Vertical heat and salinity fluxes due to resolved and parameterized meso-scale eddies

Jin-Song von Storch

Max-Planck-Institut für Meteorologie
Hamburg

J.-S. von Storch, H. Haak, E. Hertwig and I. Fast, 2016: Vertical heat and salinity fluxes due to resolved and parameterized meso-scale eddies. Submitted to Ocean Modelling

Why is high resolution required?

Parameterized eddies do not have the same effect as resolved eddies

To be demonstrated in terms of

- vertical eddy fluxes
- the GM-scheme

Net forcing due to GM: $\nabla \cdot \mathbf{u}_{GM} b = \mathbf{u}_{GM} \cdot \nabla b$

GM-induced hor. velocity: $\mathbf{u}_{GM,h} = -\kappa_{GM} L_z$

Even with a perfect GM (i.e. $\mathbf{u}_{\mathrm{GM}}$ and κ_{GM} are correct), things can go wrong because of inappropriate ∇b and L

Approach: using MPIOM at different resolutions

Two suites of ocean-only simulations with MPIOM/L80, all driven by the 6 hourly NCEP/NCAR reanalysis from 1948-2014 (analysis period 1981-2010)

1. suite	TP6M	TP04	GR15
Horizontal resolution	0.1°	0.4°	1.5°
κ_{GM} [m^2s^{-1}] for Δx=400km	0	250	250
κ_{redi} [m^2s^{-1}] for Δx=400km	1000	1000	1000

2. suite	GR15	GR15_4x	GR15_16x
Horizontal resolution	1.5°	1.5°	1.5°
κ_{GM} [m^2s^{-1}] for Δx=400km	250	1000	4000
κ_{redi} [m^2s^{-1}] for Δx=400km	1000	1000	1000

x

NOTE: All simulations use the same modified PP-scheme, the same background diffusivity, the same parameterization for convection

Approach: using MPIOM at different resolutions

The analysis focuses on

- In TP6M (TP04/GR15): divergence of the resolved eddy fluxes, e^x

$$e^x = -\nabla \cdot \left(\overline{b'\mathbf{u}'}\right),$$

$$E^x = -\frac{1}{V}\int_A \int_{k^+}^{k^-} e \, dz dA = -\frac{1}{V}\int_A \int_{k^+}^{k^-} \frac{\partial \overline{b'w'}}{\partial z} \, dz dA = \frac{1}{V}\int_A \left(\left(\overline{b'w'}\right)_{k^+} - \left(\overline{b'w'}\right)_{k^-}\right) dA$$

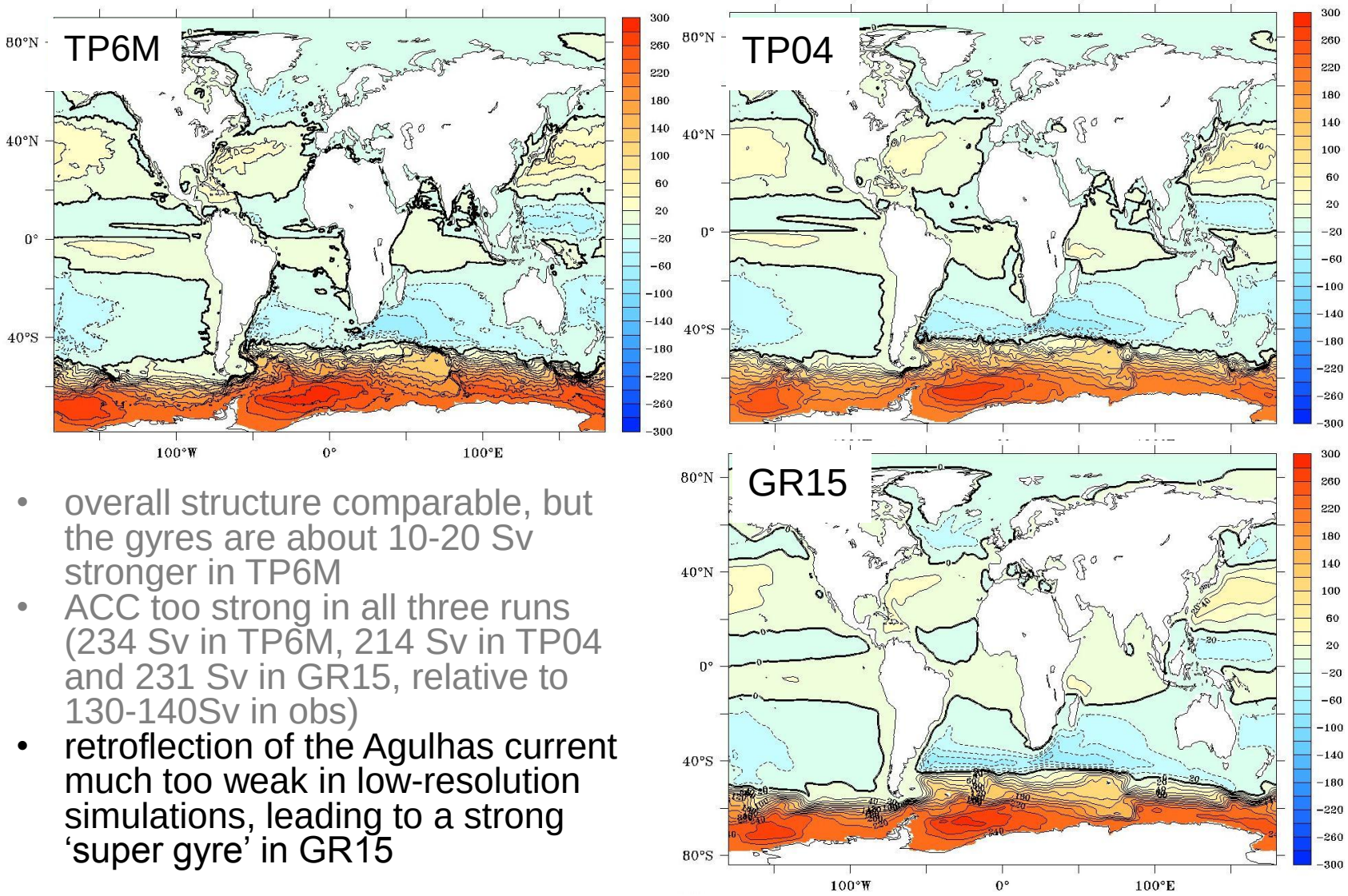
- In TP04/GR15: tendency forcing due to GM-parameterization e_{GM}

