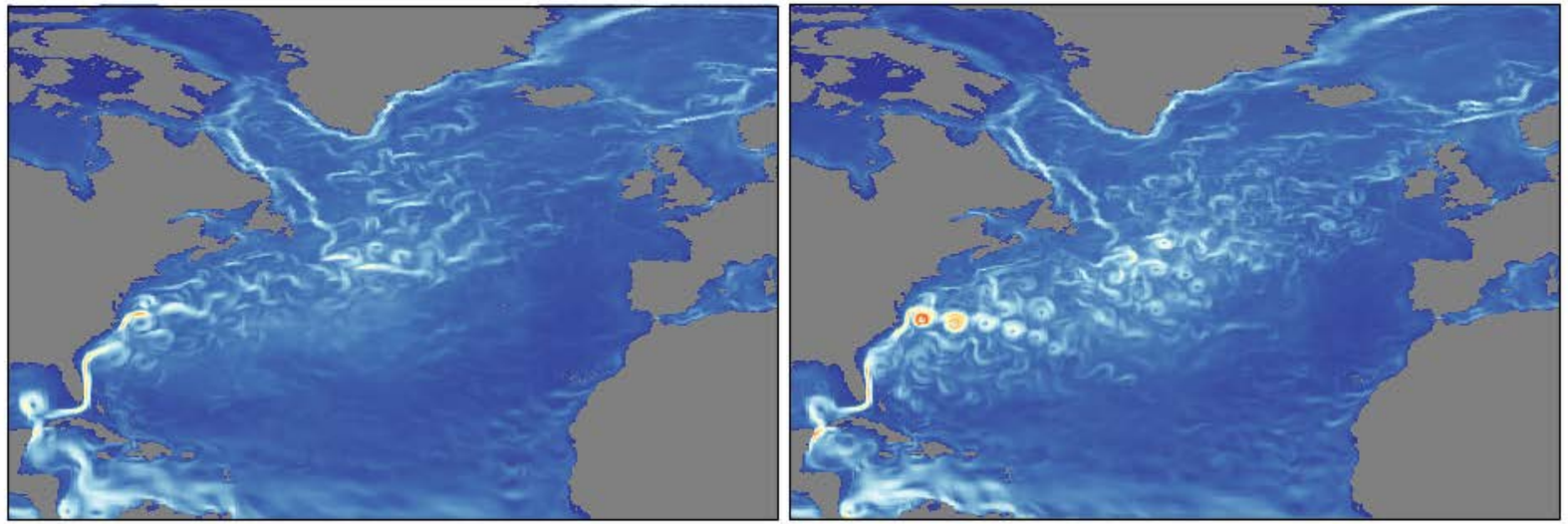
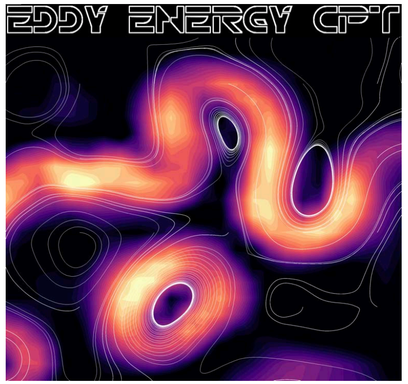
Backscatter in 1/4° CESM3-MOM6



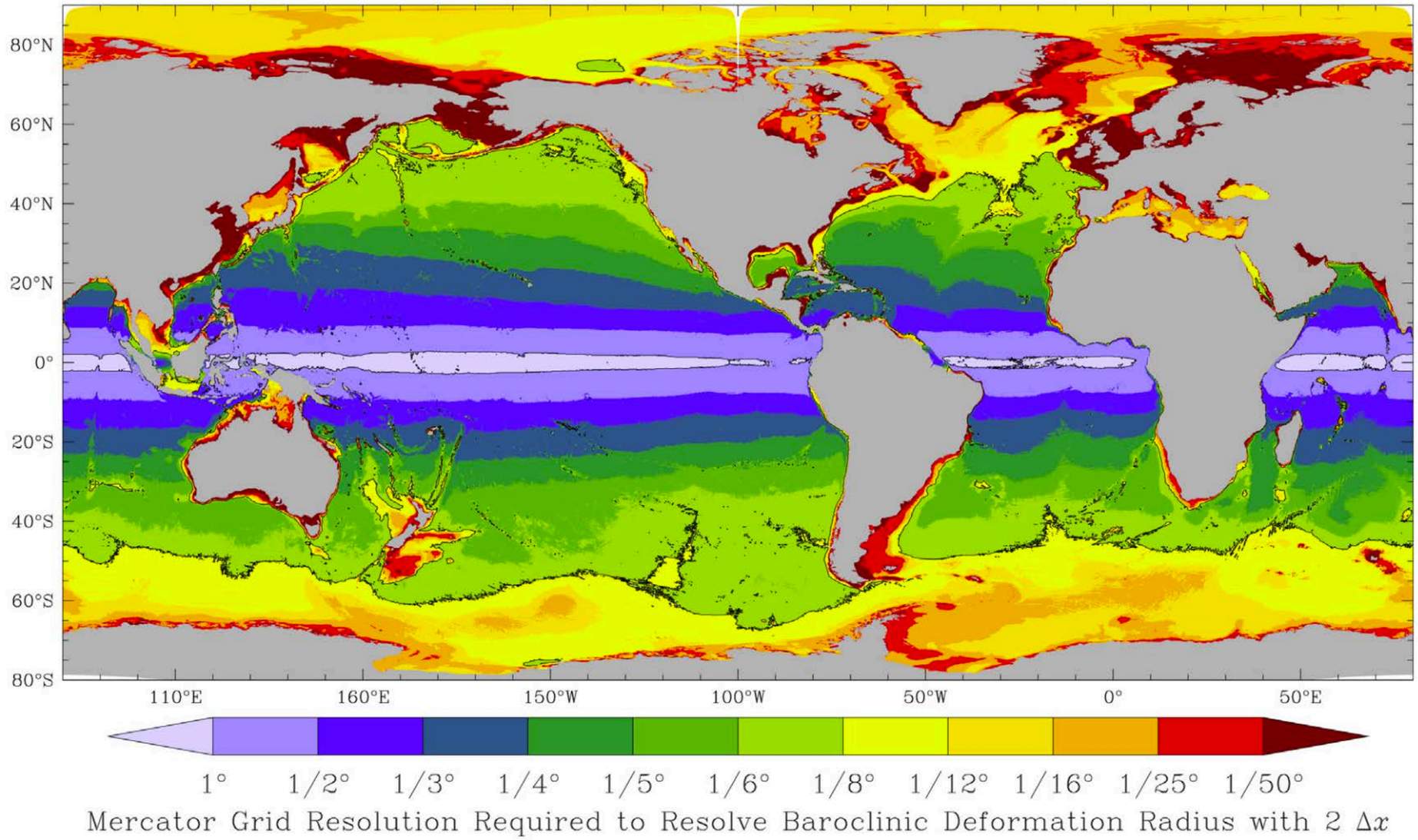


Houssam Yassin

Contributions from:
Gokhan Danabasoglu, Gustavo Marques, Ian Grooms and the *Eddy Energy Climate Process Team*

11 September 2024

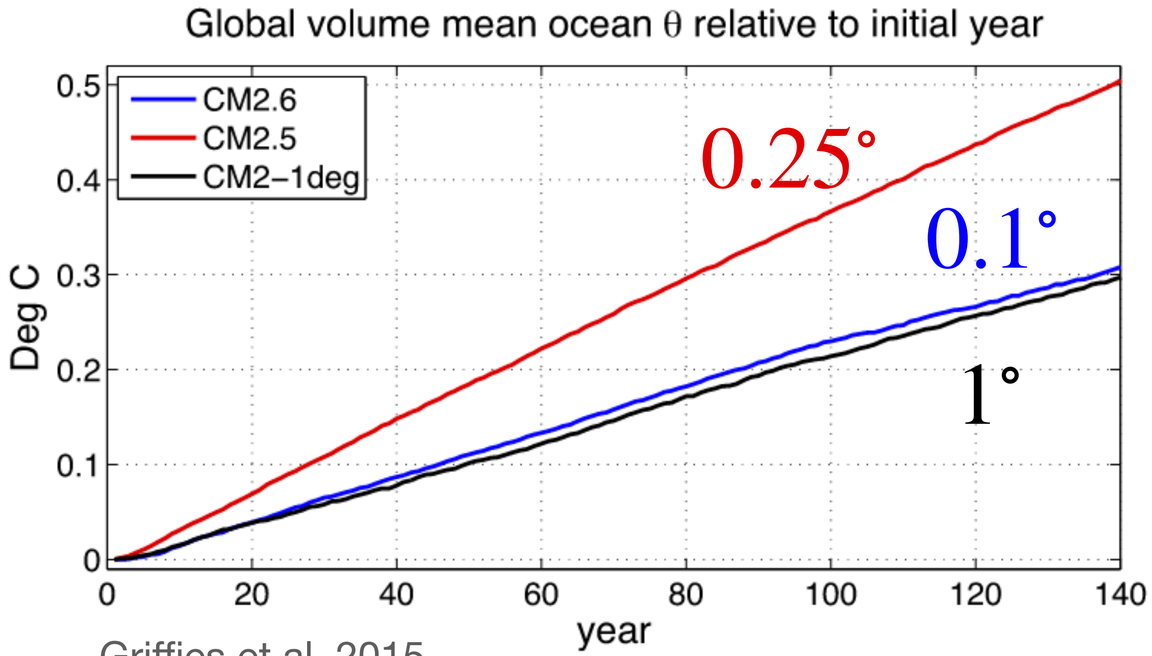
How should eddies be parameterized in $1/4^\circ$ CESM-MOM6?



Hallberg 2013

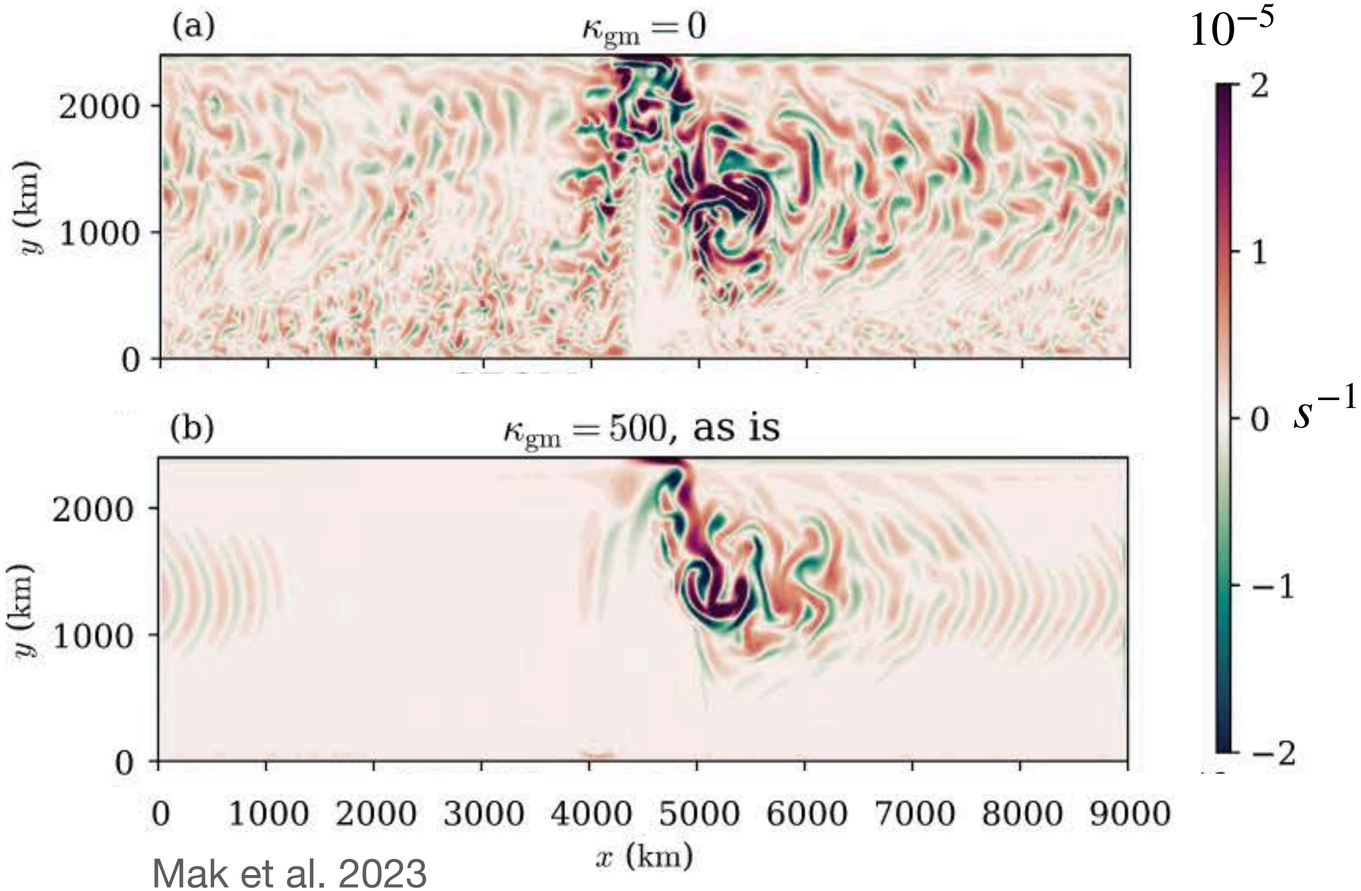
Isopycnal height diffusion

Do we need to parameterize eddies at 1/4°?



