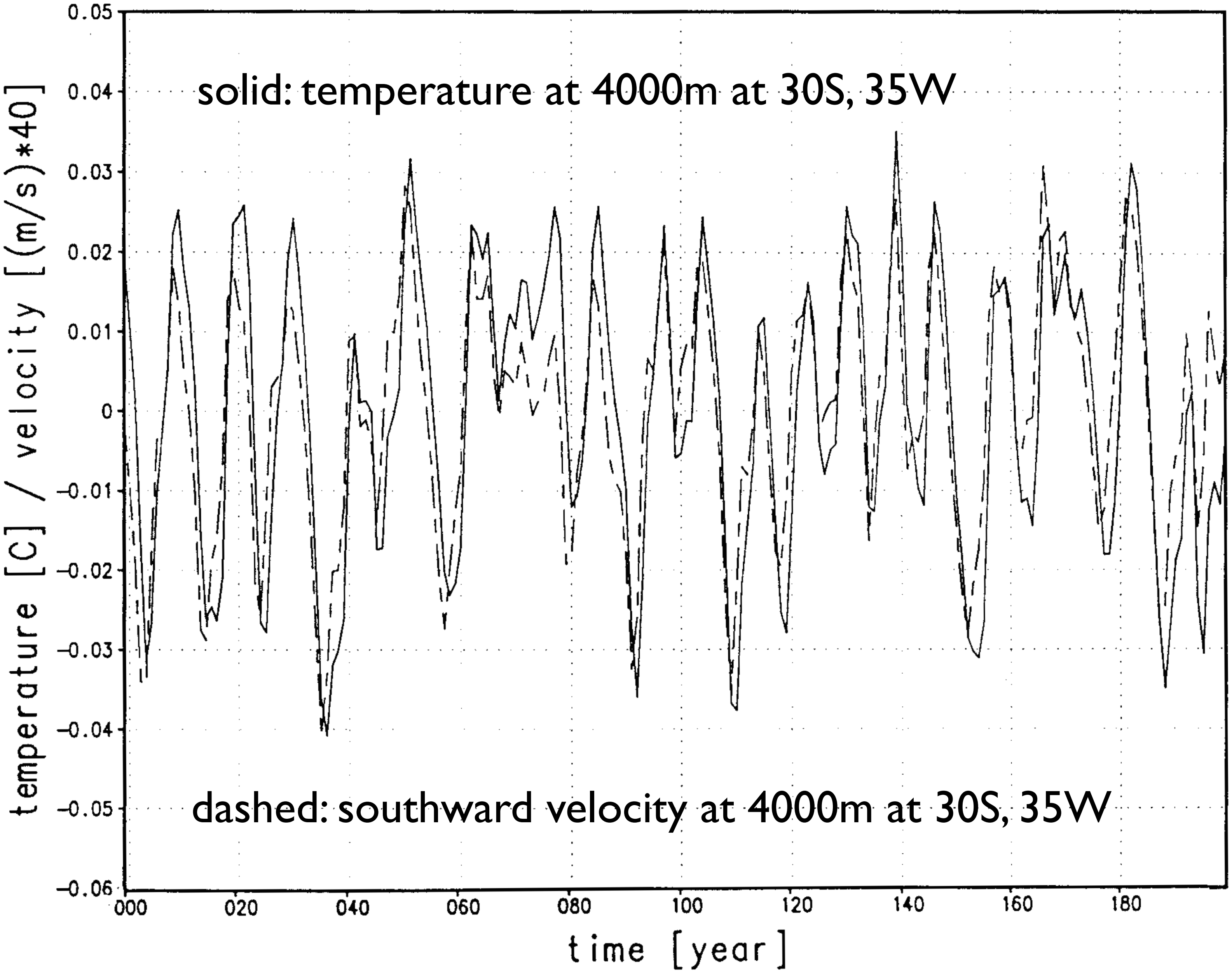
Stössel and SJKim (2001)

AABW along the deep-western boundary



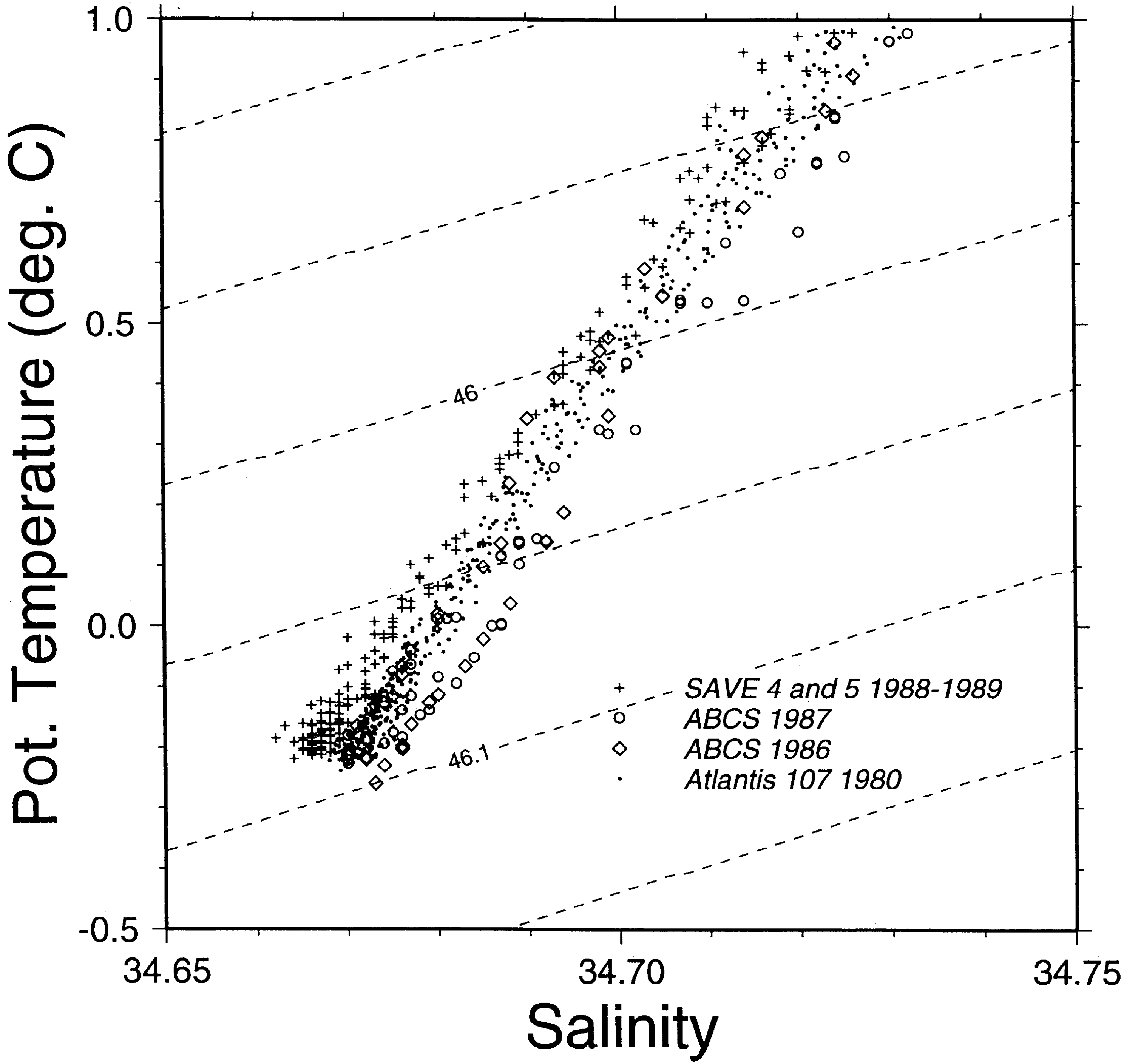
Coles et al. (1996)

Decadal variability in global ice - ocean GCM



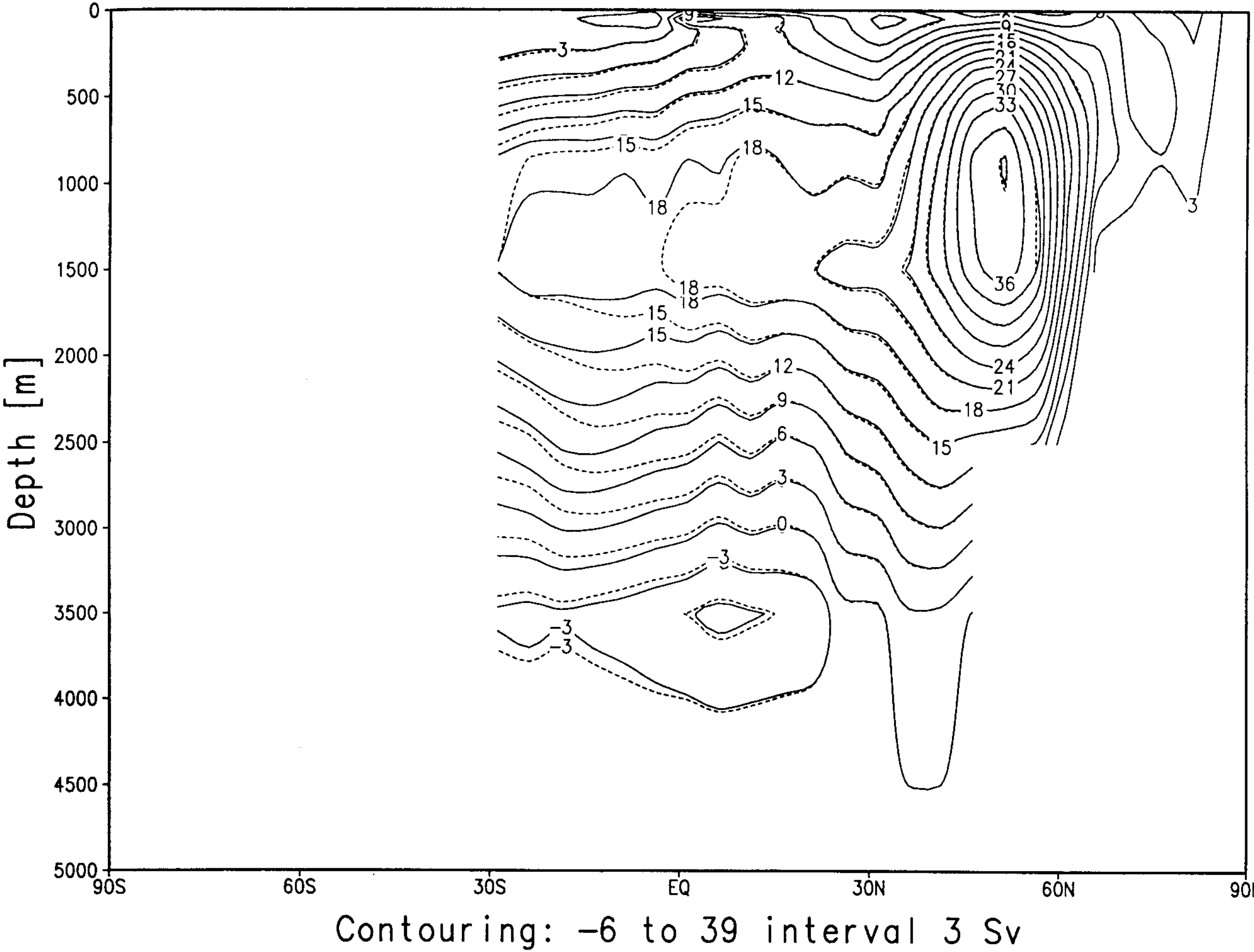
Stössel and SJKim (2001)

Decadal change of AABW properties in the Argentine Basin



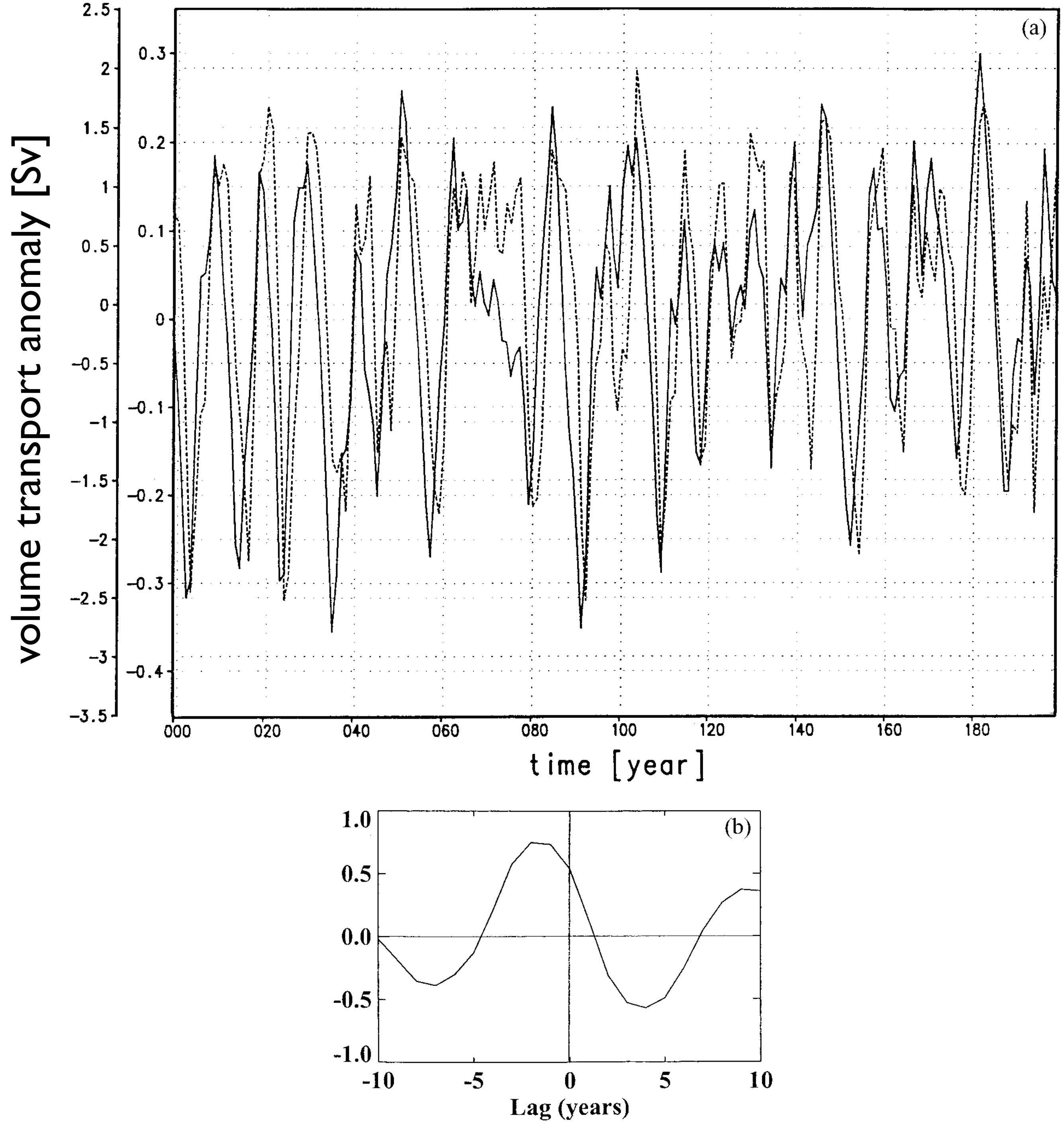
Coles et al.(1996)

Decadal variability in global ice - ocean GCM



Stössel and SJKim (2001)

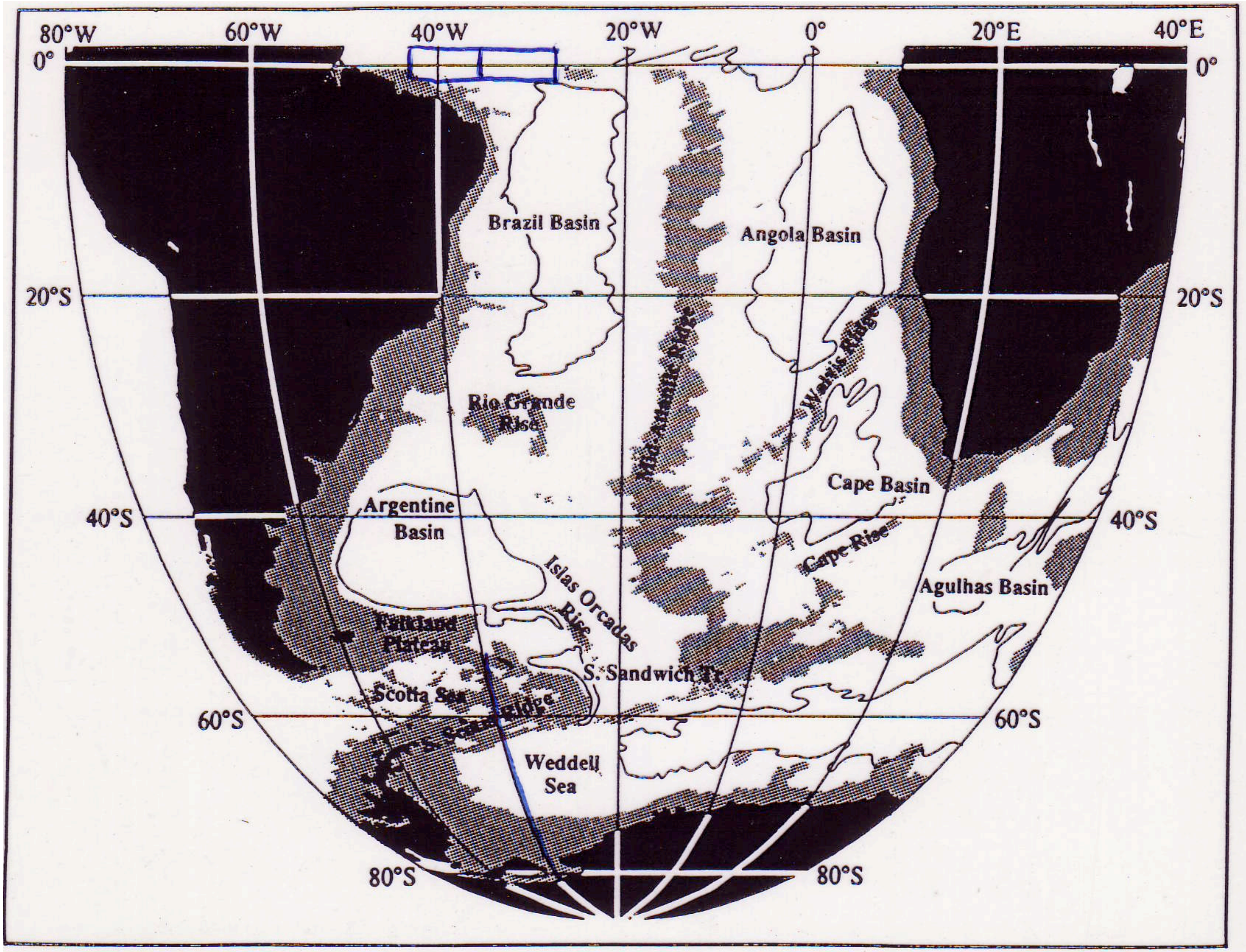
Decadal variability in global ice - ocean GCM

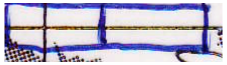


Atlantic overturning streamfunction at
solid: 3500m
dashed: 1500m

Stössel and SJKim (2001)

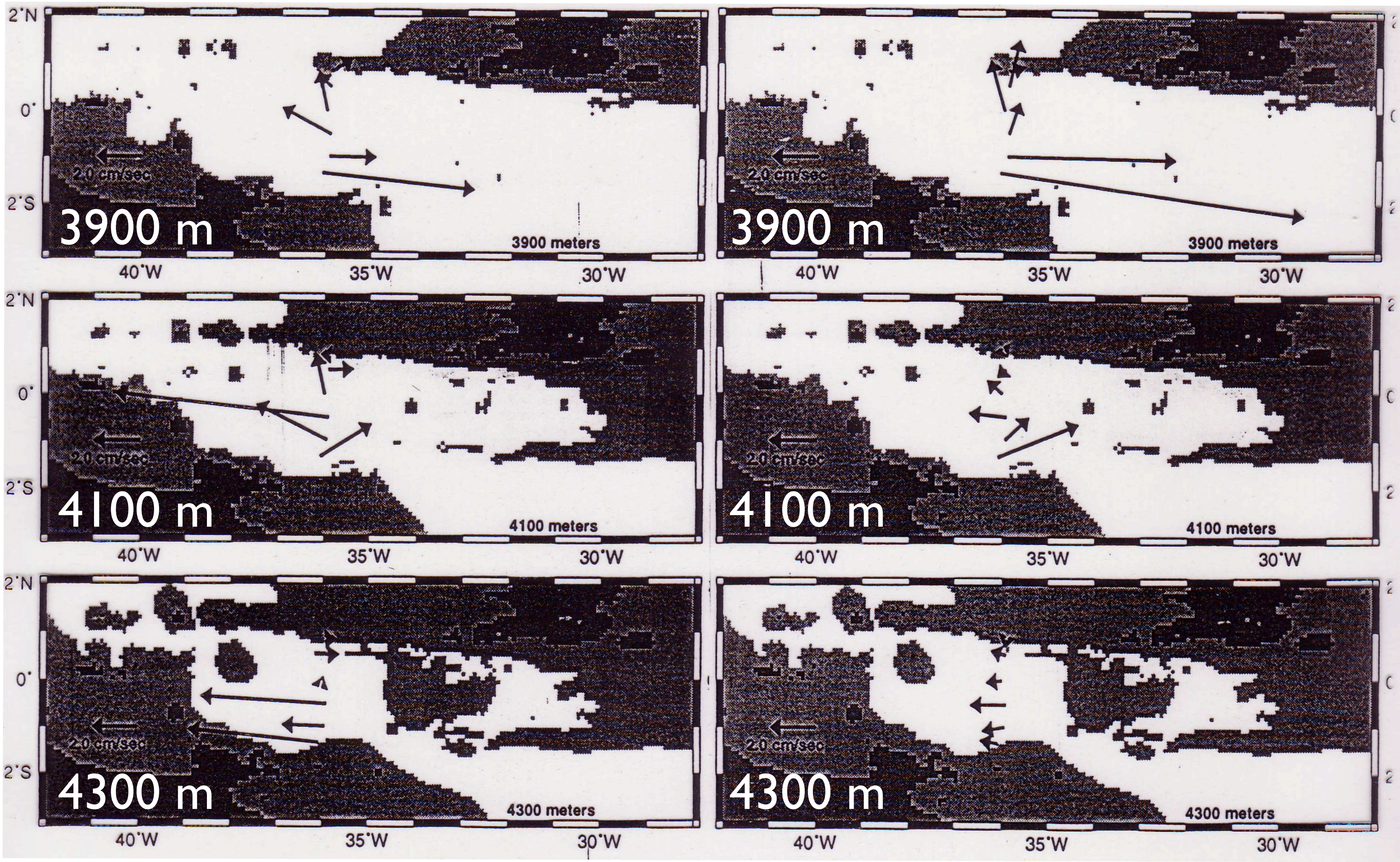
South Atlantic bathymetry



 box of *Hall et al. (1997)*

Reid (1989)