$$e_{GM} = -\nabla \cdot \left(\mathbf{u}_{GM} b\right), \qquad E_{GM} = -\frac{1}{V}\int_A \int_{k^+}^{k^-} e_{GM} \, dz dA$$

- In TP04/GR15: tendency forcing due to Redi-diffusion e_{Redi}

$$e_{\mathrm{Redi}} = -\nabla \cdot \left(K \nabla b\right), \qquad E_{\mathrm{Redi}} = -\frac{1}{V}\int_A \int_{k^+}^{k^-} e_{\mathrm{Redi}} \, dz dA$$

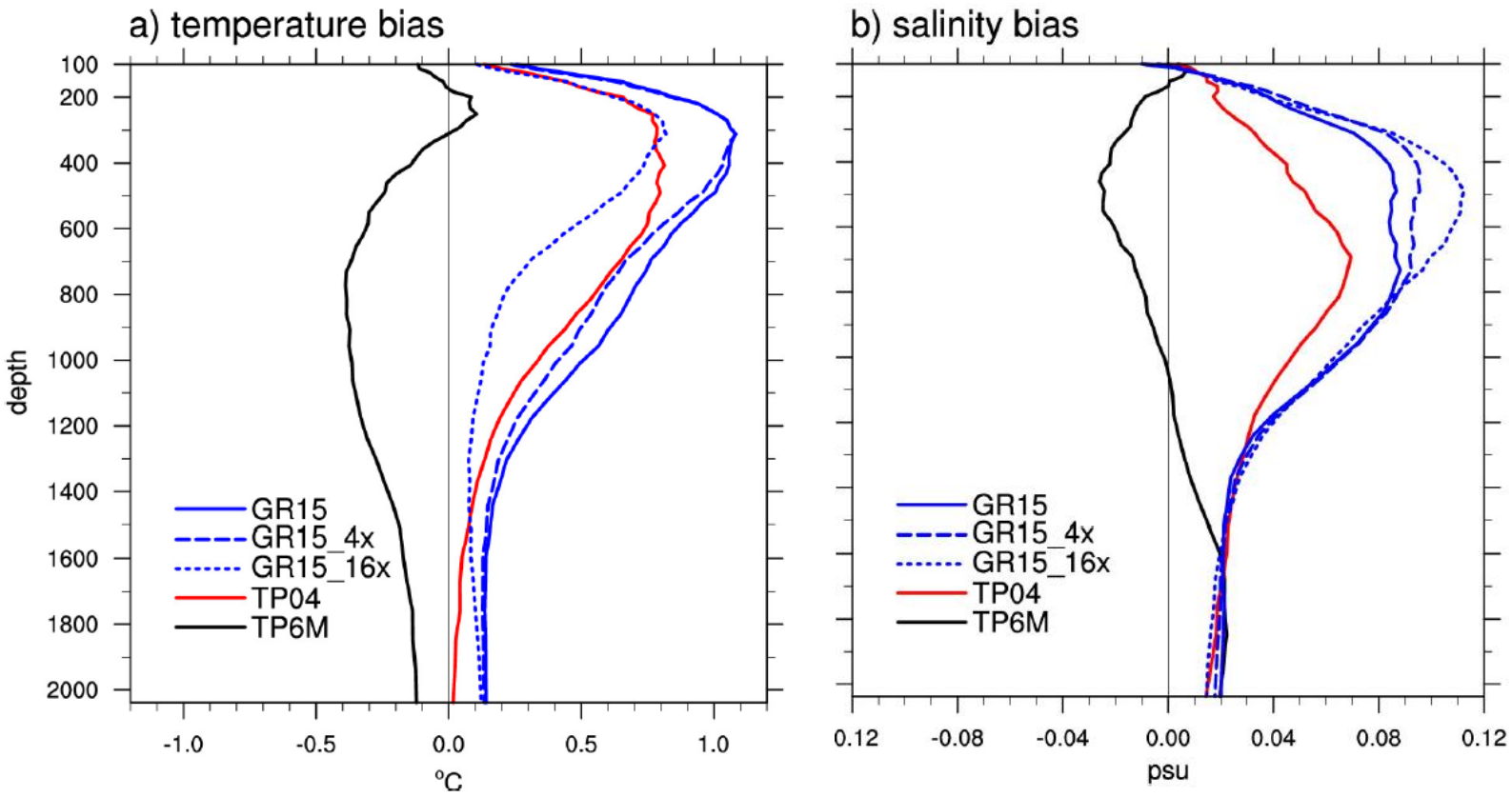
Approach: using MPIOM at different resolutions



