Parameterization of lateral boundary layer eddy diffusion in ocean models with a general vertical coordinate

Gustavo Marques, Andrew Shao, Scott Bachman, Keith Lindsay, Gokhan Danabasoglu and Frank Bryan
(gmarques@ucar.edu)

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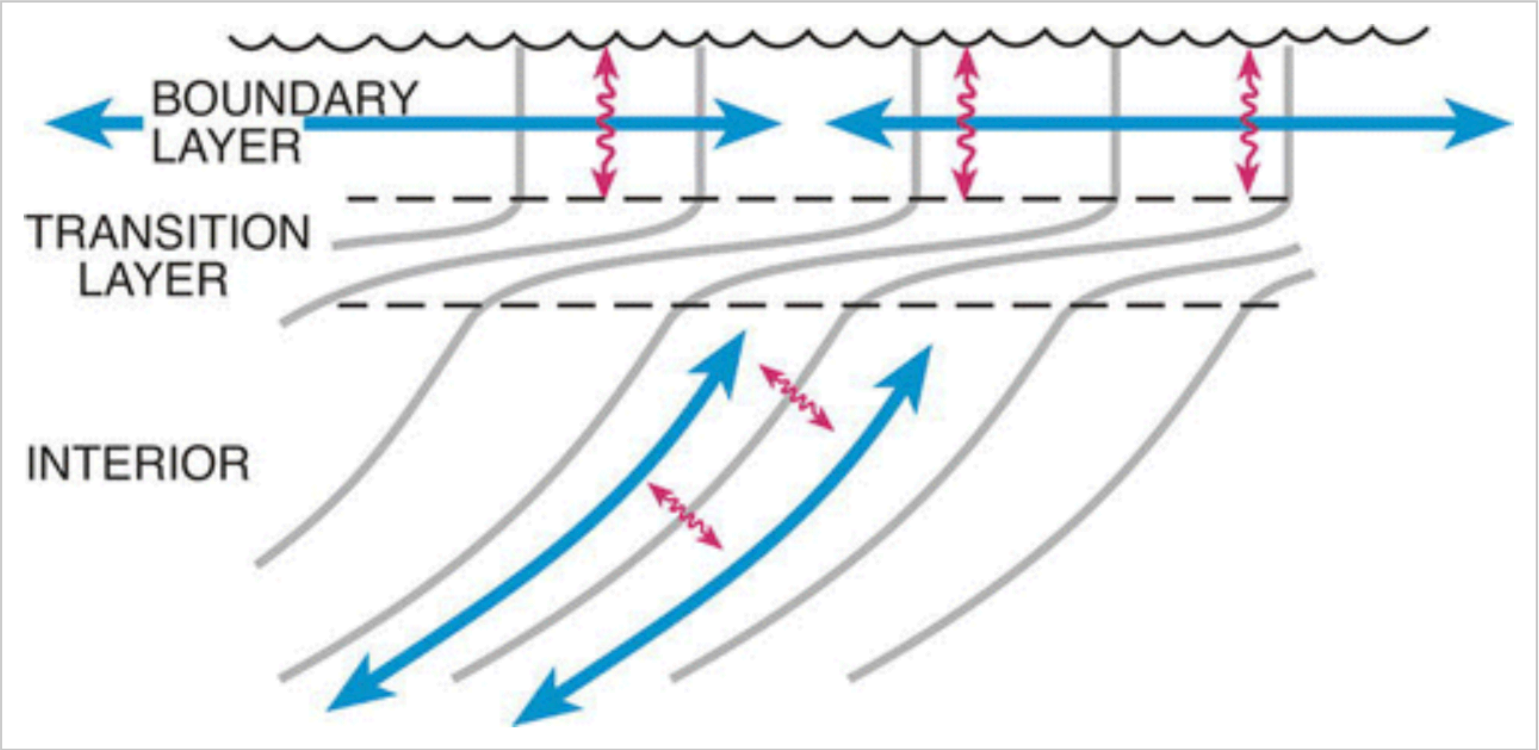
Motivation

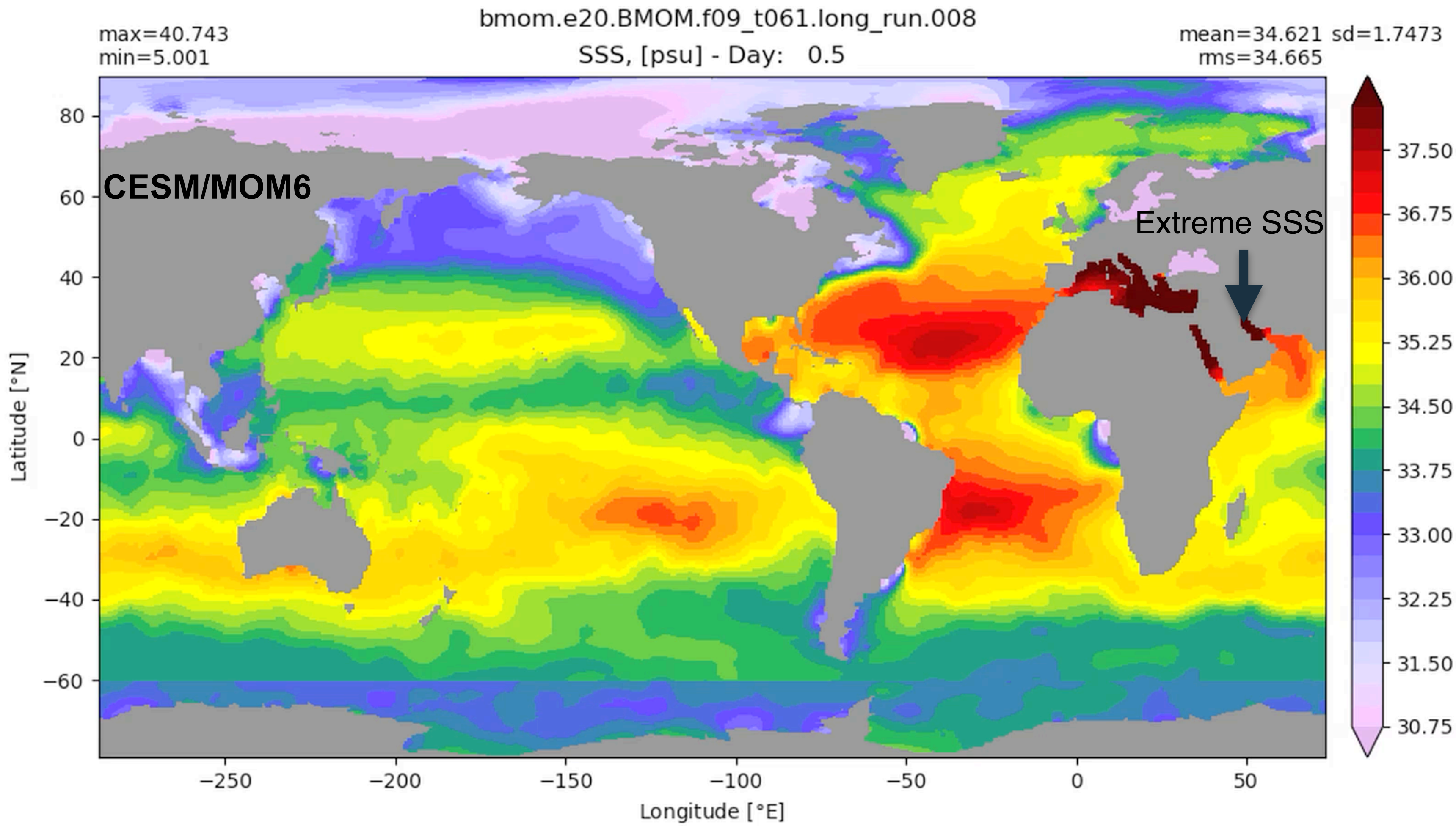
The idea of (lateral) diabatic eddy fluxes near boundaries was initially proposed by Treguier et al., (1997)