NADW and AABW across the equator



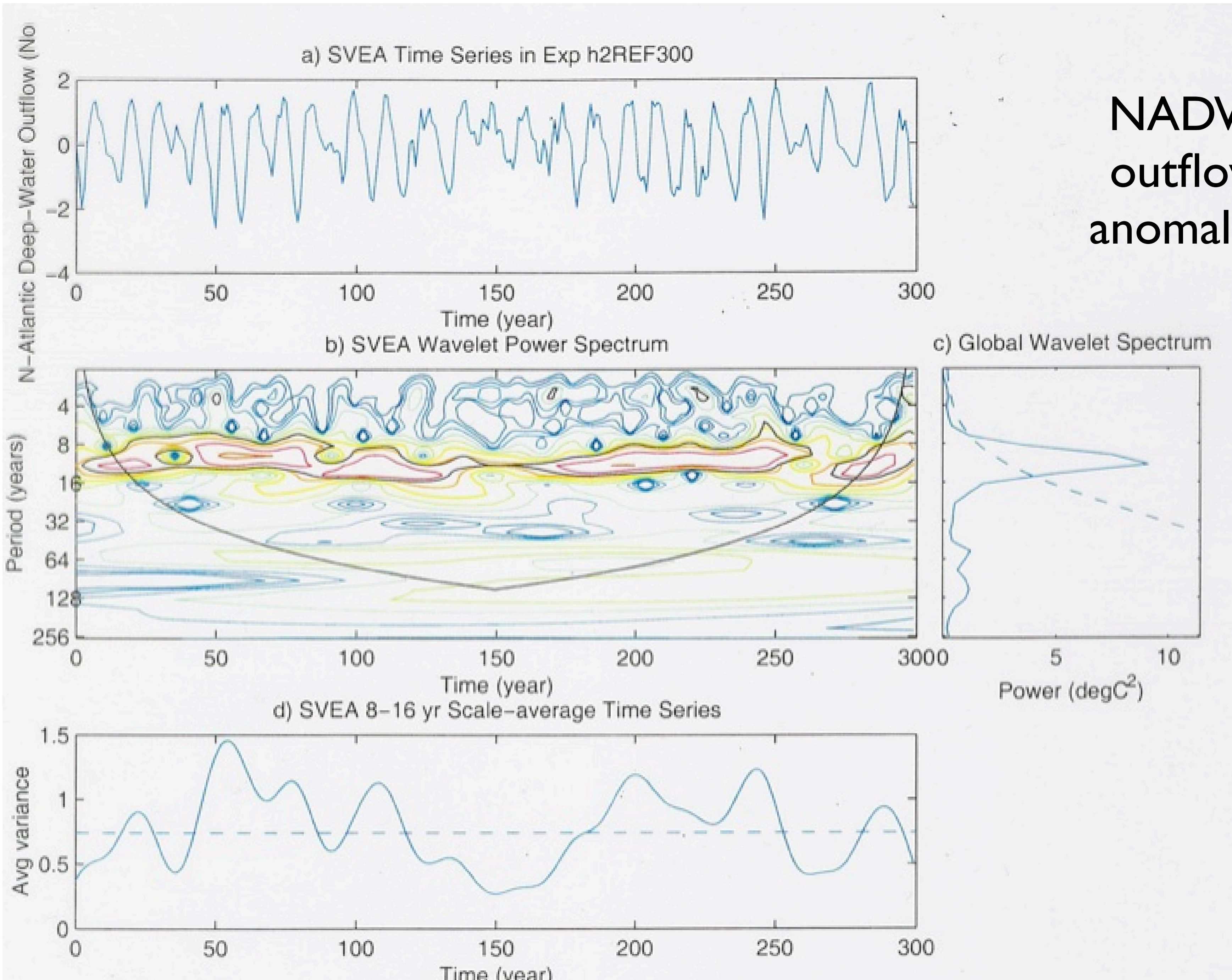
strong

weak

periods of AABW transport

Hall et al. (1997)

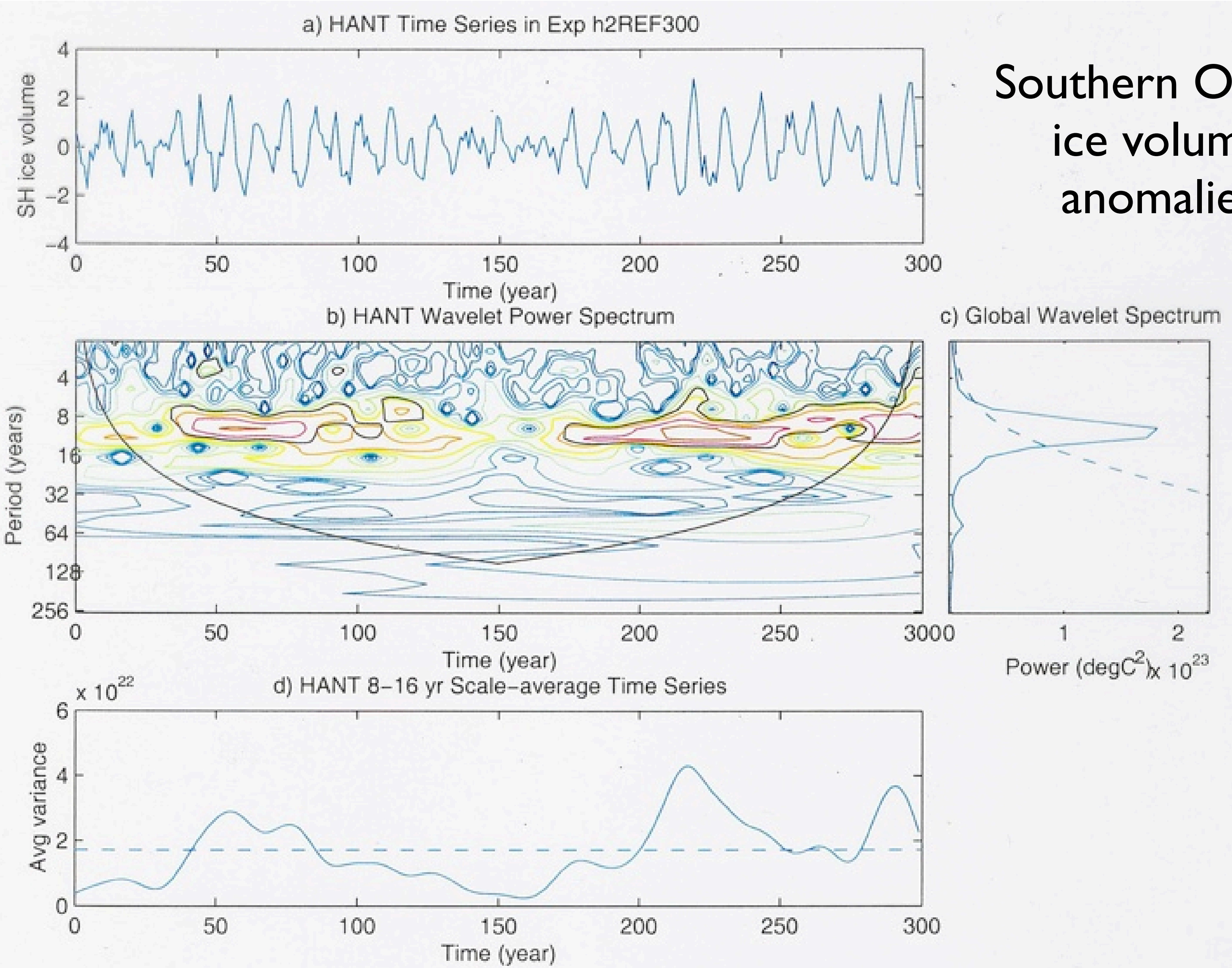
Decadal variability in global ice - ocean GCM



NADW
outflow
anomalies

Yang and Stössel (unpub.)

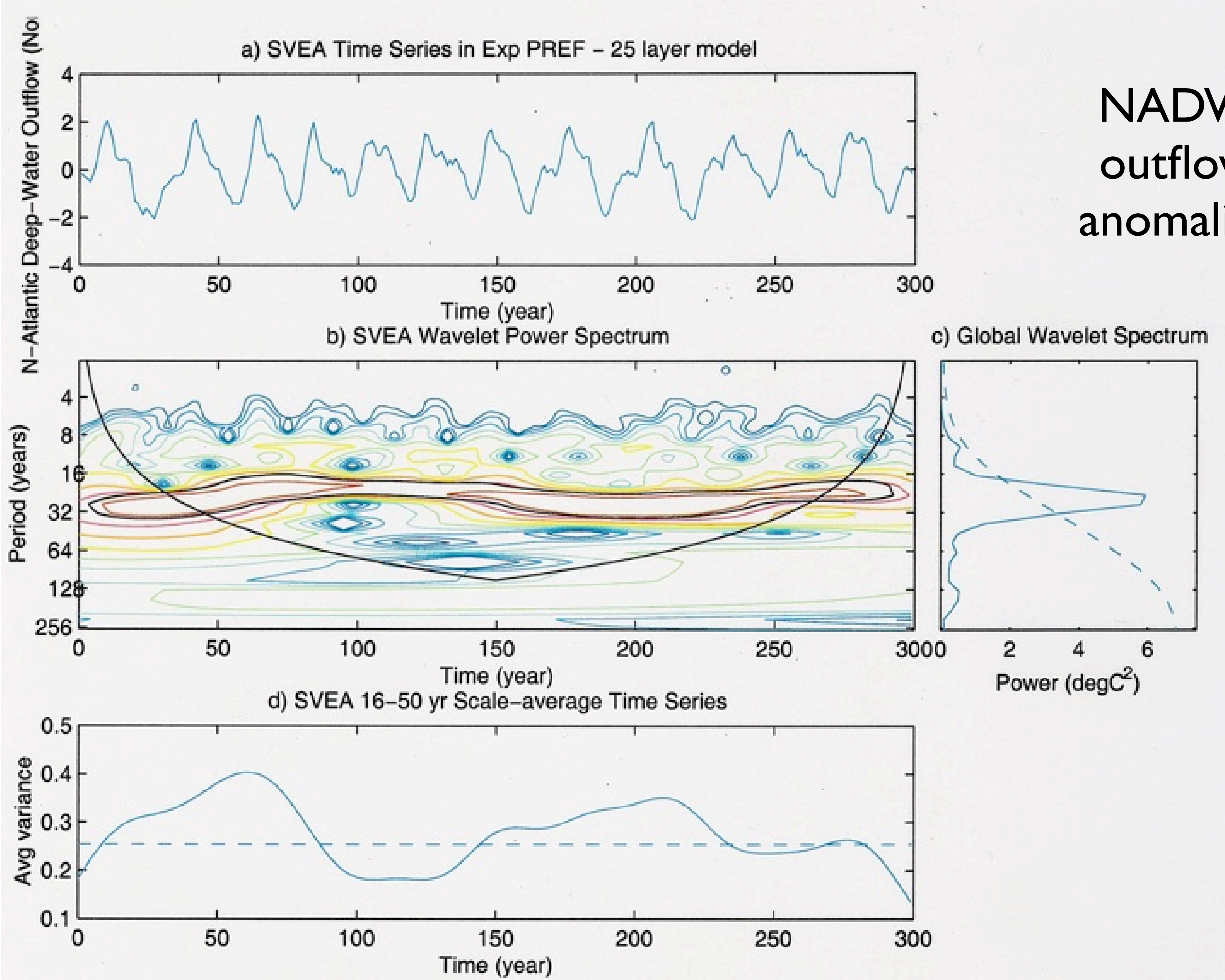
Decadal variability in global ice - ocean GCM



Southern Ocean ice volume anomalies

Yang and Stössel (unpub.)

Decadal variability in global ice - ocean GCM



NADW outflow anomalies

Yang and Stössel (unpub.)

Summary

I: Response of modelled THC is highly sensitive to parameterization of sea ice and convection in Southern Ocean

II: How meaningful is model variability that connects Southern Ocean with THC?

III: Detailed verification of Southern Ocean sea ice in global (atmosphere –) ice – ocean GCMs may lead to improved parameterizations

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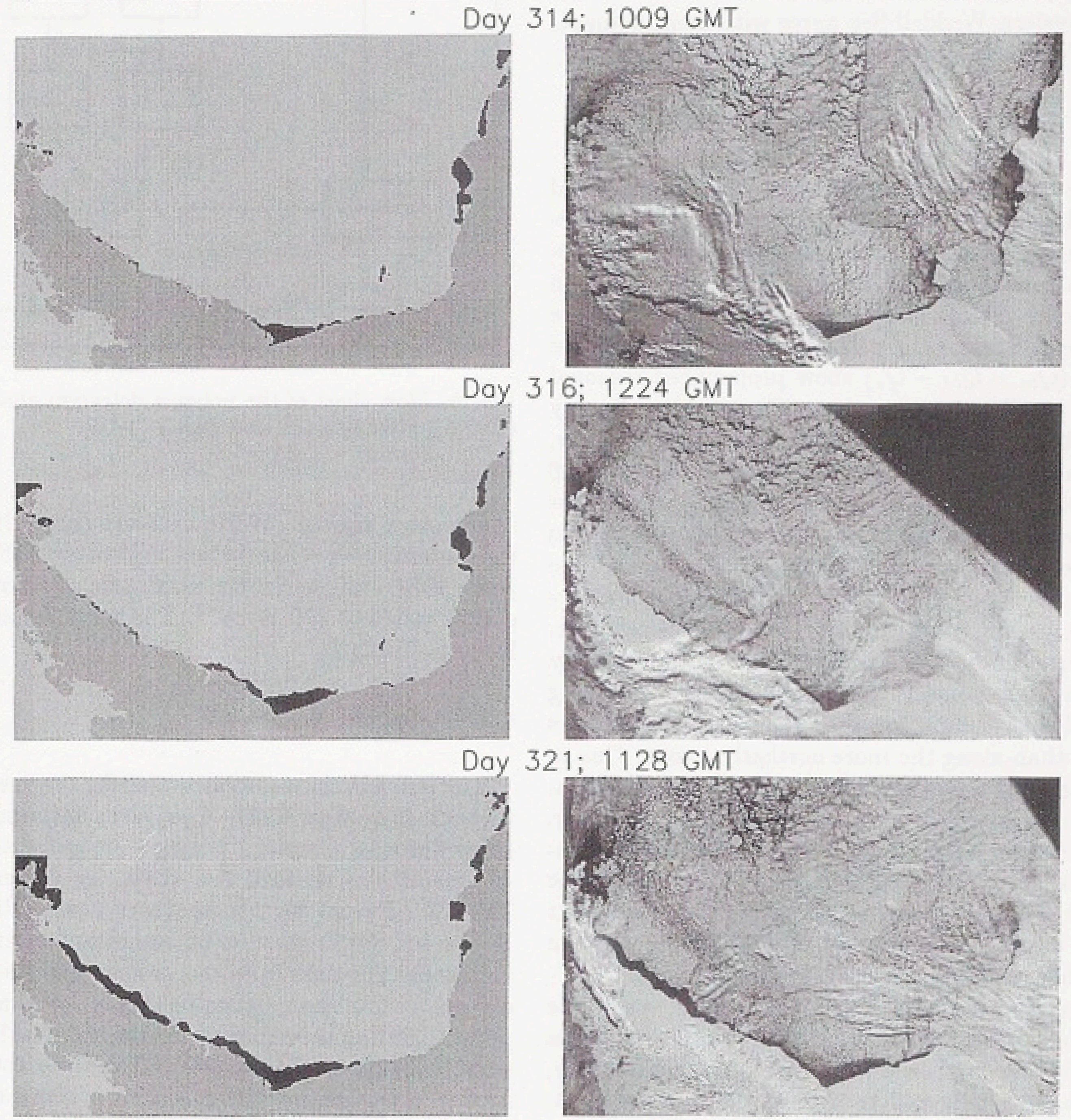
Satellite-derived Antarctic coastal polynyas



Day 314

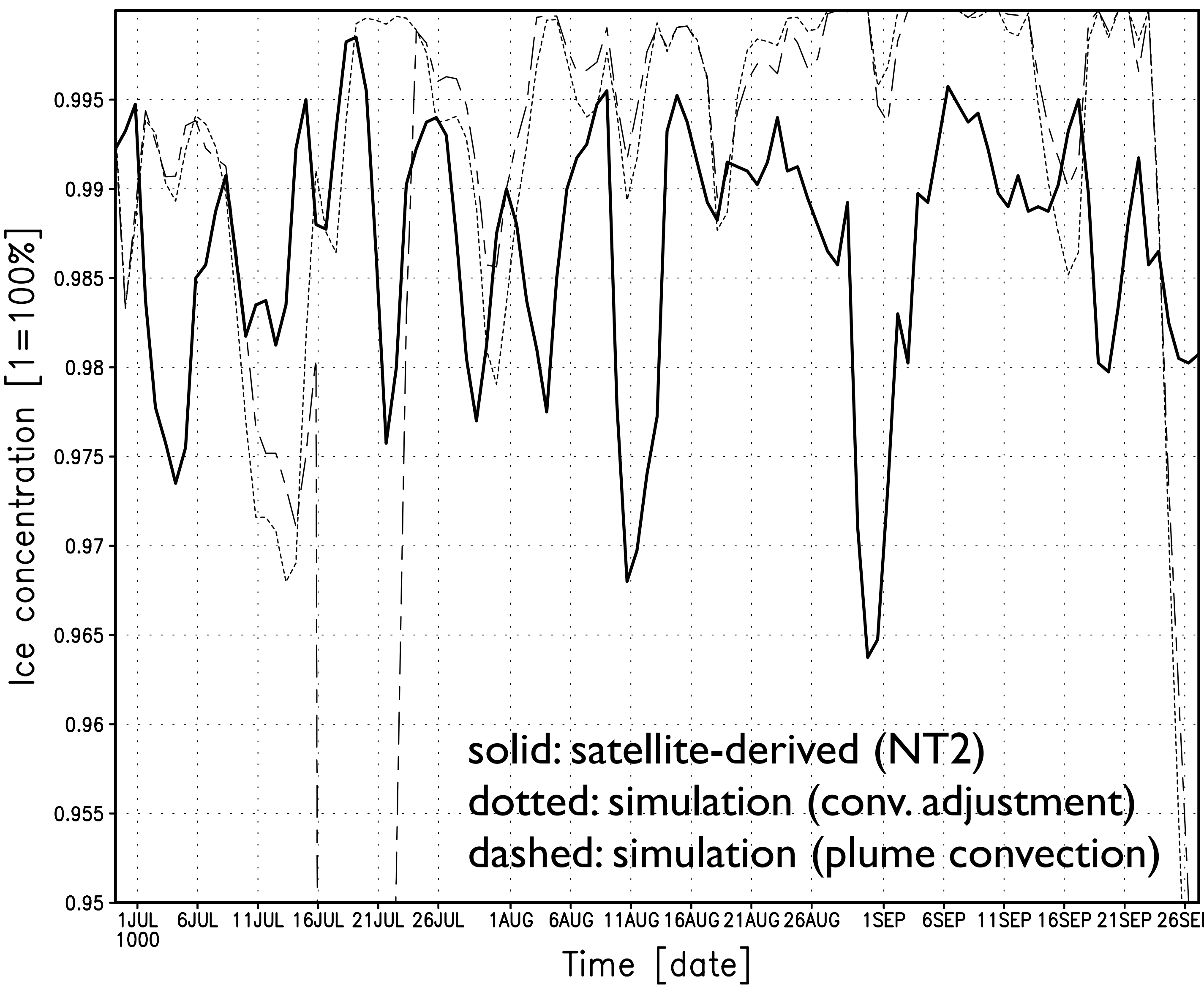
Day 316

Day 321

Fig. 9. Results from the PSSM (left) at the southern Weddell Sea coast in comparison with high resolution visible OLS data for November 1992 (right). The days are indicated

Markus et al.(1998)

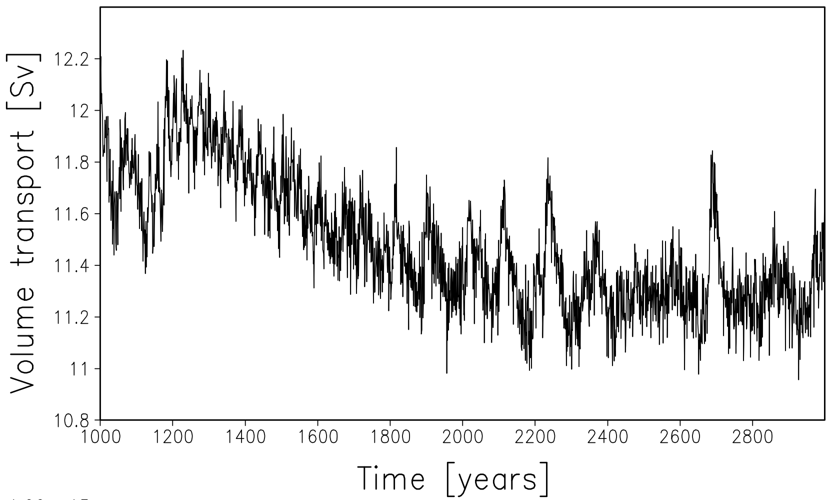
Antarctic coastal polynyas in global ice - ocean GCM



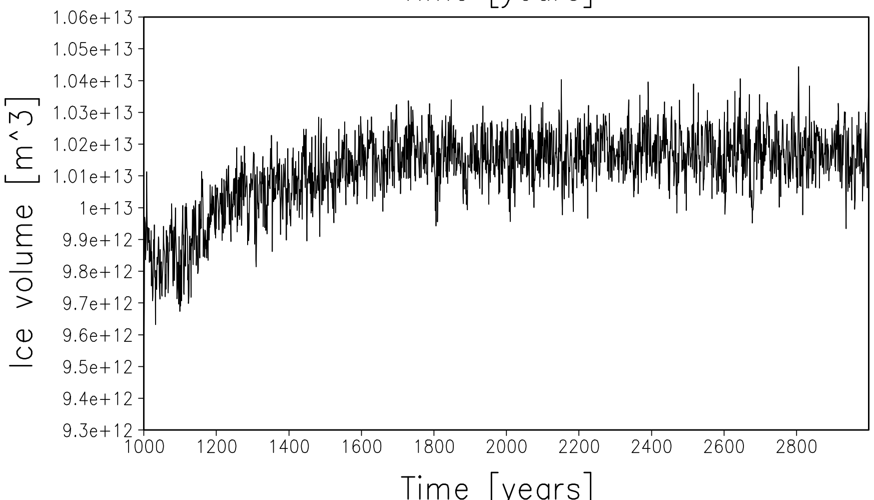
Ice concentration
at 75S, 54W
(coarse resolution)

Stössel and Markus (2004)

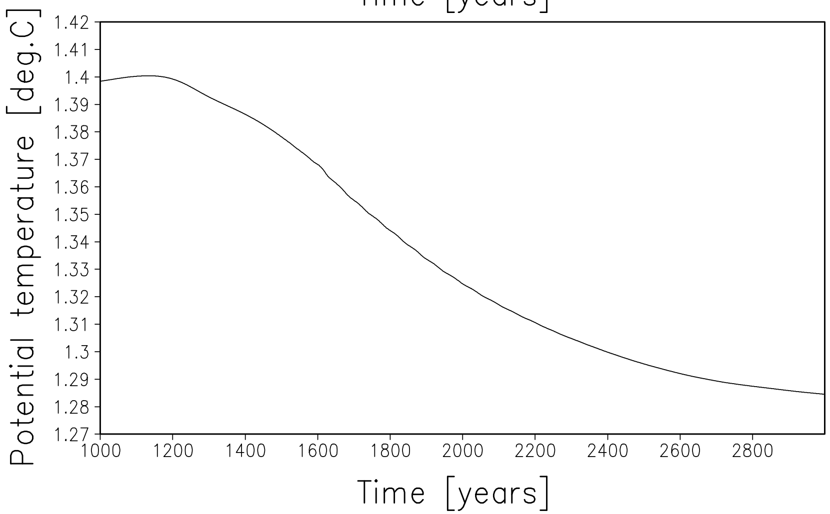
Transient response to 3% increase of Antarctic coastal polynyas in global ice - ocean GCM