Griffies et al. 2015

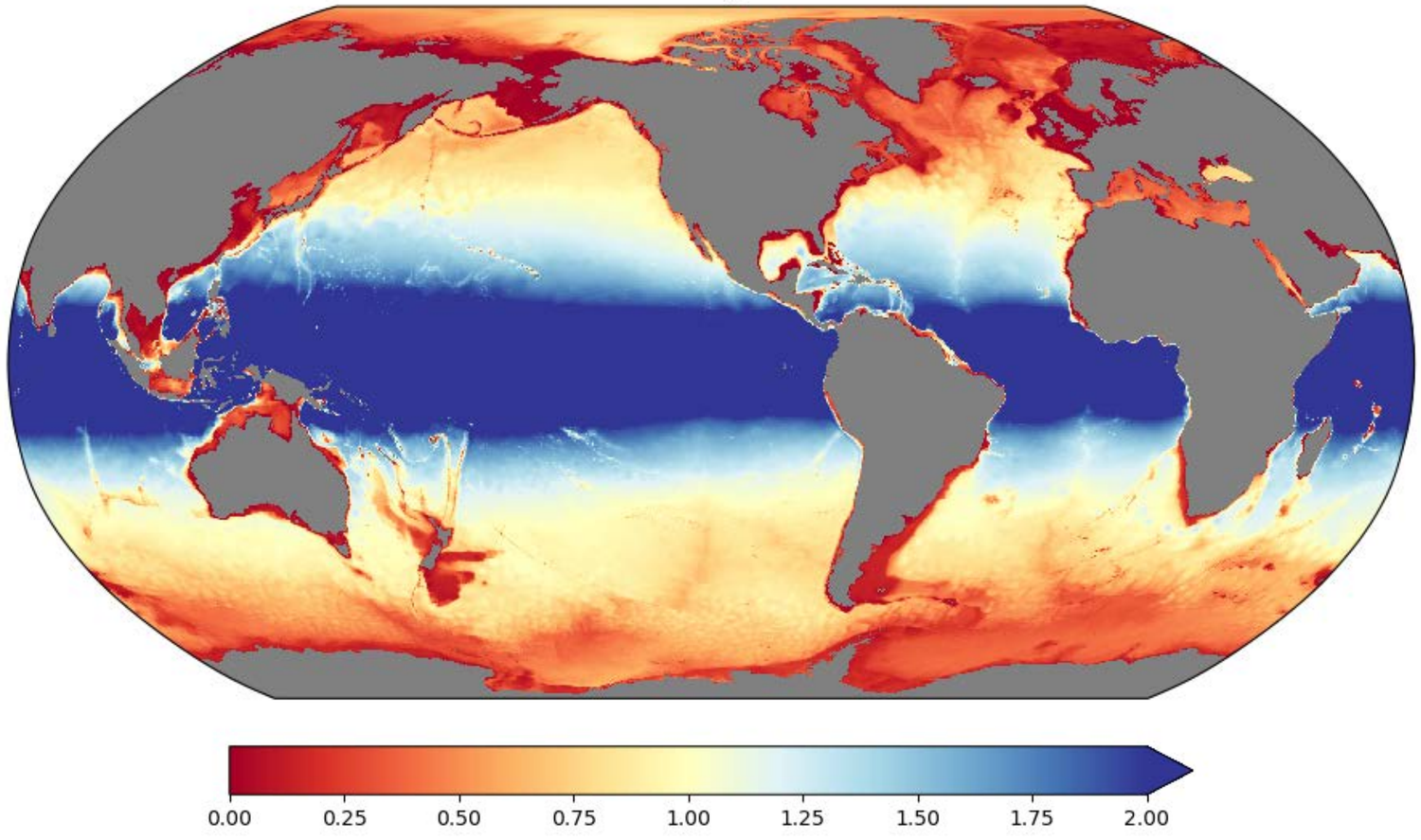
Re-entrant channel with 25 km grid spacing



Mak et al. 2023

Hyperviscosity and eddies

$R = L_d/\Delta$



$\max(R) \approx 6.5$ near the equator

QG: Six-layer, double gyre

$R = L_d/\Delta$	KE fraction
8	1
4.5	$0.8 - 0.92$
2.6	$0.55 - 0.8$
1.9	$0.35 - 0.7$
1.3	$0.2 - 0.6$

Grooms (2023)

Challenges in modeling eddies in the gray zone

1) Isopycnal height diffusion eliminates most eddies

2) Eddies are excessively dissipated by hyperviscosity

Challenges in modeling eddies in the gray zone

1) Isopycnal height diffusion eliminates most eddies

2) Eddies are excessively dissipated by hyperviscosity

Solution: Use backscatter instead of isopycnal height diffusion.

Momentum equation:

$$\partial_t \boldsymbol{u} + \ldots = -\underbrace{\nabla\left[\nu_4 \nabla\left(\nabla^2 \boldsymbol{u}\right)\right]}_{\text{hyperviscosity}} + \underbrace{\nabla\left(\nu_2 \nabla \boldsymbol{u}\right)}_{\text{anti-viscosity}}$$

Backscatter in global models:

Juricke et al. 2020: FESOM2

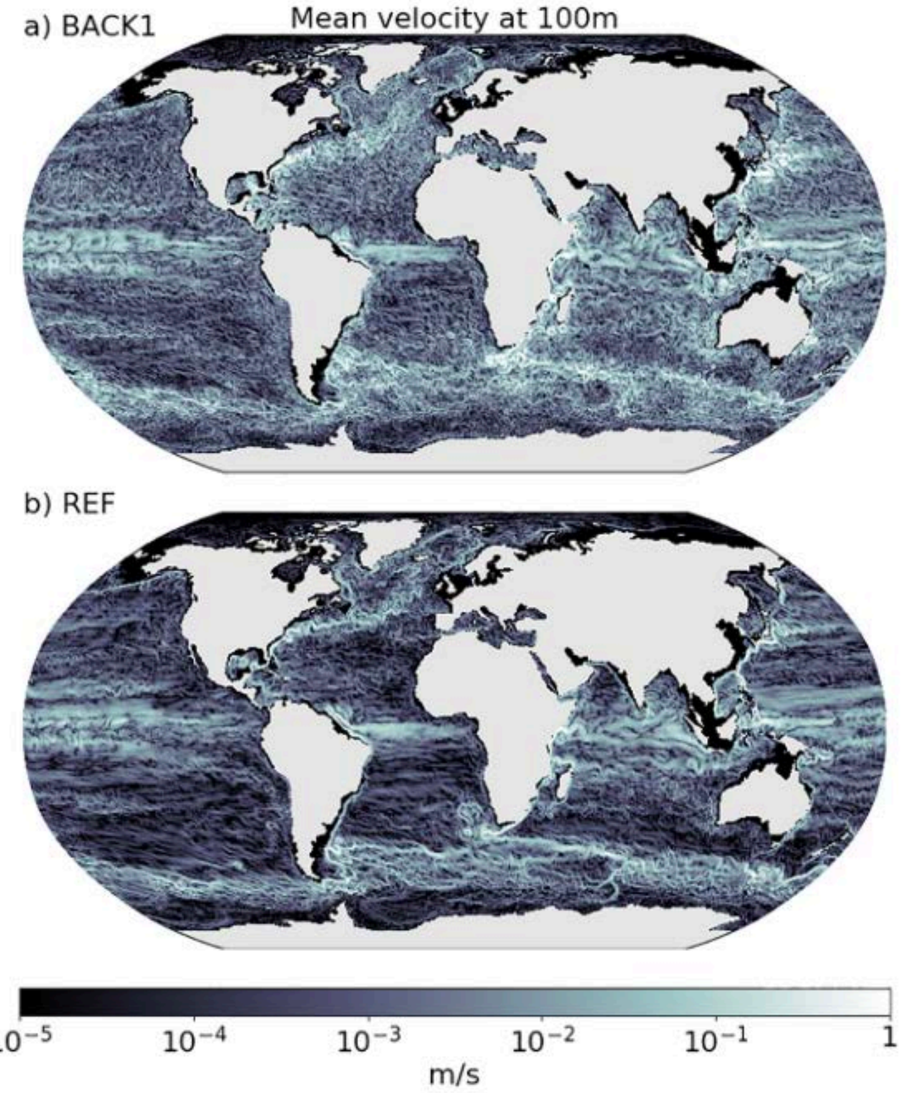
Chang et al. 2023: OM4-MOM6

Backscatter in global models:

Juricke et al. 2020: FESOM2

Chang et al. 2023: OM4-MOM6

Increases eddy energy



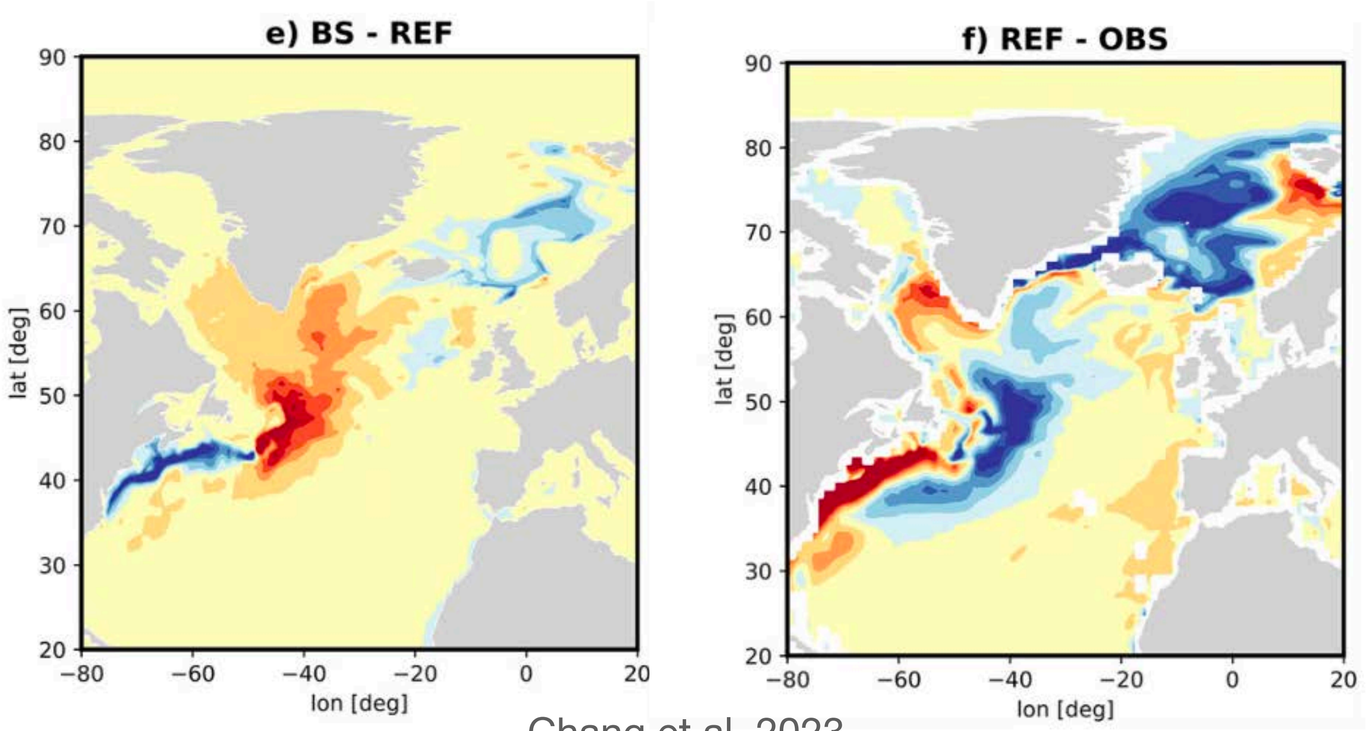
Juricke et al. 2020

Backscatter in global models:

Juricke et al. 2020: FESOM2

Chang et al. 2023: OM4-MOM6

Reduces SST biases



Chang et al. 2023

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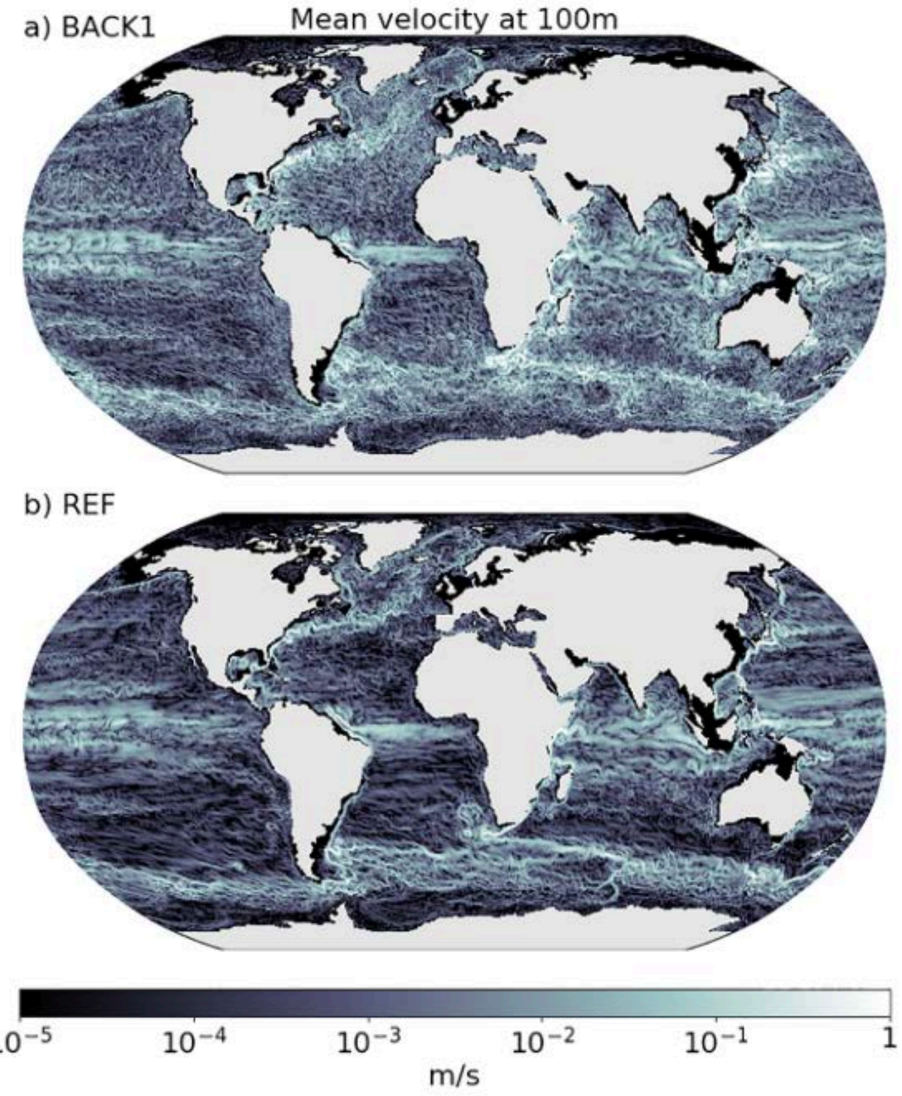

Juricke et al. 2020

Momentum equation:

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How do you choose ν_2?

Scheme	Prognostic equation?	Vertical structure	Reference
MEKE + BK *Chang et al. 2023*	2D	*No*	Jansen et al. (2015)
Dynamic BK *Juricke et al. 2019*	3D	Yes	Jansen et al. (2020)
Kinematic BK *Juricke et al. 2020*	*None*	Yes	Juricke et al. (2020)
MEKE+BK (EBT)	*2D*	Yes	Yankovsky et al. (2024)
Leith+E	*None*	Yes	Grooms (2023)

Model Setup

Model	CESM-MOM6 forced ice-ocean configuration
Grid	- 1/4 degree - hybrid vertical coordinates (75 levels).
Forcing	JRA-55
Initial conditions	WOA18 January
Vertical parameterization	KPP
Lateral parameterizations	- Biharmonic Smagorinksy - Mixed-layer restratification