Conceptual model of eddy fluxes in the upper ocean



From: Ferrari et al., 2008

Extreme surface salinity in fully-coupled simulations



We were compelled to follow previous conceptual model hoping to minimize this issue

Plan of action

Goal: represent the lateral diffusive tracer fluxes due to mesoscale eddies within the boundary layers of general vertical coordinate ocean models

Neutral (Redi)

$$\kappa_n = \kappa \begin{bmatrix} 1 & 0 & S_x \\ 0 & 1 & S_y \\ S_y & S_x & S_x^2 + S_y^2 \end{bmatrix}$$

Lateral

$$\kappa_L = \kappa \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

We need a method that works in conjunction with neutral diffusion schemes in general vertical coordinate ocean models ⟶ Andrew Shao's seminar

Methods proposed

- **Layer by layer**: more straight forward, diffusion is applied layer by layer using only information from neighboring cells
- **Bulk approach**: lower order representation (Kraus-Turner like), assumes eddies are acting along well mixed layers (i.e., eddies don't know about vertical tracer profiles within the boundary layer)

Layer by layer method

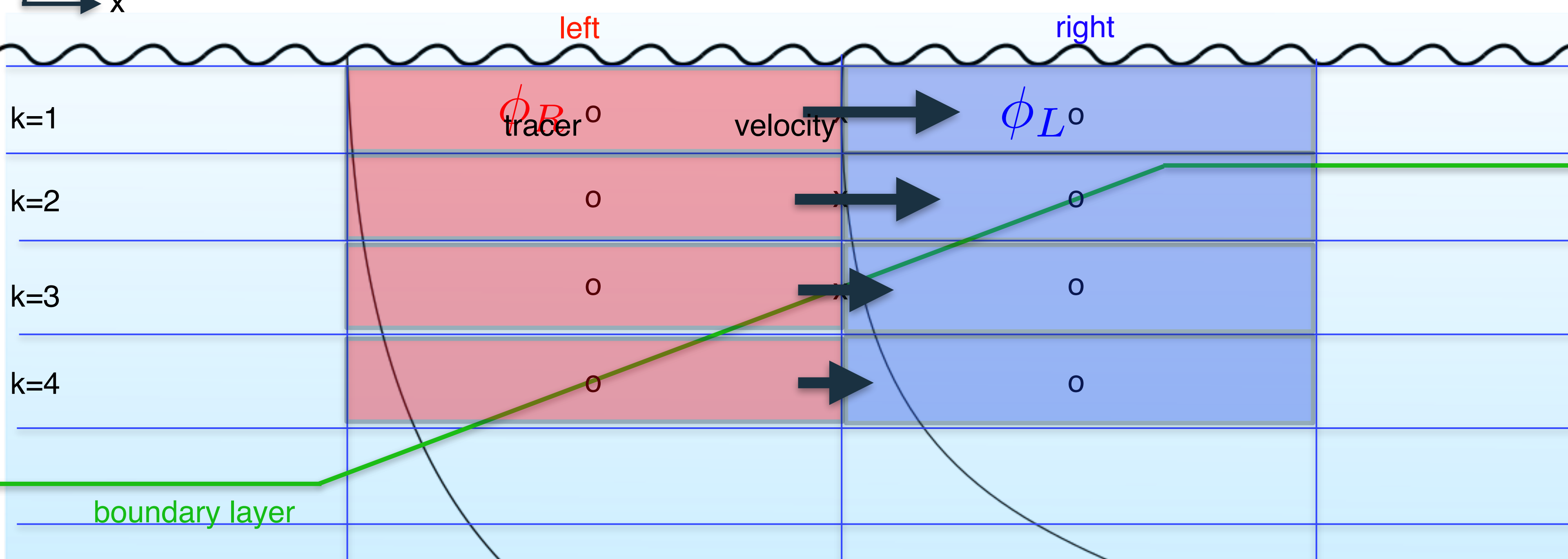
1) vertical indices containing boundary layer (k=4,2)

2) calculate diffusive flux at each layer

$$F(k) = -\kappa_u \times h_{eff}(k) \times [\phi_R(k) - \phi_L(k)]$$ ⟶ always down-gradient $\phi_R > \phi_L$

$$h_{eff}(k) = \frac{2 \times h_L(k) \times h_R(k)}{h_L(k) + h_R(k)}$$ ⟶ harmonic mean of thicknesses at each layer

3) flux decays linearly between k=4,2



Module MOM_lateral_boundary_diffusion

Branch: near_surface_f... MOM6 / src / tracer / MOM_lateral_boundary_diffusion.F90 Find file Copy path

gustavo-marques Change flux limiting calculation 0525a4c 2 days ago

2 contributors

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!> Calculates and applies diffusive fluxes as a parameterization of lateral mixing (non-neutral) by
!! mesoscale eddies near the top and bottom (to be implemented) boundary layers of the ocean.