NADW outflow across 30S

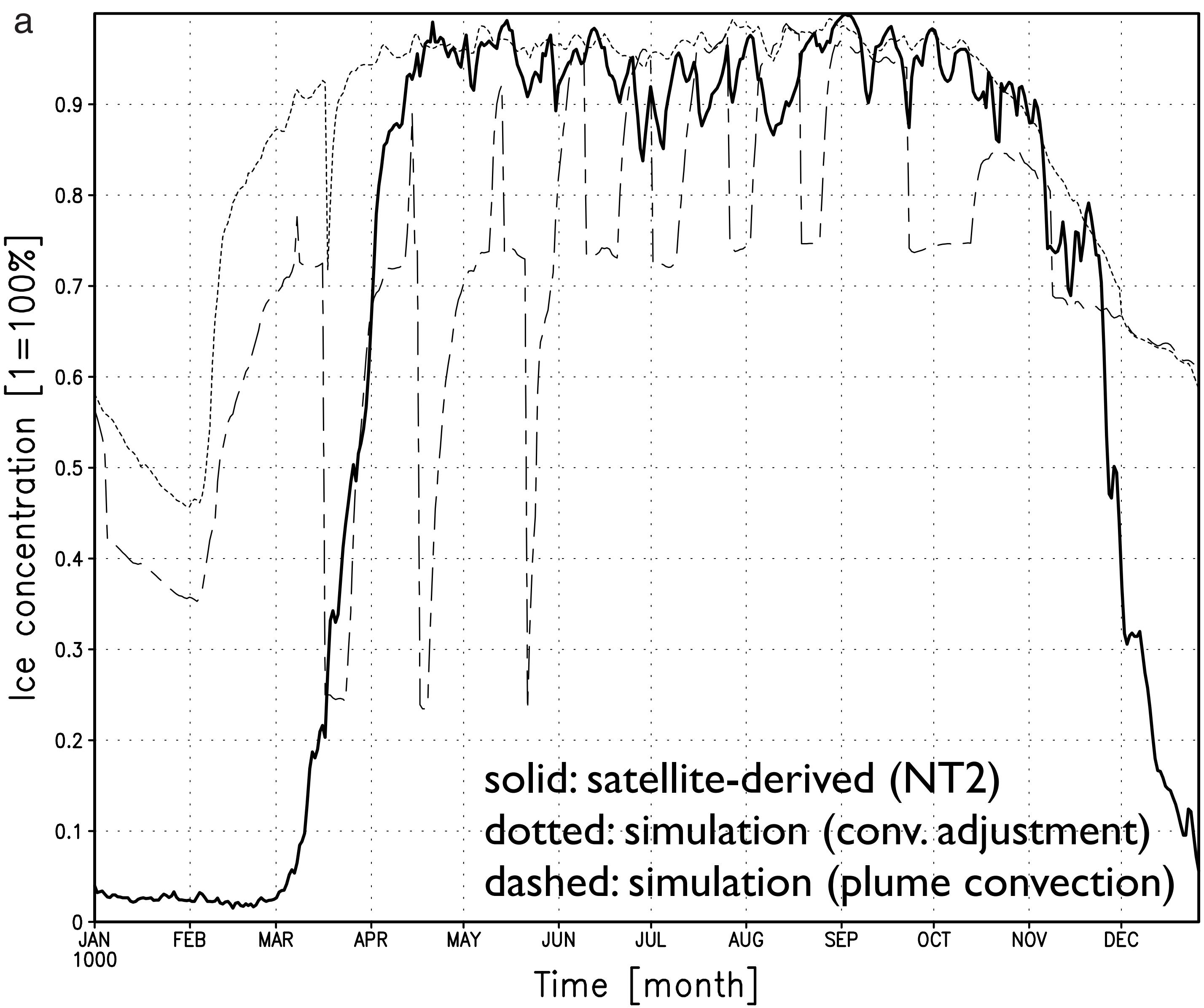


Southern Ocean ice volume



Global mean temperature at 5000m

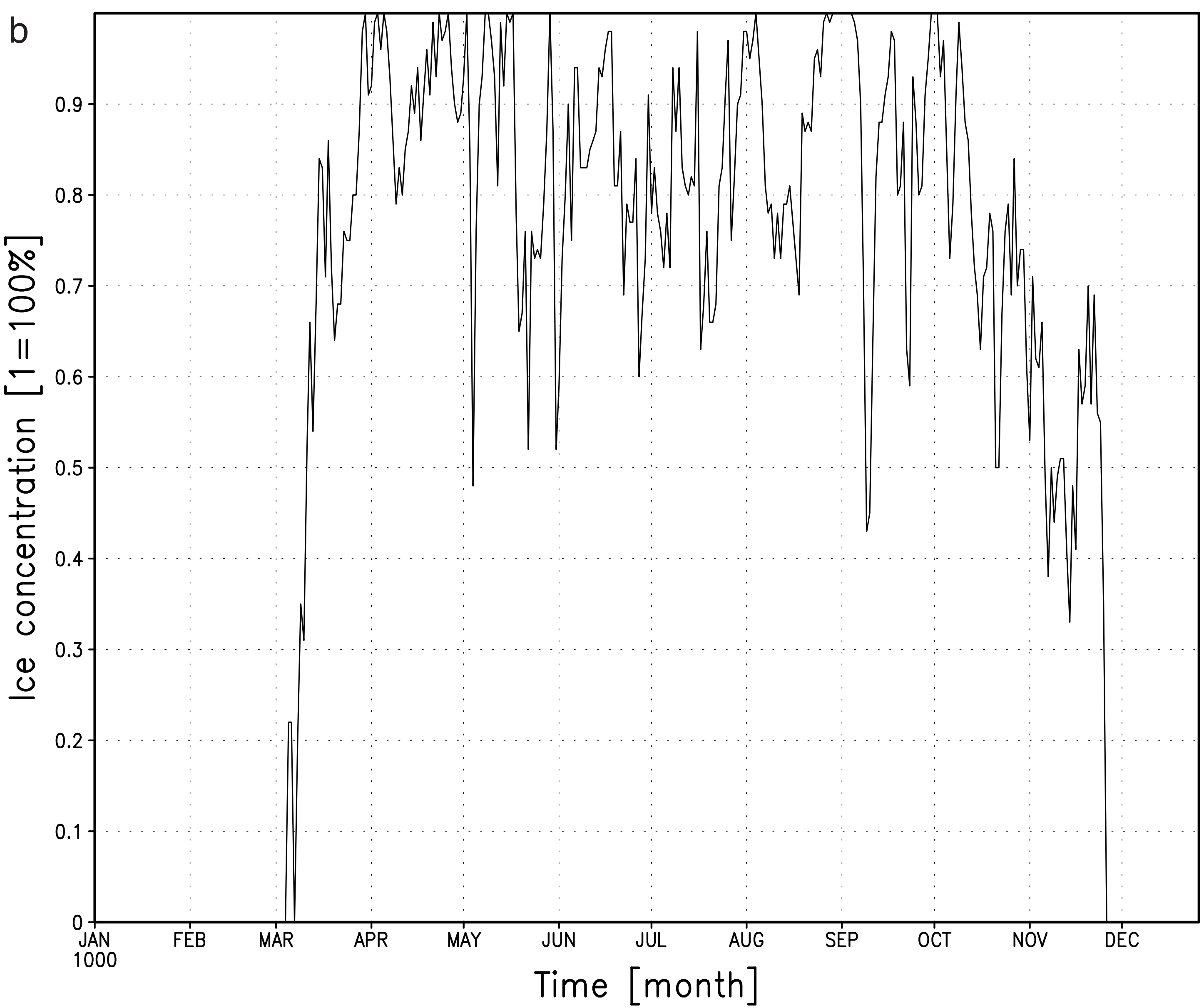
Antarctic coastal polynyas in global ice - ocean GCM



Simulated ice concentration at 77S, 174E (coarse resolution)

Stössel and Markus (2004)

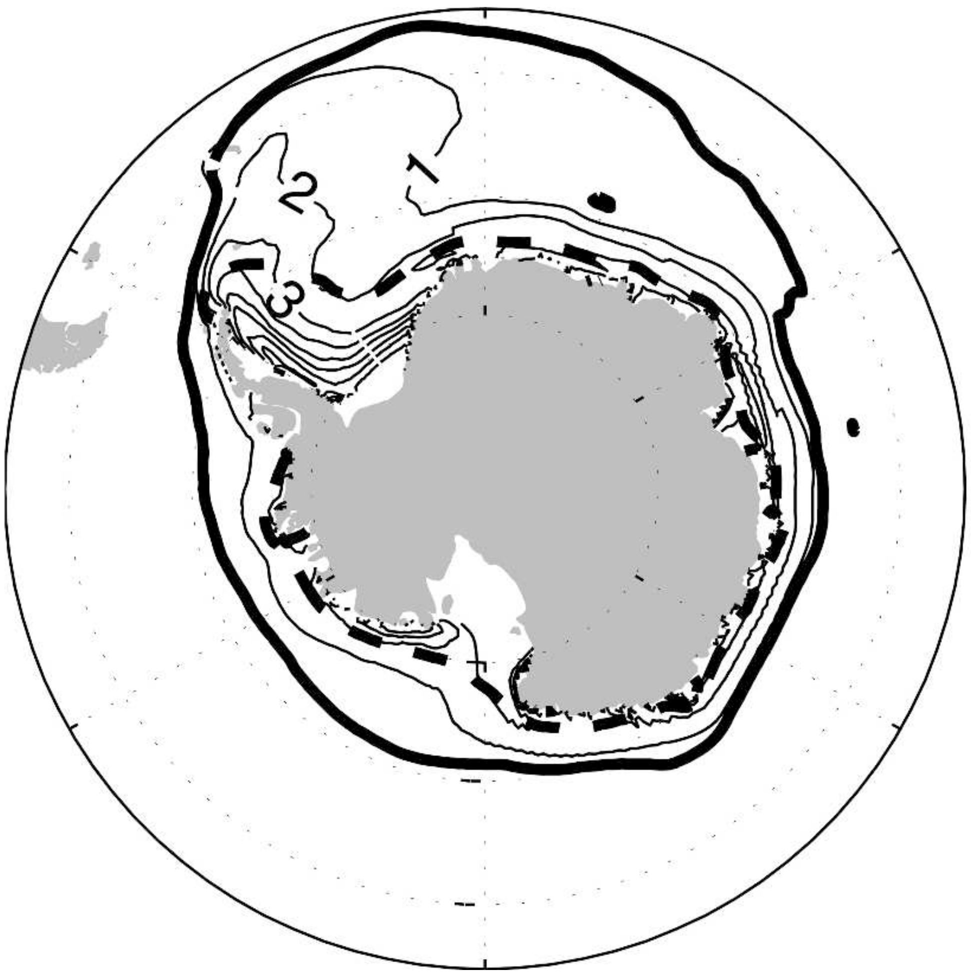
Satellite-derived Antarctic coastal polynyas



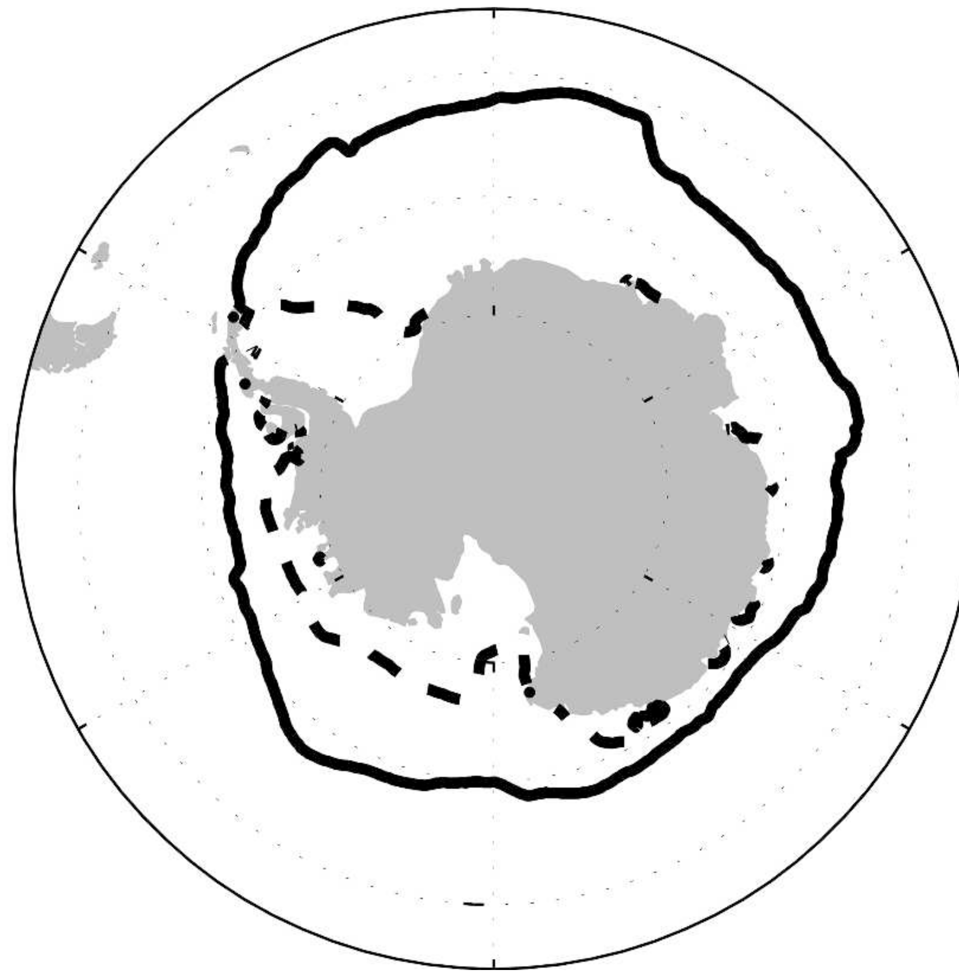
NT2 ice concentration at 77S, 174E (high resolution)

Stössel and Markus (2004)

Global atmosphere - ice - ocean GCM (NCAR)



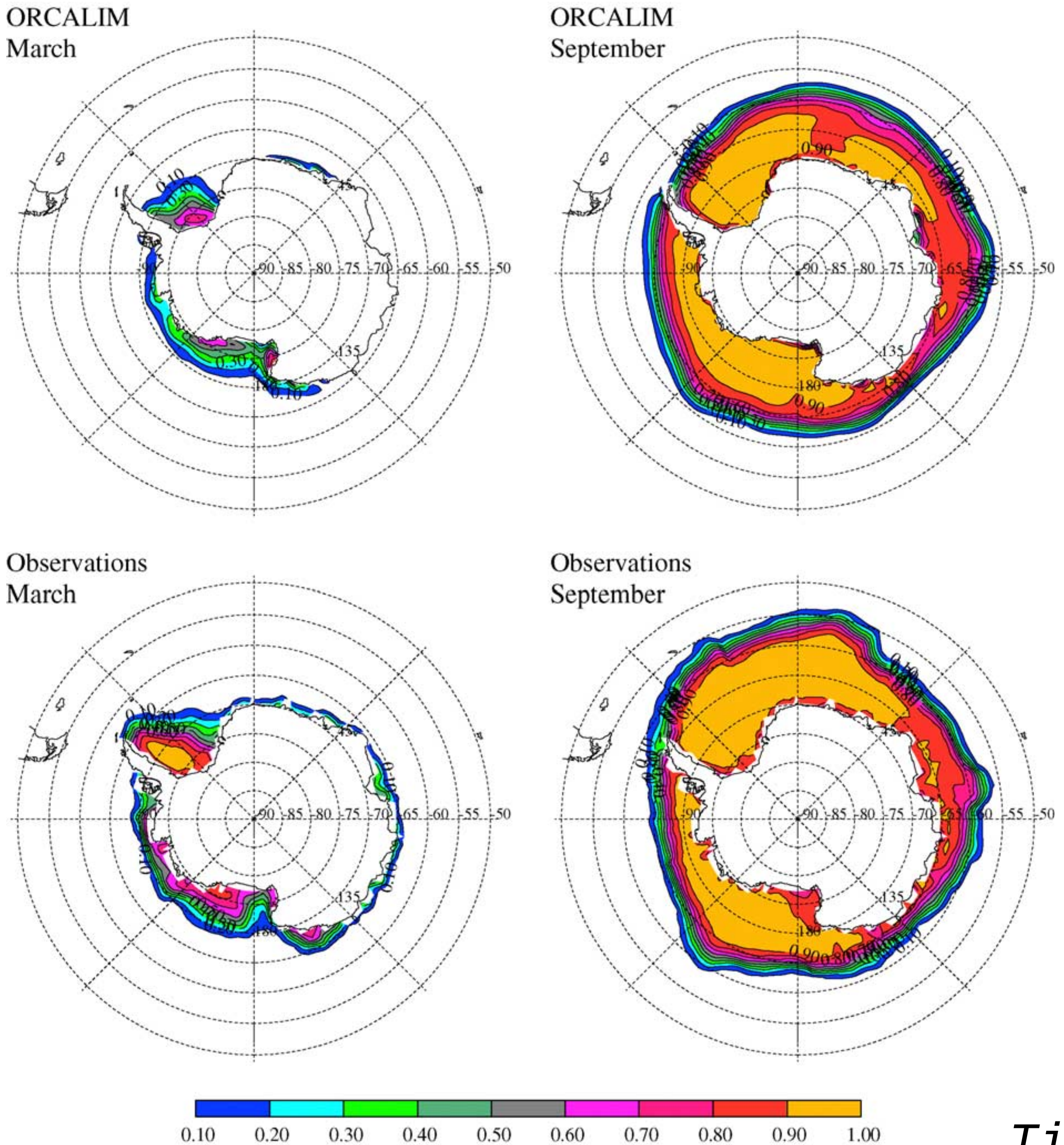
Coupled GCM



Satellite

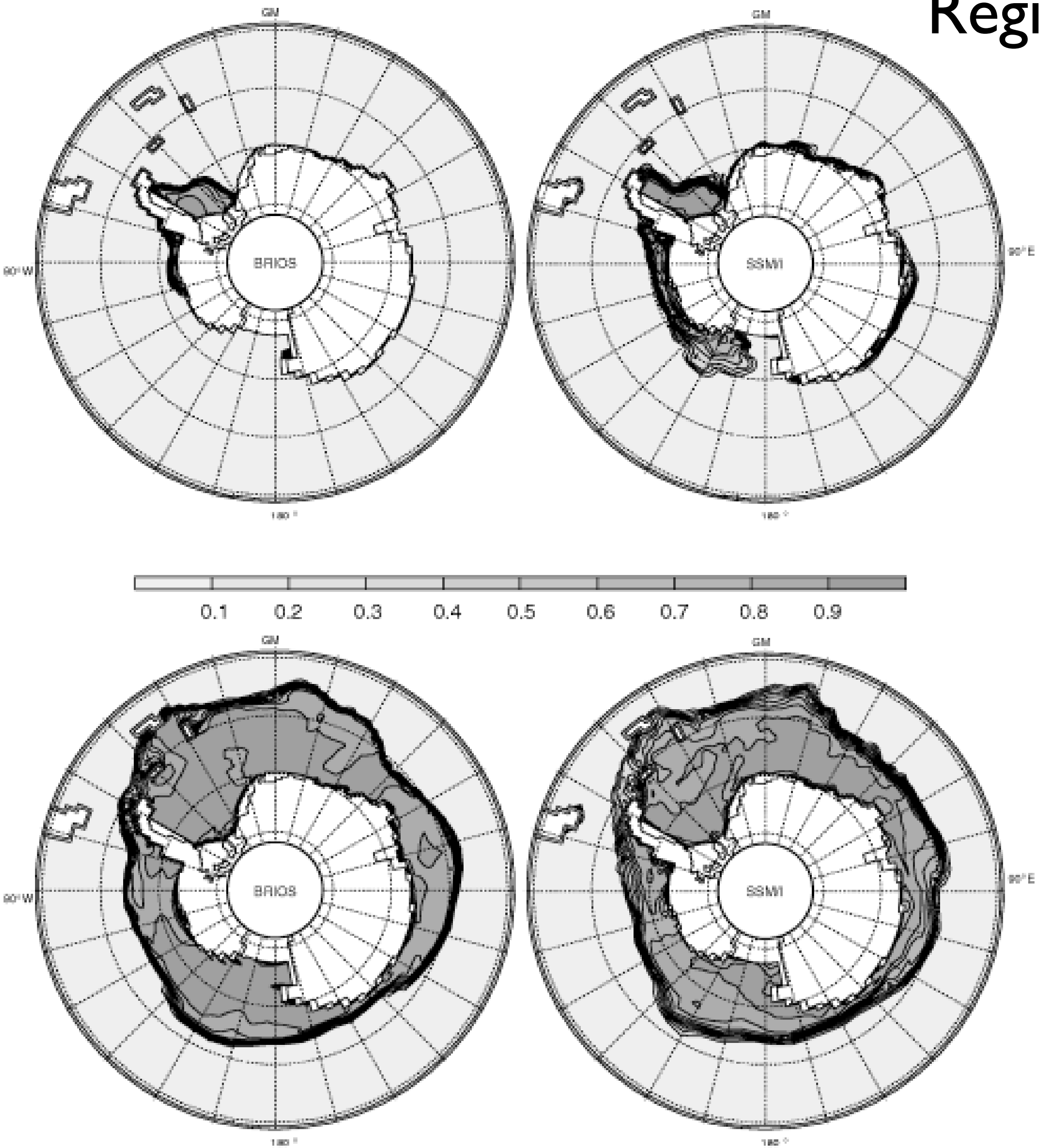
Bitz et al.(2005)

Global ice - ocean GCM



Timmermann et al.(2005)

Regional ice - ocean GCM



February 1987

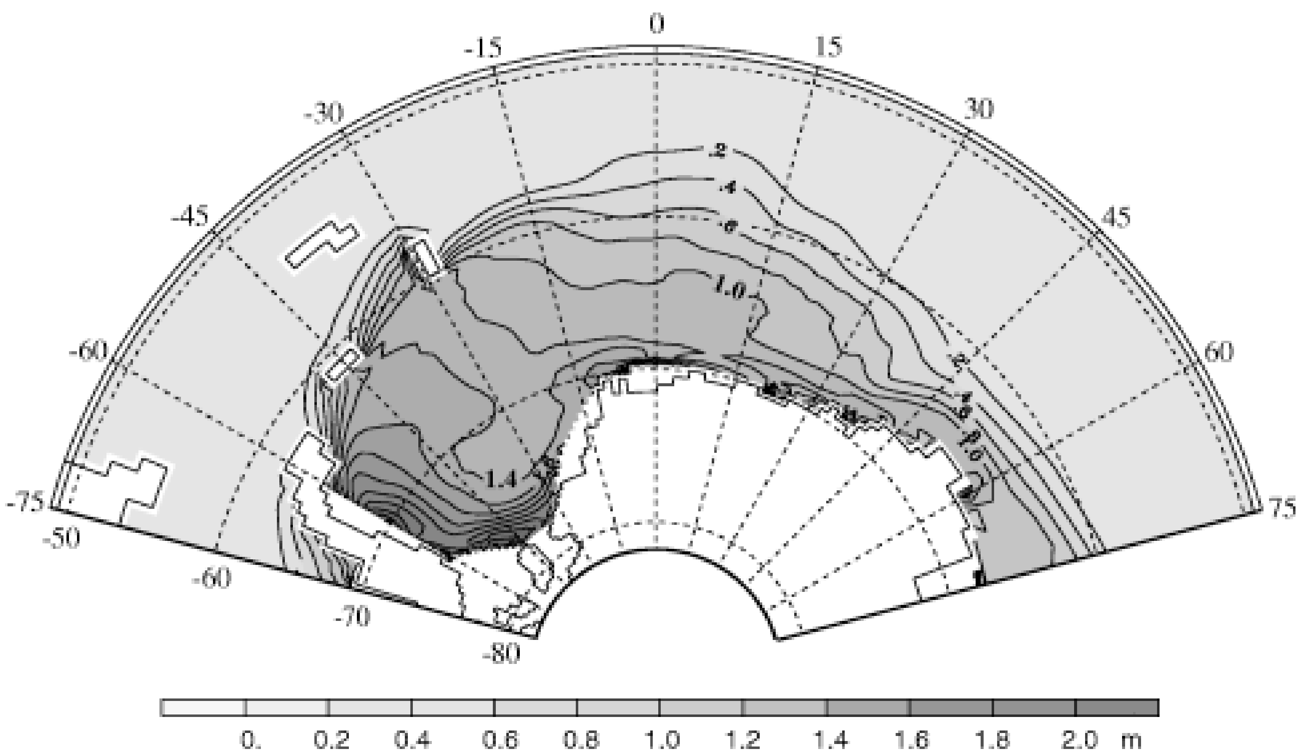
September 1987

Model

SSM/I

Timmermann et al.(2002)

Regional ice - ocean GCM

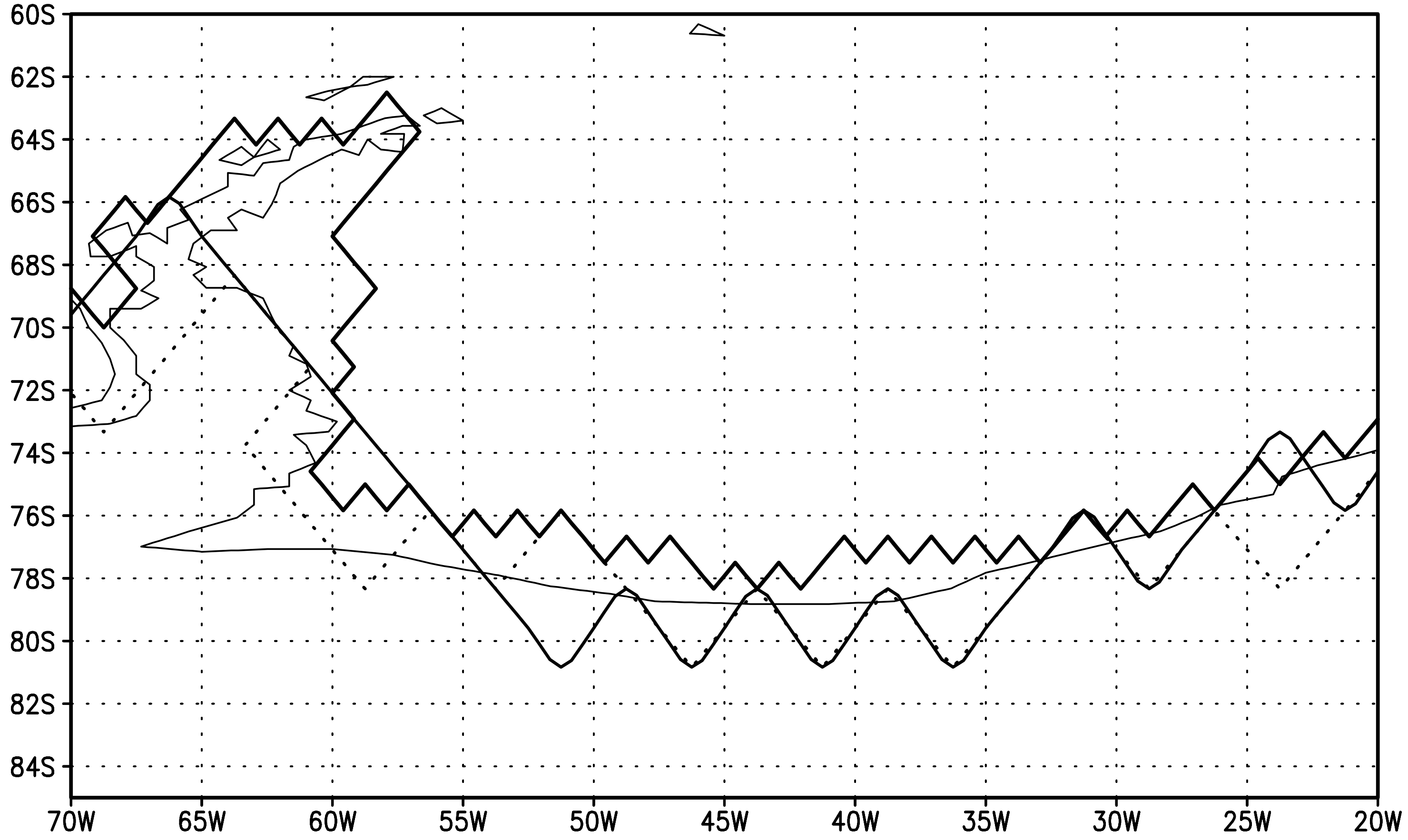


September mean ice thickness

Timmermann et al.(2002)