Experiments

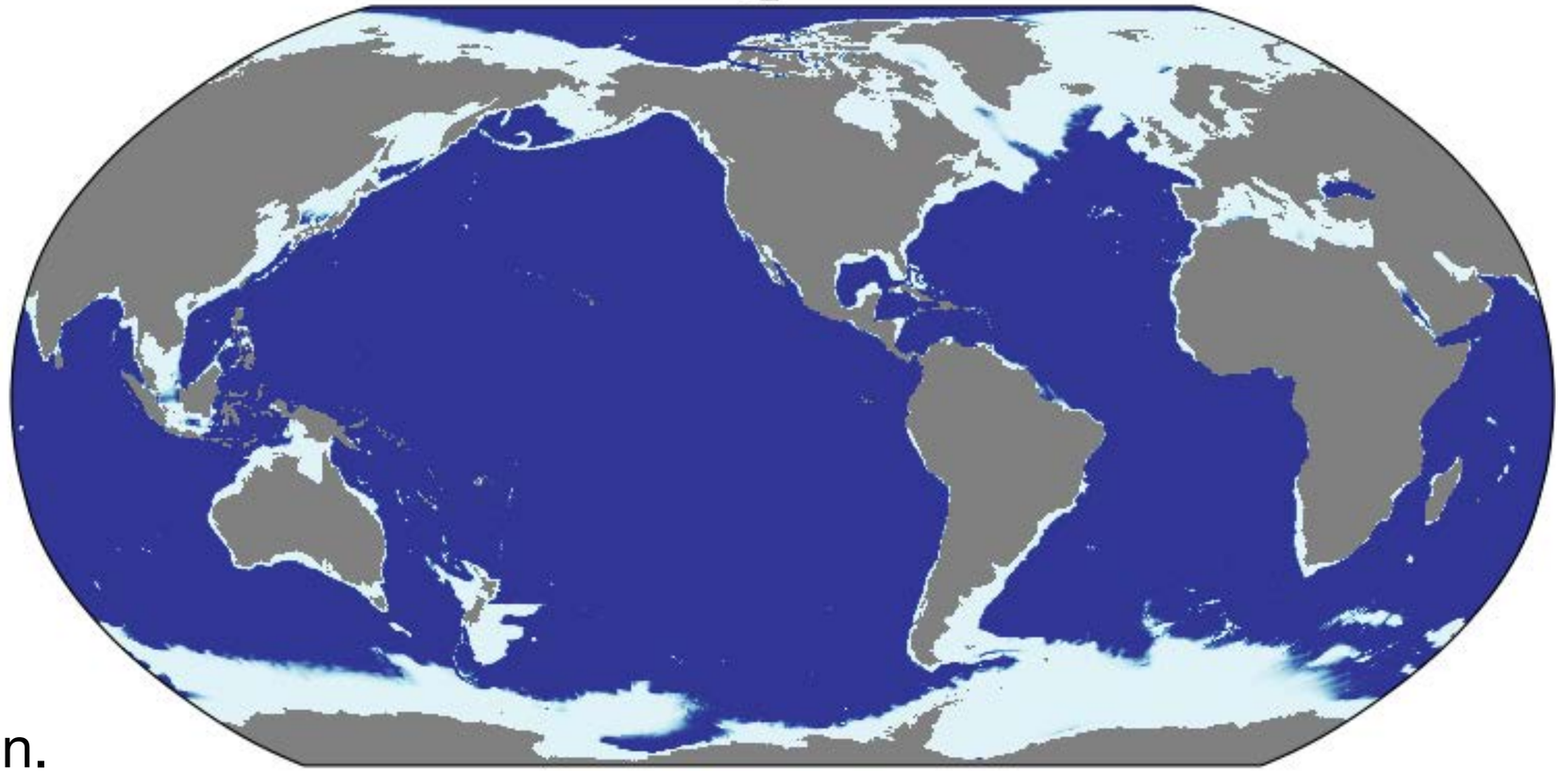
Model Run	**GM & Reddi**	**Backscatter scheme**	**Condition**	**Time** (Years)
Control	—	None	—	10
BK	—	MEKE *Equivalent barotropic*	Backscatter when $L_d > \Delta/2$	10
GM	1000 m²/s *Equivalent barotropic*	None	GM when $L_d < \Delta/2$	10
GM+BK	1000 m²/s *Equivalent barotropic*	MEKE *Equivalent barotropic*	GM when $L_d < \Delta/2$ Backscatter when $L_d > \Delta/2$	10
GM+LeithBK	1000 m²/s *Equivalent barotropic*	Leith+E	GM when $L_d < \Delta/2$ Backscatter when $L_d > \Delta/2$	0

GM: Only apply GM in ***light blue region***

BK: Only apply backscatter in ***dark blue region***

GM+BK: Only apply GM in ***light blue region***
Only apply backscatter in ***light blue region***

$L_d < \Delta/2$



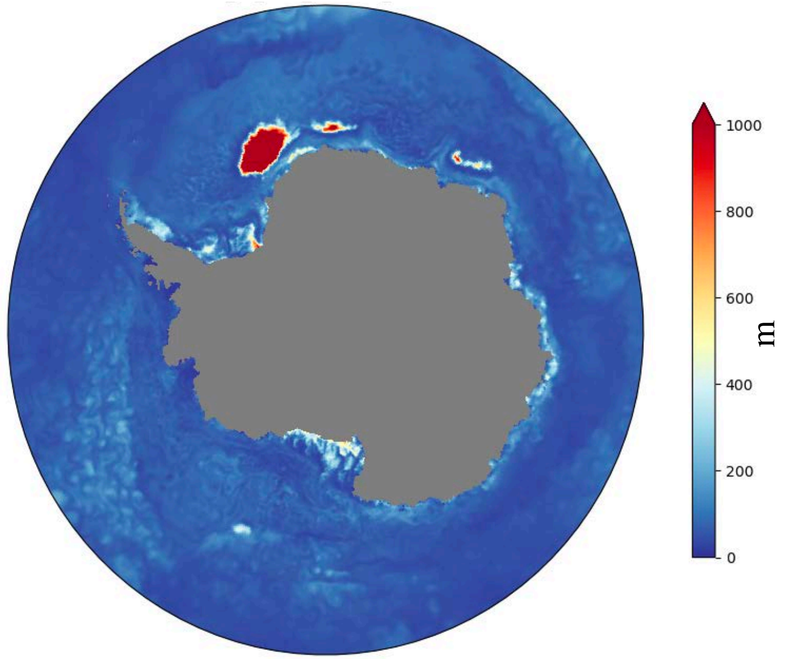
We *never* apply GM and backscatter in the same location.

Why use a resolution function to apply backscatter?

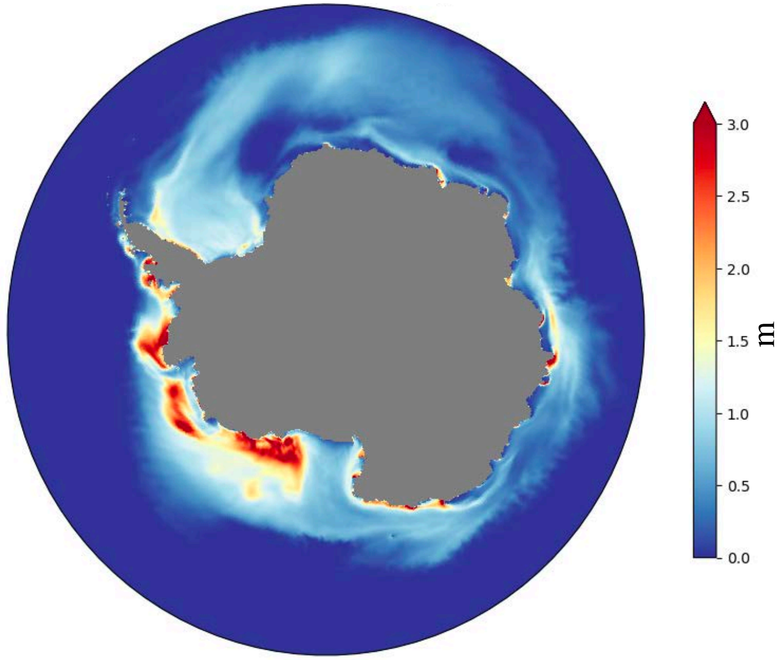
1) If $L_d \ll \Delta$, we no longer marginally resolve eddies.

2) We get a large polynya in the Weddell Sea

Mixed layer depth



Sea ice



What does backscatter do?

After 10 years of model time…

Energizes eddies. Increase SSH variability.

Reduces SST biases in Northern Hemisphere.

More barotropic ocean.

Increases SST and SSS of Southern Ocean.

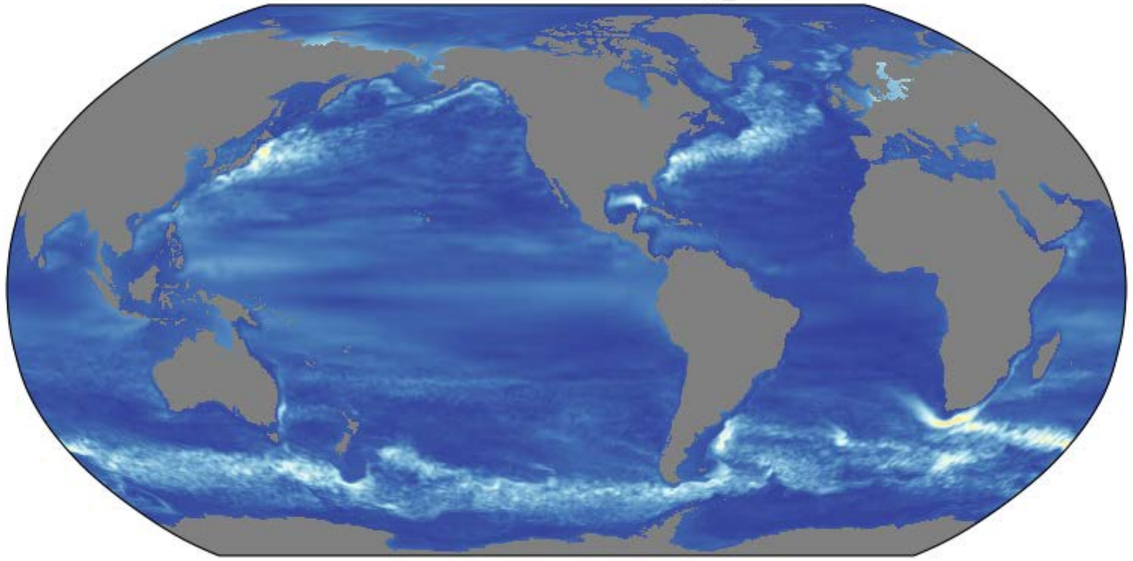
Increases southward heat transport.

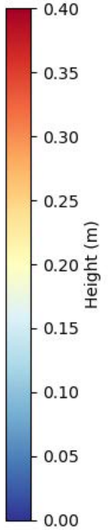
Deepens Southern Ocean mixed layers

Shifts deep mixed layers in Southern Ocean to the south.