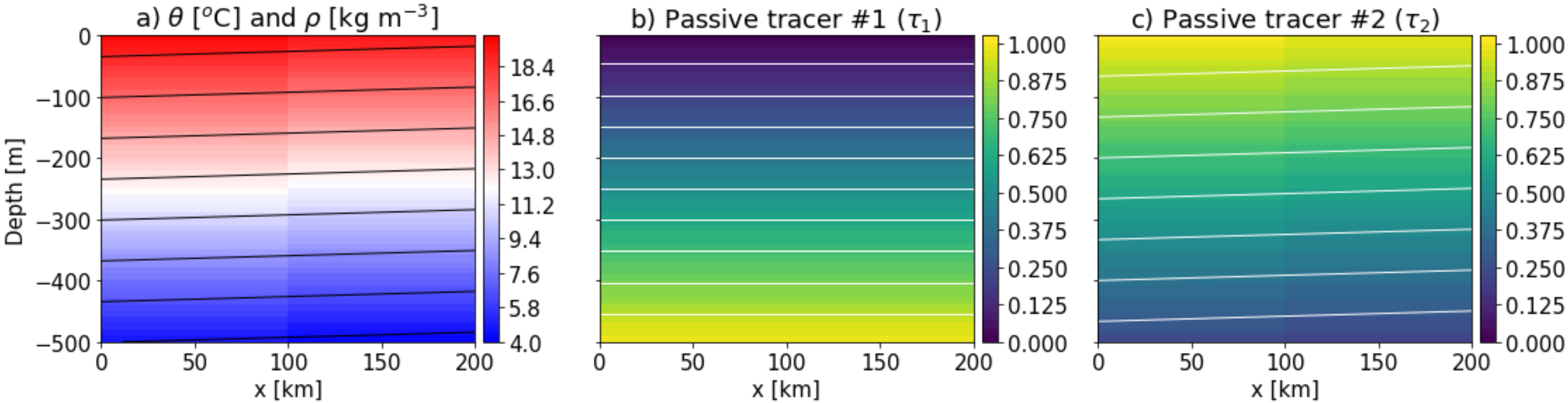
module MOM_lateral_boundary_diffusion

! This file is part of MOM6. See LICENSE.md for the license.

```

- Follows MOM6 code style guide
- dOxyGenized
- Unit tests
- Dimensional consistency testing
- Diagnostics: diffusive flux (x,y; 2D and 3D), tracer tendencies (2D and 3D)

Proof of concept using simple experiments



$\partial_x \tau_1 = 0$ $\tau_2 \parallel \rho$