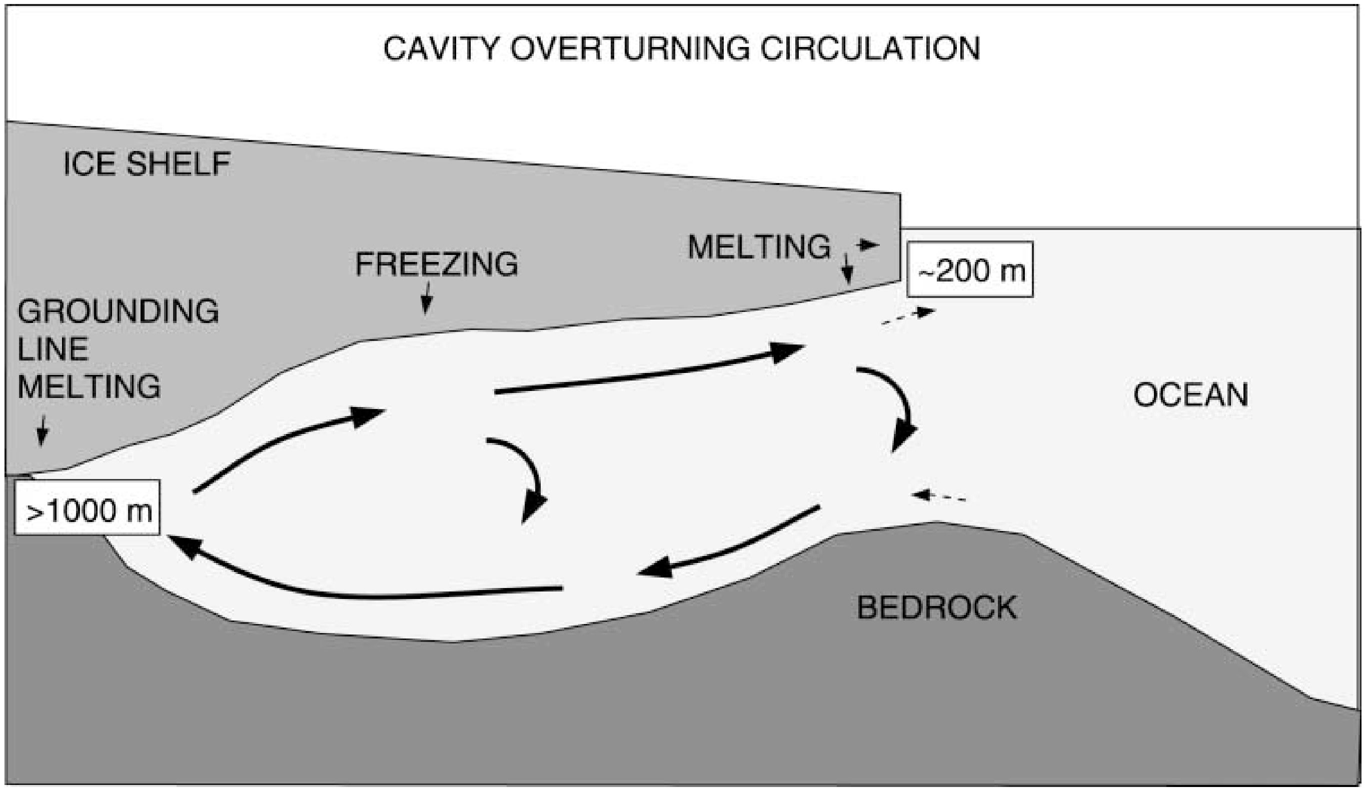
Global higher-resolution ice - coarse-resolution ocean GCM

Artificial coastal lid: opportunity for “ice-shelf” melt



Stössel and JTKim (2006)

Parameterization of ice-shelf - ocean interaction



Beckmann and Goosse (2003)

Effect of precipitation in sea-ice - ocean GCM

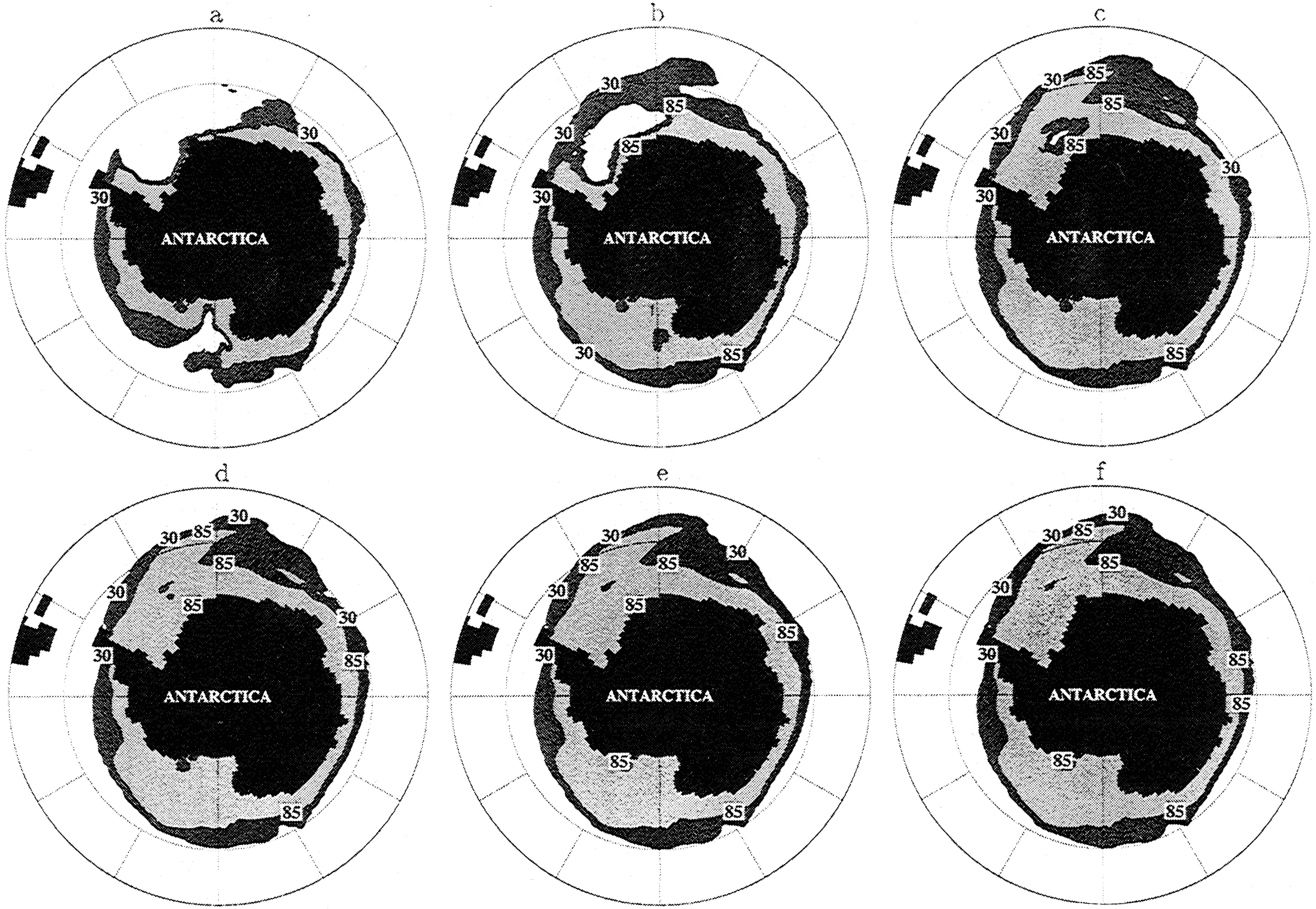
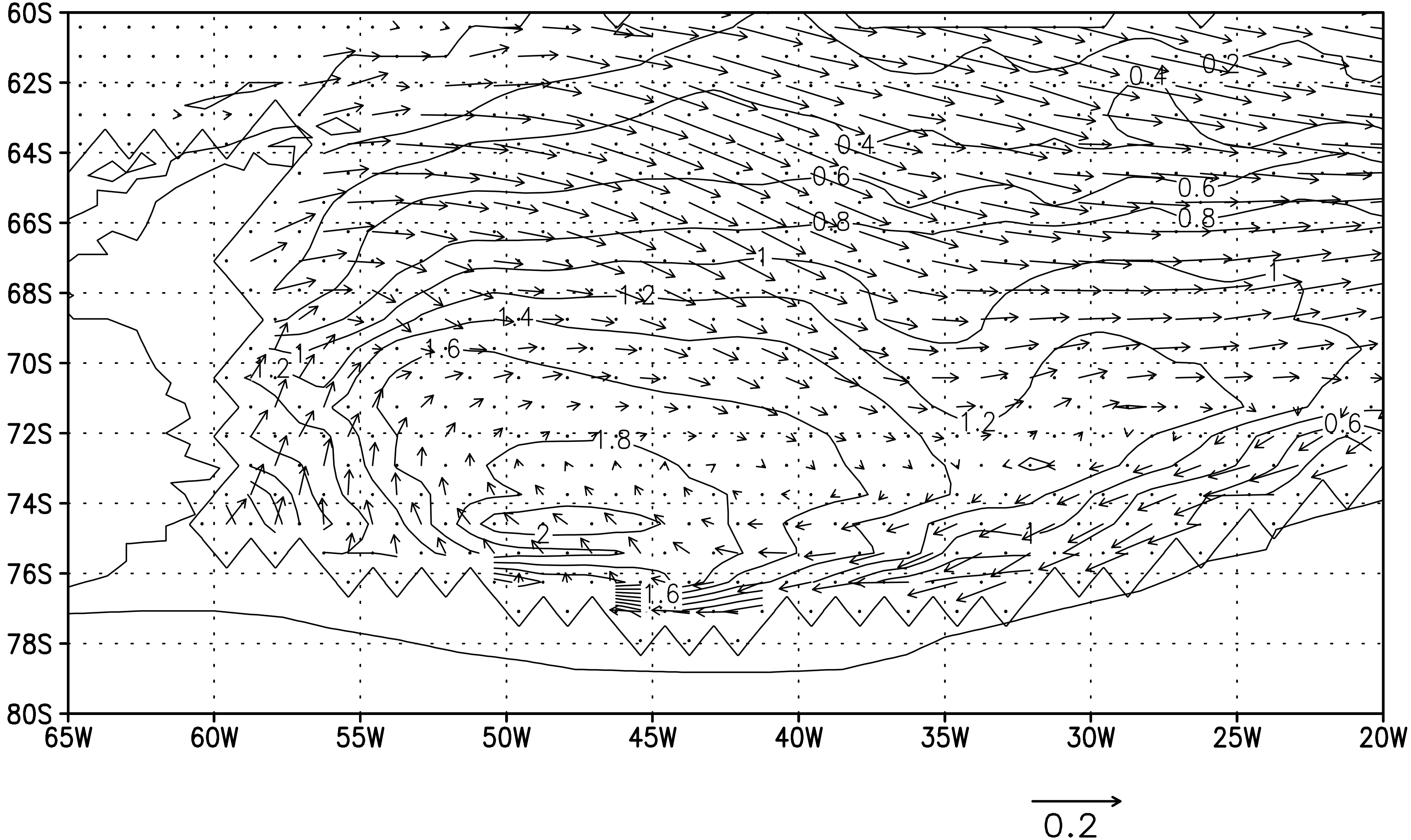


Figure 9. Mean September sea ice concentration (percent) averaged over the final 3 years for (a) and (d) CSIRO9, (b) and (e) GASP, and (c) and (f) ECMWF $P-E$ climatologies. Figures 9a–9c show the cases where only the relevant $P-E$ climatology is used as SFWF, and Figures 9d–9f show the cases where SFWF consists of the $P-E$ plus 10 cm yr^{-1} of glacial meltwater in the region south of 60°S.

Marsland and Wolff (2001)

Global higher-resolution ice - coarse-resolution ocean GCM



Stössel and JTKim (2006)

Global higher-resolution ice - coarse-resolution ocean GCM

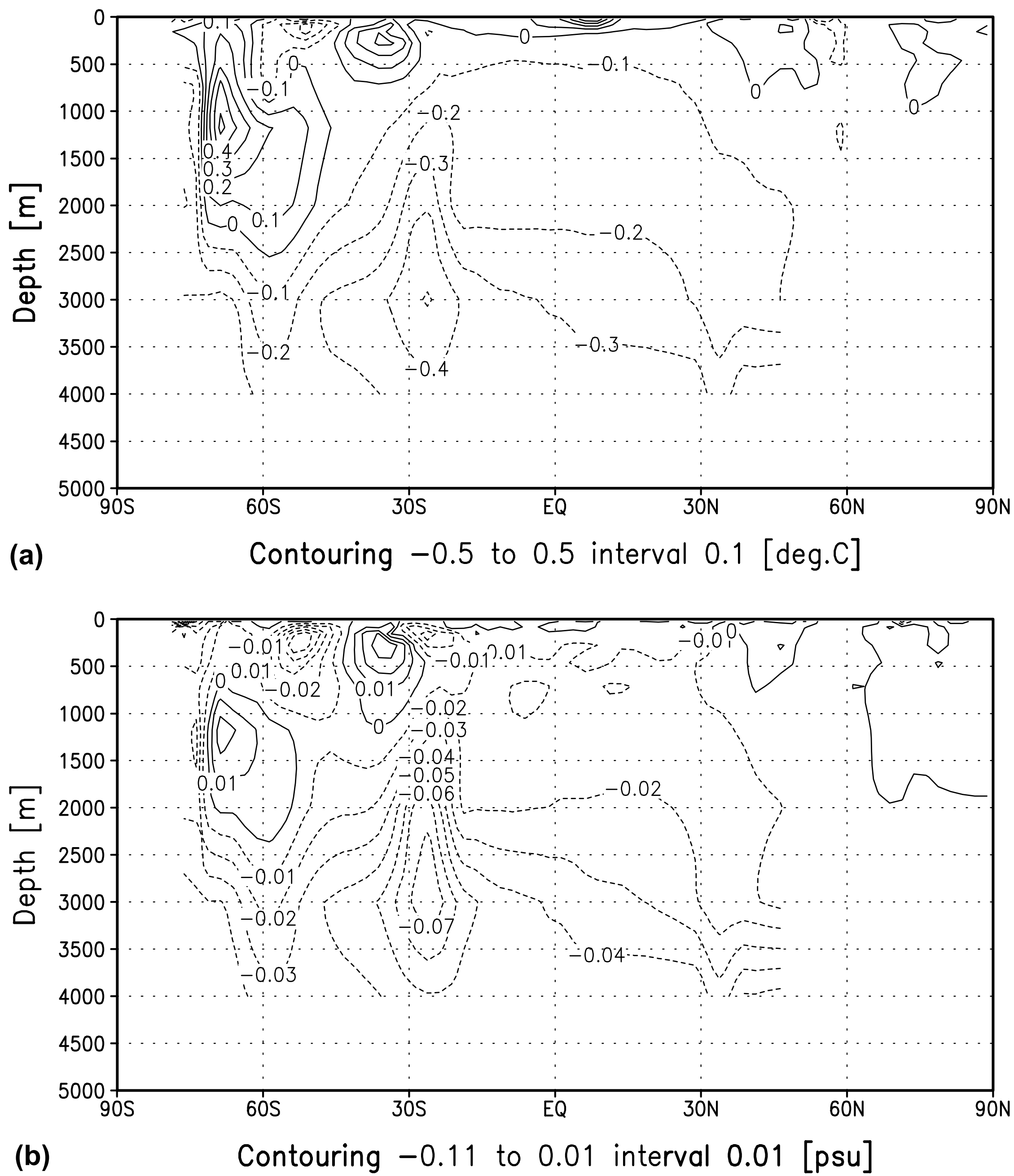
Near-equilibrium sensitivity experiments

Exp.	NADW outflow [Sv]	DP throughflow [Sv]	$\Theta_{4000\ \mathrm{m}}$ [degC]	$S_{4000\ \mathrm{m}}$ [psu]
CCC	12.1	105	1.43	34.746
CCC/V	11.1	108	1.26	34.750
CCC/L	10.7	112	1.11	34.749
CCC/CP	11.3	110	1.26	34.747
CCC/K	11.1	107	1.15	34.730
CFC	11.5	97	1.30	34.720
CFC/V	11.1	99	1.25	34.732
CFF	10.5	81	0.56	34.657

Stössel and JTKim (2006)

Global higher-resolution ice - coarse-resolution ocean GCM

Difference fine minus coarse of Atlantic annual, zonal mean



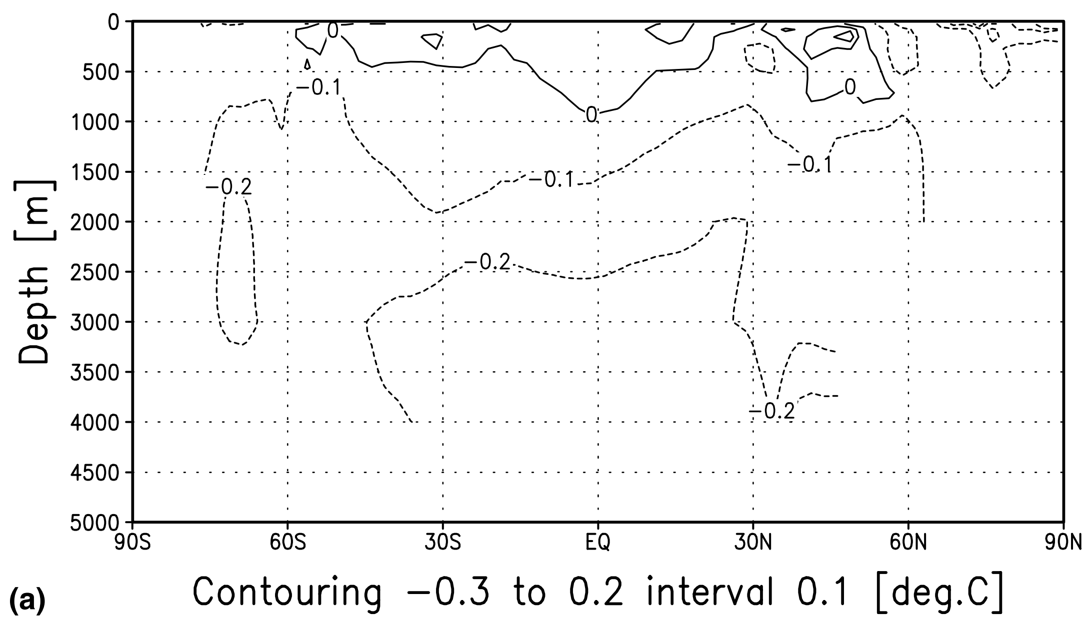
Potential temperature

Salinity

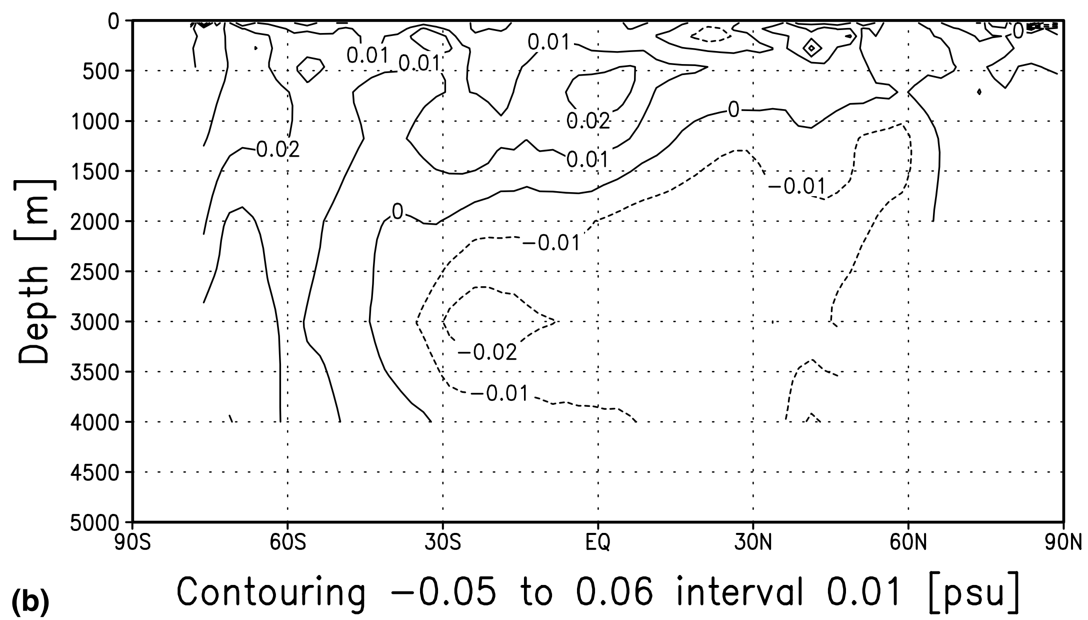
Stössel and JTKim (2006)

Global higher-resolution ice - coarse-resolution ocean GCM

Difference coarse with higher wind variability minus coarse of Atlantic annual, zonal mean



Potential temperature

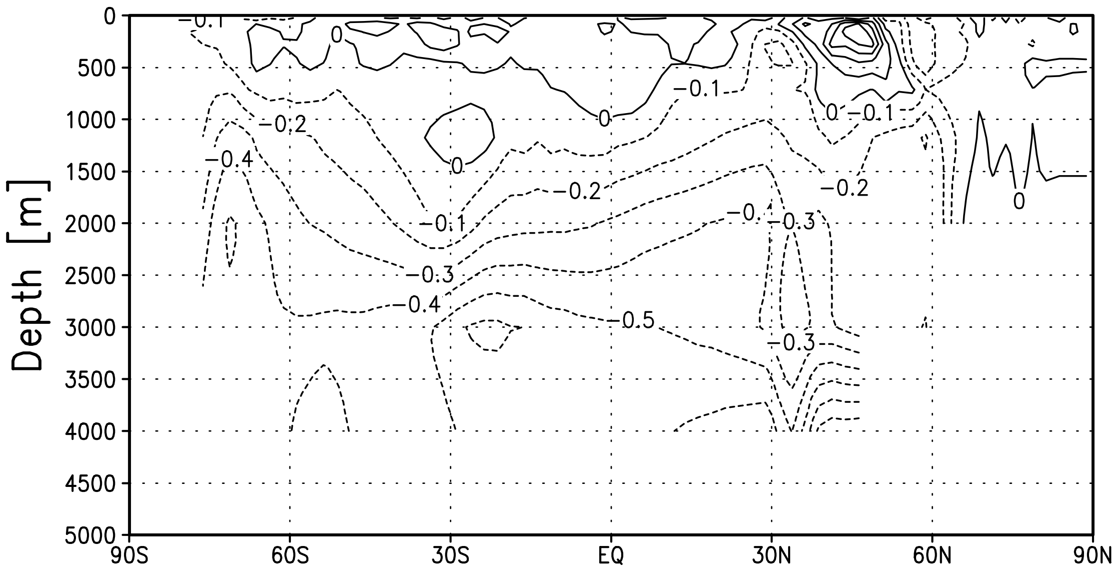


Salinity

Stössel and JTKim (2006)