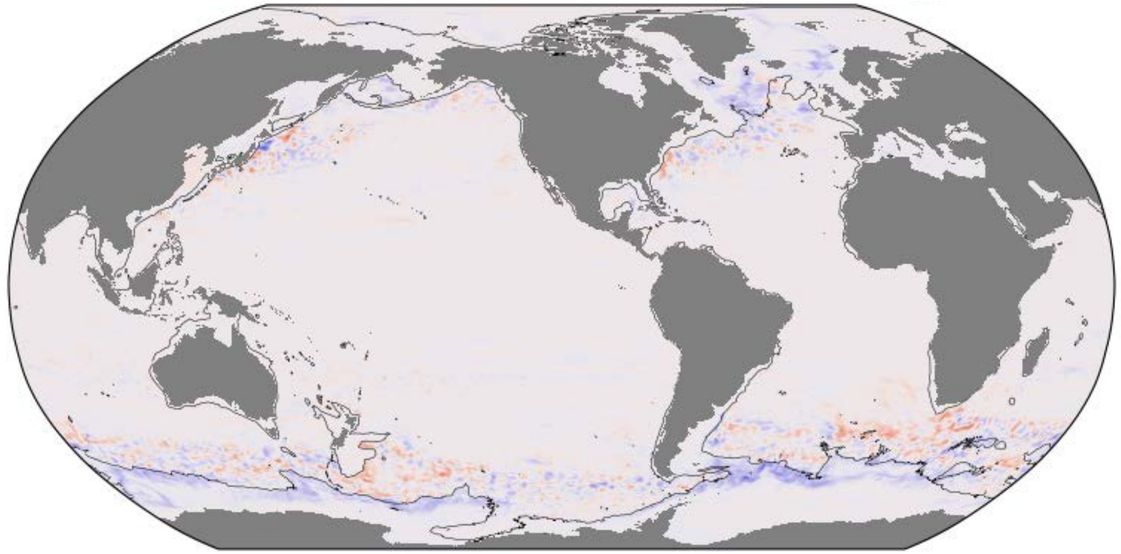
SSH Standard Deviation

Control

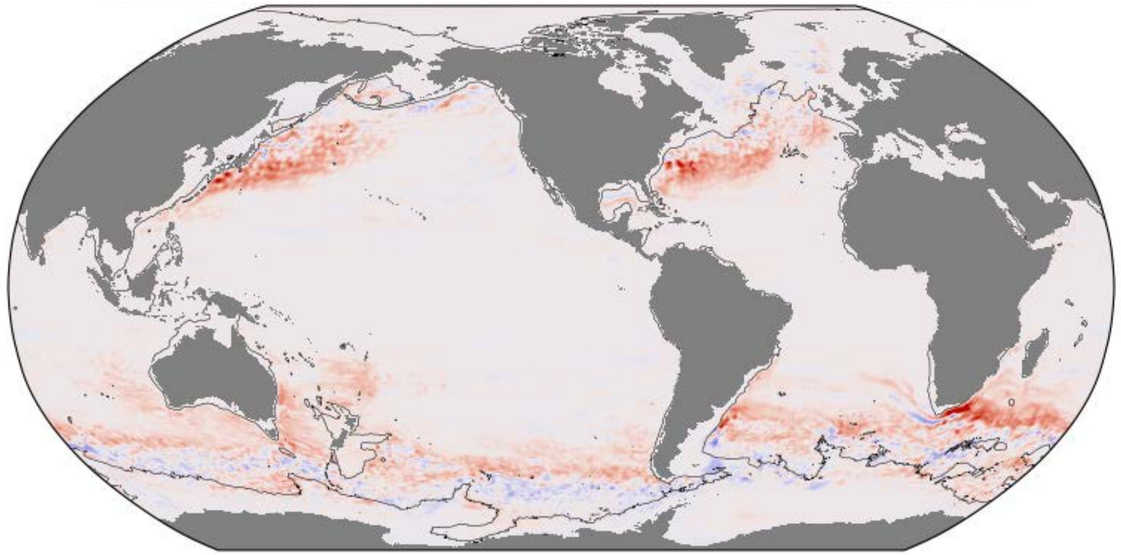


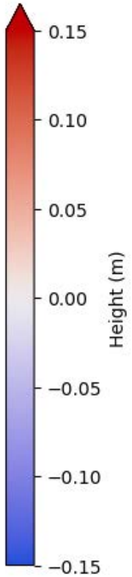


GM - Control

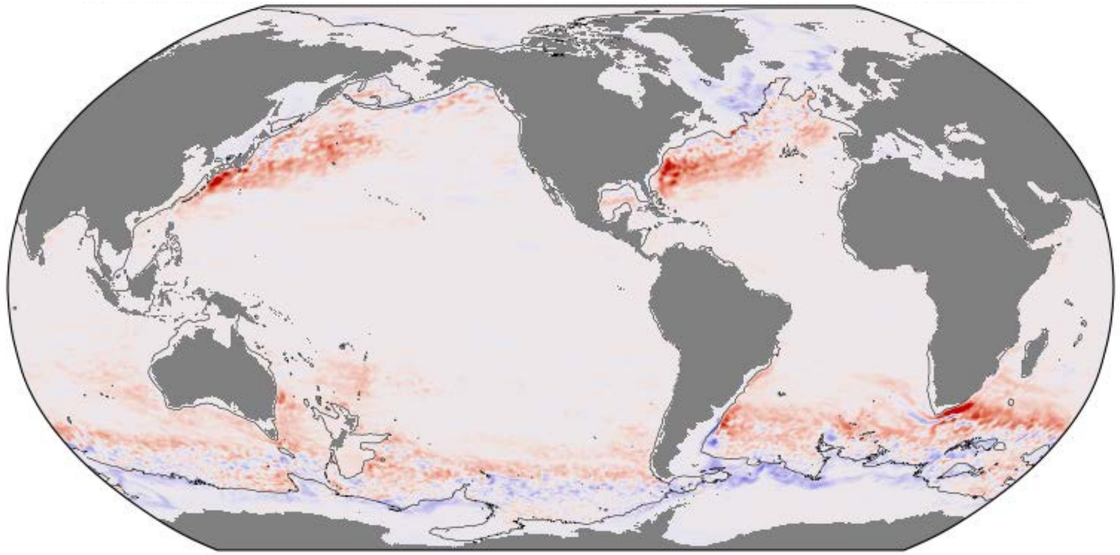


BK - Control



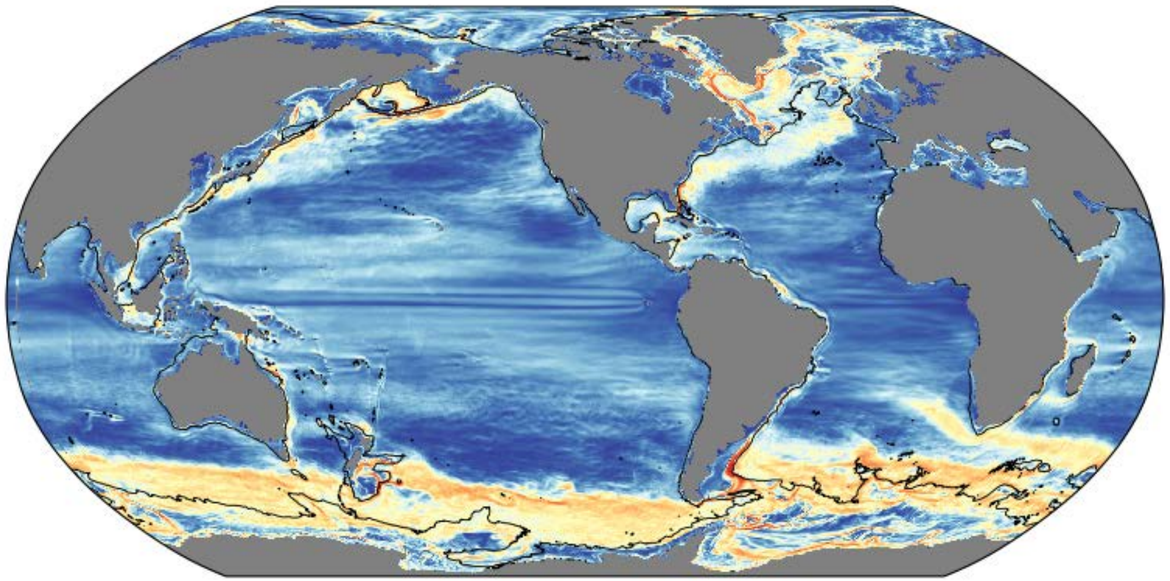


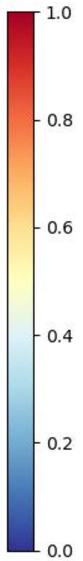
GM+BK - Control



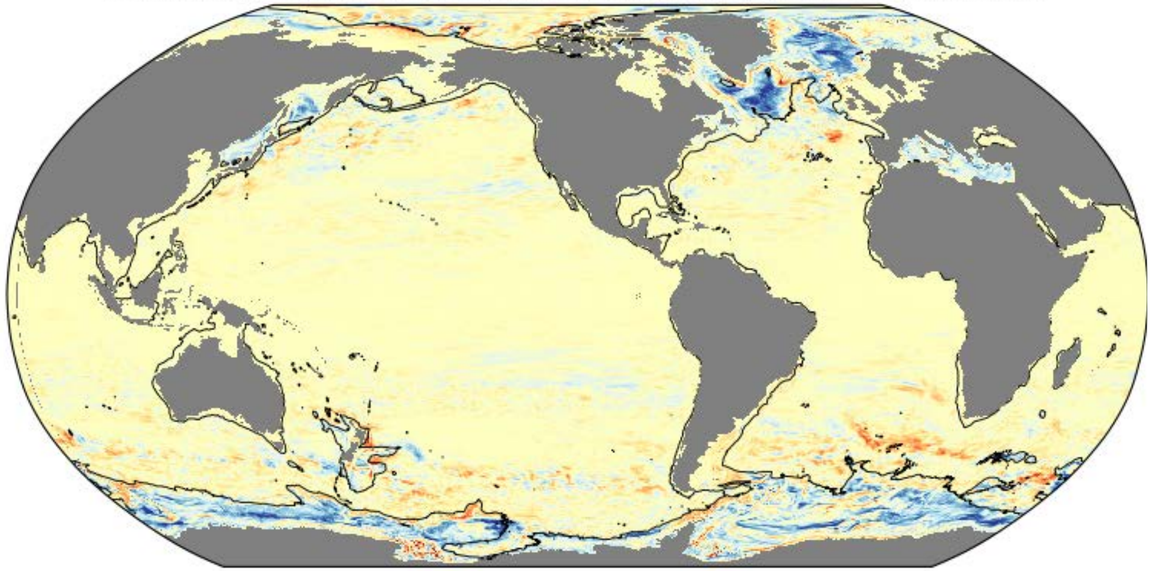
Barotropic KE fraction

Control

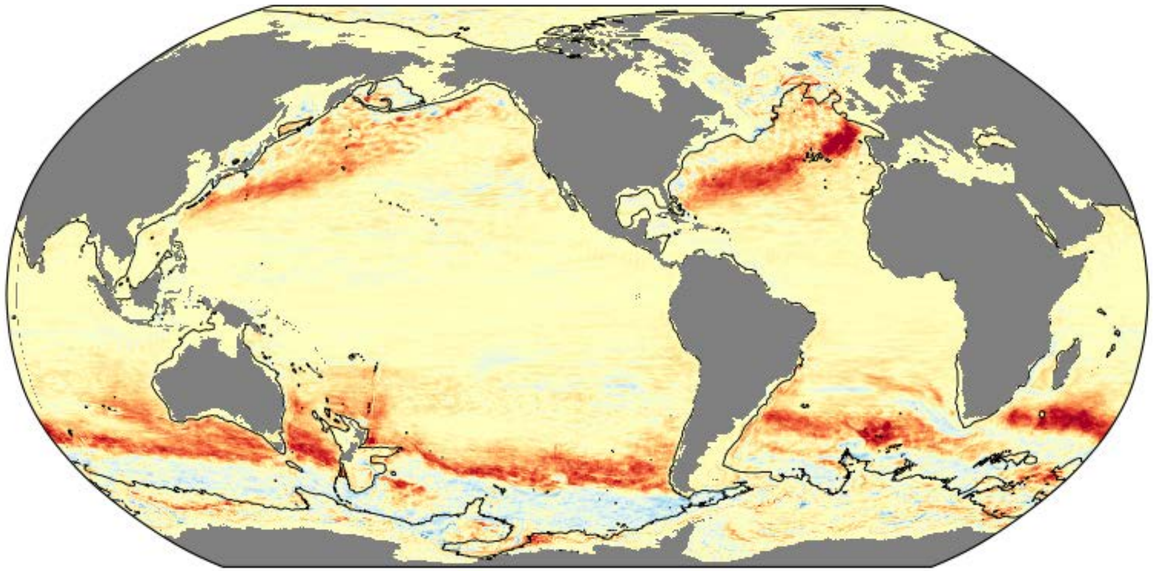


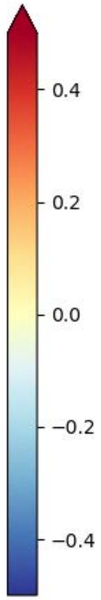


GM - Control