- overall structure comparable, but the gyres are about 10-20 Sv stronger in TP6M
- ACC too strong in all three runs (234 Sv in TP6M, 214 Sv in TP04 and 231 Sv in GR15, relative to 130-140Sv in obs)
- retroflection of the Agulhas current much too weak in low-resolution simulations, leading to a strong ‘super gyre’ in GR15

The role of ∇b

Horizontally averaged biases (relative to PHC3)

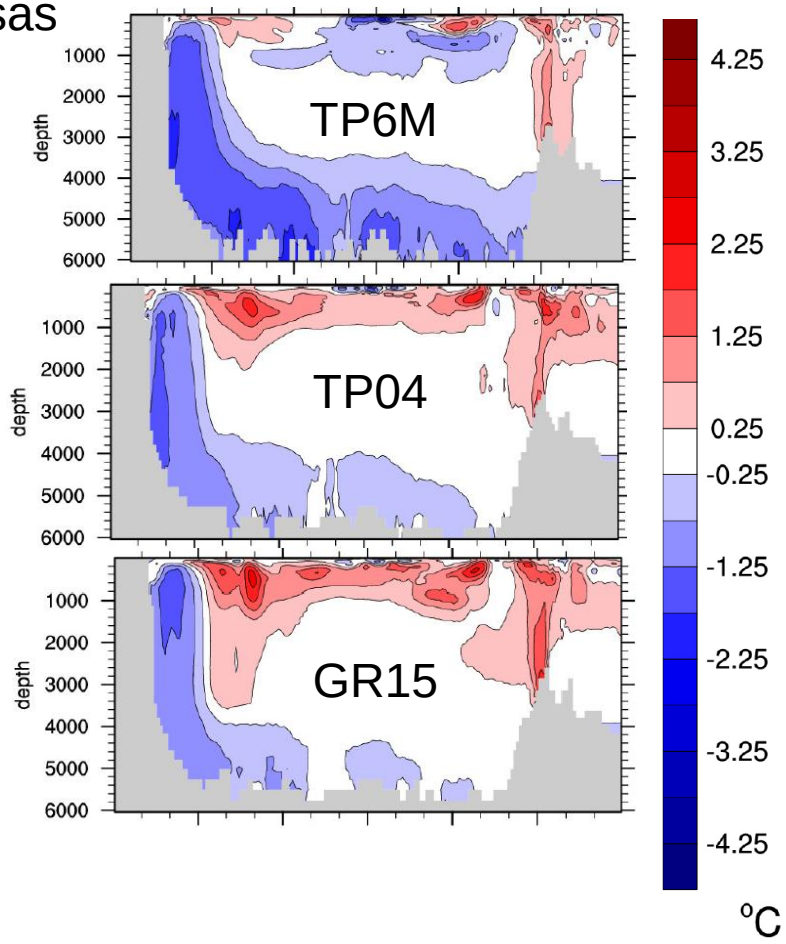


- The long-standing warm and saline biases in TP04 and GR15 at the intermediate depths from 100-1500 m are reduced in TP6M