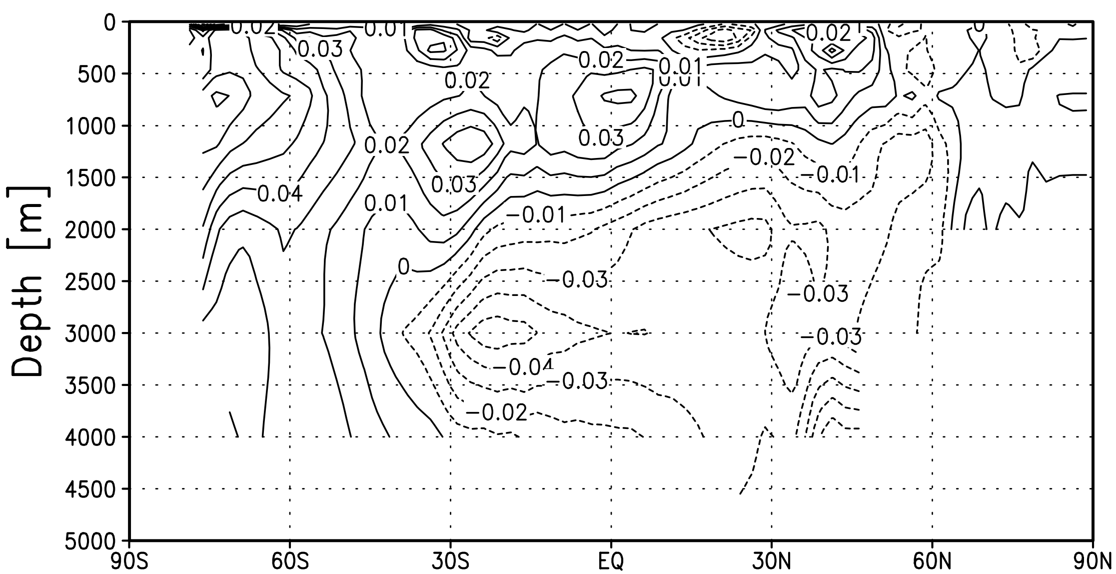
Global higher-resolution ice - coarse-resolution ocean GCM

Difference coarse with higher lead fraction minus coarse of Atlantic annual, zonal mean



(a) Contouring −0.8 to 0.4 interval 0.1 [deg.C]

Potential temperature



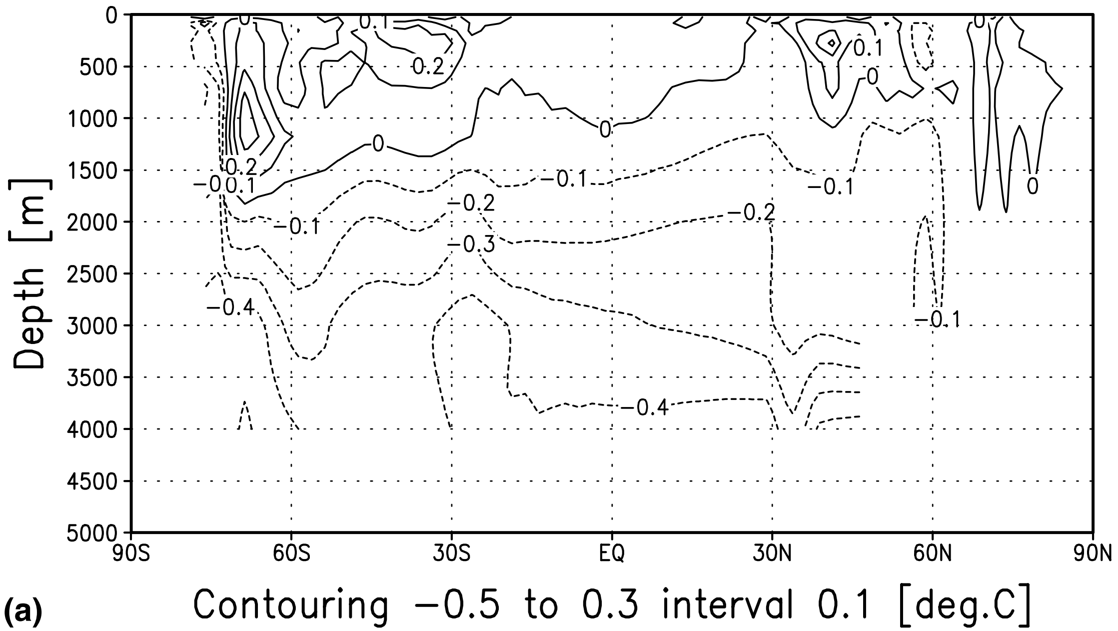
(b) Contouring −0.07 to 0.08 interval 0.01 [psu]

Salinity

Stössel and JTKim (2006)

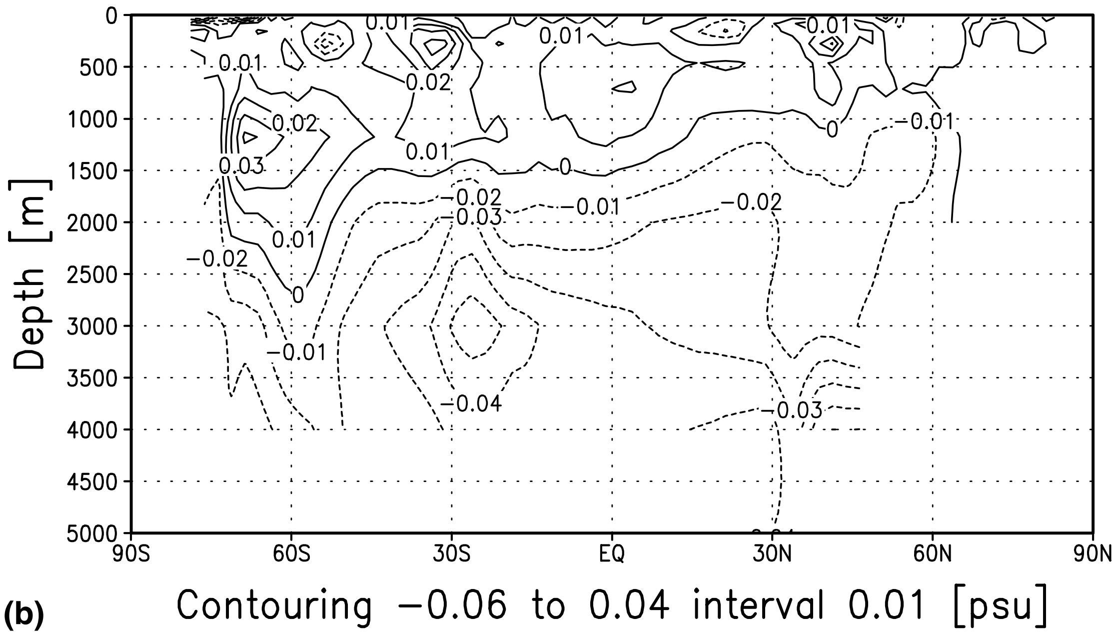
Global higher-resolution ice - coarse-resolution ocean GCM

Difference coarse with coastal winds minus coarse of Atlantic annual, zonal mean



(a)

Potential temperature

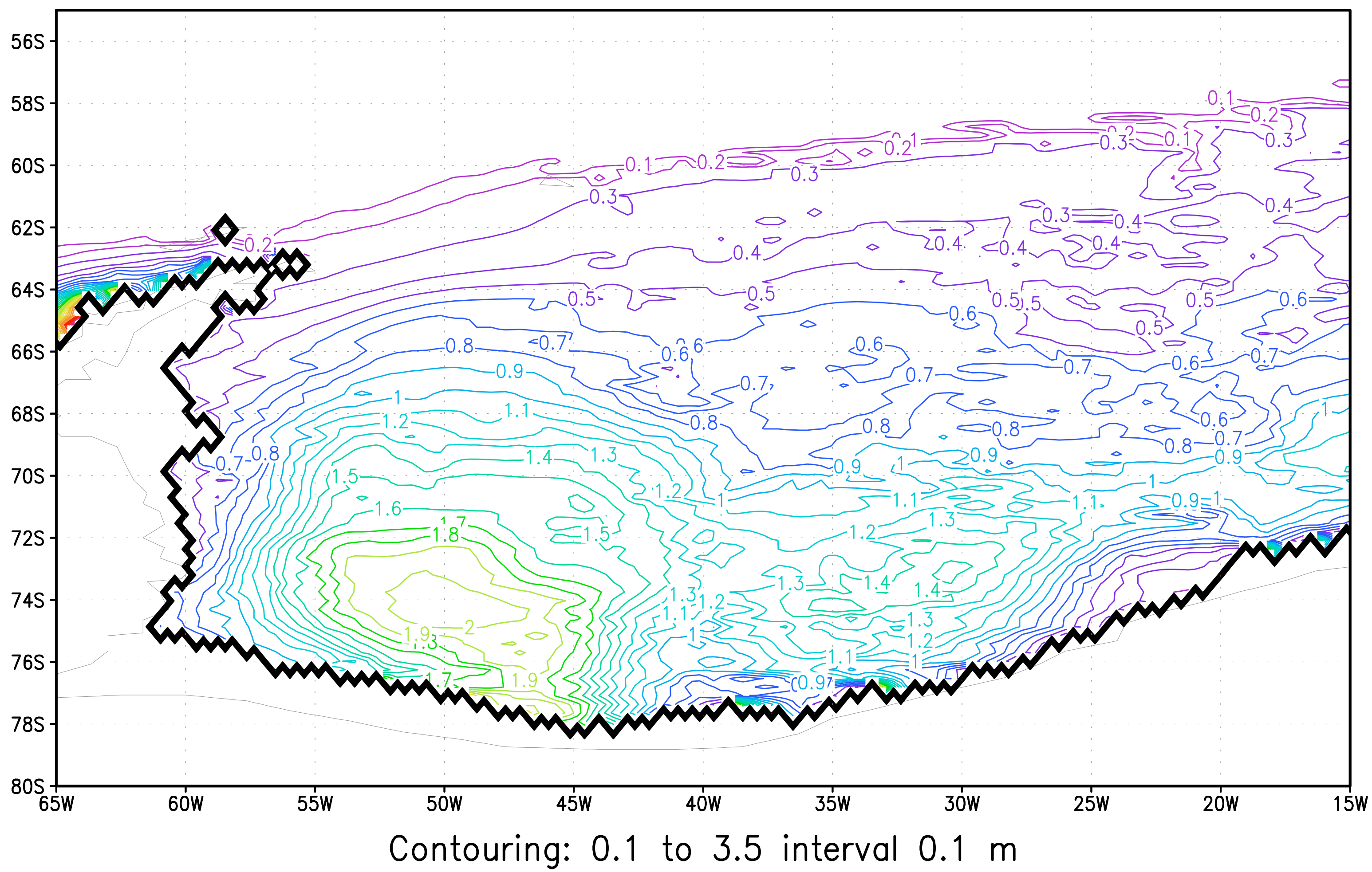


(b)

Salinity

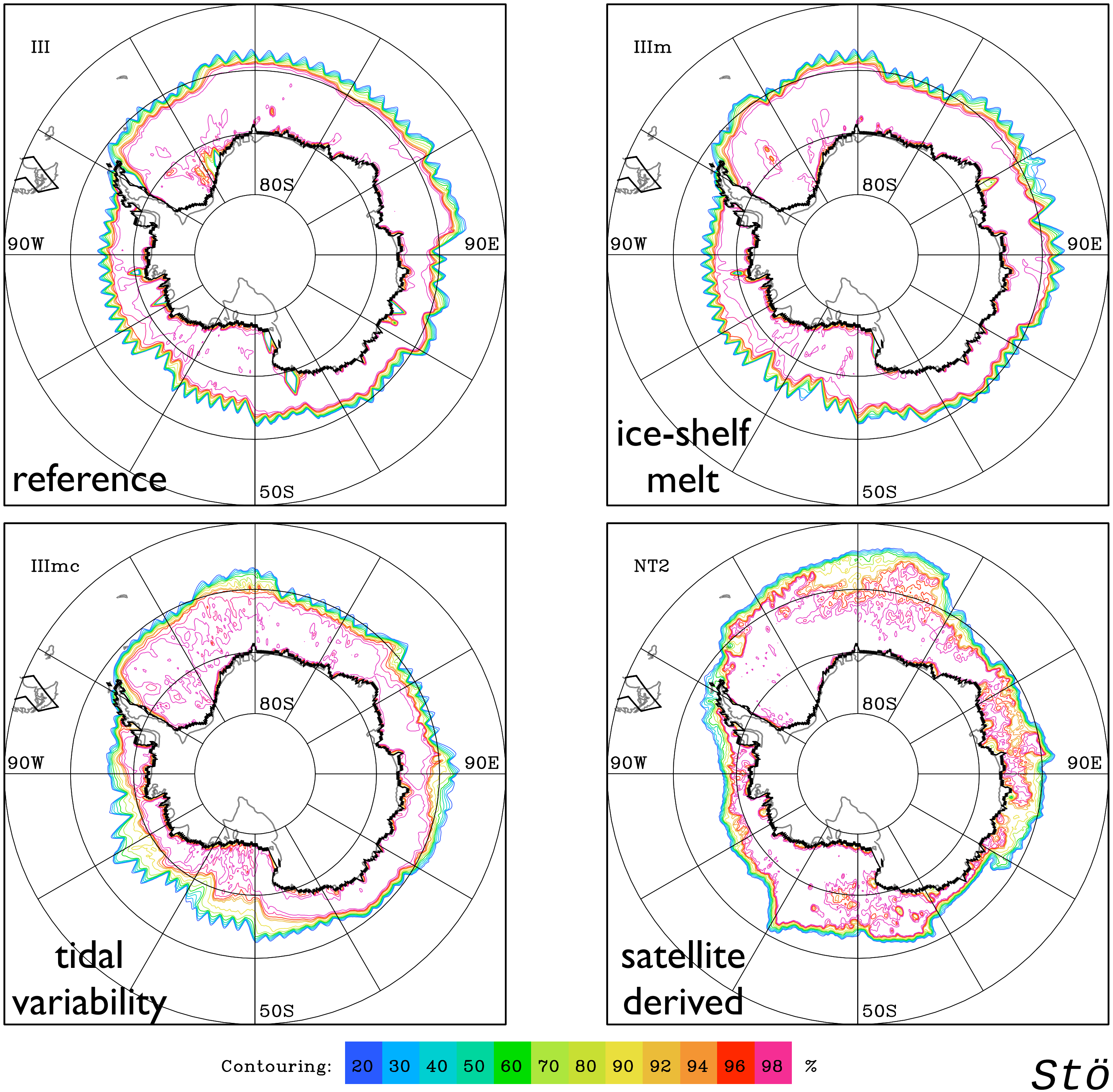
Stössel and JTKim (2006)

Global high-resolution ice - coarse-resolution ocean GCM



September mean model ice thickness

Global high-resolution ice - coarse-resolution ocean GCM

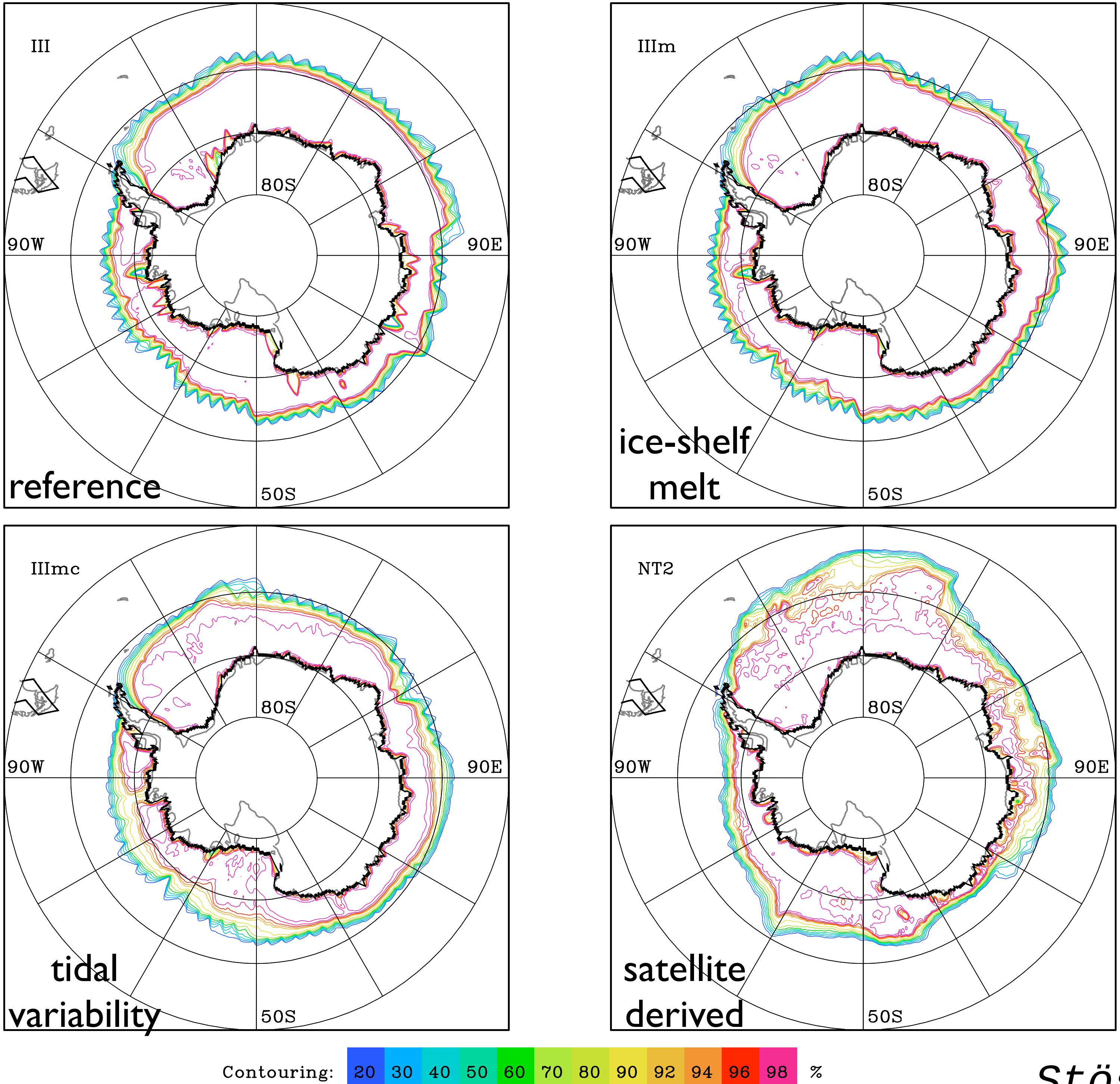


Mid September

ice concentration

Stössel et al.(2007)

Global high-resolution ice - coarse-resolution ocean GCM



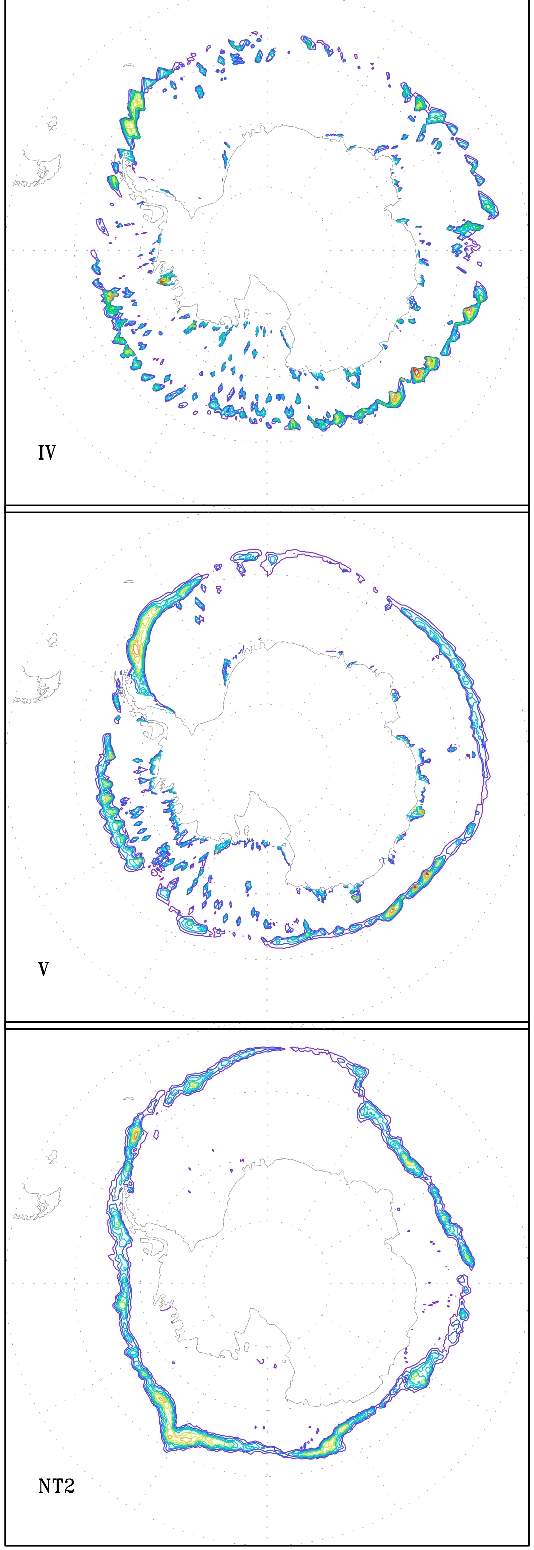
September mean

ice concentration

Stössel et al.(2007)

Global high-resolution ice - coarse-resolution ocean GCM

September variance of ice concentration



Contouring: 0.02 to 0.2 interval 0.02

ice-shelf melt

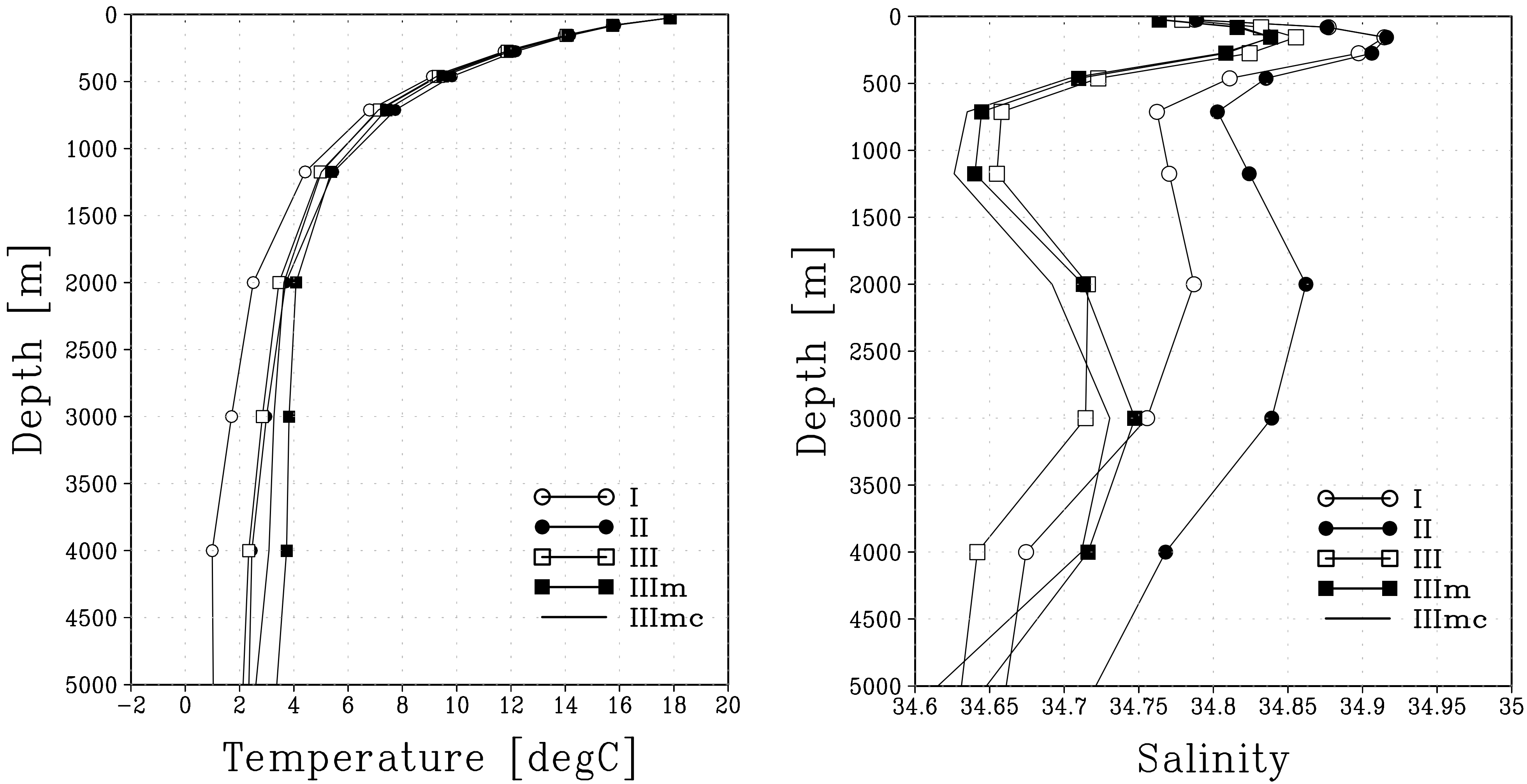
tidal variability

NT2 data

Stössel et al.(2007)