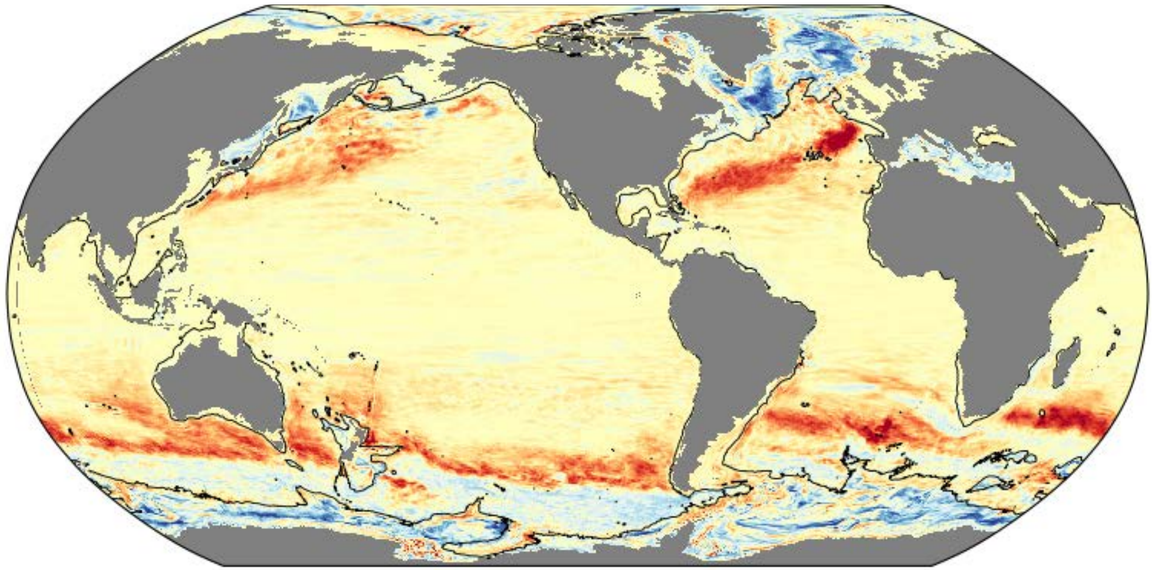


BK - Control



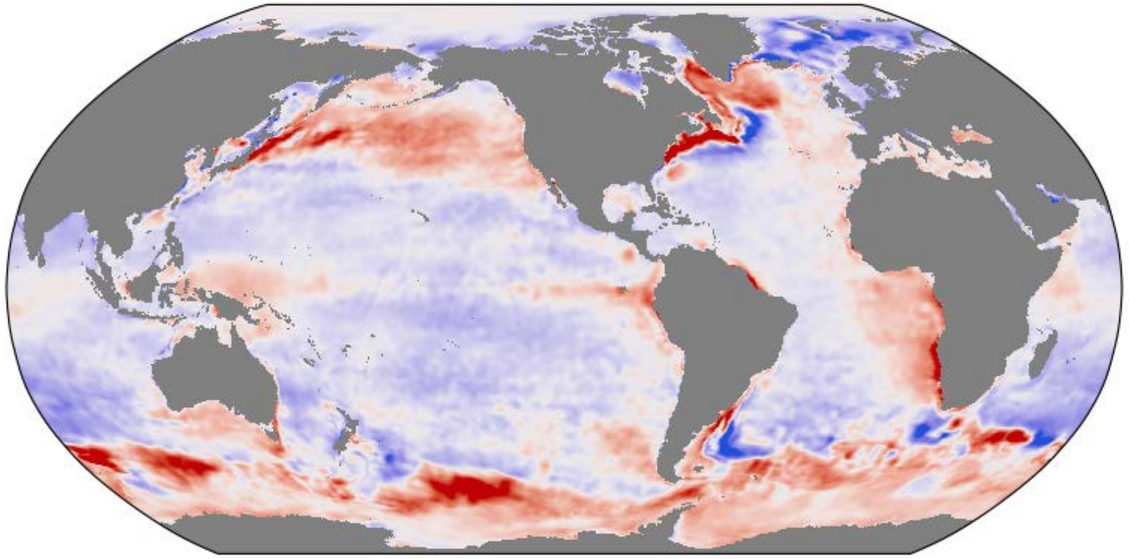


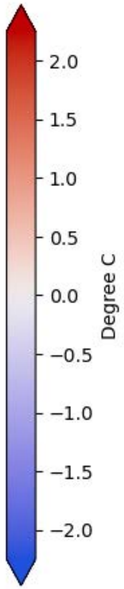
GM+BK - Control



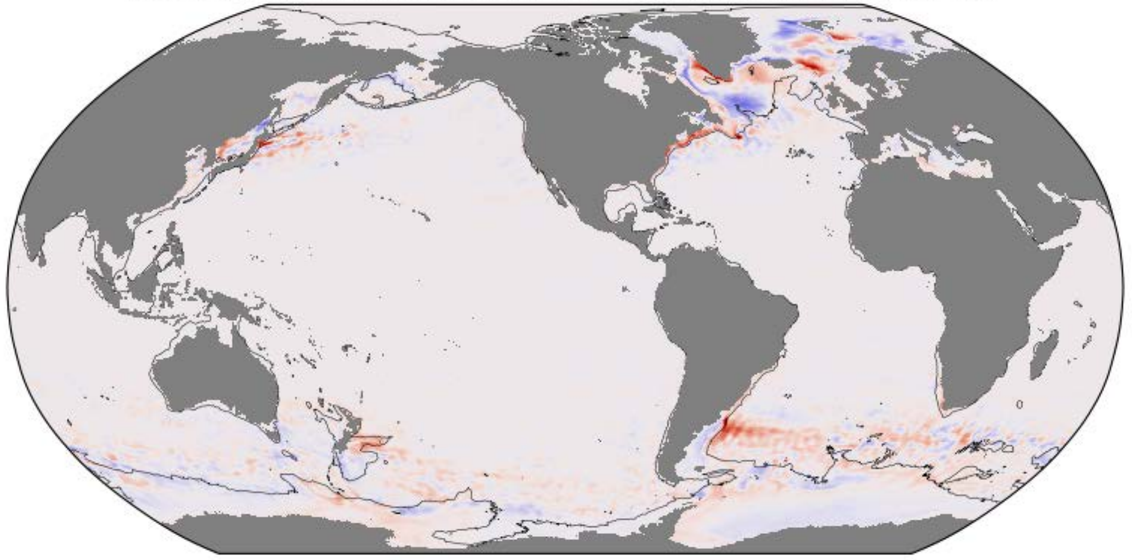
SST

Control - Obs

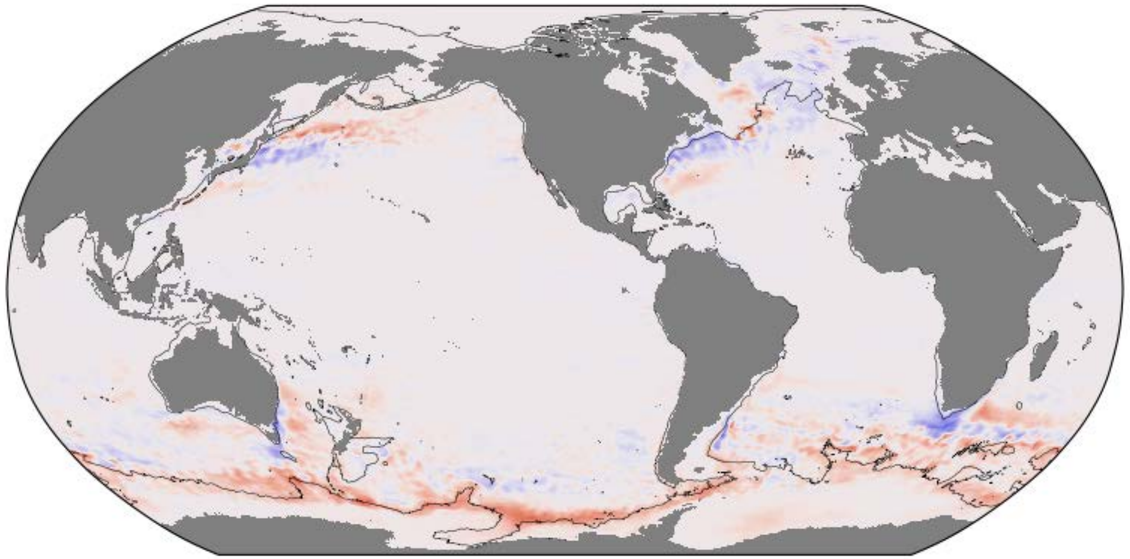




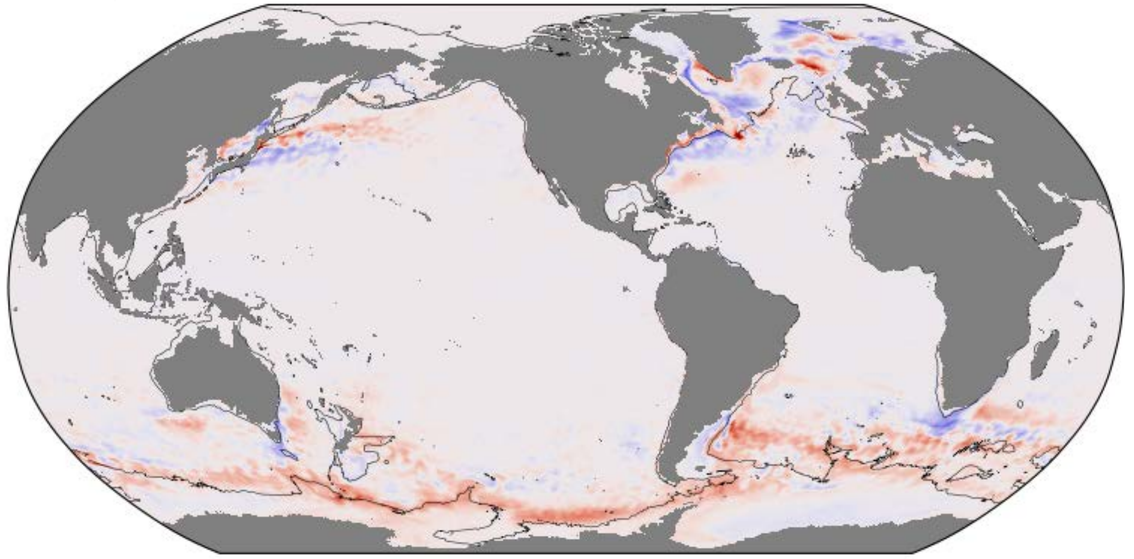
GM - Control

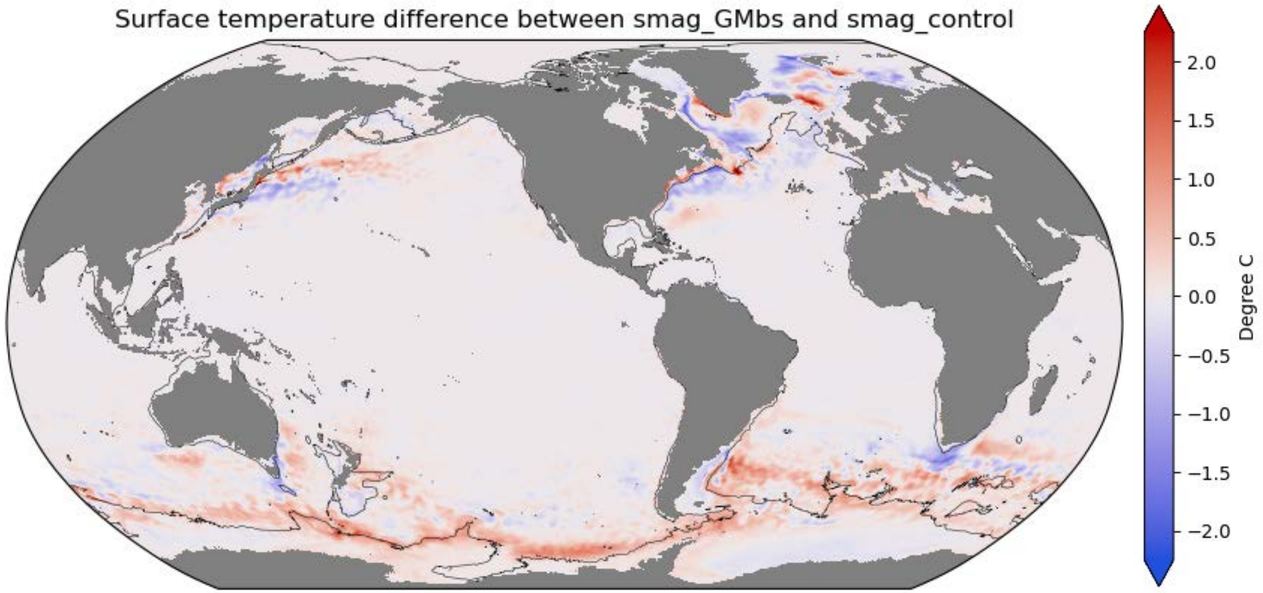


BK - Control

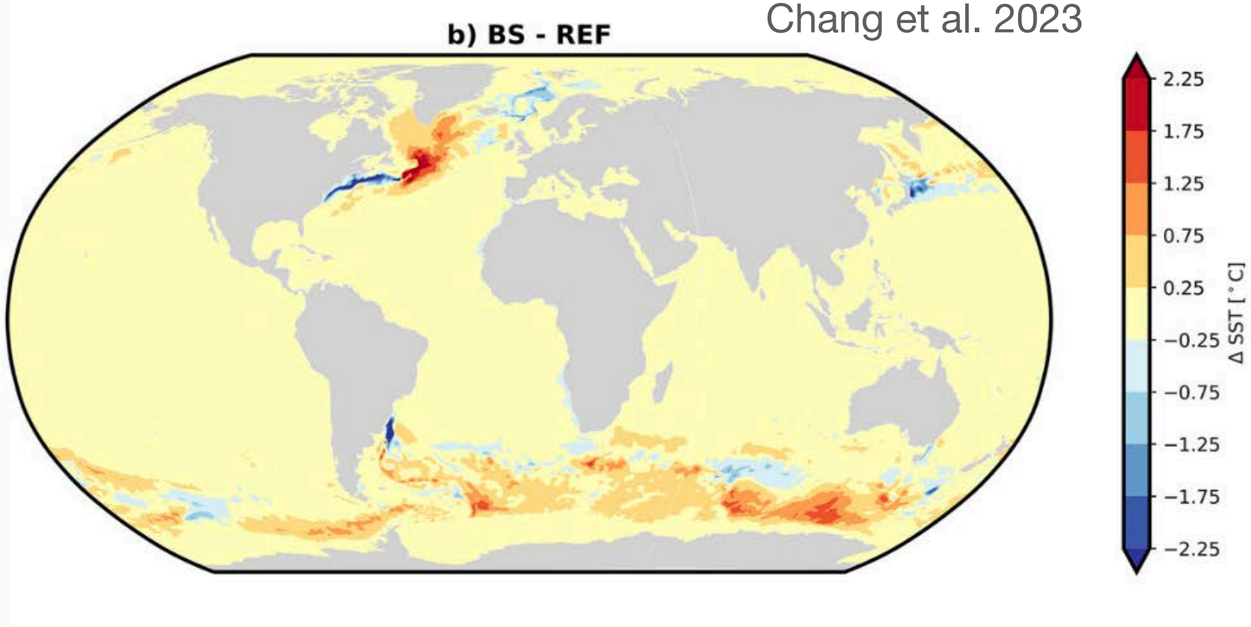


GM+BK - Control

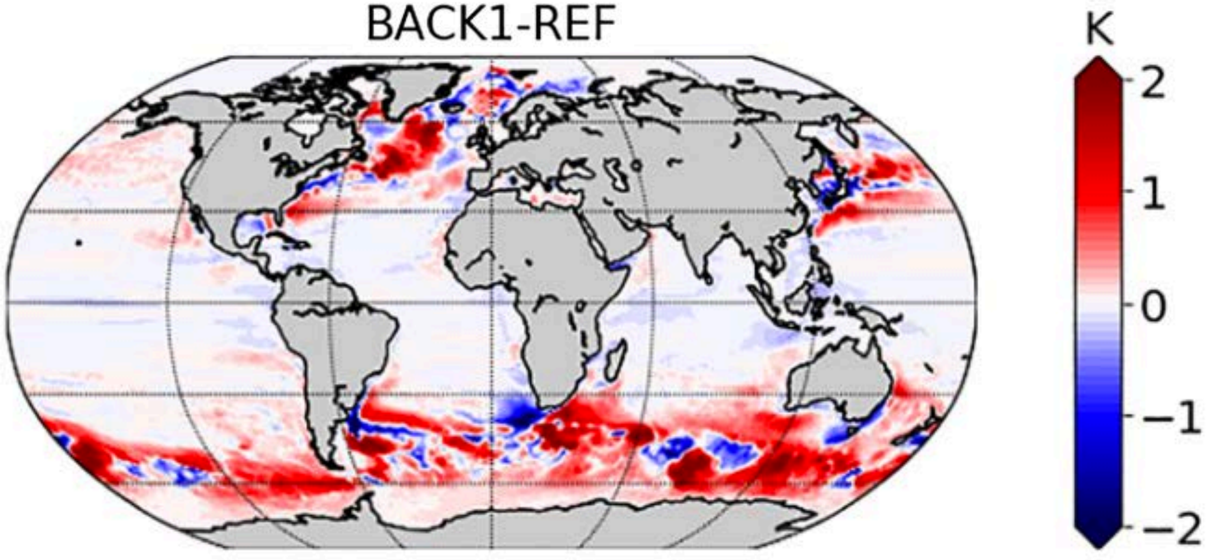




Chang et al. 2023