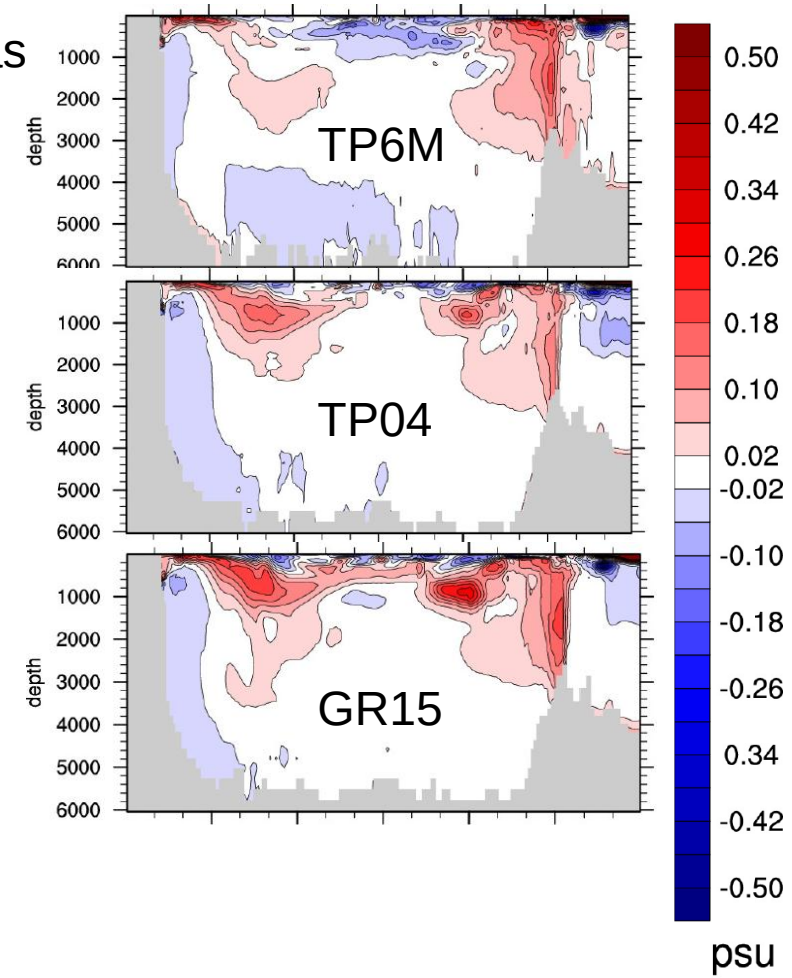
The role of ∇b

Zonally averaged biases (relative to PHC3)

T bisas

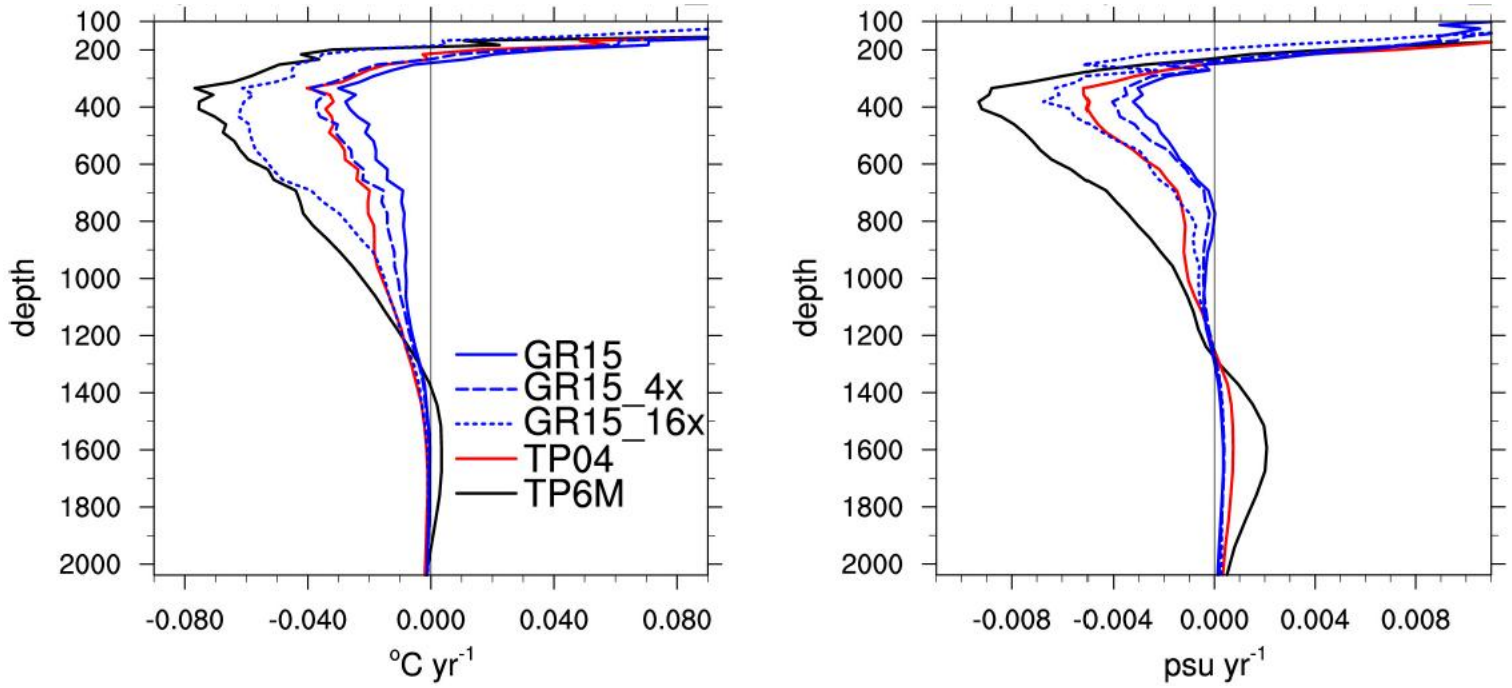


S bias



The role of ∇b

Hor. averaged eddy forcing E (TP6M: $\nabla \cdot \overline{\mathbf{u}'b'}$, TP04/GR15: $\nabla \cdot \overline{\mathbf{u}'b'}$ +tend$_{GM}$+tend$_{Redi}$)