Global high-resolution ice - coarse-resolution ocean GCM

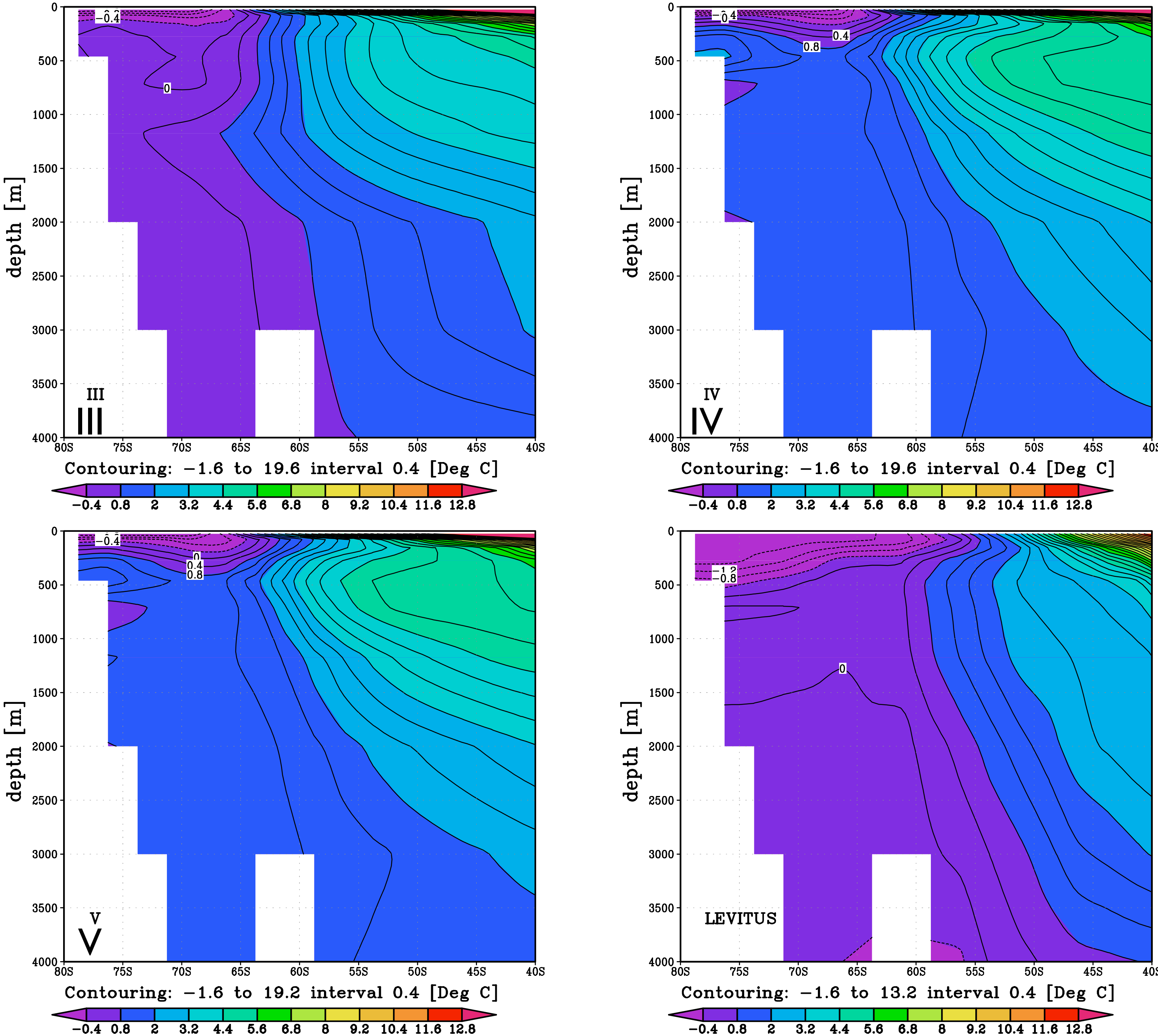
Global mean profiles



I and II: reduced vertical diffusion
IIIm: ice-shelf melt
IIImc: tidal variability

Stössel et al.(2007)

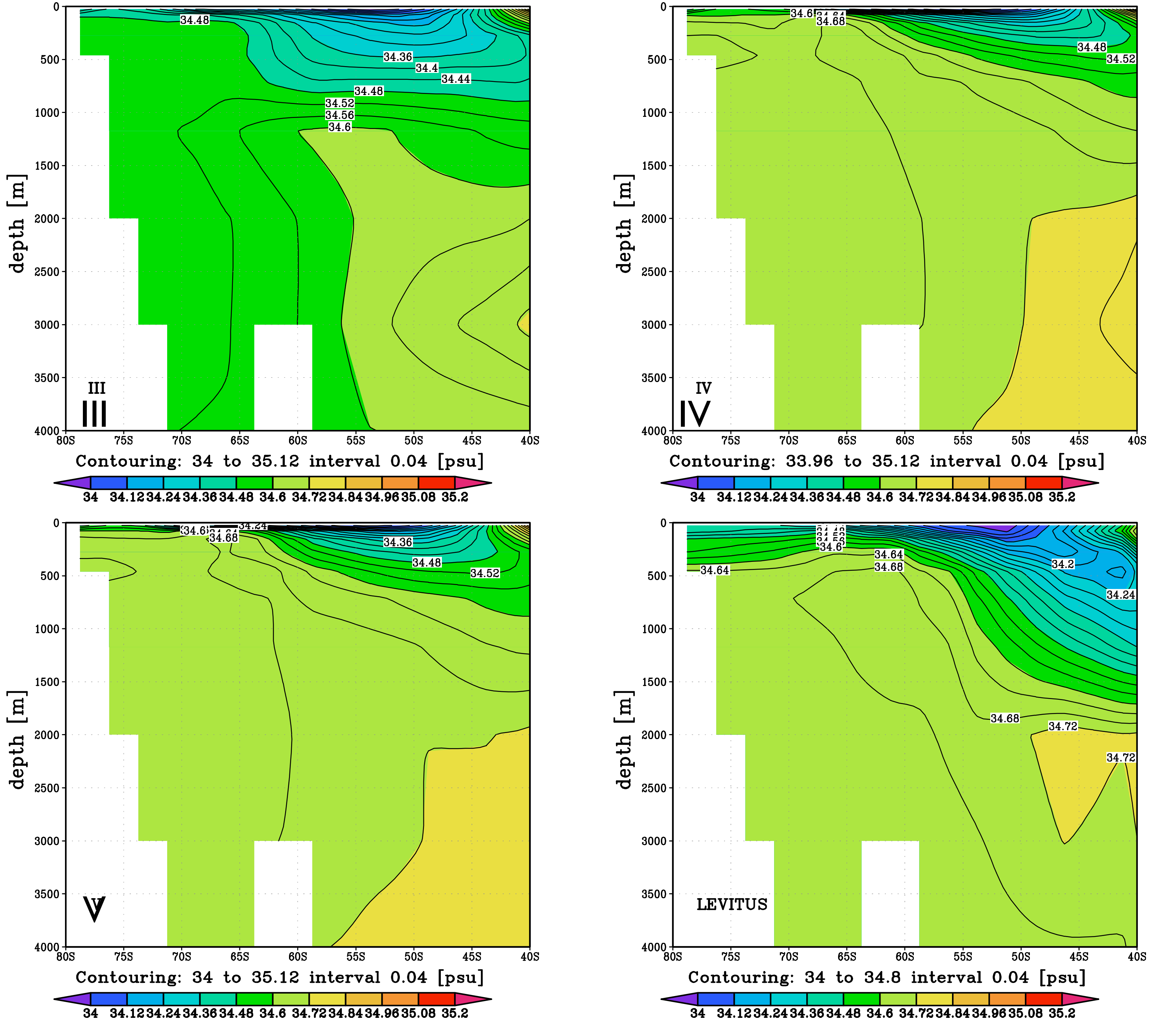
Global high-resolution ice - coarse-resolution ocean GCM



Temperature sections along 40W

Stössel et al.(unpub.)

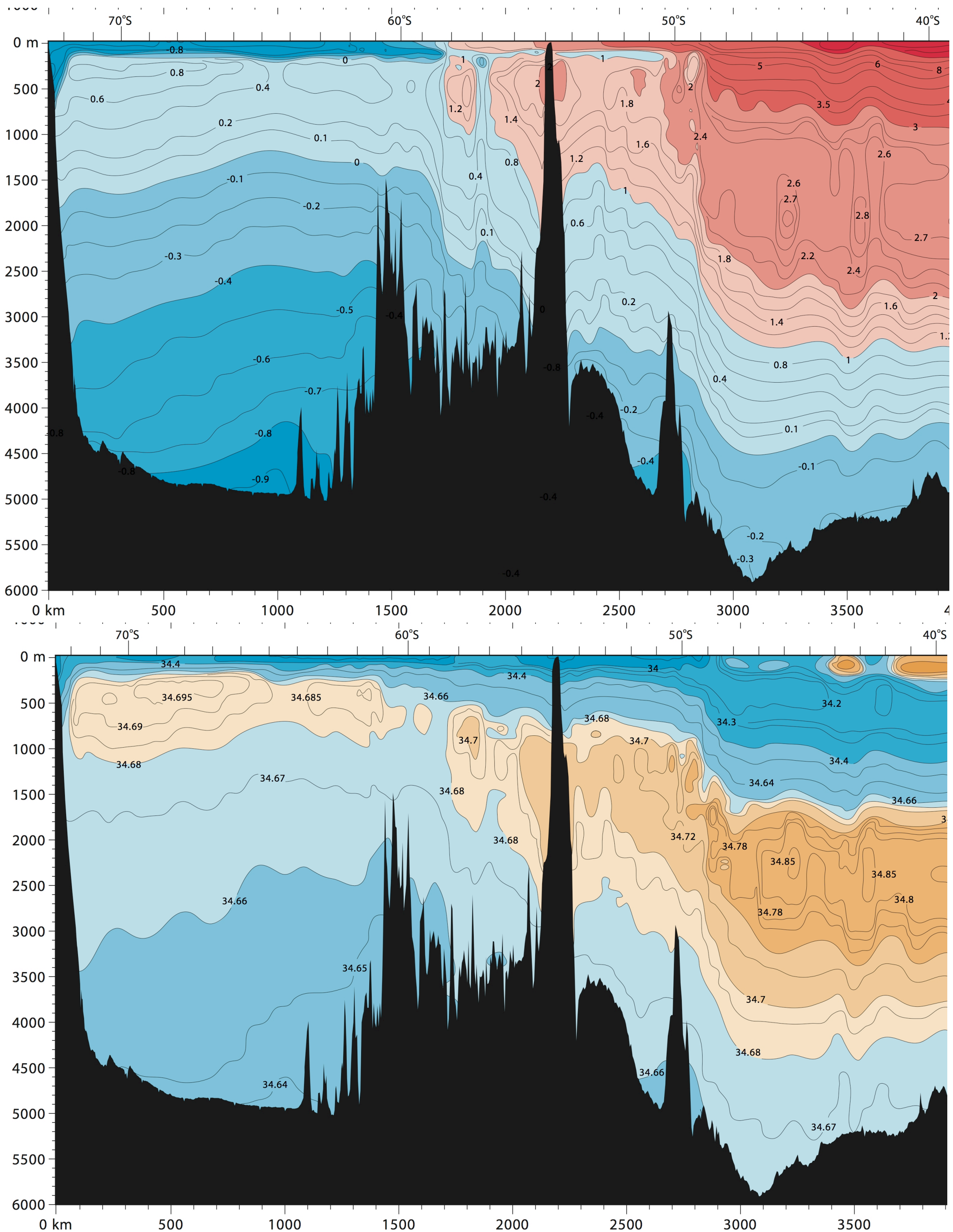
Global high-resolution ice - coarse-resolution ocean GCM



Salinity sections along 40W

Stössel et al.(unpub.)

Observed section along 30W

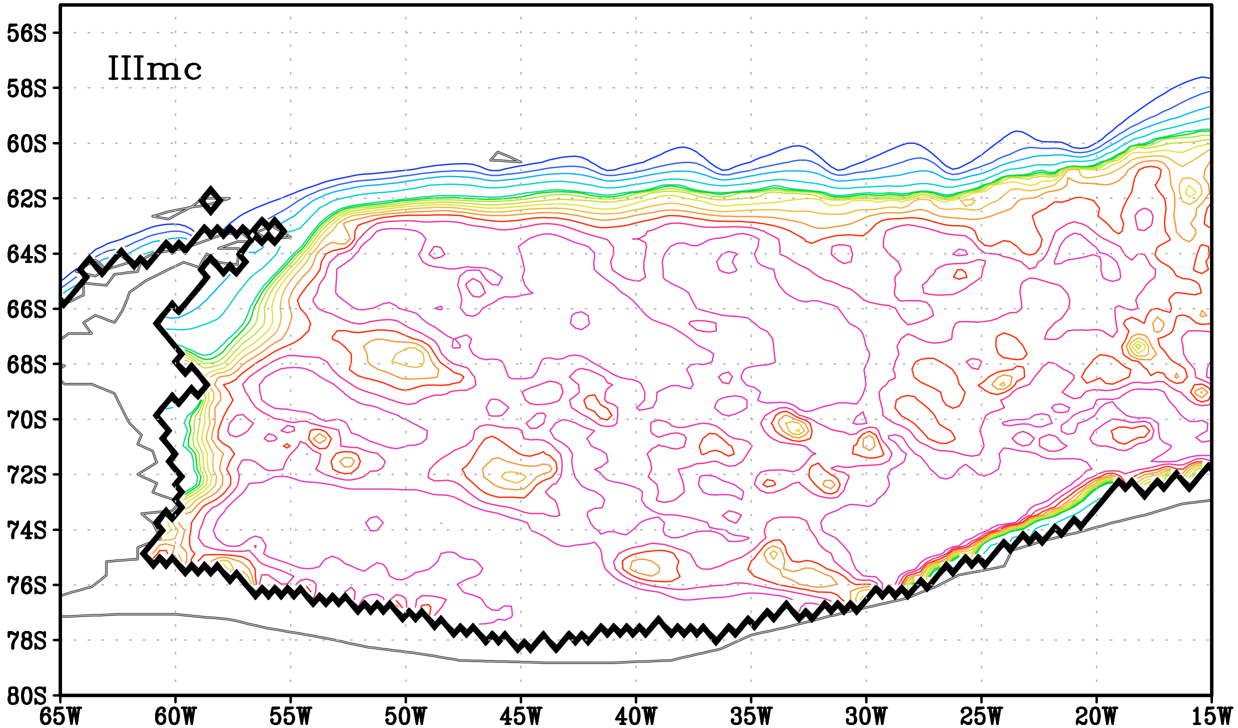


Temperature

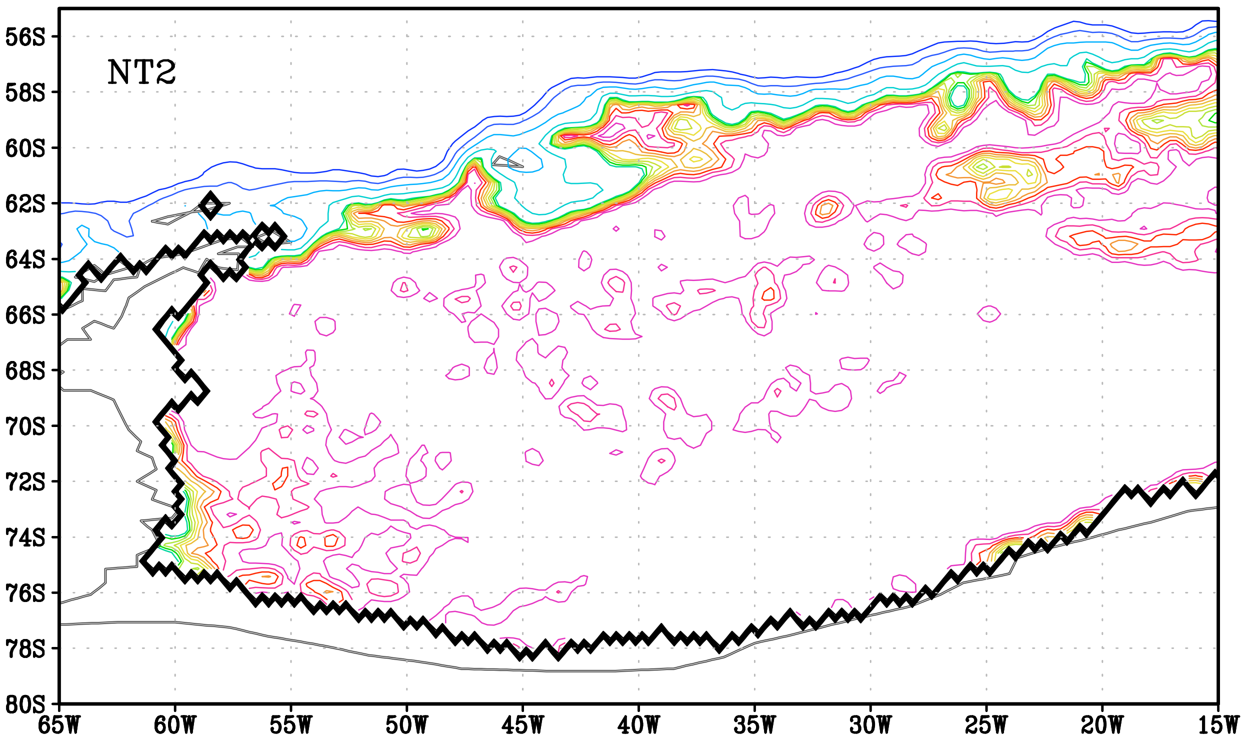
Salinity

Orsi and Whitworth (2005)

Global high-resolution ice - coarse-resolution ocean GCM



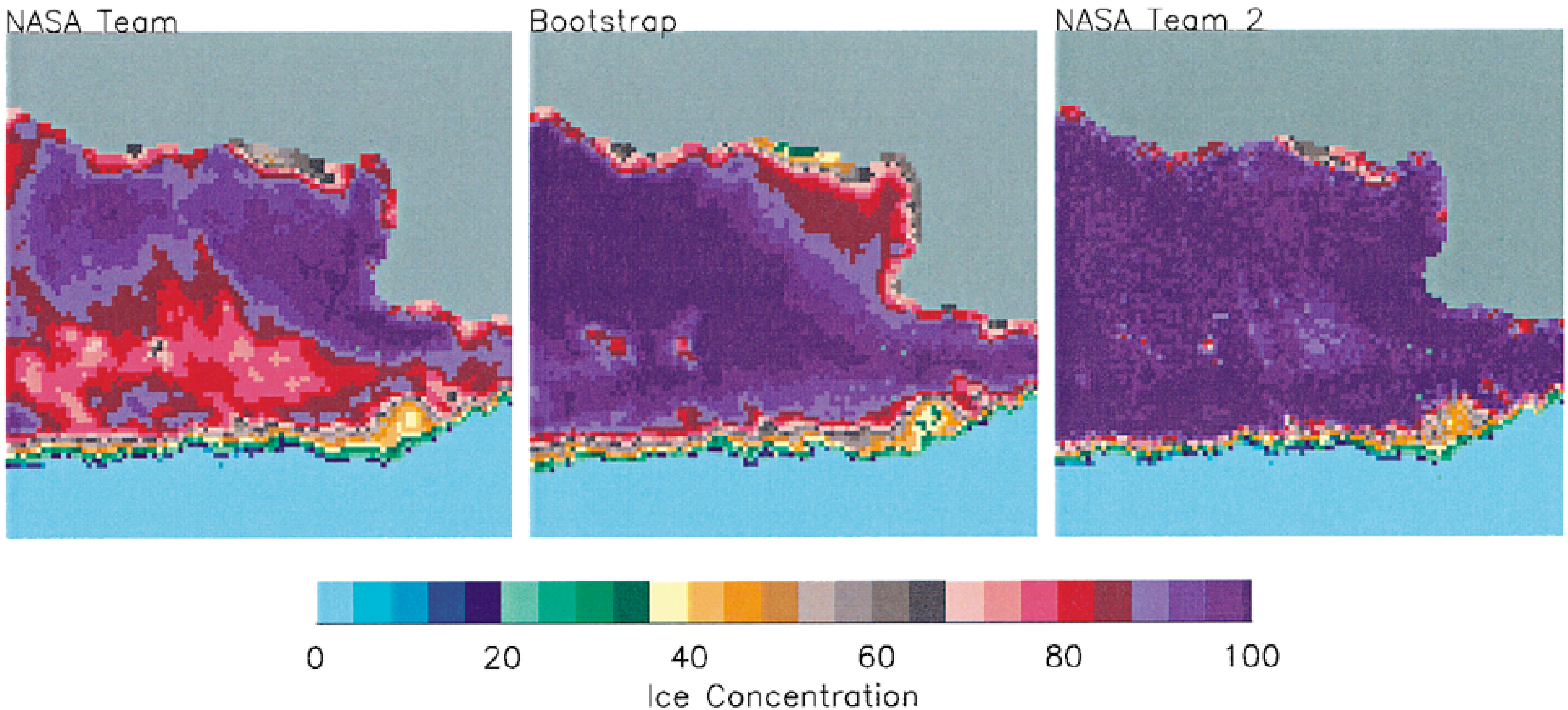
Early September model ice concentration



Early September NT2 ice concentration

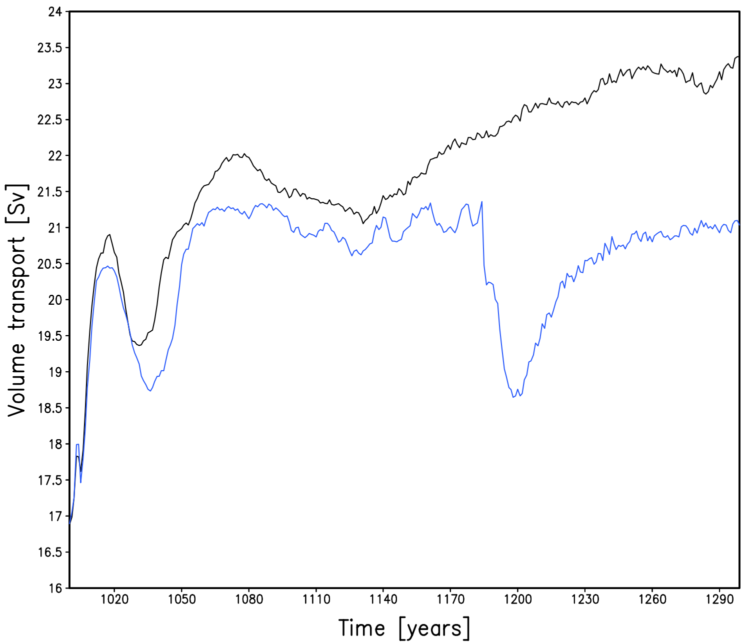
Stössel et al.(2007)

Satellite-derived ice concentration

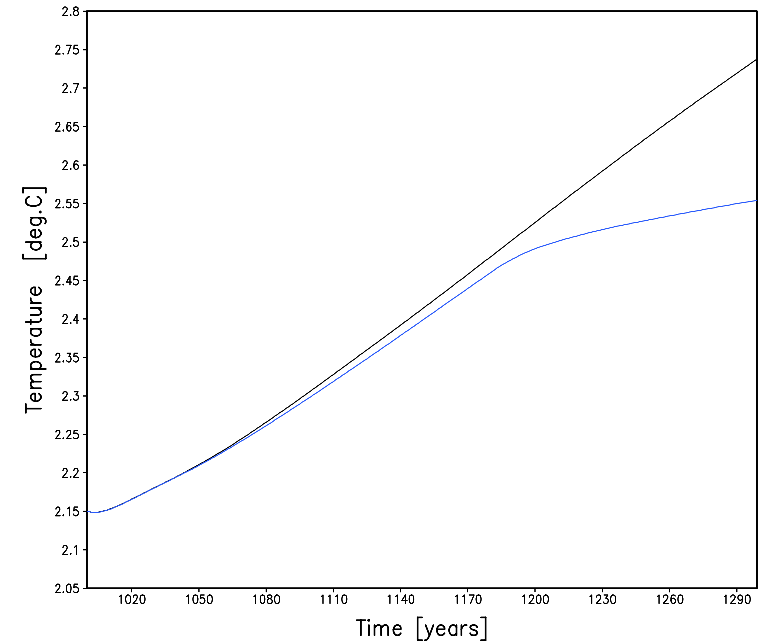


Markus and Cavalieri (2000)