- $\Delta x = \Delta y = 100$ km
- $\Delta z = 10$ m (vertical coord = Z*)
- $\kappa = 1000$ m^2 s^{-1}
- Linear equation of state
- Prescribed BLD
- No dynamics

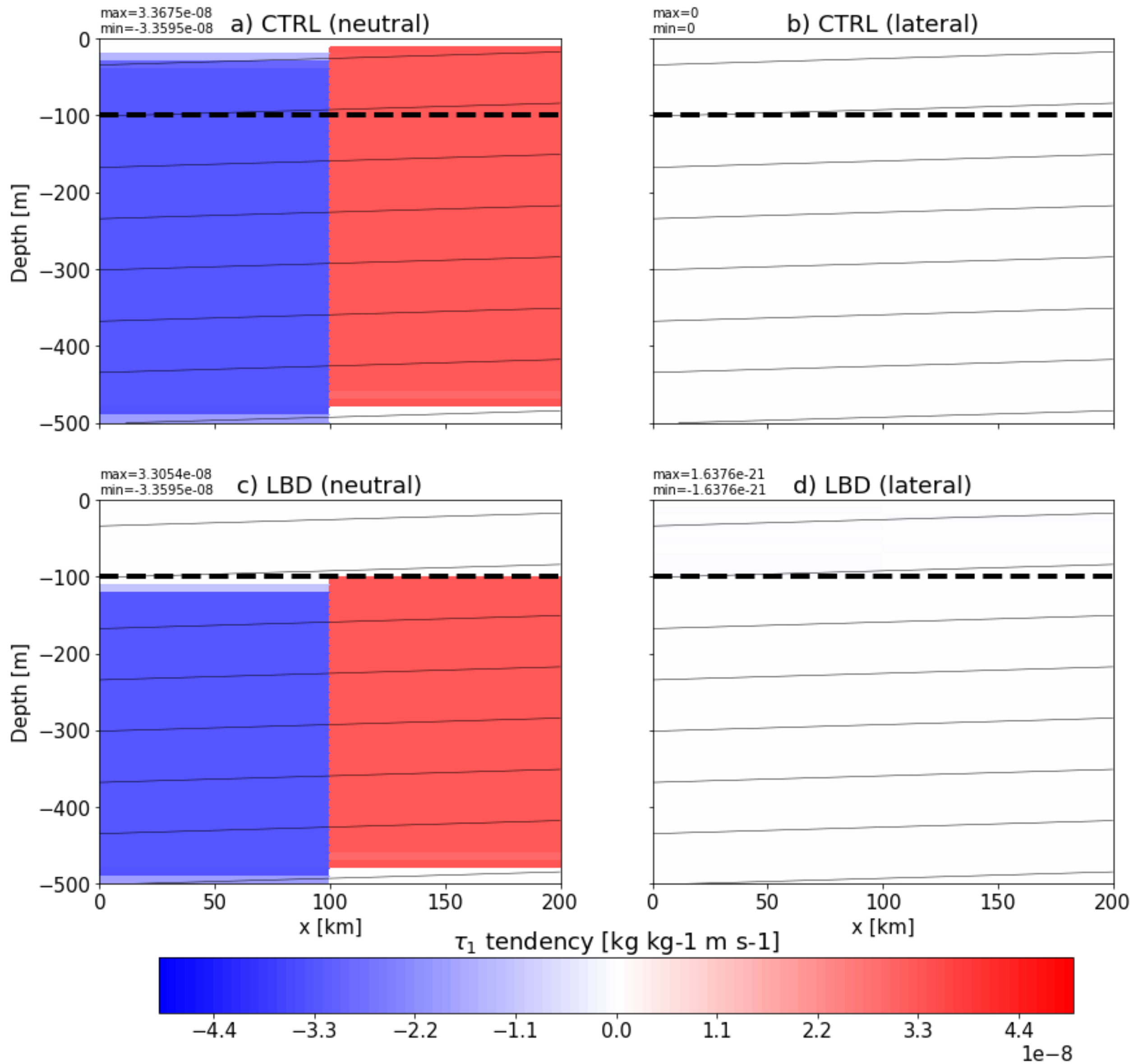
Experiments:

- **CTRL**: neutral diffusion only
- **LBD**: neutral diffusion in the interior; lateral diffusion in the surface BL

$$\partial_t \theta = \underbrace{\nabla_h \cdot (\kappa_l \cdot \nabla_h \theta)}_{\text{Lateral}} + \underbrace{\nabla \cdot (\kappa_n \cdot \nabla \theta)}_{\text{Neutral}} + \underbrace{R_V}_{\text{vertical remapping}}$$

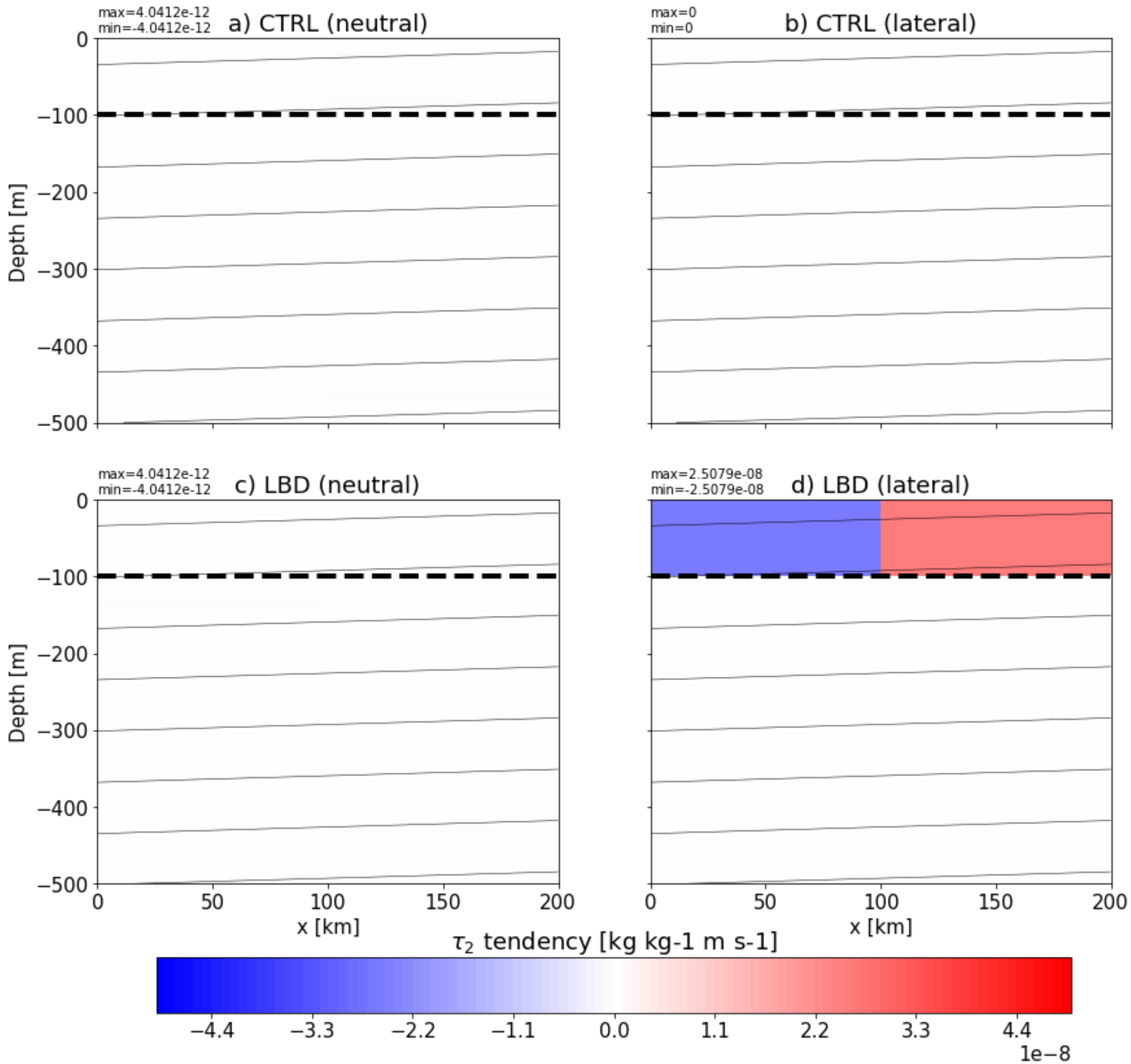
Proof of concept: problem 1 (BLD=100 m), tracer # 1

$$\partial_x \tau_1 = 0$$



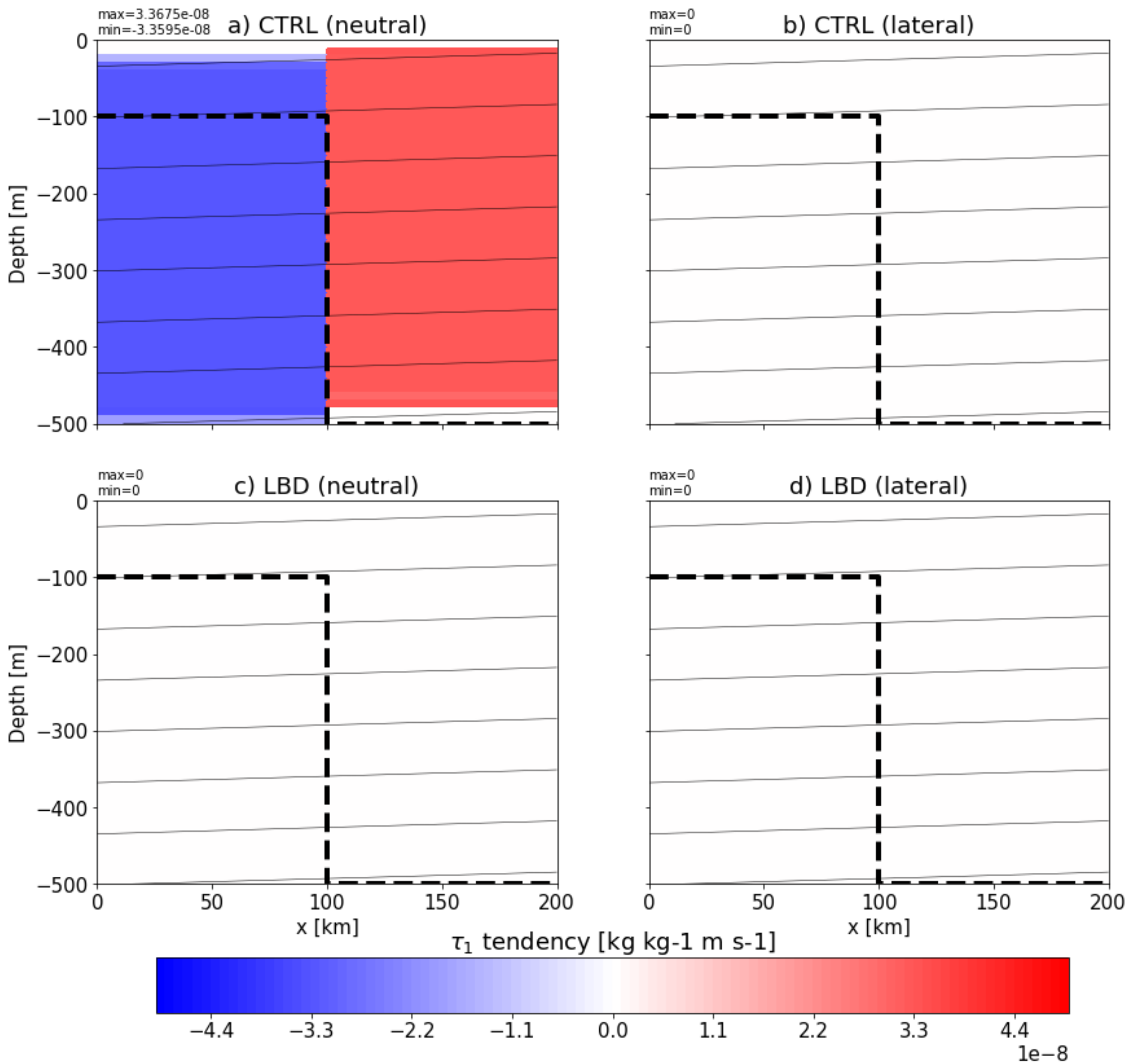
Proof of concept: problem 1 (BLD=100 m), tracer # 2

$\tau_2 \parallel \rho$