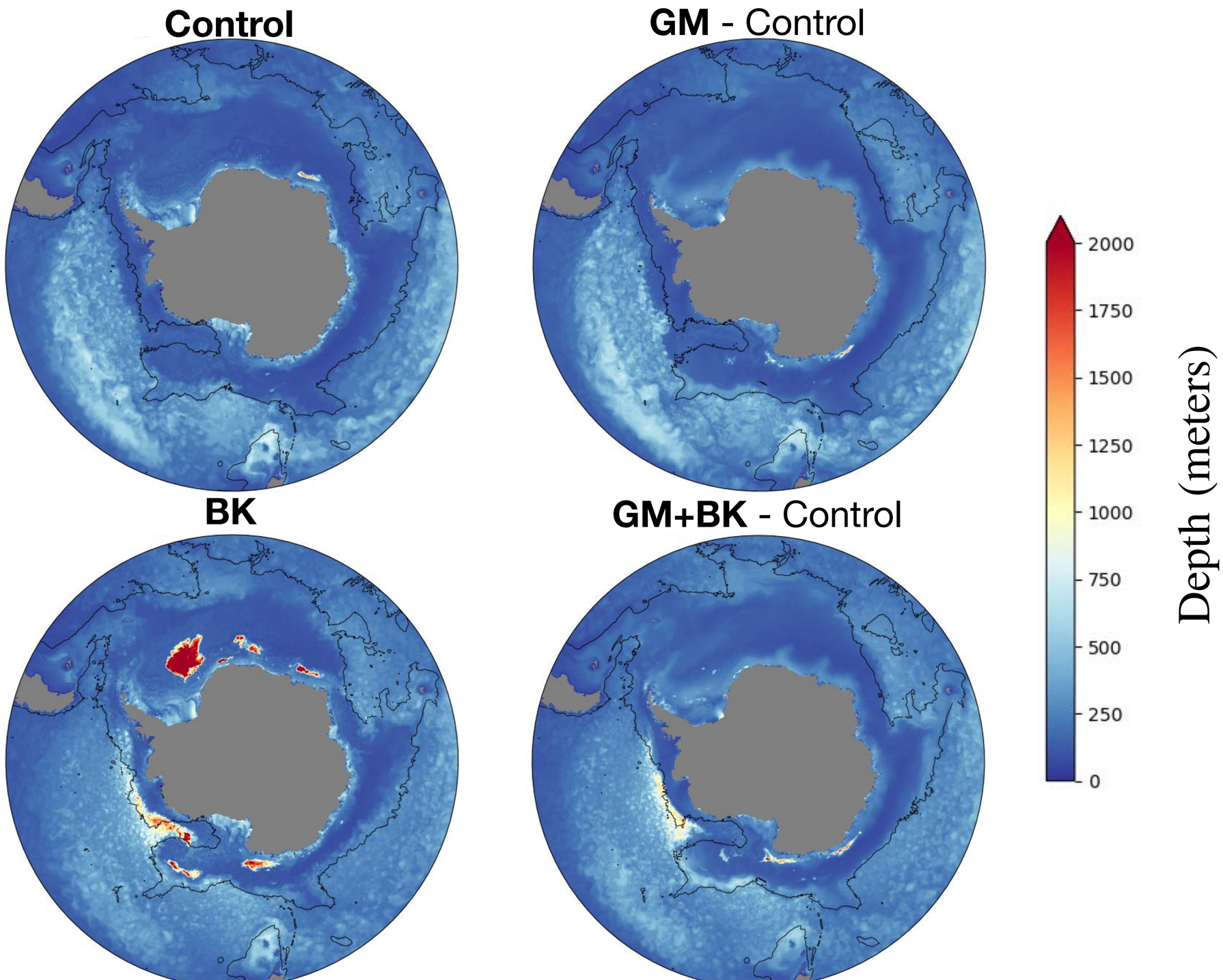


ΔSST for different models

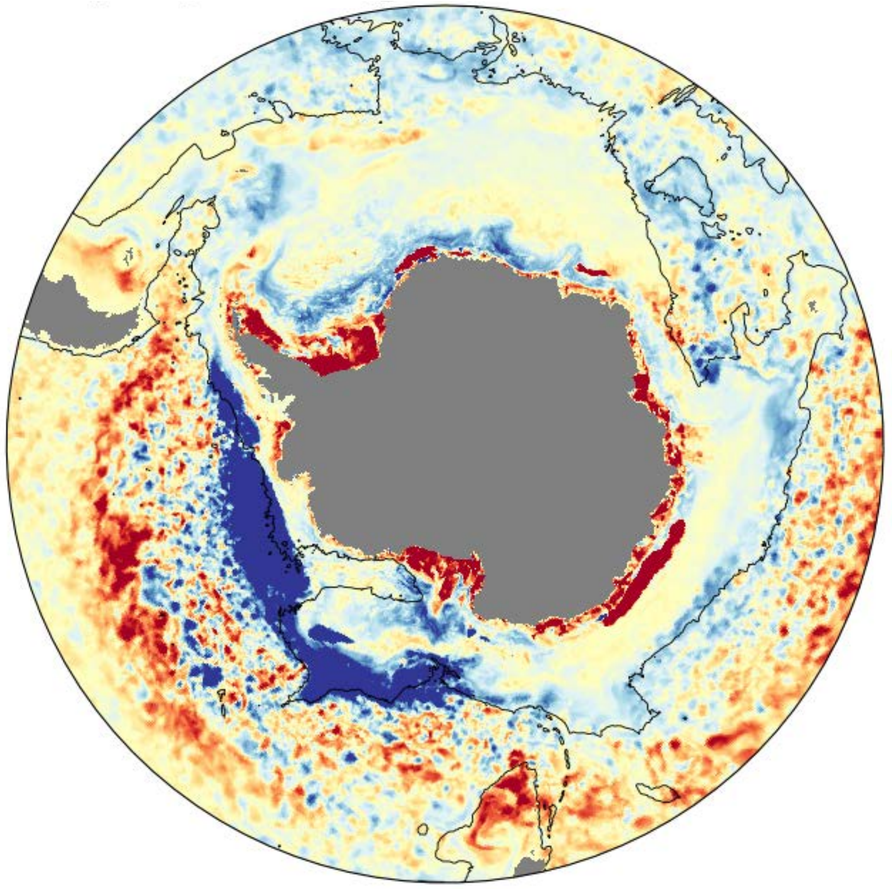


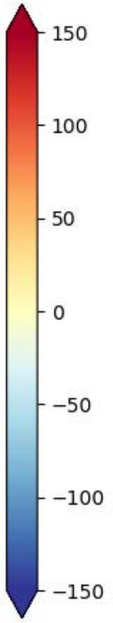
Juricke et al. 2020

Maximum Mixed Layer Depth



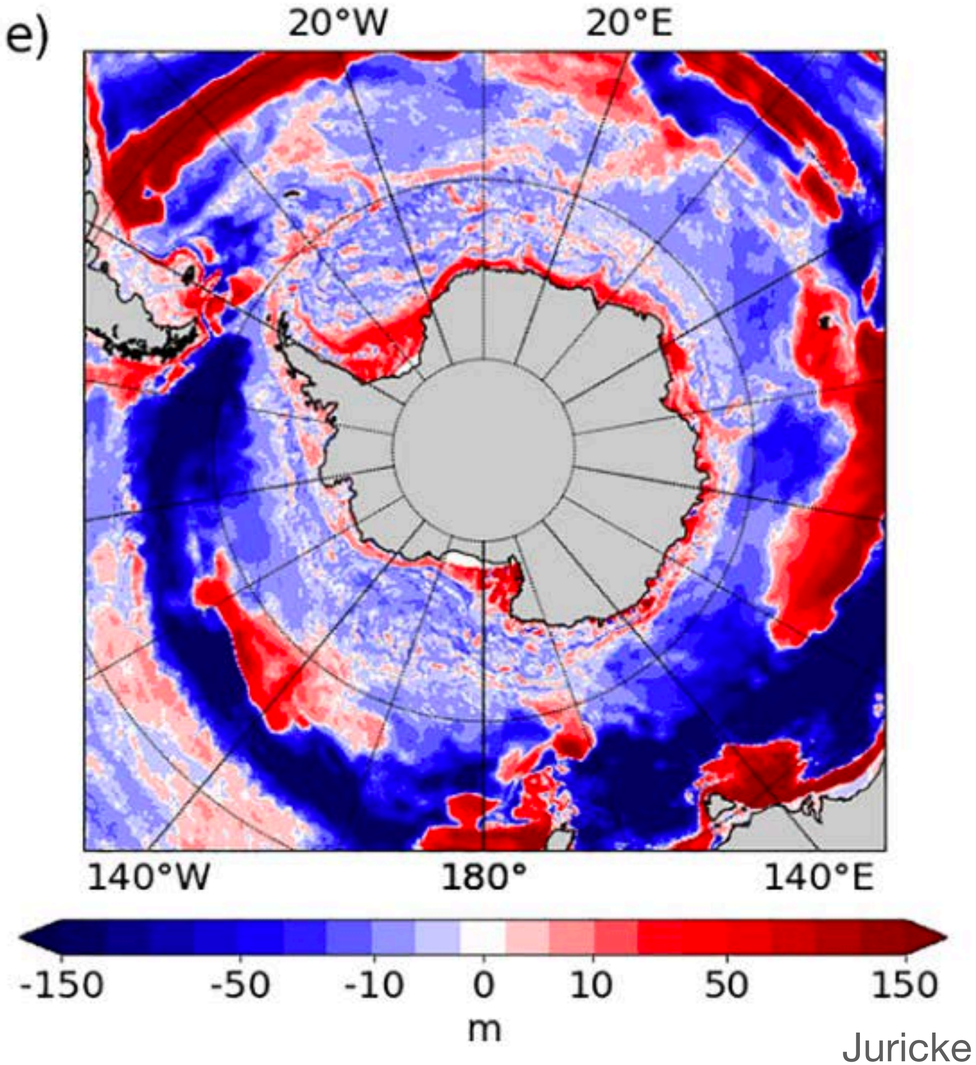
GM+BK - Control





Depth (meters)

Back1 - Ref



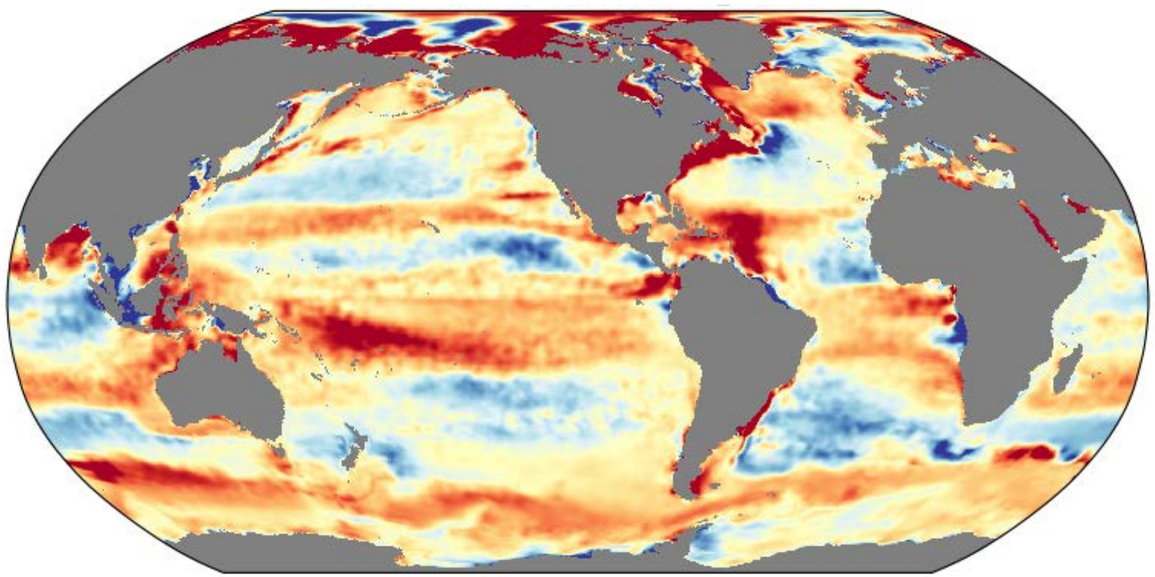
Juricke et al. 2020

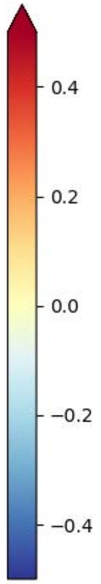
Deep MLs **shift poleward** in CESM-MOM6 but **remain fixed** in FESOM2

Shallowing of mixed-layers on the Antarctic coastal shelf.