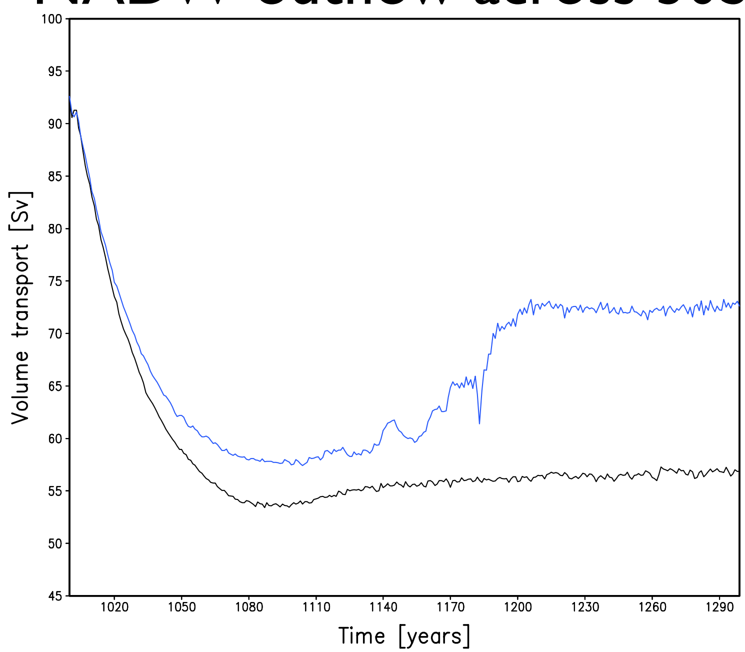
Antarctic coastal ice concentration: NT2 versus BS



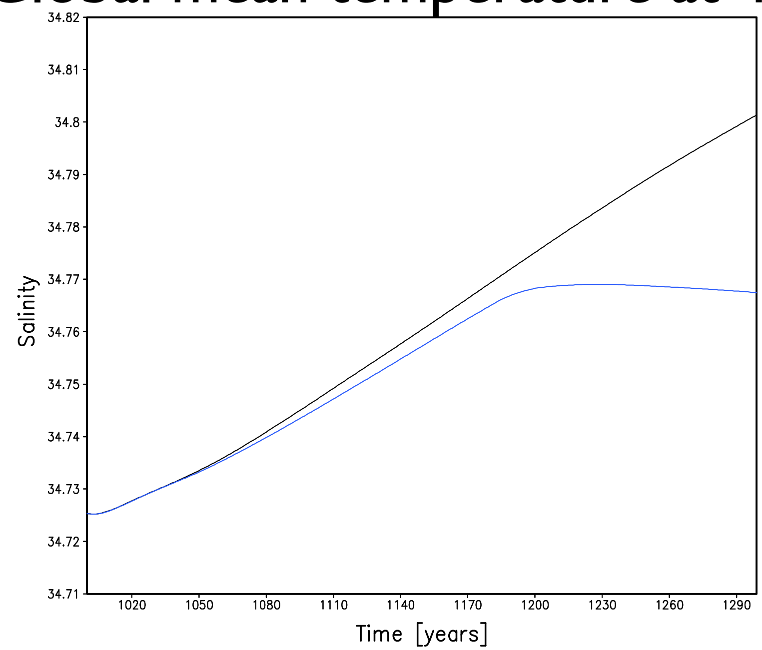
NADW outflow across 30S



Global mean temperature at 4000m



Drake Passage throughflow



Global mean salinity at 4000m

Summary

III: 1) Detailed evaluation of Southern Ocean sea ice in global (atmosphere -) ice - ocean GCMs may lead to improved parameterizations

2) Fine-grid sea-ice pattern highly influenced by ocean upper-layer temperature

3) Number of high-latitude coarse-grid coastal grid points decisive for long-term global deep-ocean properties

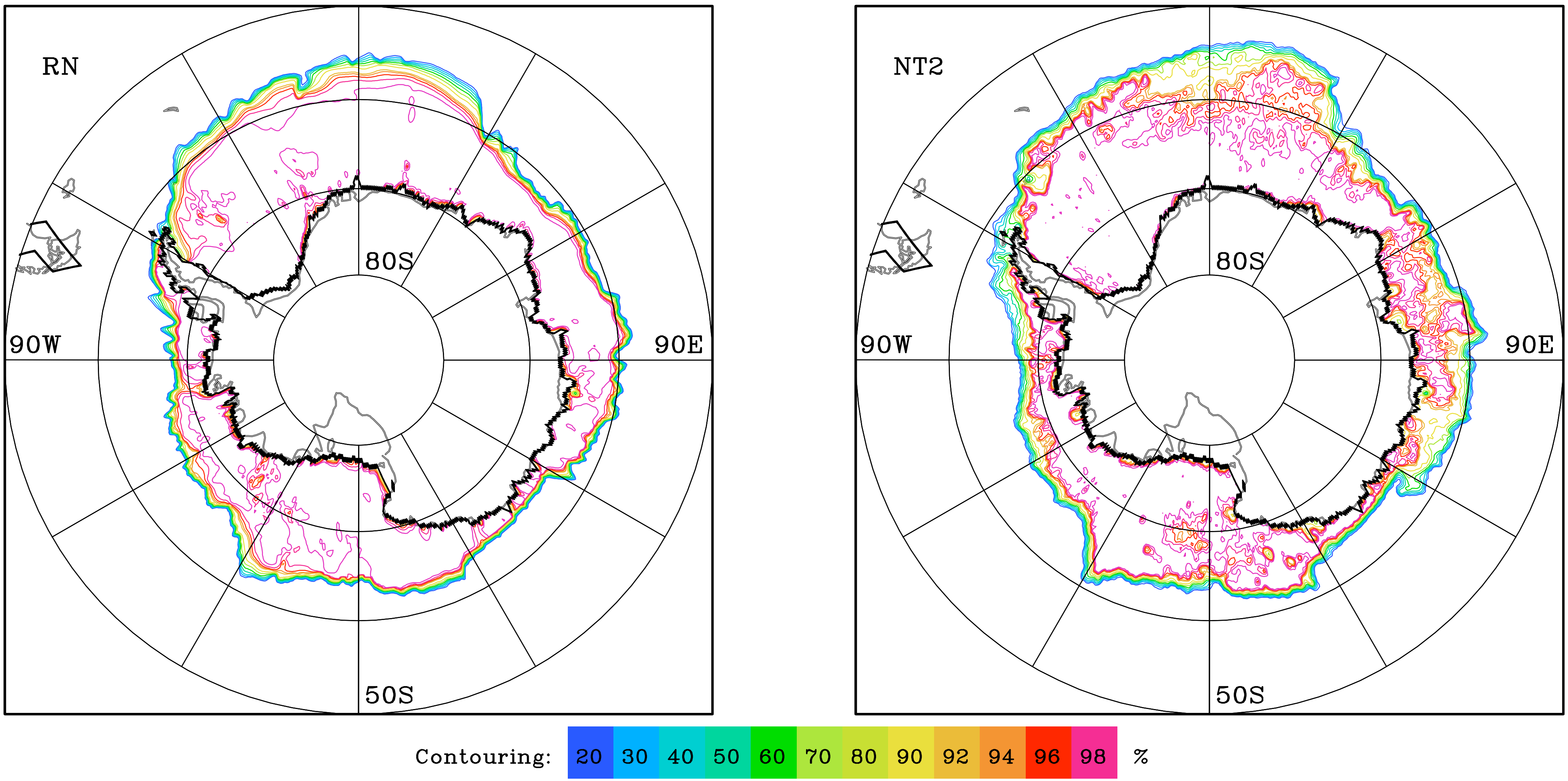
4) Ice shelf melt and tidal variability important for determining lead fraction, polynya width, and ice edge variability

Global high-resolution ice - coarse-resolution ocean GCM

Mid September ice concentration

upper ocean temperature constrained by NT2 ice concentration

NT2 ice concentration

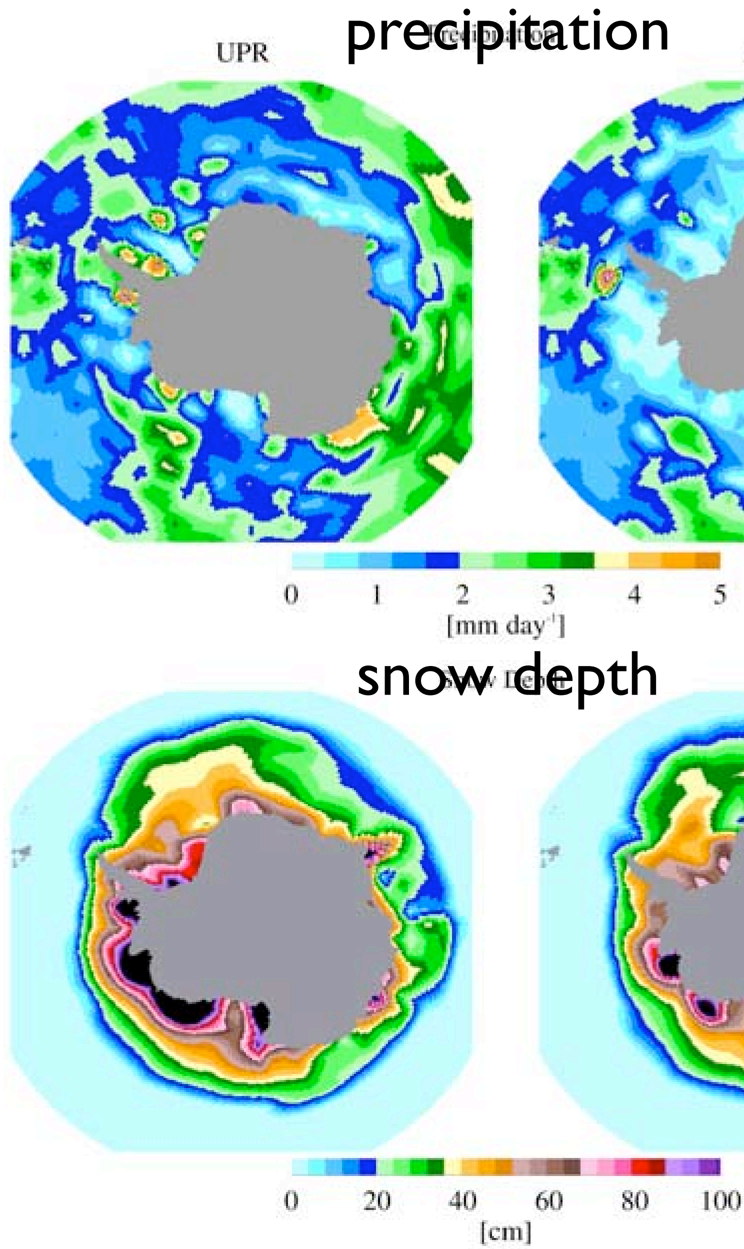


Stössel (in prep.)

Contents

Satellite-derived snow on sea ice

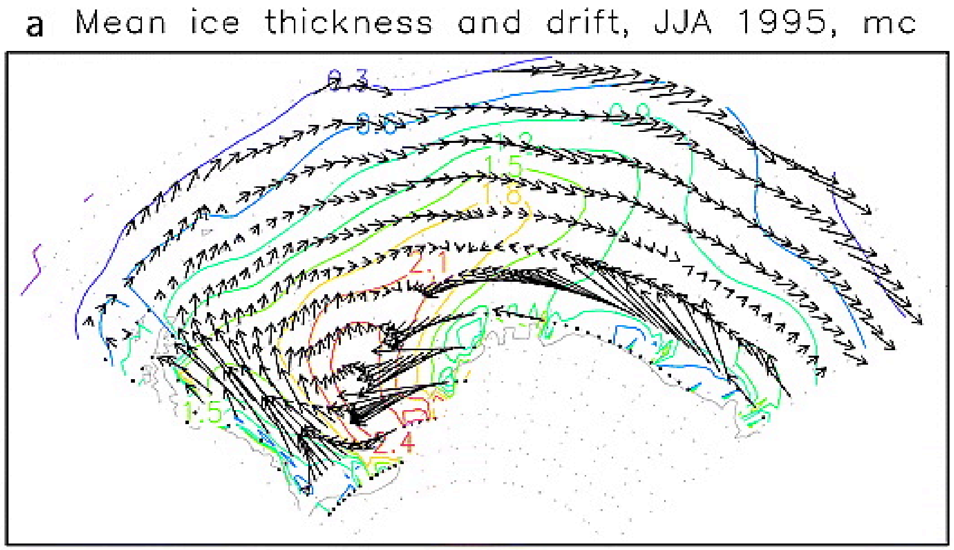
Without SSM/I assimilation



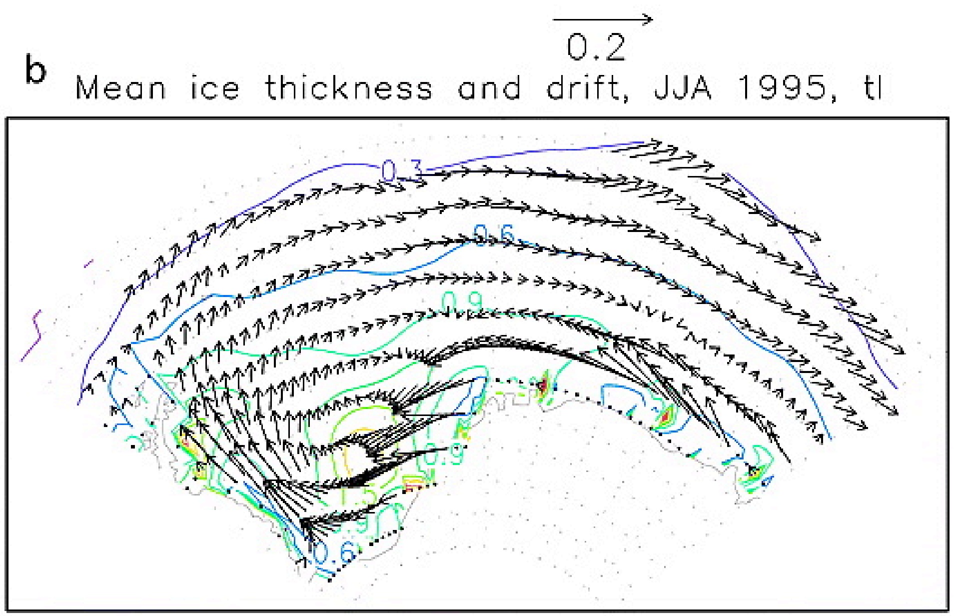
With SSM/I assimilation

Powell, Markus, & Stössel (2005)

Subgrid-scale ice thickness



Multi ice-thickness categories



Two ice-thickness categories

Haapala, Lönnroth, & Stössel (2005)

Atmospheric boundary layer over heterogeneous sea ice

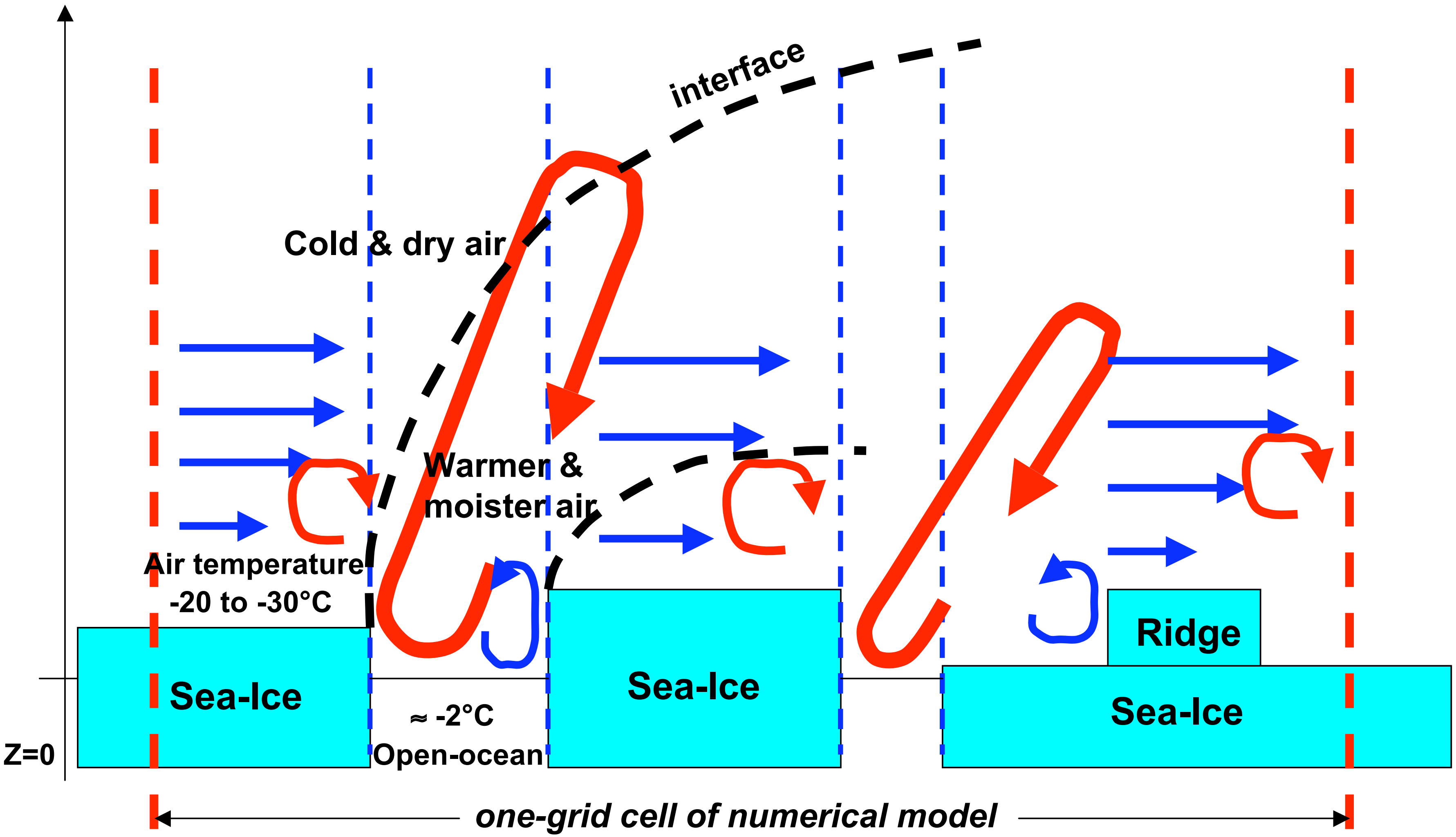


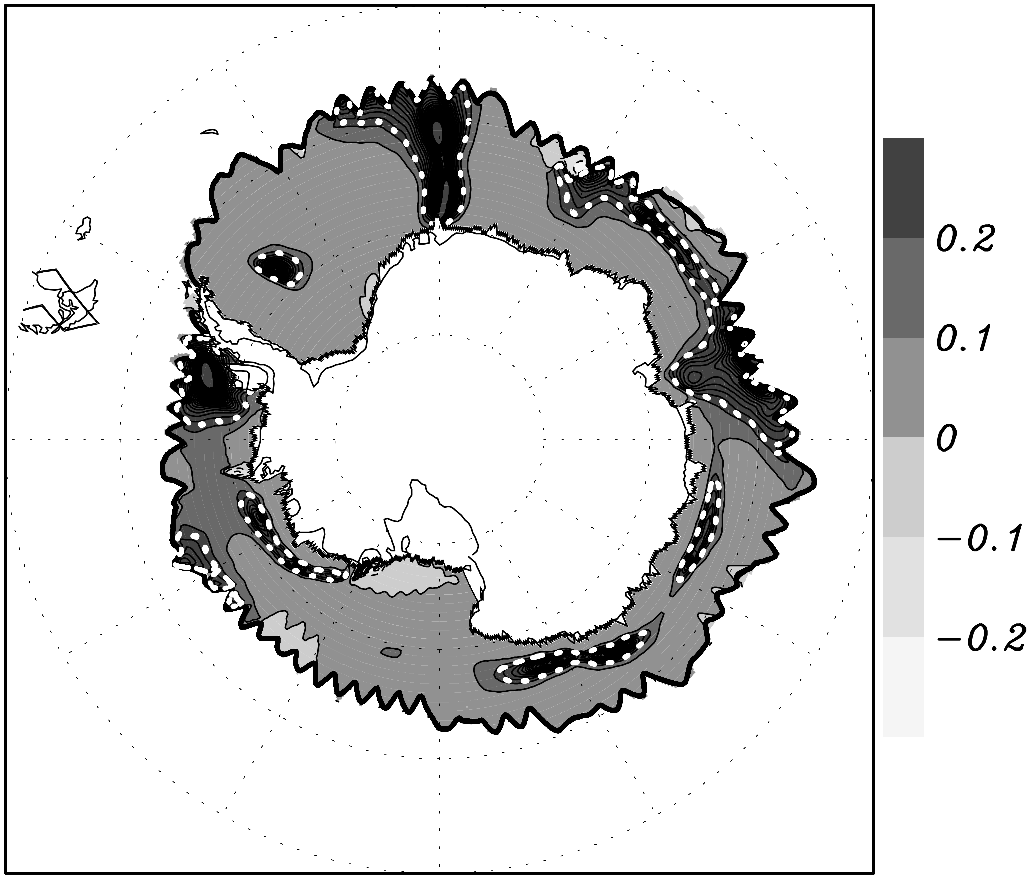
Fig.3 Schematic diagram of heterogeneous condition of sea-ice

(blue arrow : wind & blue circle : form drag & red circle : turbulent eddy)

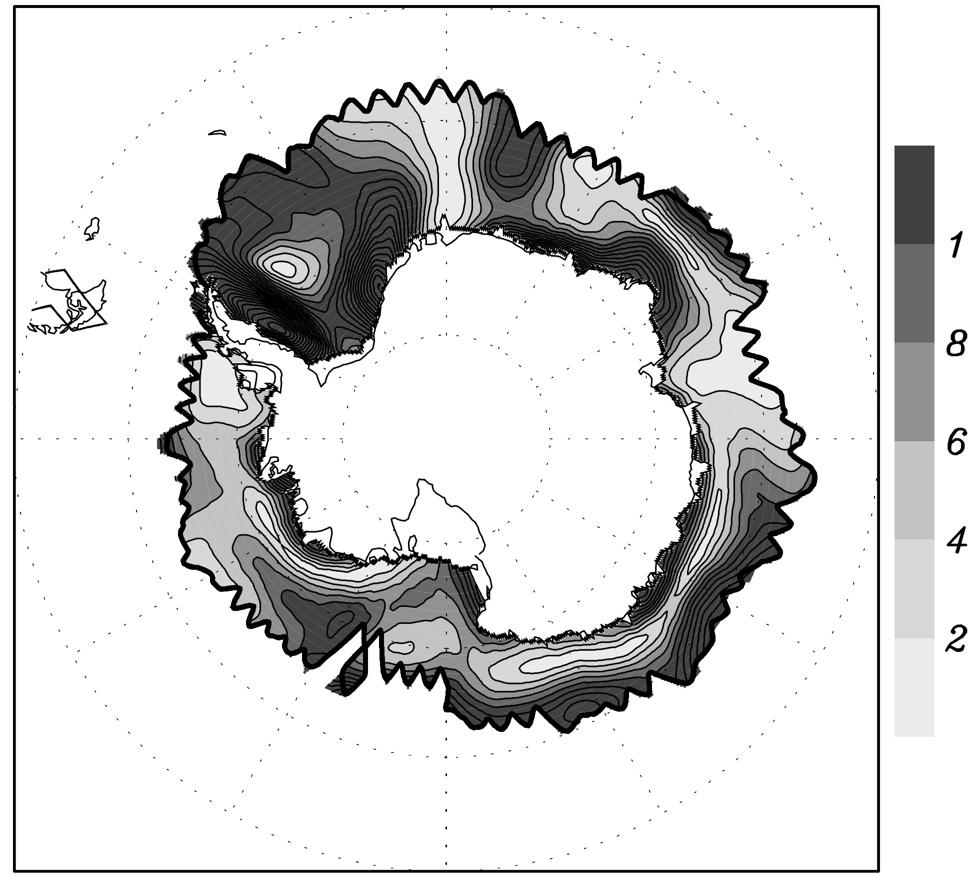
Cheon (2006)