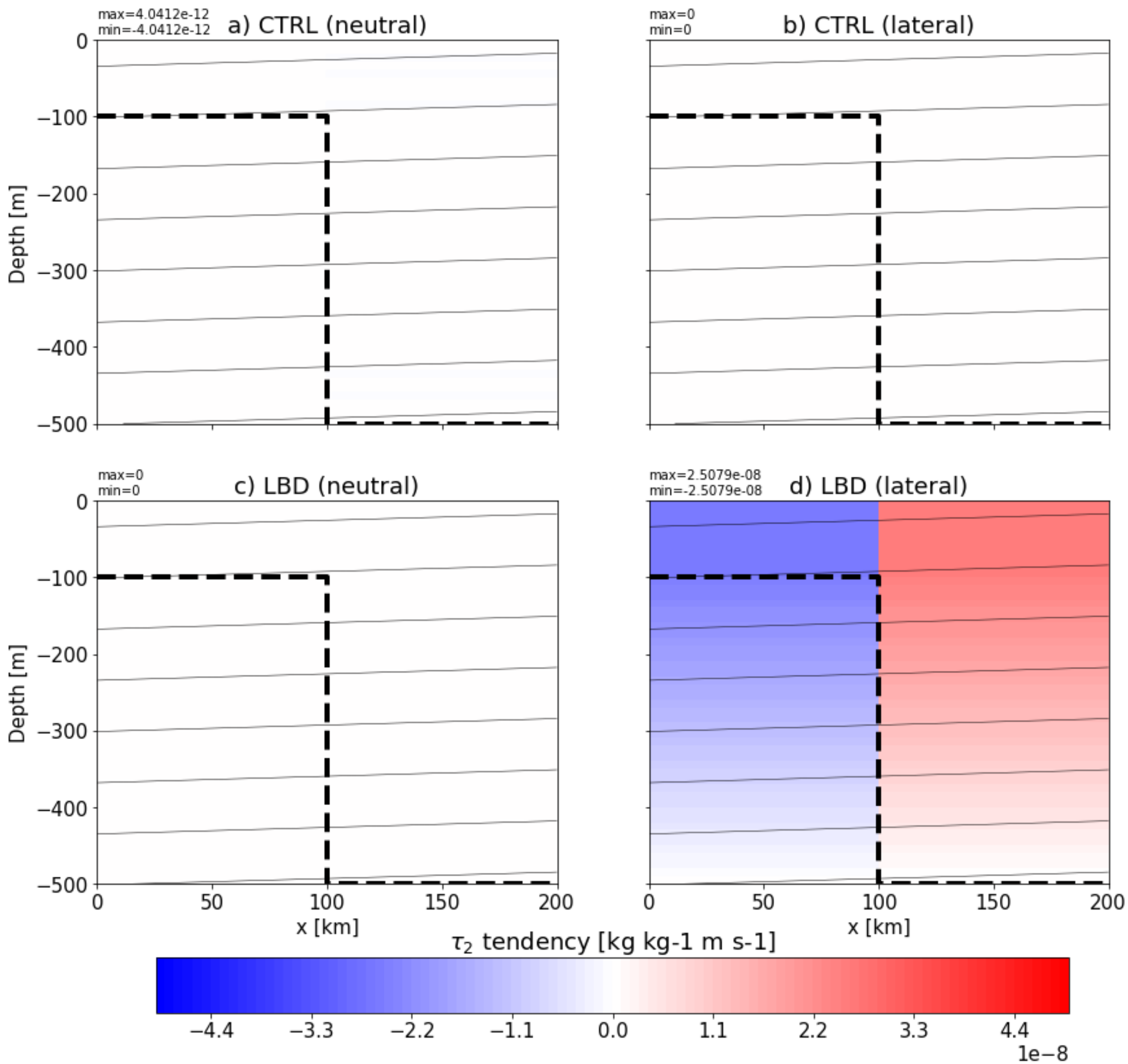
Proof of concept: problem 2 (BLD=100,500 m), tracer # 1

$$\partial_x \tau_1 = 0$$

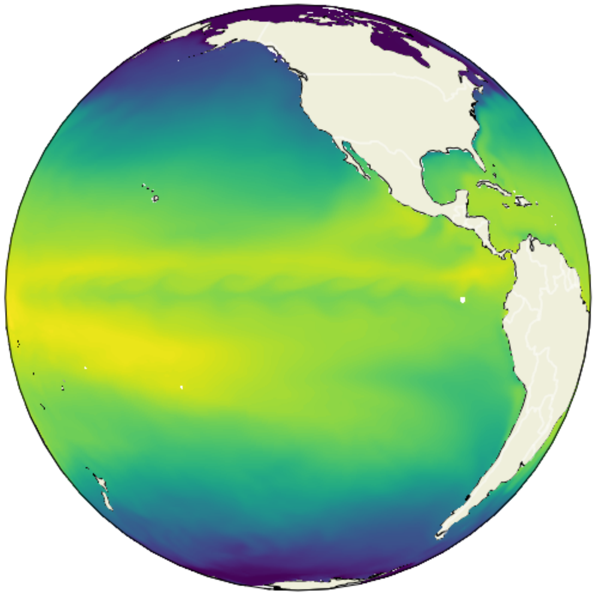


Proof of concept: problem 2 (BLD=100,500 m), tracer # 1

$\tau_2 \parallel \rho$



Global ocean/sea ice experiments with CESM/MOM6



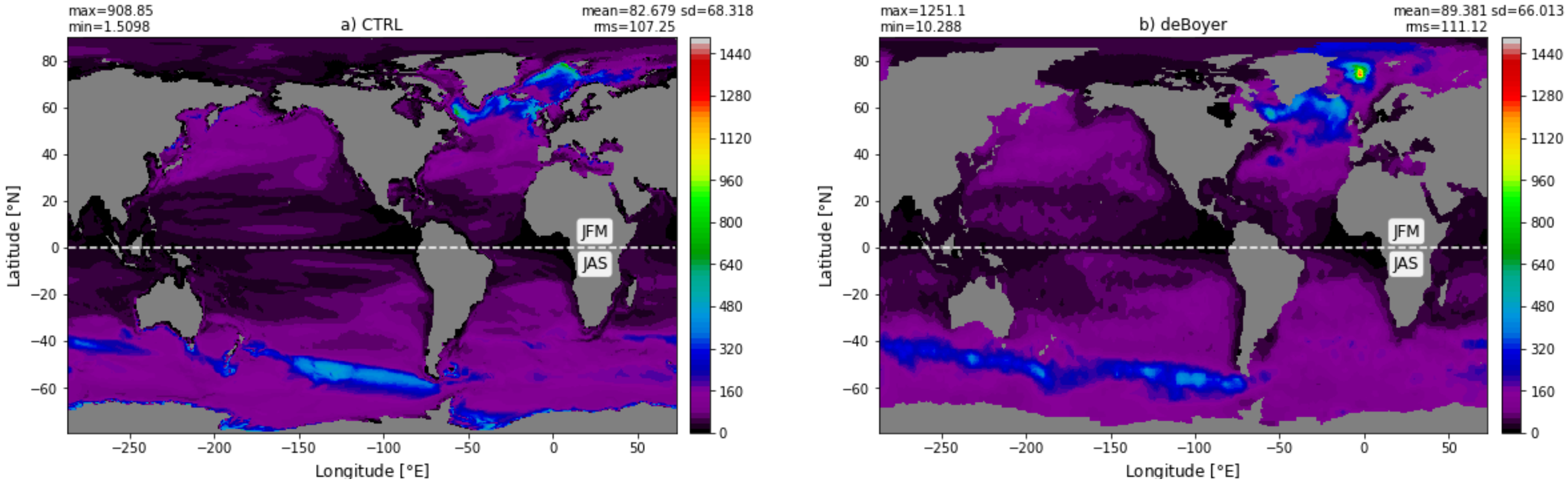
- MOM6/CICE5, JRA-55
- Nominal 2/3^{o} grid spacing, equatorial refinement