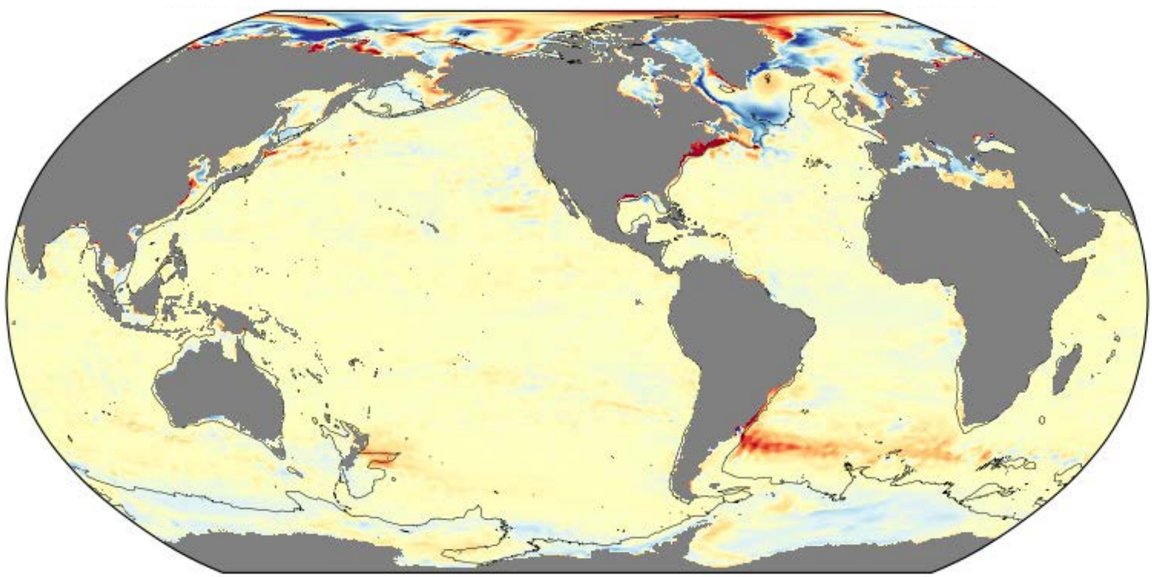
Surface salinity

Control - Obs

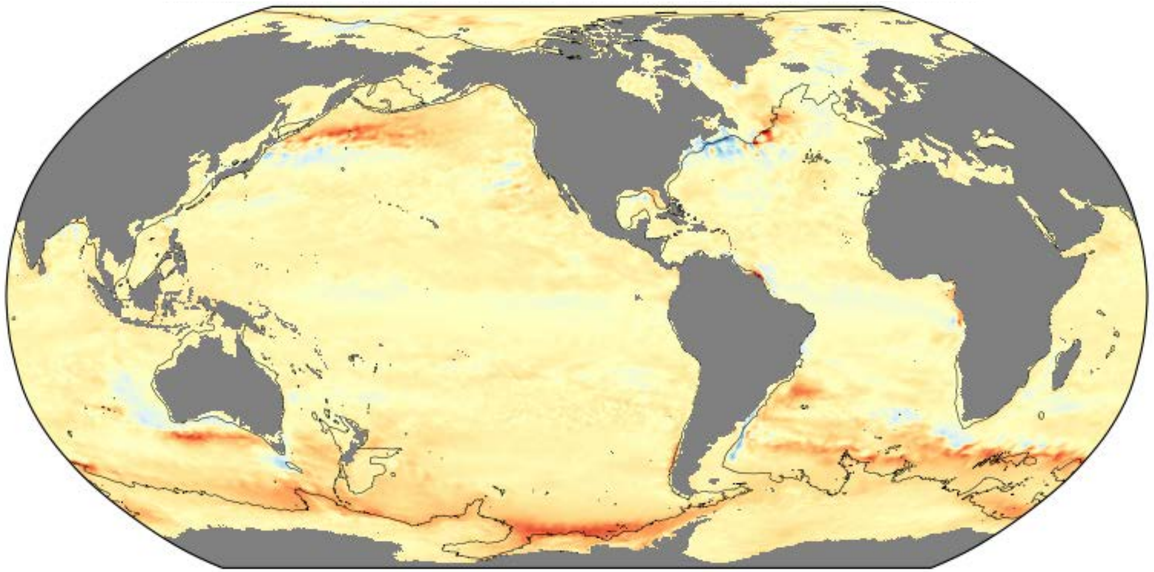




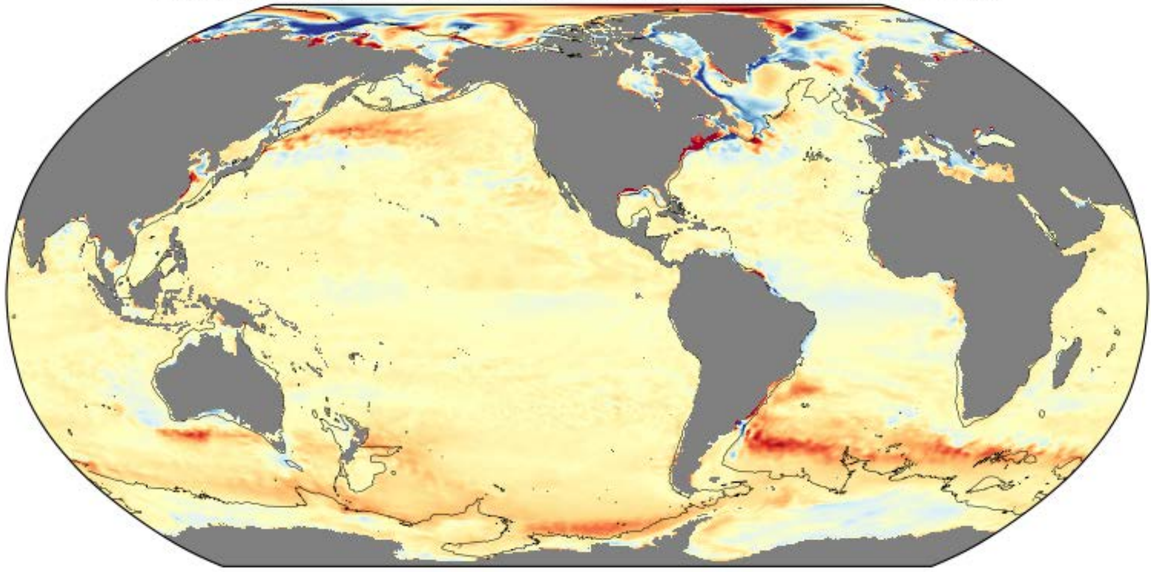
GM - Control

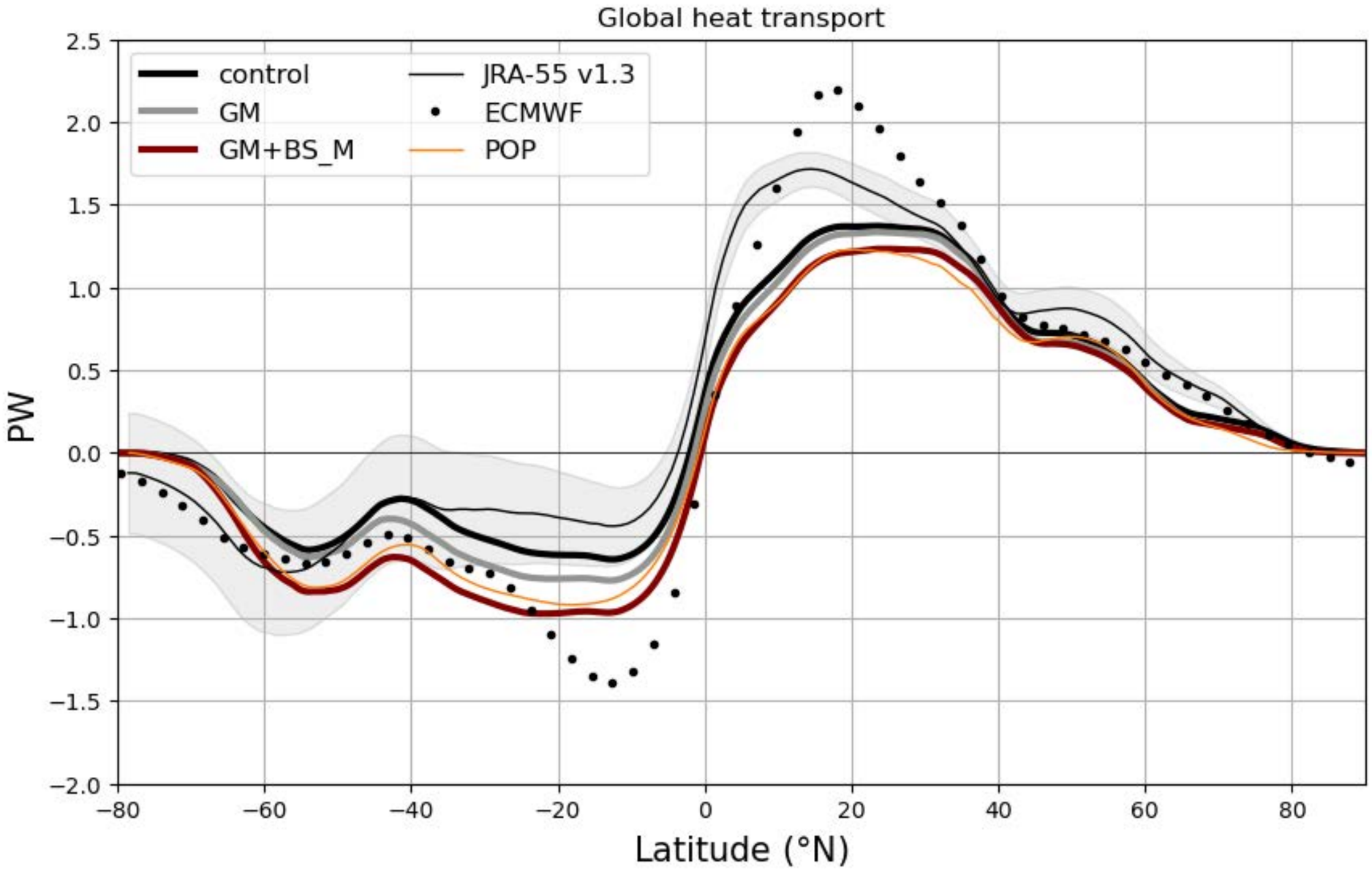


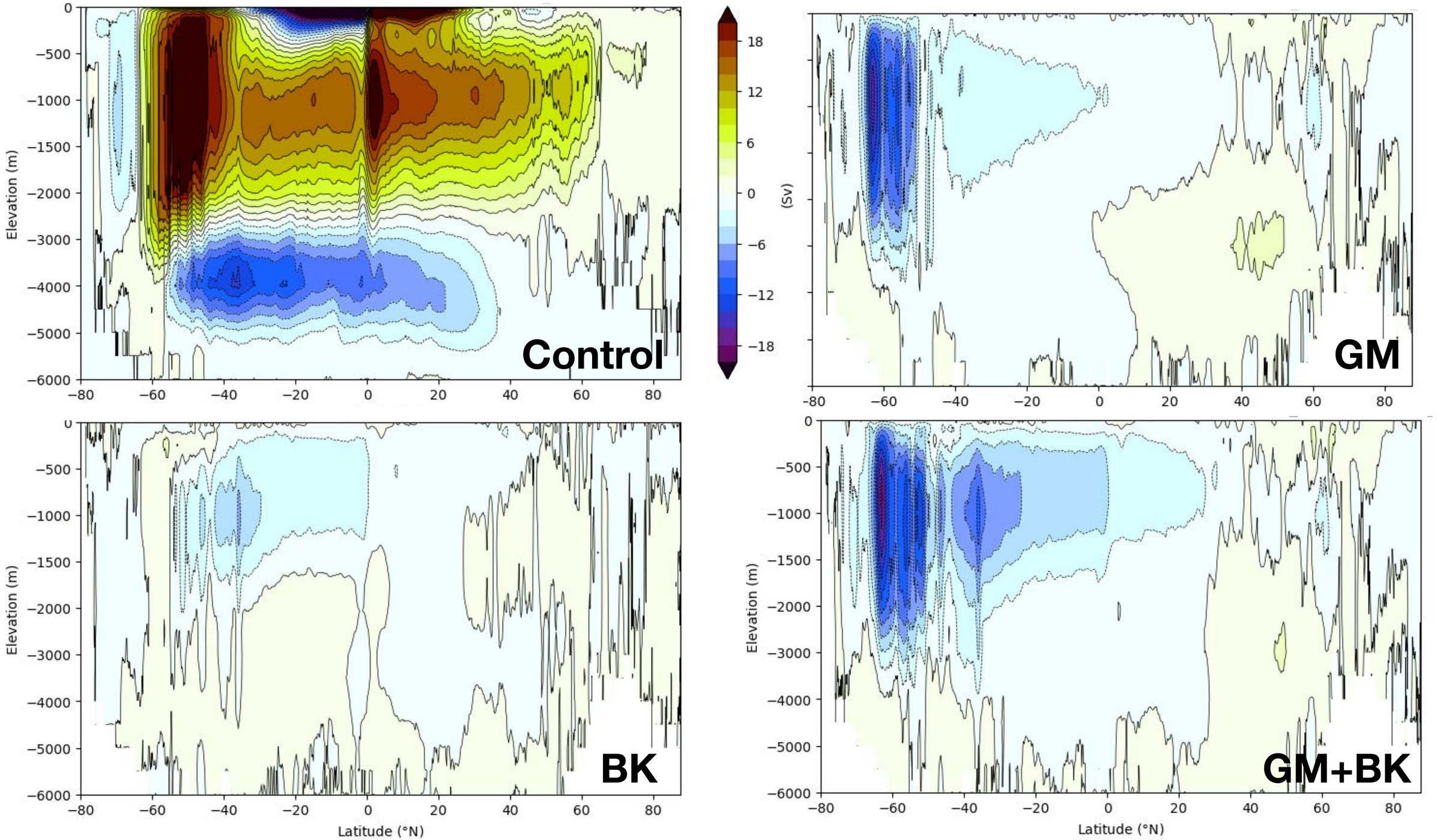
BK - Control



GM+BK - Control




Global heat transport
control
GM
GM+BS_M
JRA-55 v1.3
ECMWF
POP
PW
Latitude (°N)
2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−80
−60
−40
−20
0
20
40
60
80

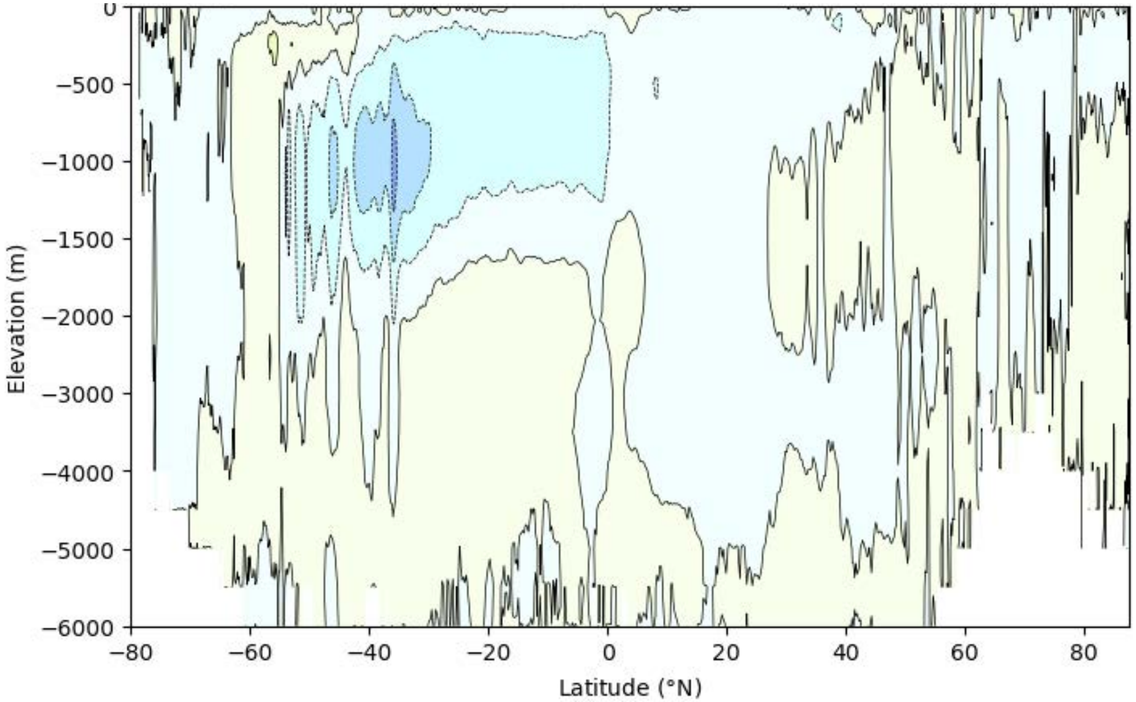

Control
GM
BK
GM+BK
Elevation (m)
Latitude (°N)
(Sv)
0
−500
−1000
−1500
−2000
−3000
−4000
−5000
−6000
−80
−60
−40
−20
0
20
40
60
80
18
12
6
0
−6
−12
−18

Mechanism for increased heat transport

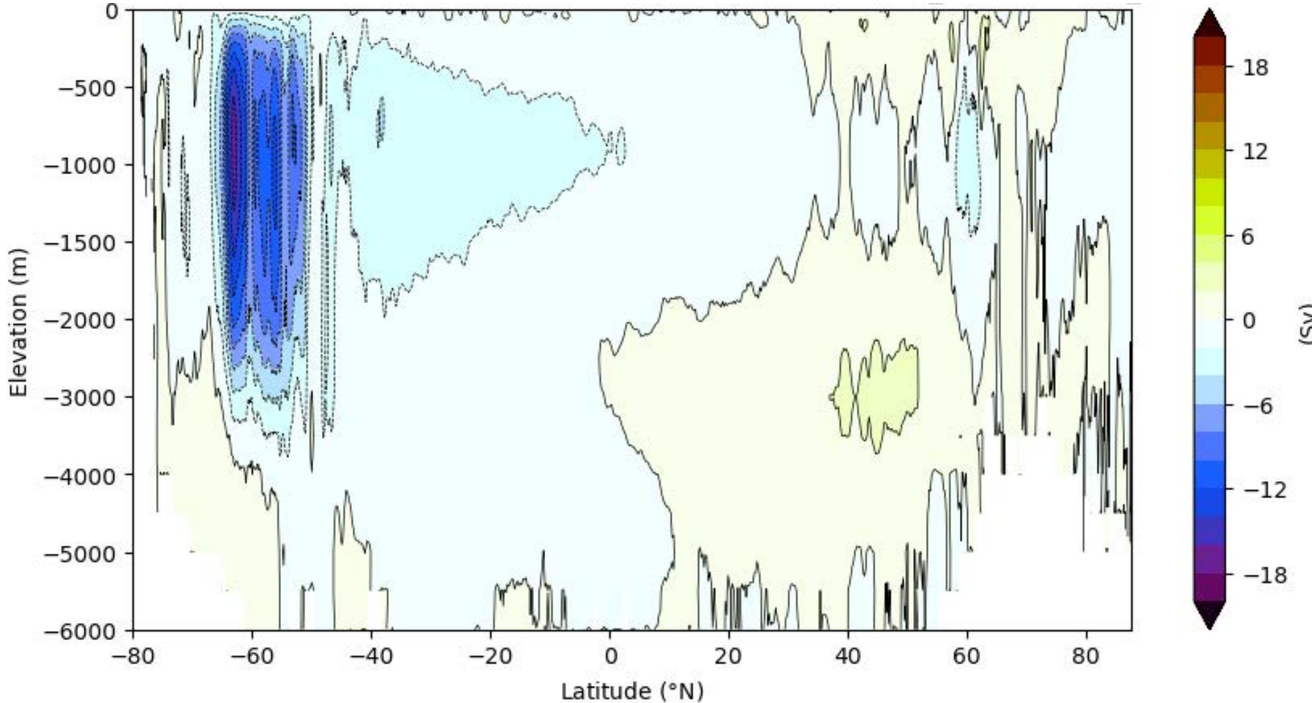
Mid-depth cell in southern hemisphere transports heat northwards.

Eddies set up opposing circulation, weakening mid-depth cell, leading to larger southward heat transport.

BK



GM



What does backscatter do?

After 10 years of model time…

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More barotropic ocean.

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Increases southward heat transport.