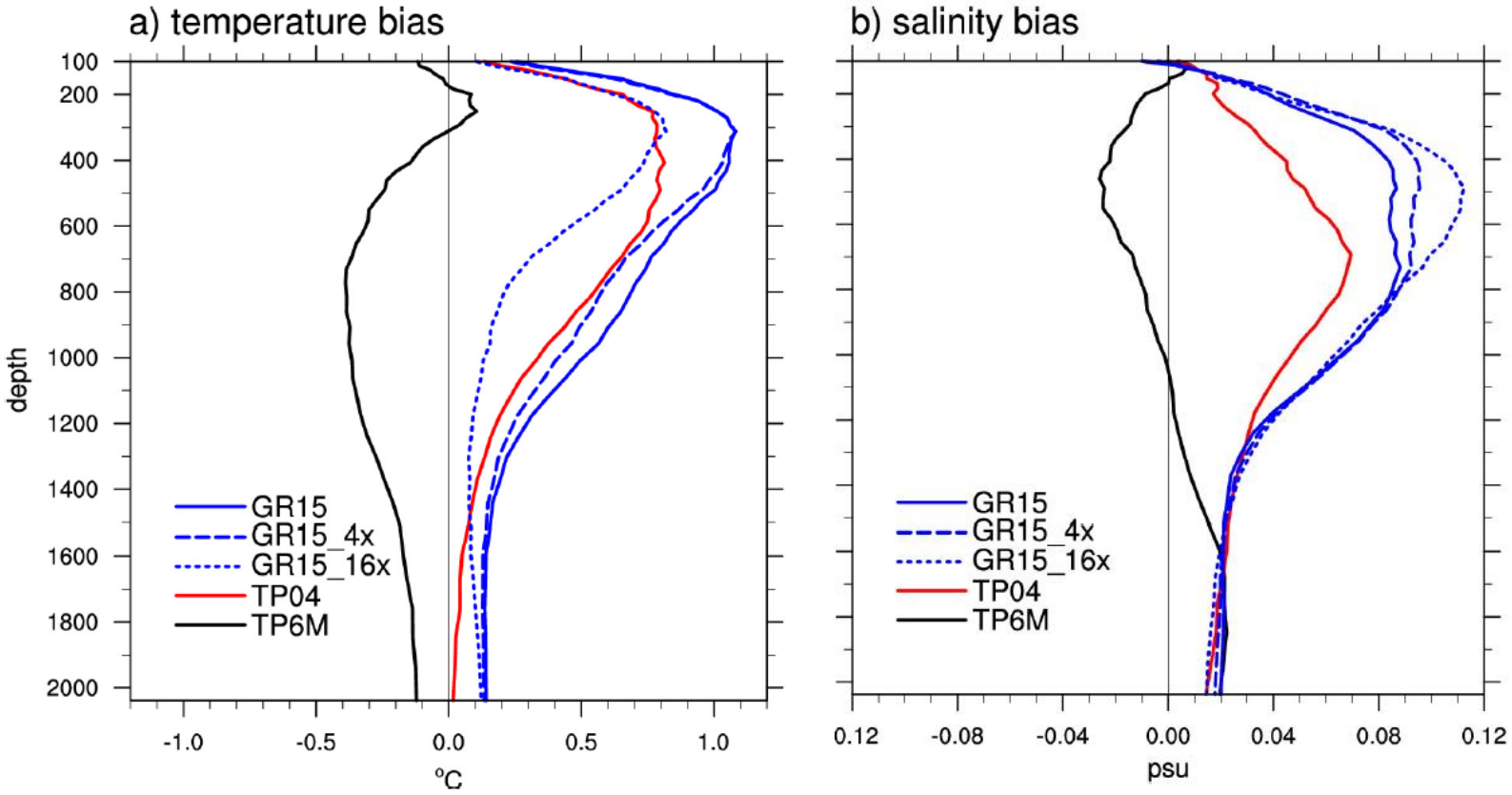


At intermediate depths:

- Both resolved and parameterized eddy forcing cools and freshens the water masses, with E=E^{x} + E_{GM} in GR15/TP04 being weaker than E=E^{x} in TP6M
- Increasing thickness diffusivity increases |E|

The role of ∇b

Area-averaged biases (relative to PHC3)