- Z* vertical coordinate, 63 layers
- Vertical mixing via CVMix
- GM and tracer diffusivity (Redi) controlled via MEKE/GEOMETRIC
- See my previous talk for a complete description of this configuration

It does not have all the whistles and bells that we want

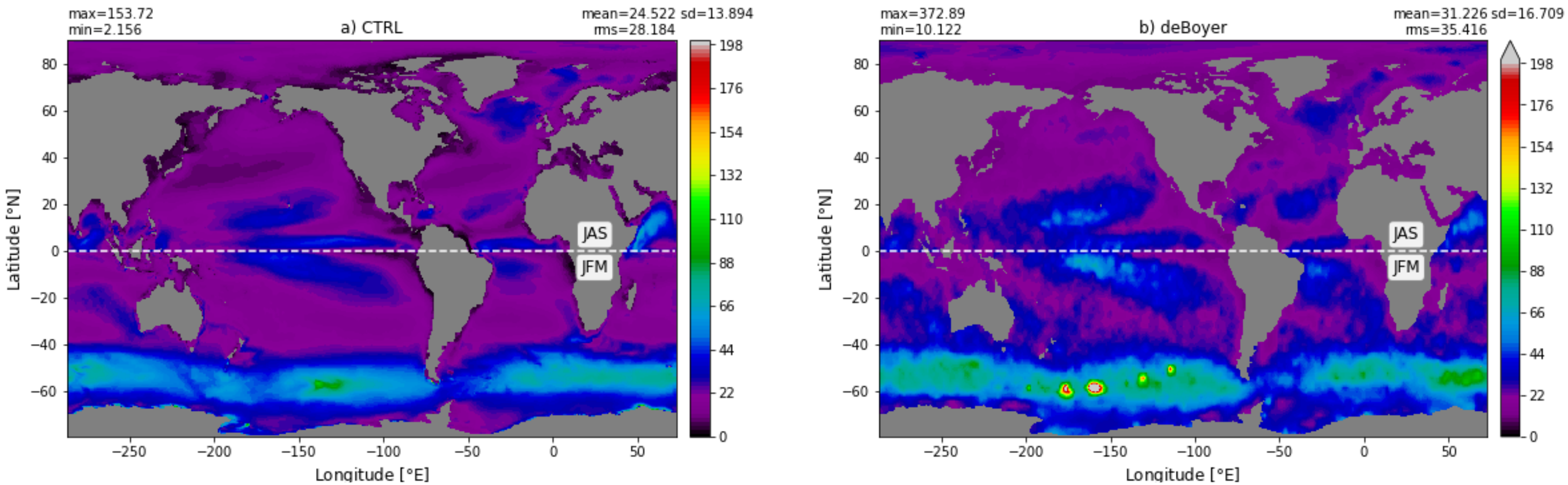
Experiments

- **CTRL**: neutral diffusion throughout the water column
- **LBD**: neutral in the interior, lateral in the surface boundary layer