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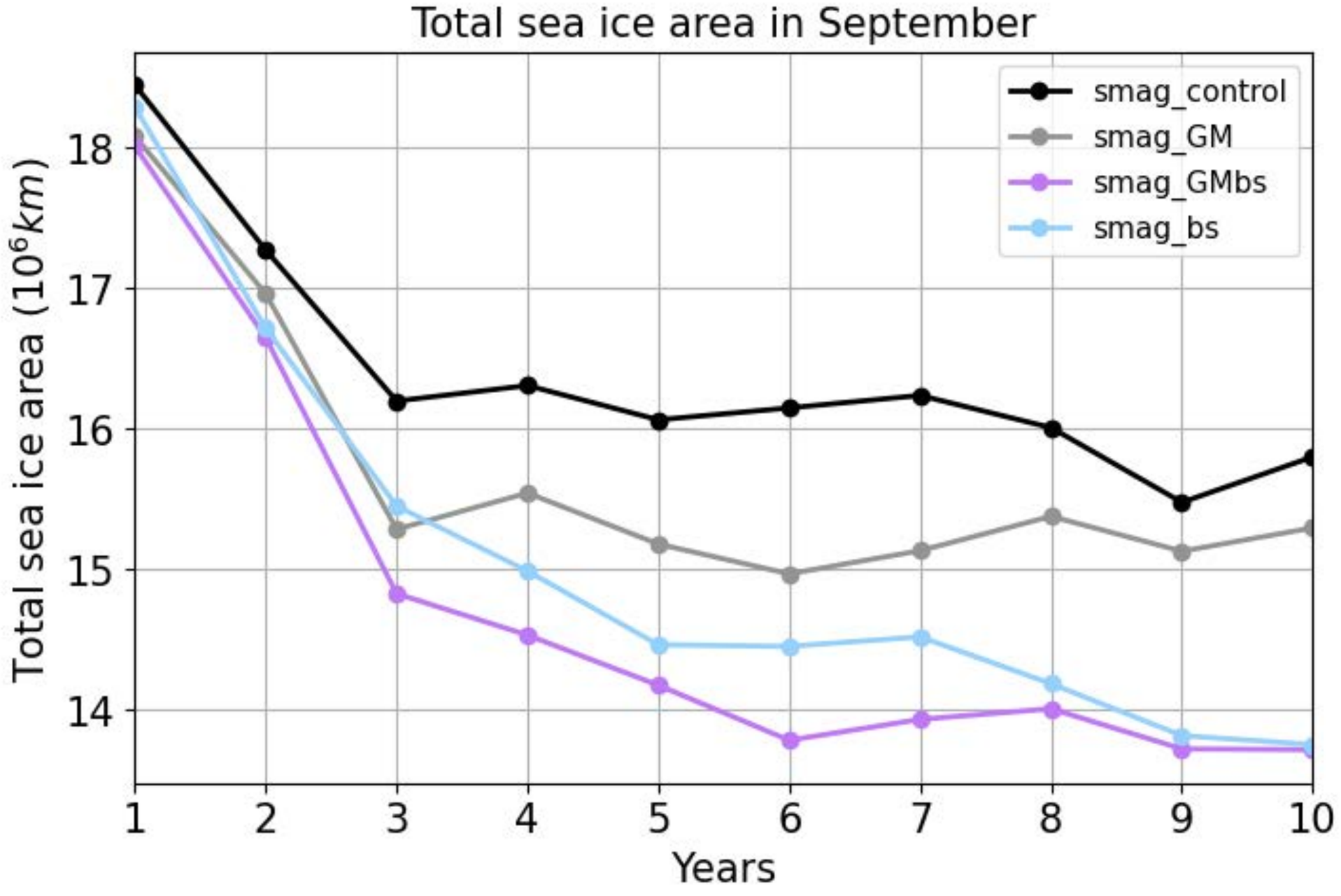
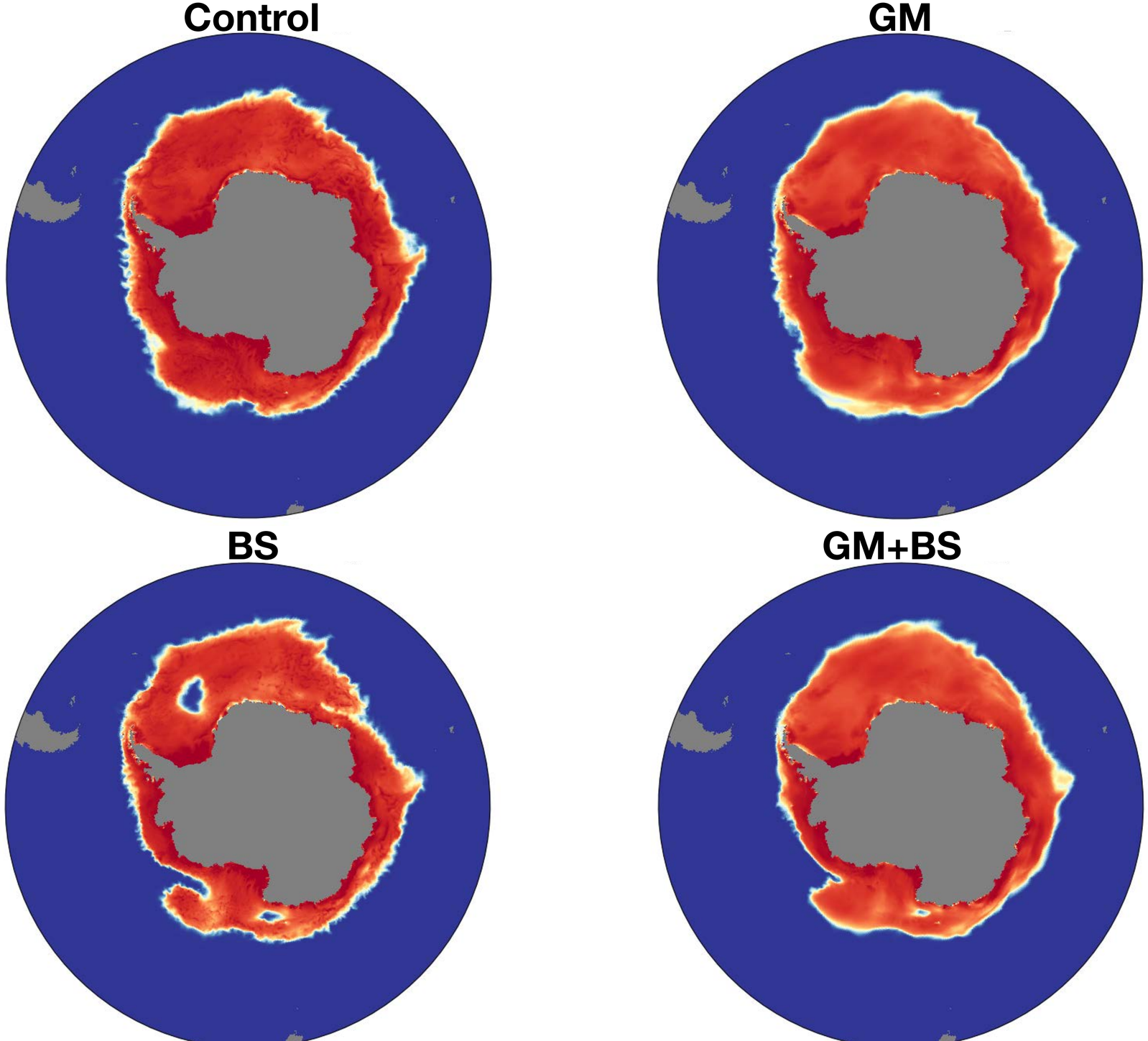
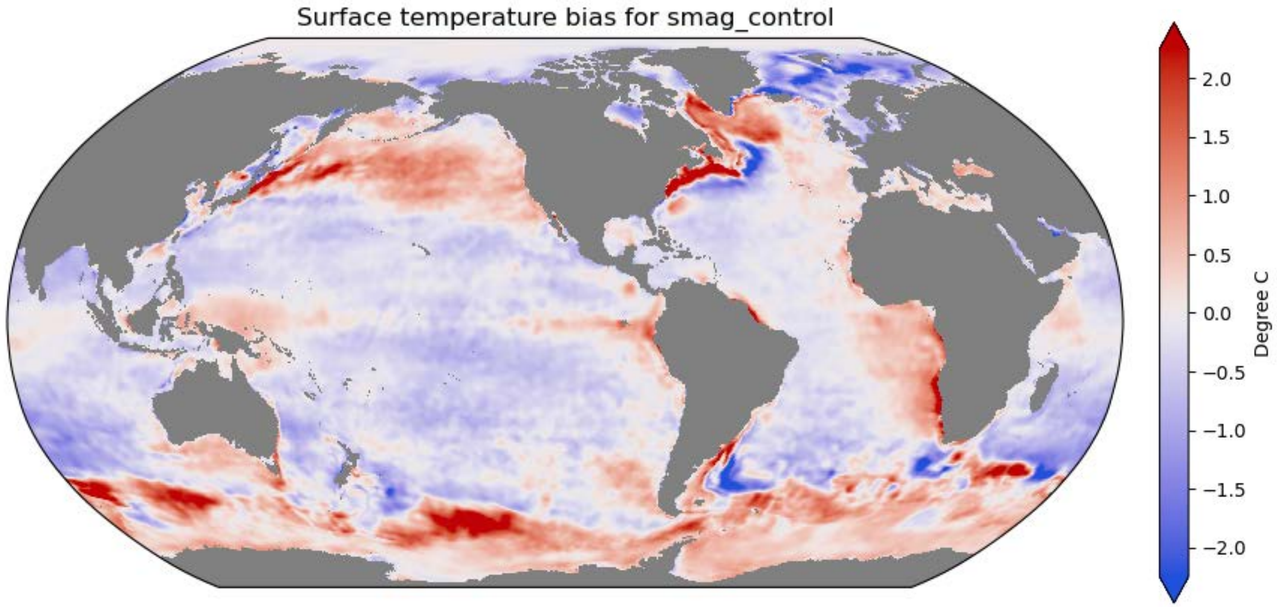
Shifts deep mixed layers in Southern Ocean to the south.

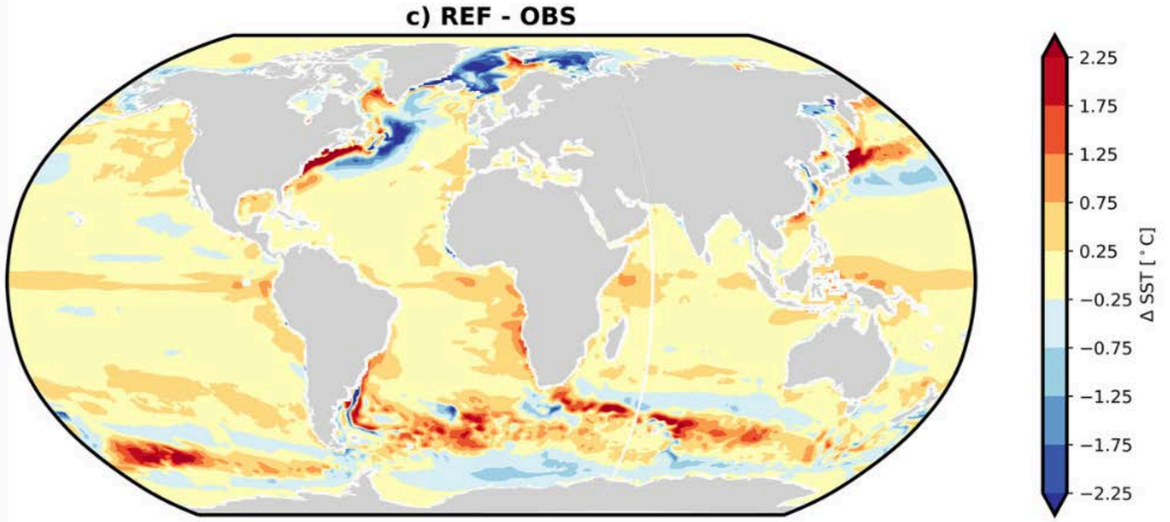

Total sea ice area in September
Total sea ice area ($10^6 km$)
Years
smag_control
smag_GM
smag_GMbs
smag_bs
18
17
16
15
14
1
2
3
4
5
6
7
8
9
10

Sea ice area on
0010-09



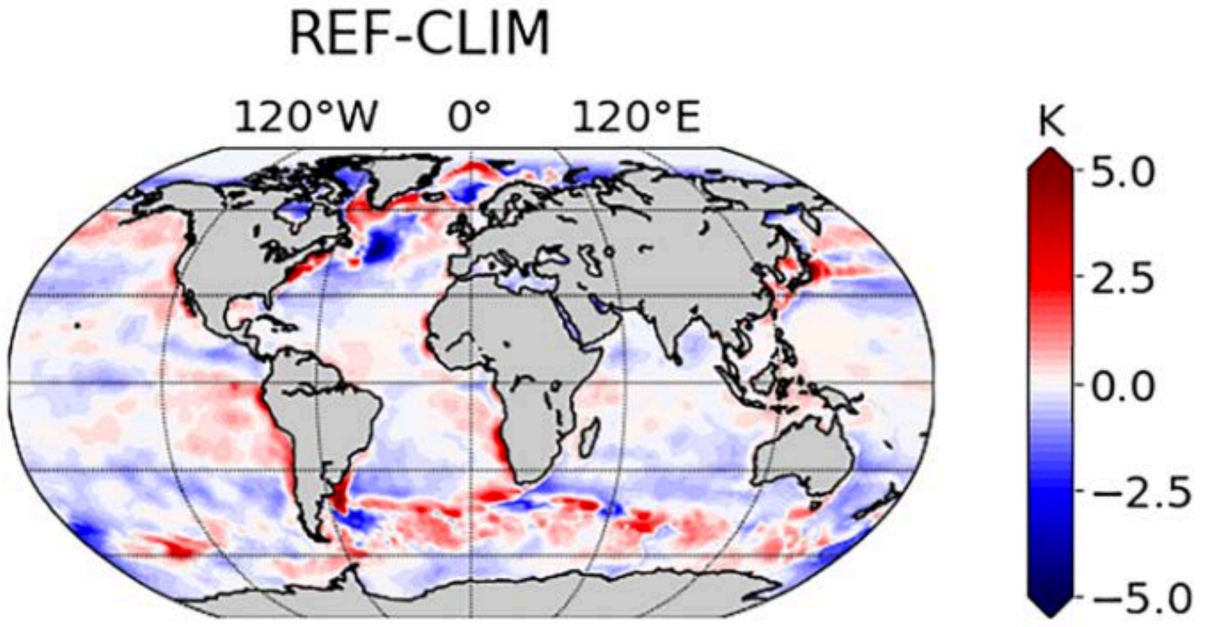
Chang et al. 2023





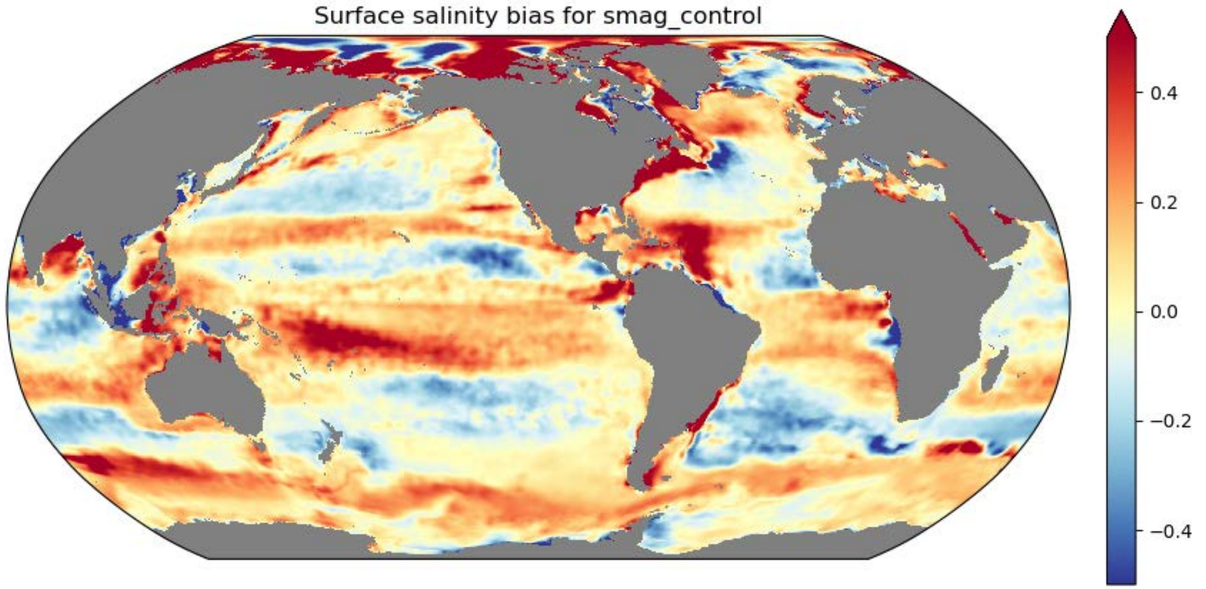
SST bias for control

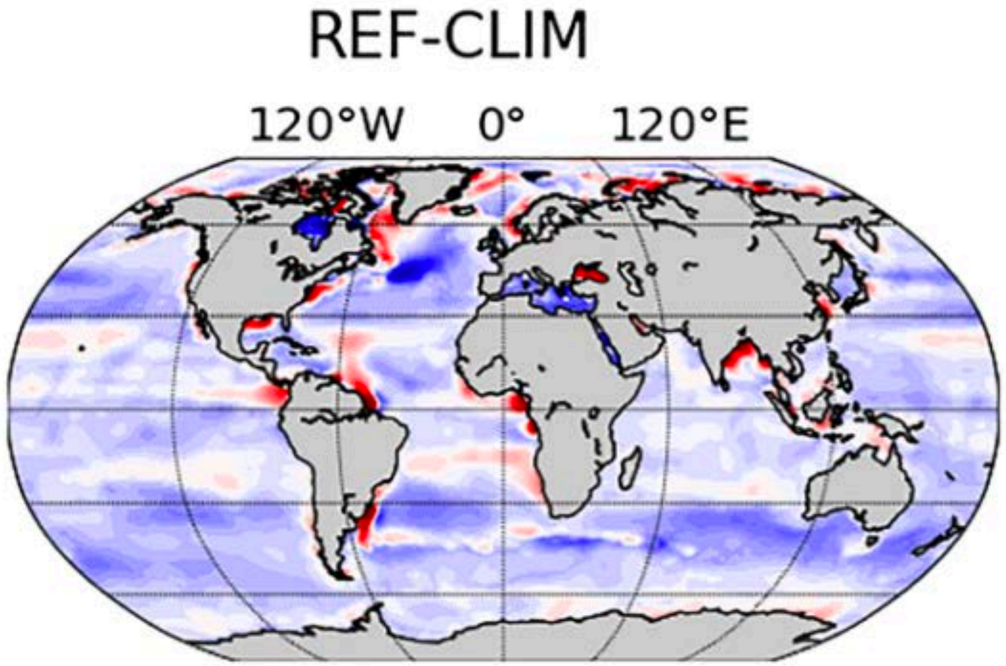
CESM3 has a warmer SO!

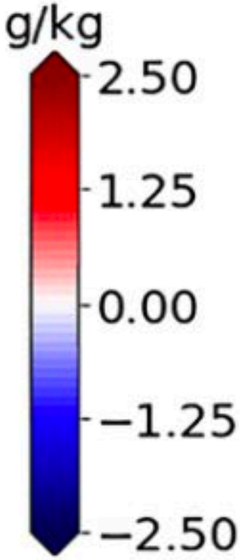


Juricke et al. 2020

Surface salinity bias in control







Maybe the problem is with the control?

FESOM2 saw largest bias reductions in the Southern Ocean

Southern ocean cooler and less saline than observations

If southward transport of heat/freshwater is due to eddies…
then we need a control with the appropriate biases

What does backscatter do?

Energizes eddies.

Reduces SST biases (in NH)

More barotropic ocean.

Increases SST and SSS of Southern Ocean.

Increases southward heat transport.

Deepens Southern Ocean mixed layers

Shifts deep mixed layers in Southern Ocean to the south.