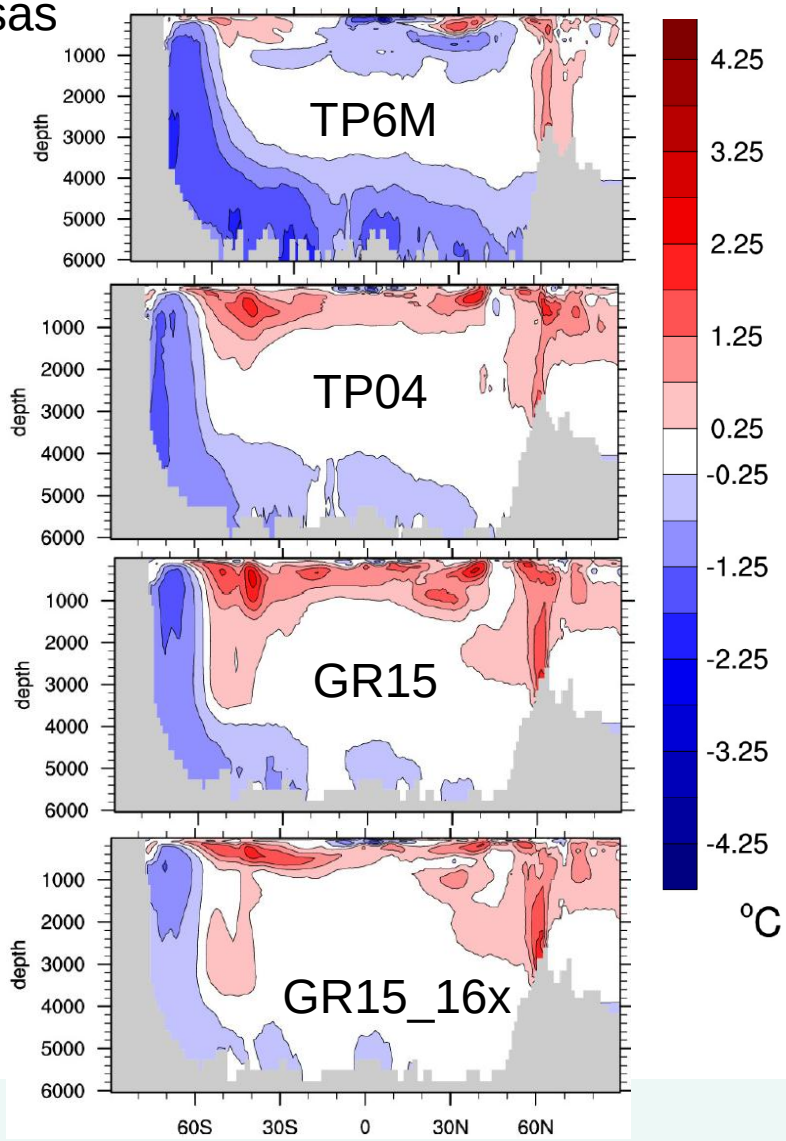


- Increasing thickness diffusivity reduces the warm biases, but increases the saline biases