Interactive momentum flux forcing over sea ice

Mid-winter snapshot



Local Richardson Number

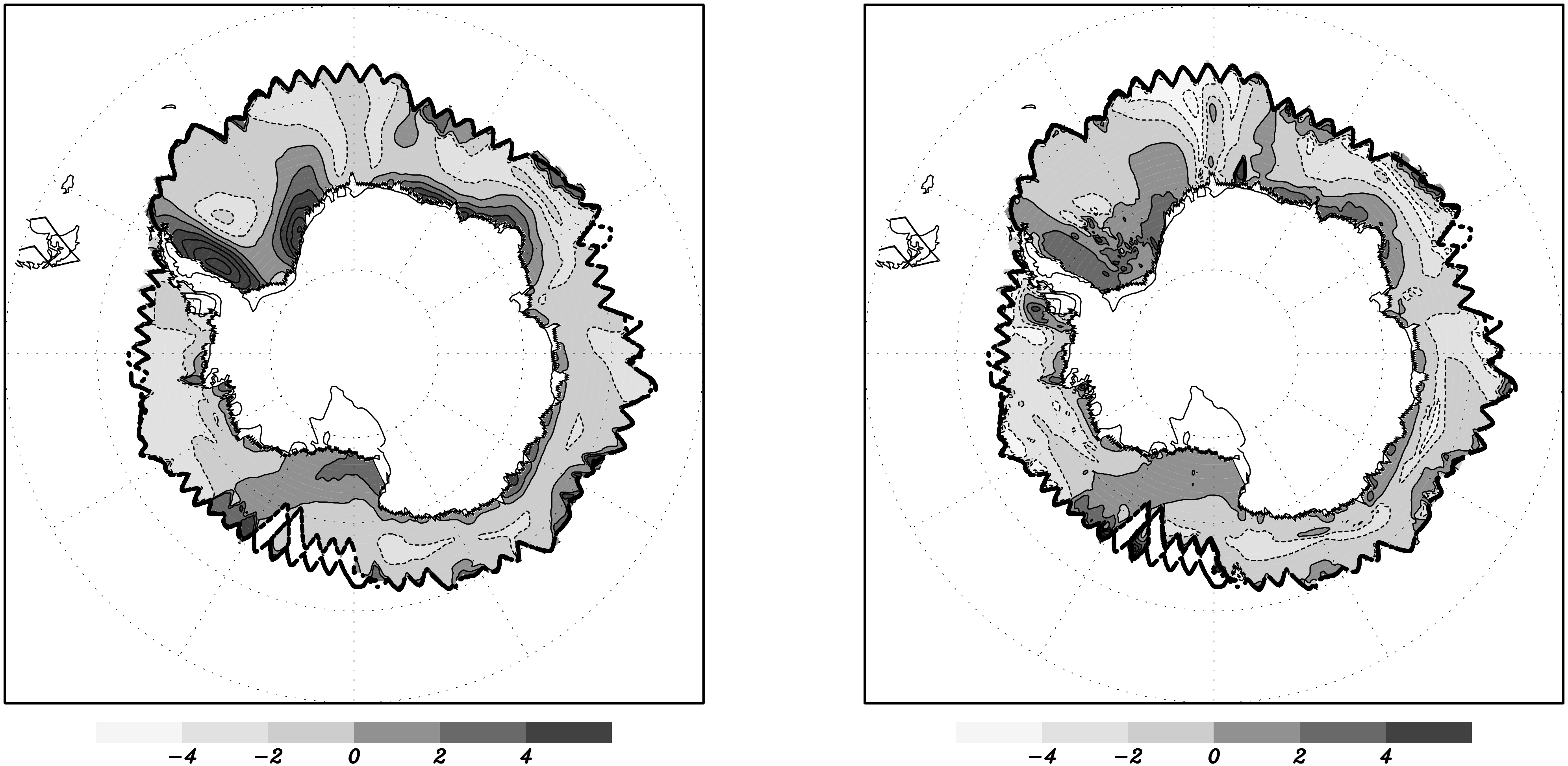


Wind stress [10^{-2}Pa]

Stössel, Cheon, and Vihma (subm.)

Interactive momentum flux forcing over sea ice

Mid-winter snapshot: difference local feedback minus no feedback



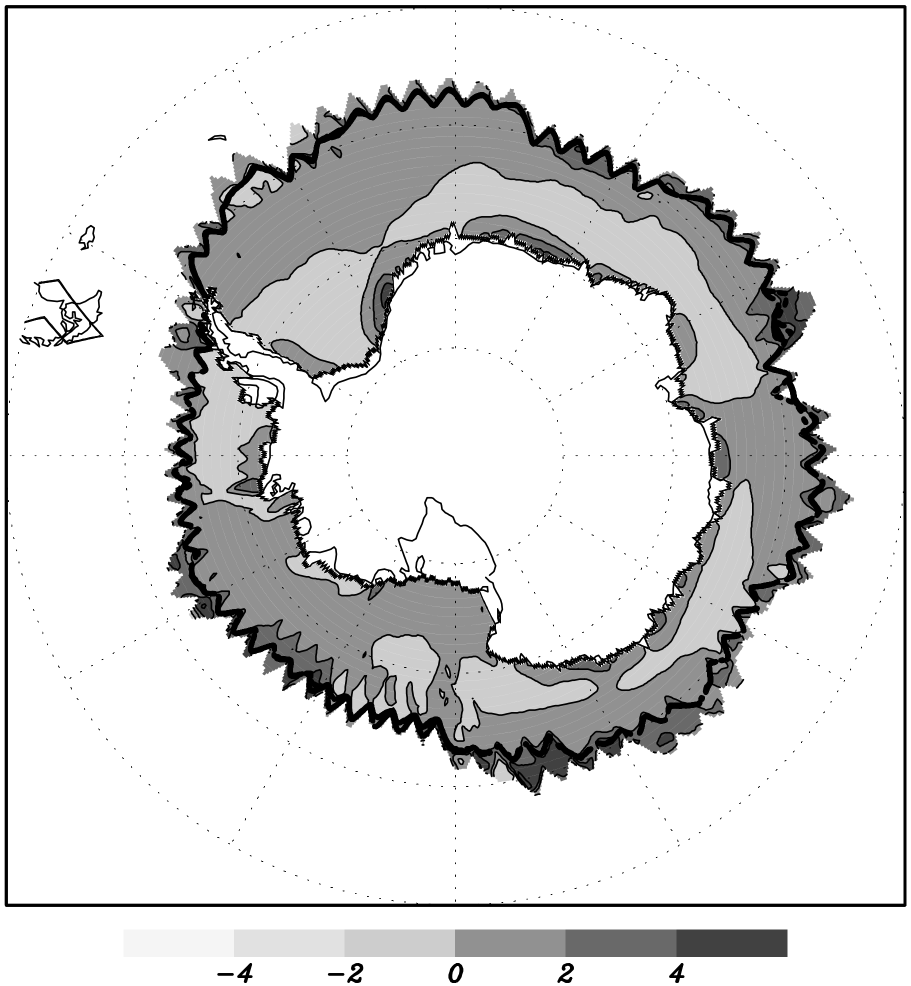
Wind stress [10^{-2}Pa]

Ice velocity [cm/s]

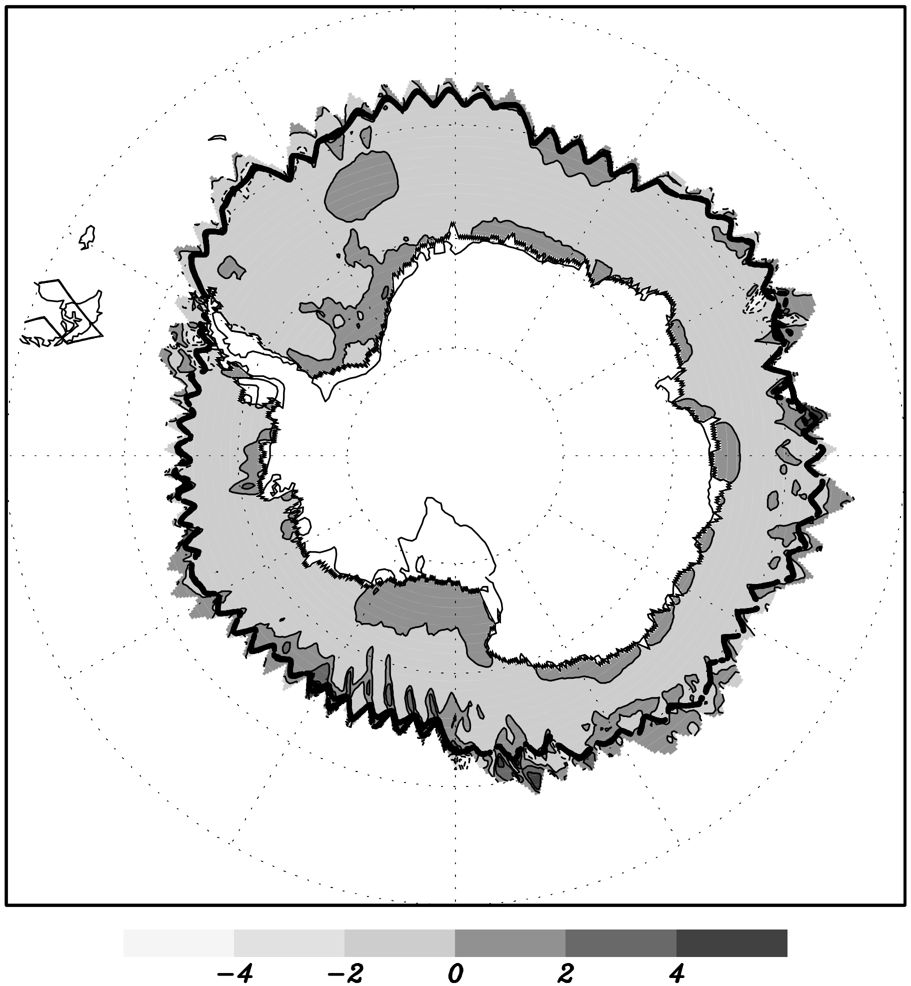
Stössel, Cheon, and Vihma (subm.)

Interactive momentum flux forcing over sea ice

Winter mean: difference local feedback minus no feedback



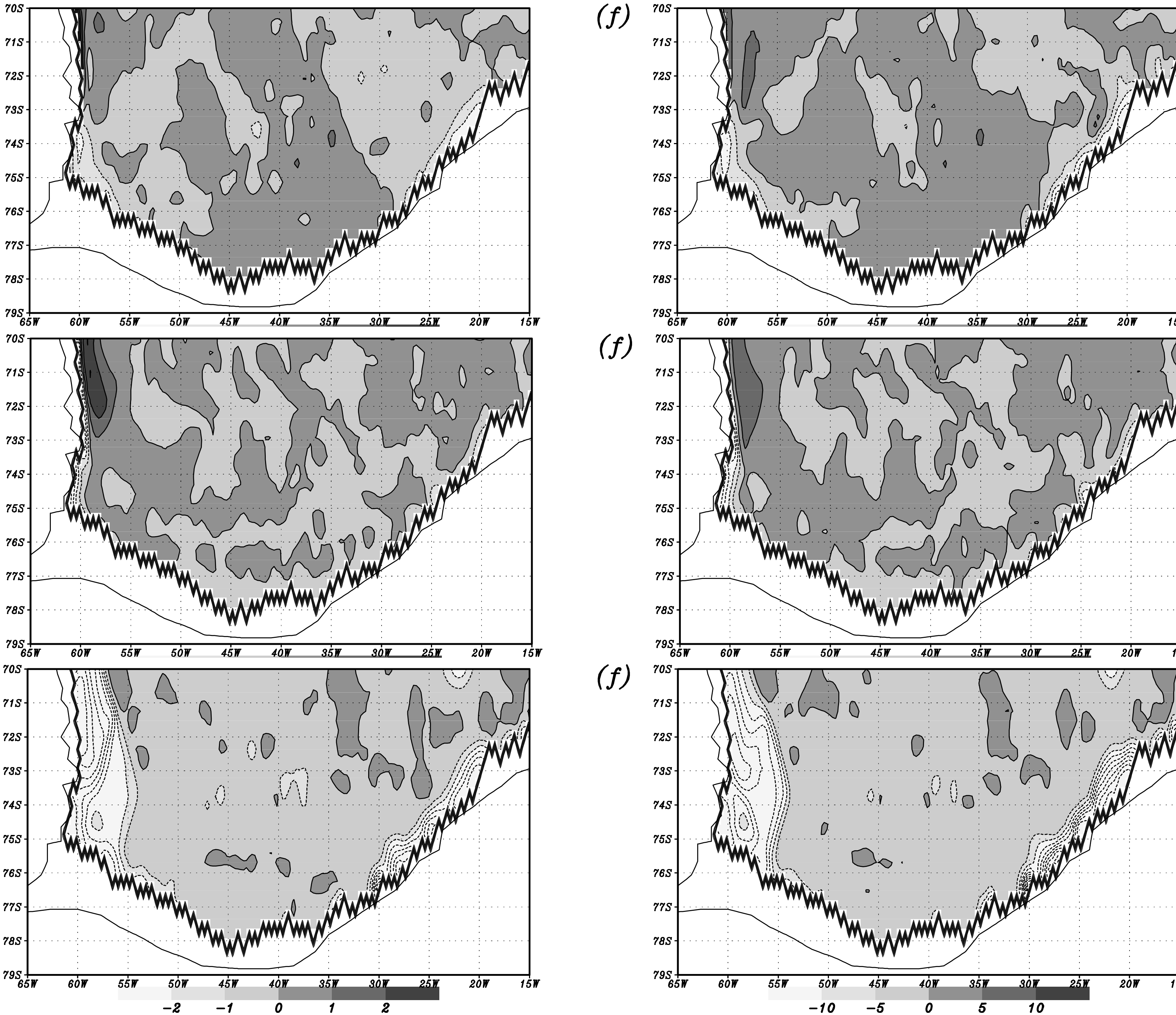
Wind stress [10^{-2}Pa]



Ice velocity [cm/s]

Stössel, Cheon, and Vihma (subm.)

Winter mean difference:



Local minus no feedback

Large-scale minus local feedback

Higher form drag minus large-scale feedback

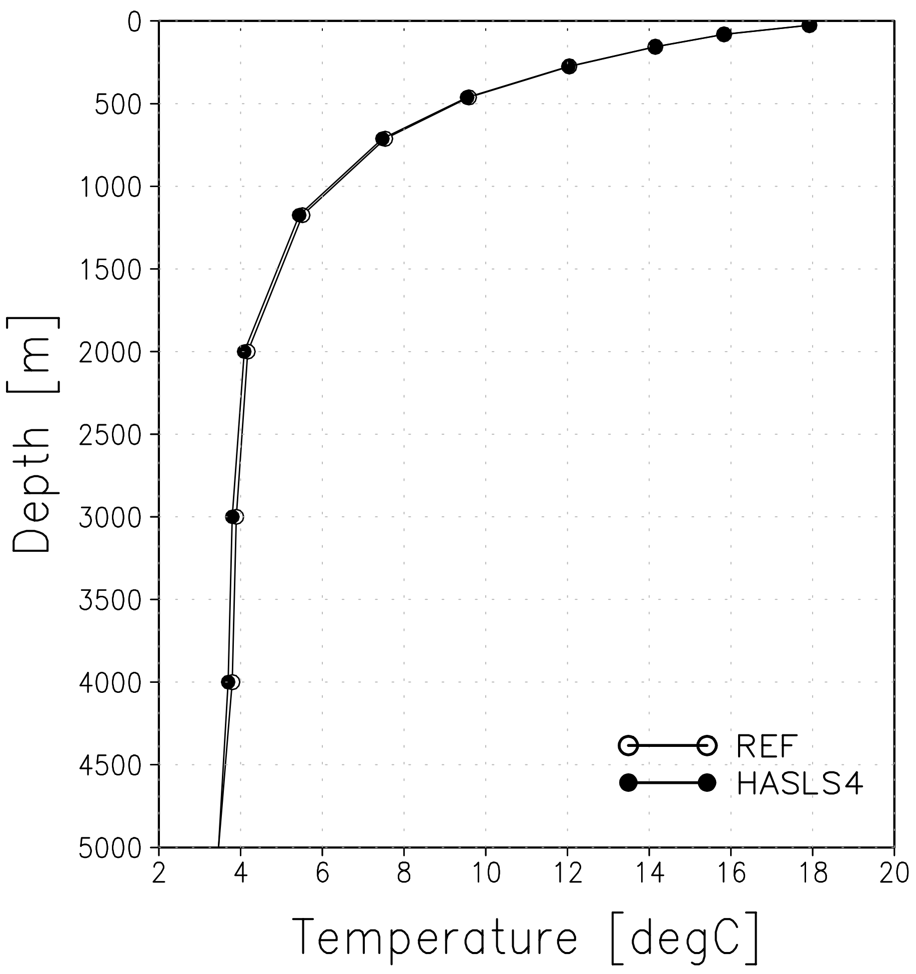
Wind stress [10^{-2}Pa]

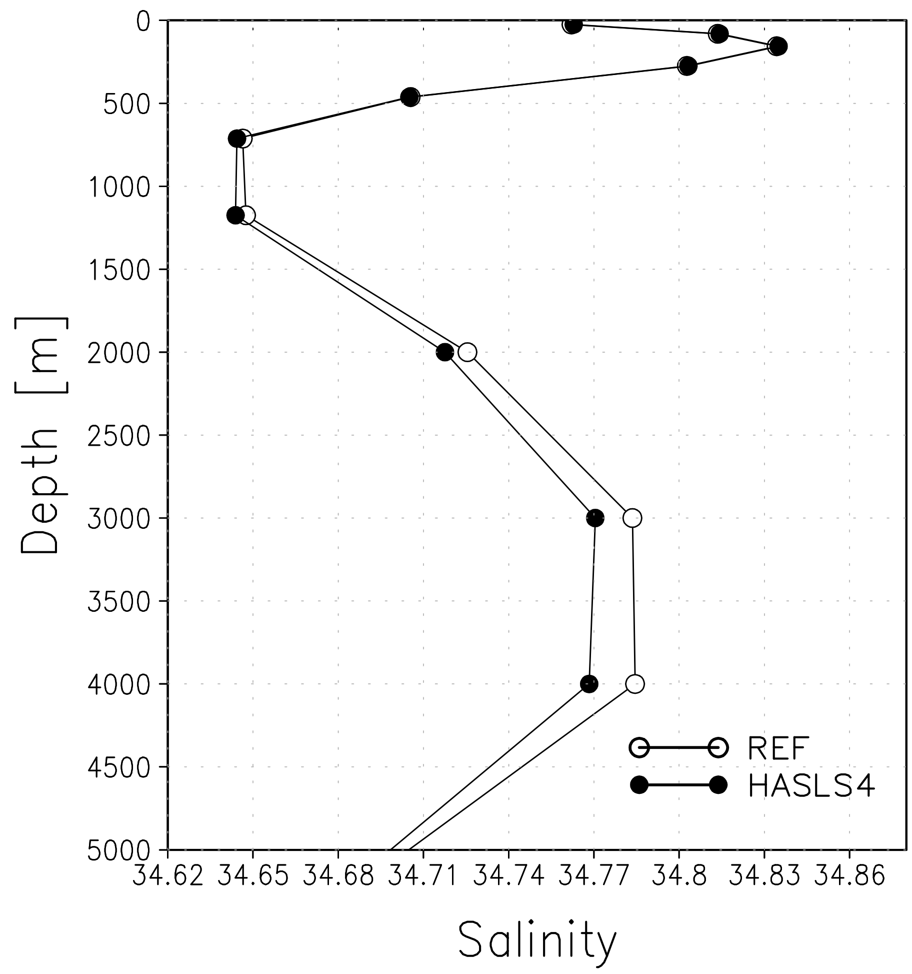
Ice velocity [cm/s]

Stössel, Cheon, and Vihma (subm.)

Interactive momentum flux forcing over sea ice

Long-term impact on deep ocean





Stössel, Cheon, and Vihma (subm.)

Summary

IV: Other issues of concern: snow on sea ice, subgrid-scale multi ice-thickness categories, atmospheric boundary layer over heterogeneous sea ice

Recommendations for ocean GCM improvements

- Parameterization of convection
- Parameterization of downslope bottom plumes
- Slopes of model bathymetry
- Mixing due to tidal energy dissipation
- Coupling to the atmosphere
- etc., etc.

Recommendations for observational programs

- Continued availability of satellite-derived ice concentration
- Monitoring of oceanic meridional sections across the Southern Ocean
- Long-term monitoring of deep-ocean variables along deep-western boundary

Finally

- Global THC simulations will depend decisively on the quality of the atmospheric variables over the Southern Ocean, in particular winds and precipitation

Effect of precipitation in sea-ice - ocean GCM

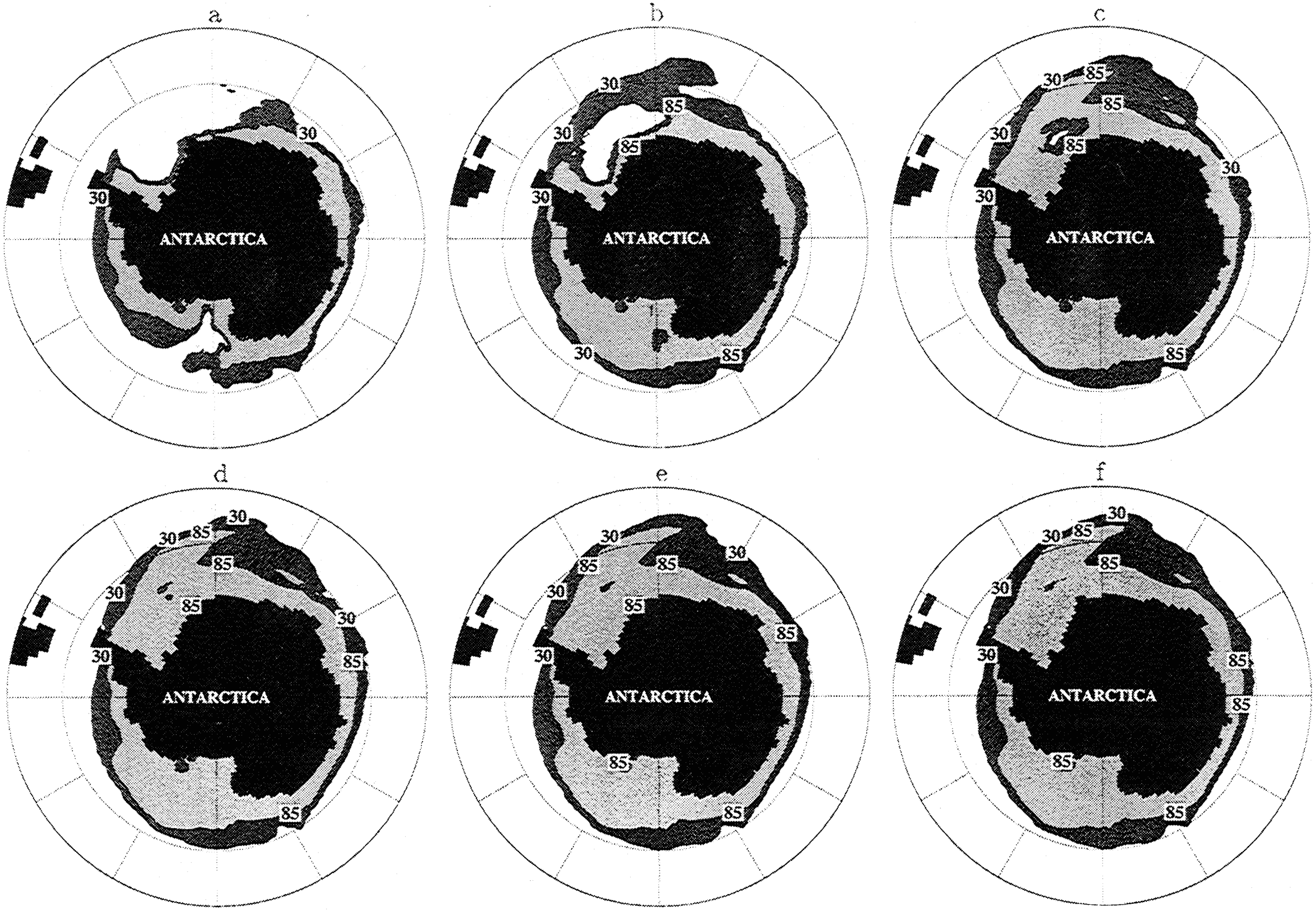


Figure 9. Mean September sea ice concentration (percent) averaged over the final 3 years for (a) and (d) CSIRO9, (b) and (e) GASP, and (c) and (f) ECMWF $P-E$ climatologies. Figures 9a–9c show the cases where only the relevant $P-E$ climatology is used as SFWF, and Figures 9d–9f show the cases where SFWF consists of the $P-E$ plus 10 cm yr^{-1} of glacial meltwater in the region south of 60°S.

Marsland and Wolff (2001)