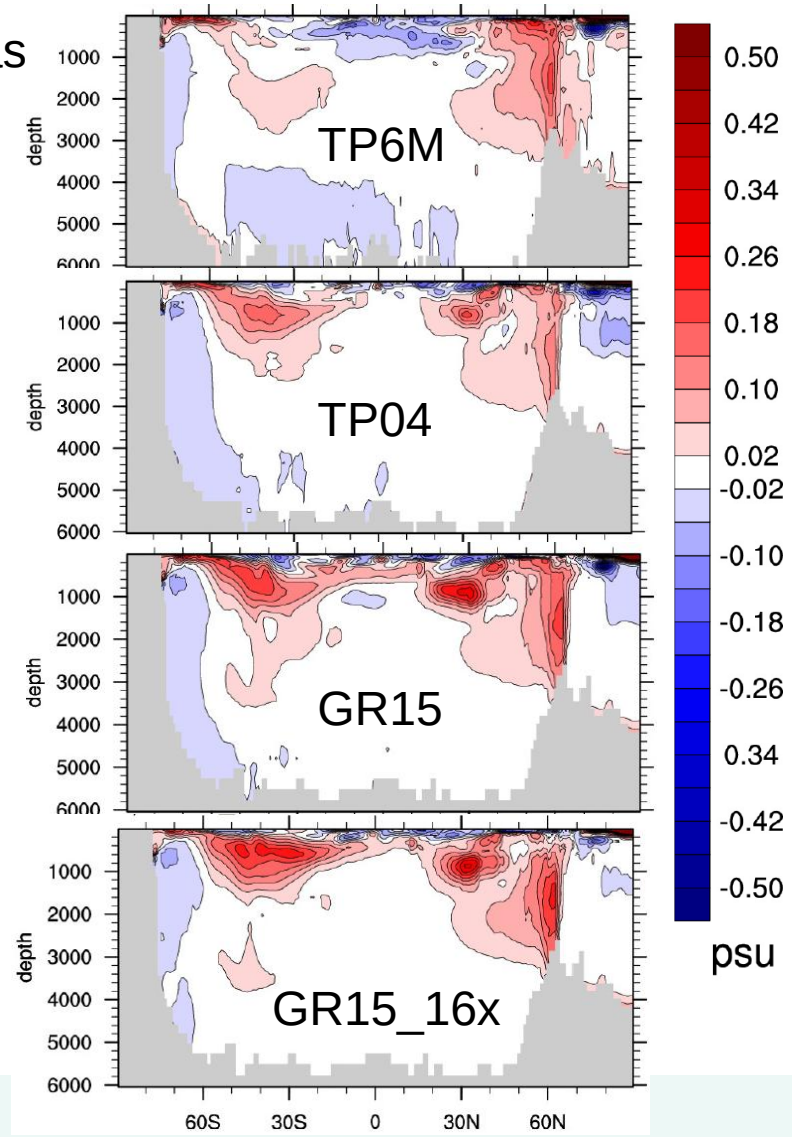
The role of ∇b

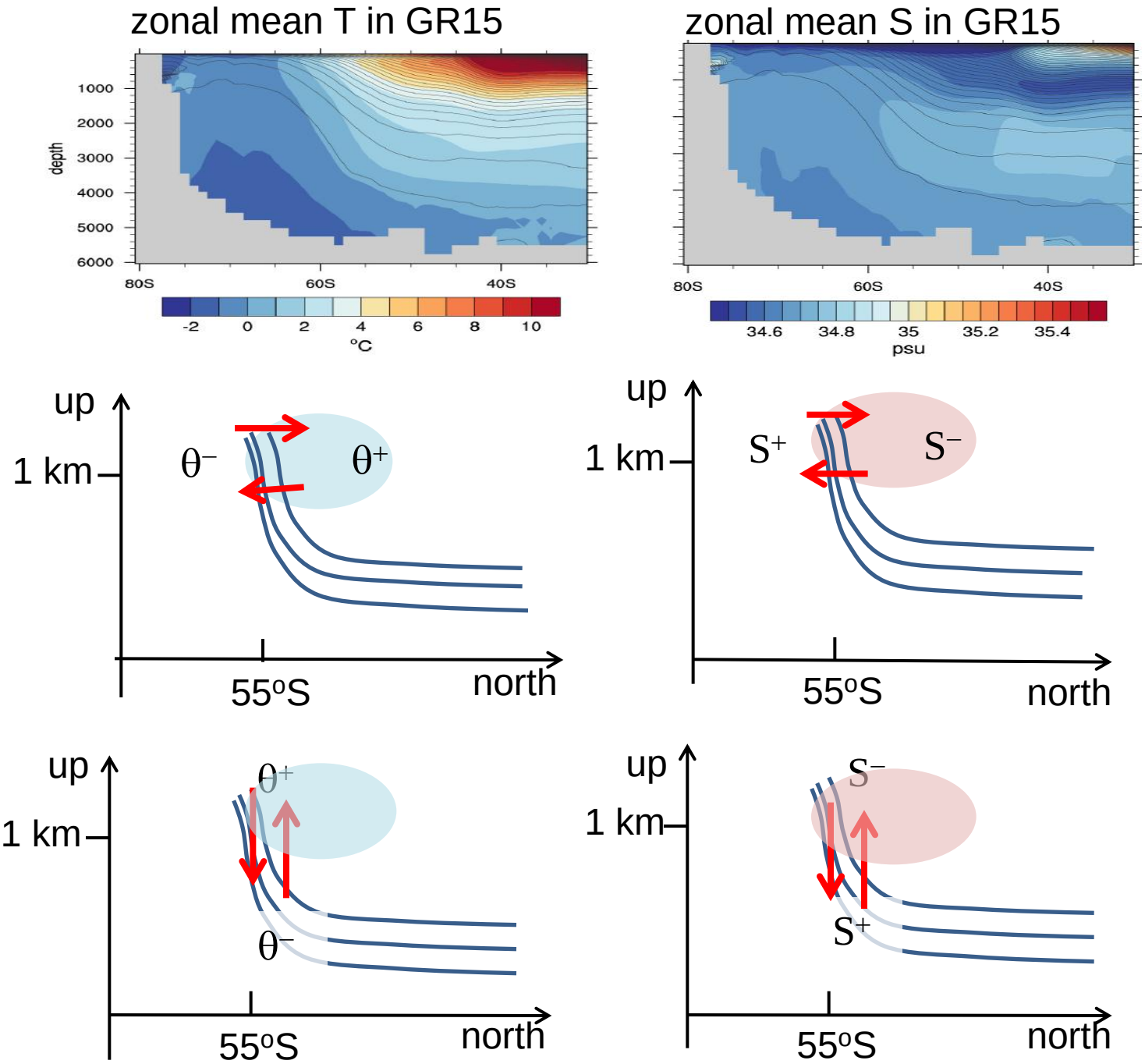
Zonally averaged biases (relative to PHC3)

T bisas



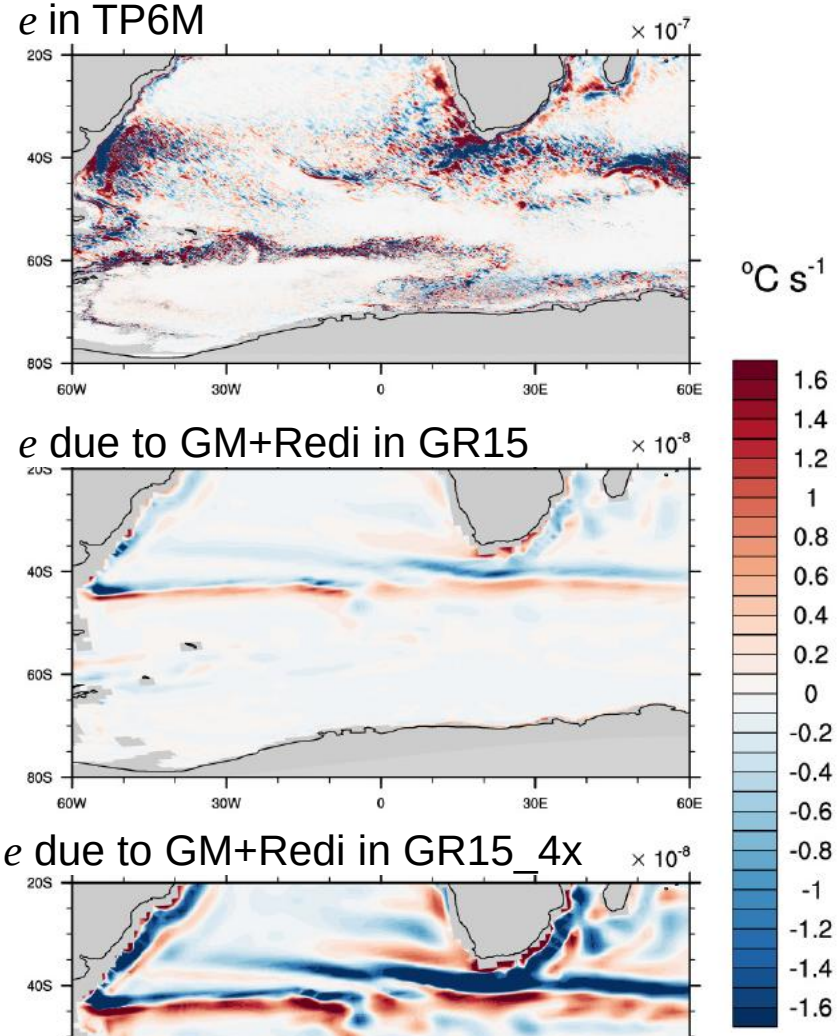
S bias




zonal mean T in GR15
zonal mean S in GR15
depth
1000
2000
3000
4000
5000
6000
80S
60S
40S
-2
0
2
4
6
8
10
°C
34.6
34.8
35
35.2
35.4
psu
up
1 km
θ−
θ+
55ºS
north
S+
S−

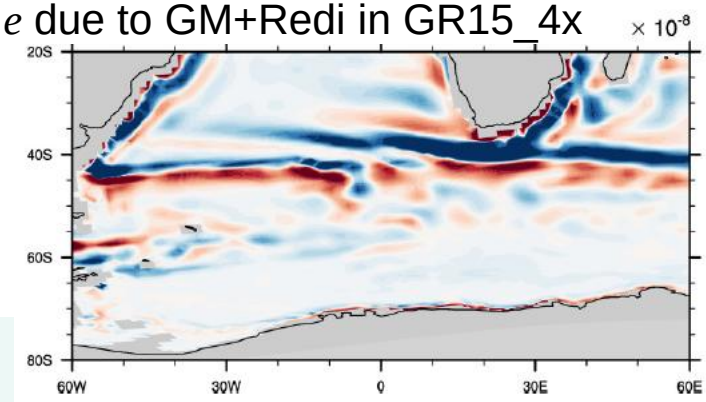
The role of L

e in TP6M

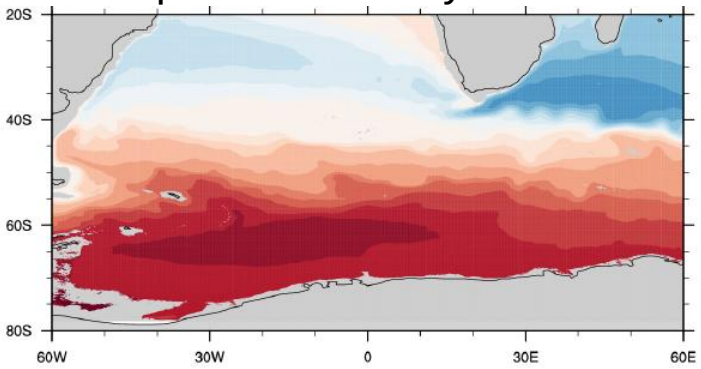


e due to GM+Redi in GR15

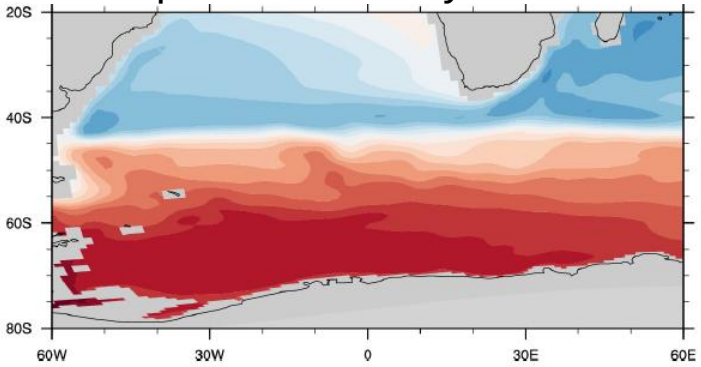
e due to GM+Redi in GR15_4x

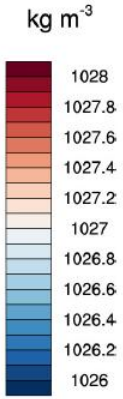


Local potential density in TP6M



Local potential density in GR15





Conclusions

Regarding to GM-parameterization: $\nabla \cdot \mathbf{u}_{GM} b = \mathbf{u}_{GM} \cdot \nabla b$, $\mathbf{u}_{GM,h} = -\kappa_{GM} L_z$

- The net effect depends not only on $\mathbf{u}_{GM}$ but also on the simulated tracer distribution ∇b

  Given a S-distribution with a tongue of fresh AAIW, salinity advection via eddy-induced meridional circulation tends to strengthen the saline biases in the Southern Ocean.

- $\mathbf{u}_{GM}$ depends not only on the thickness diffusivity, but also on the simulated isoneutral slope L

  Due to the density biases in low-resolution simulation parameterized eddy-induced transports do not always occur where they should

General problem:
For a parameterization $\mathscr{P}(\alpha,\boldsymbol{X})$ (α = parameter, $\boldsymbol{X}$=model state), the effect of $\mathscr{P}(\alpha,\boldsymbol{X})$ can be wrong because of the dependence of $\mathscr{P}(\alpha,\boldsymbol{X})$ on $\boldsymbol{X}$, normally a biased state simulated by a low-resolution model-

Thanks!