Mixed layer depth: winter (last 20 years)

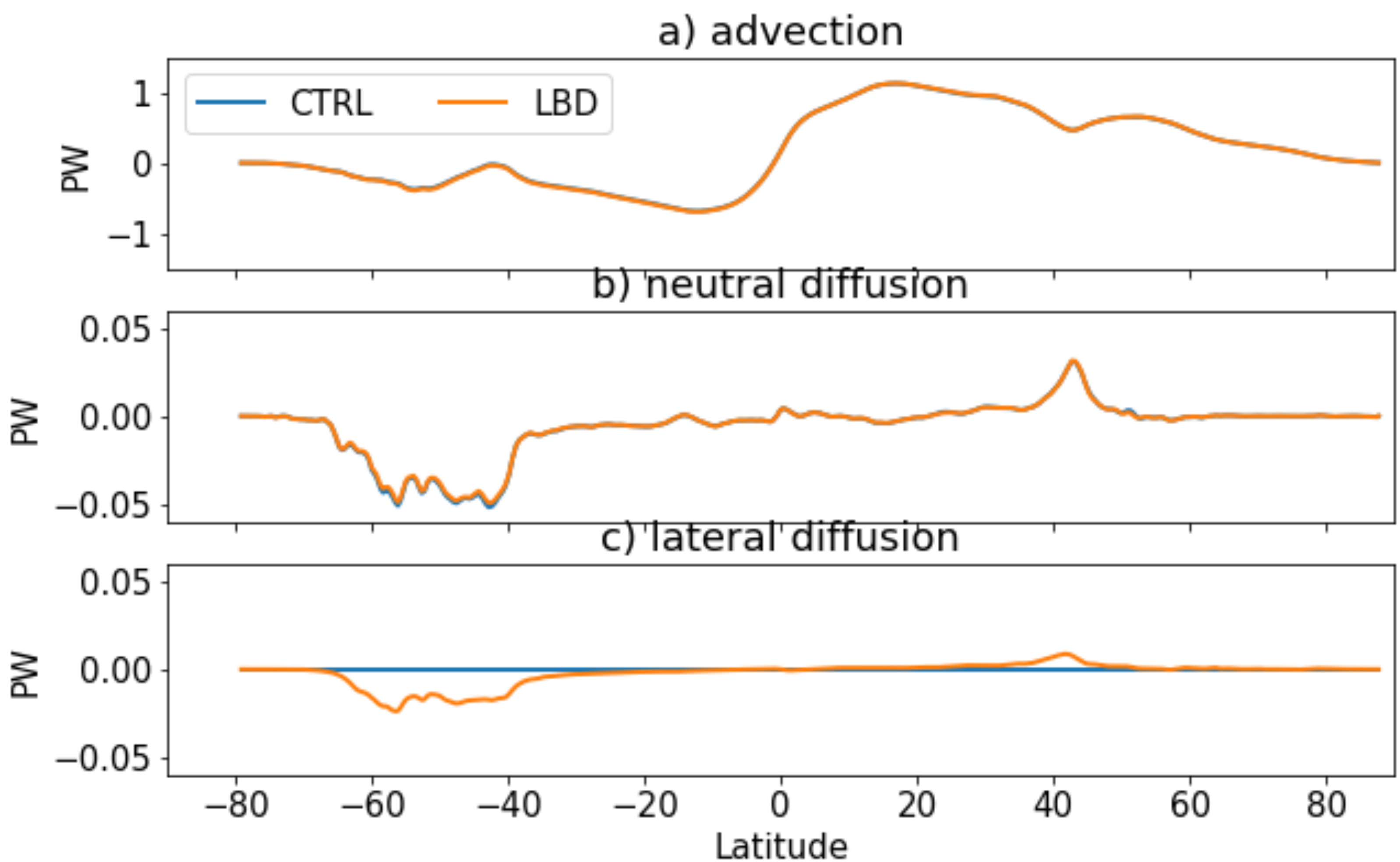


Mixed layer depth: summer (last 20 years)

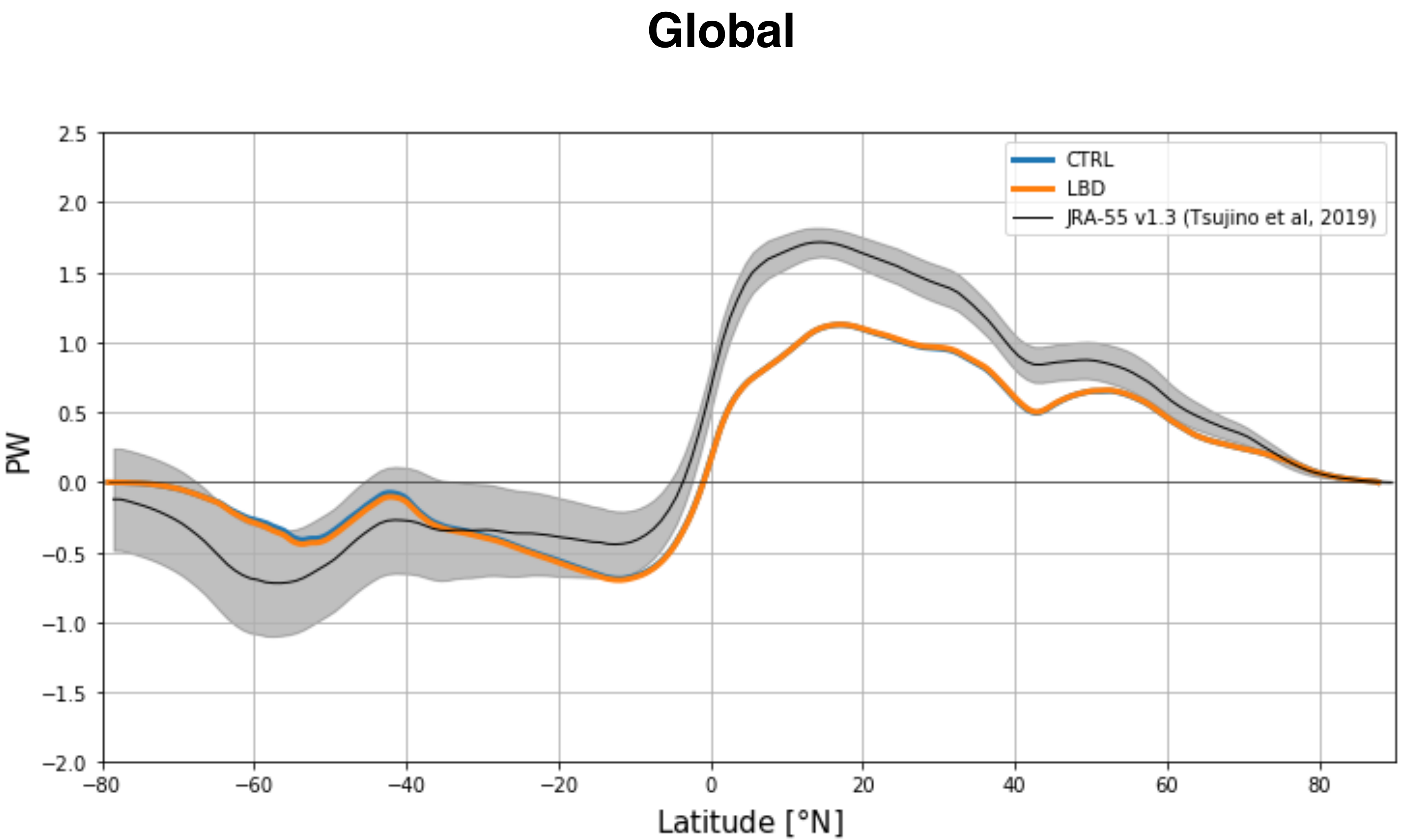


Poleward heat transport (last 20 years)

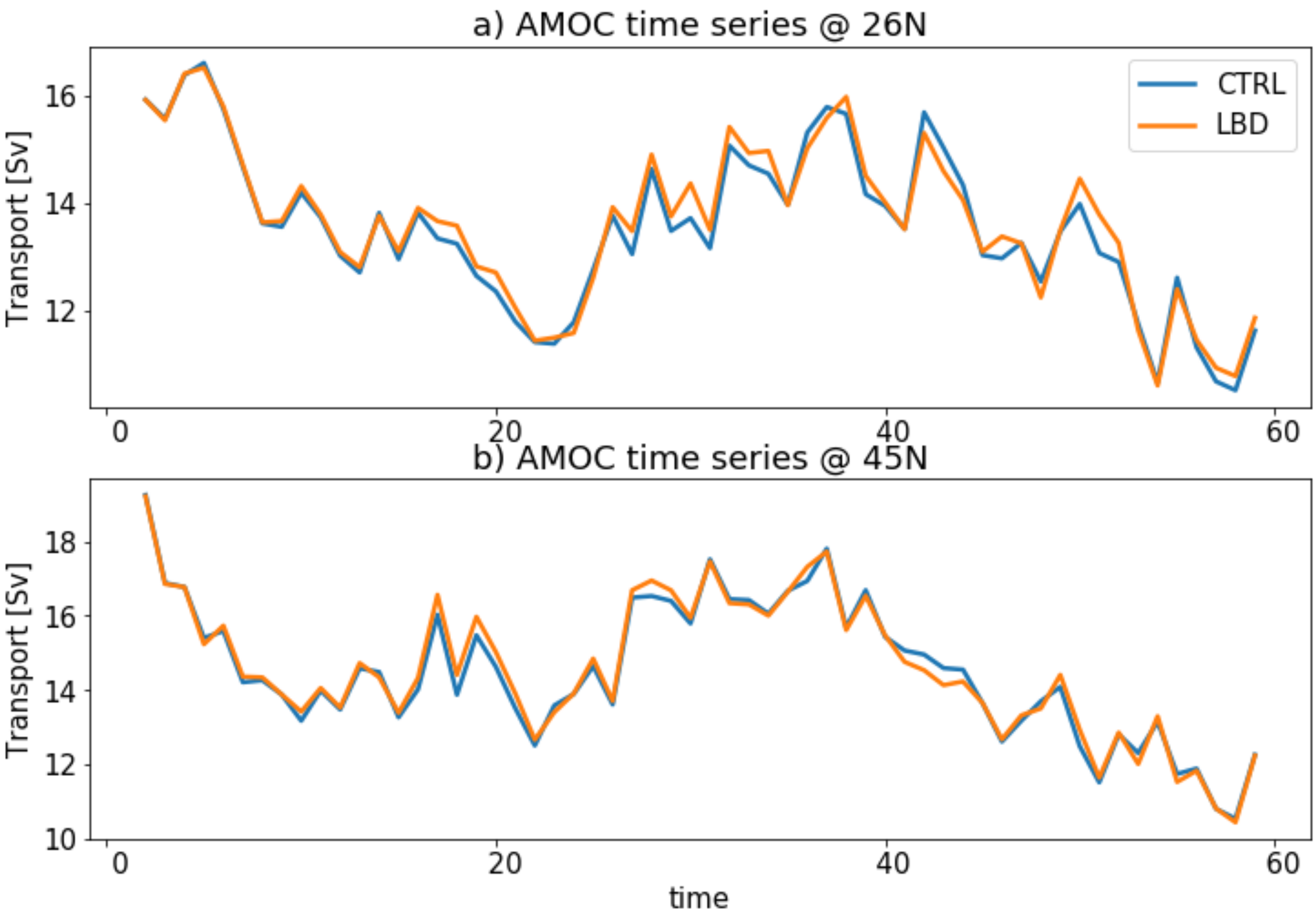
Global contribution from each component



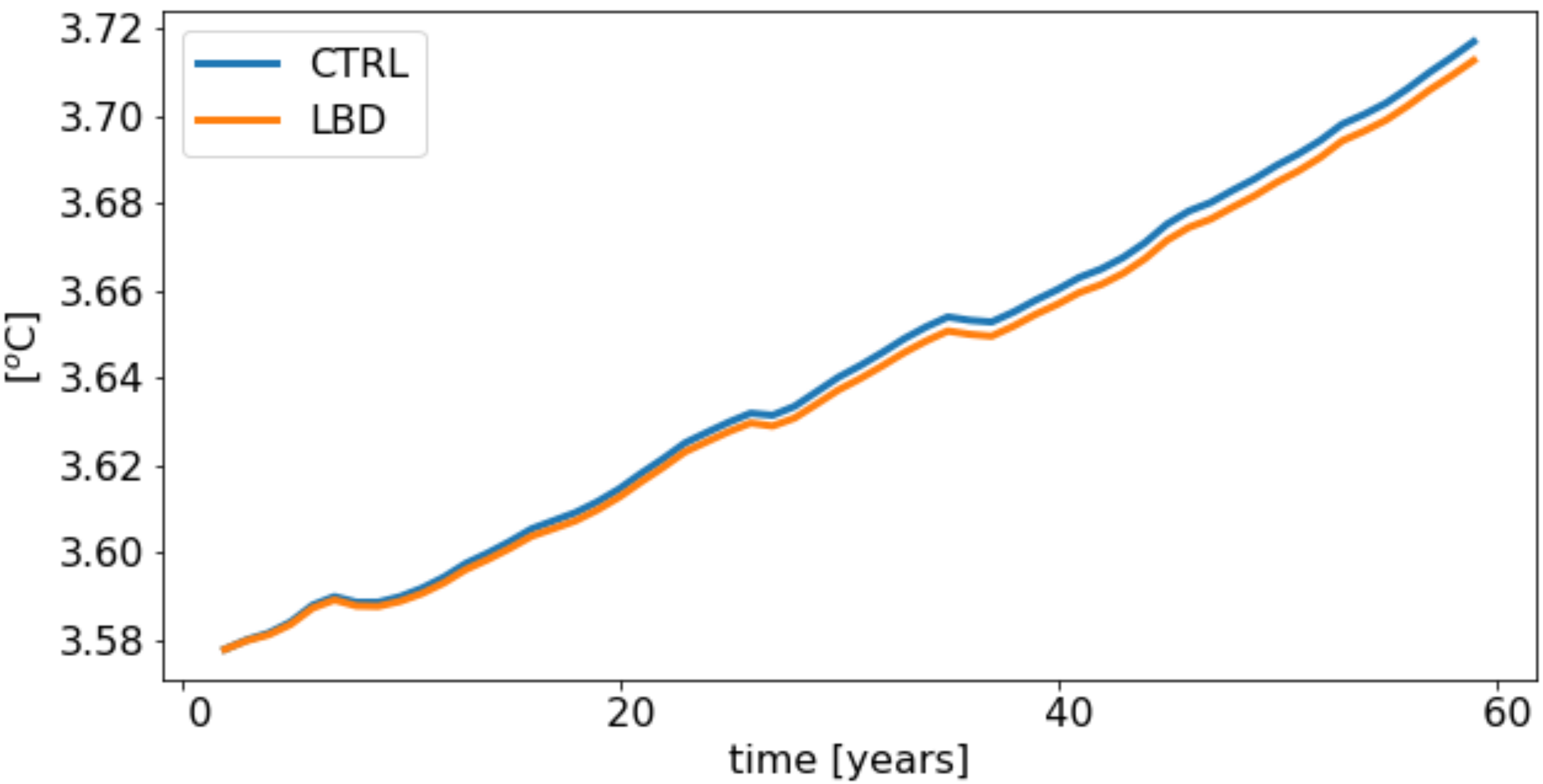
Poleward heat transport (last 20 years)



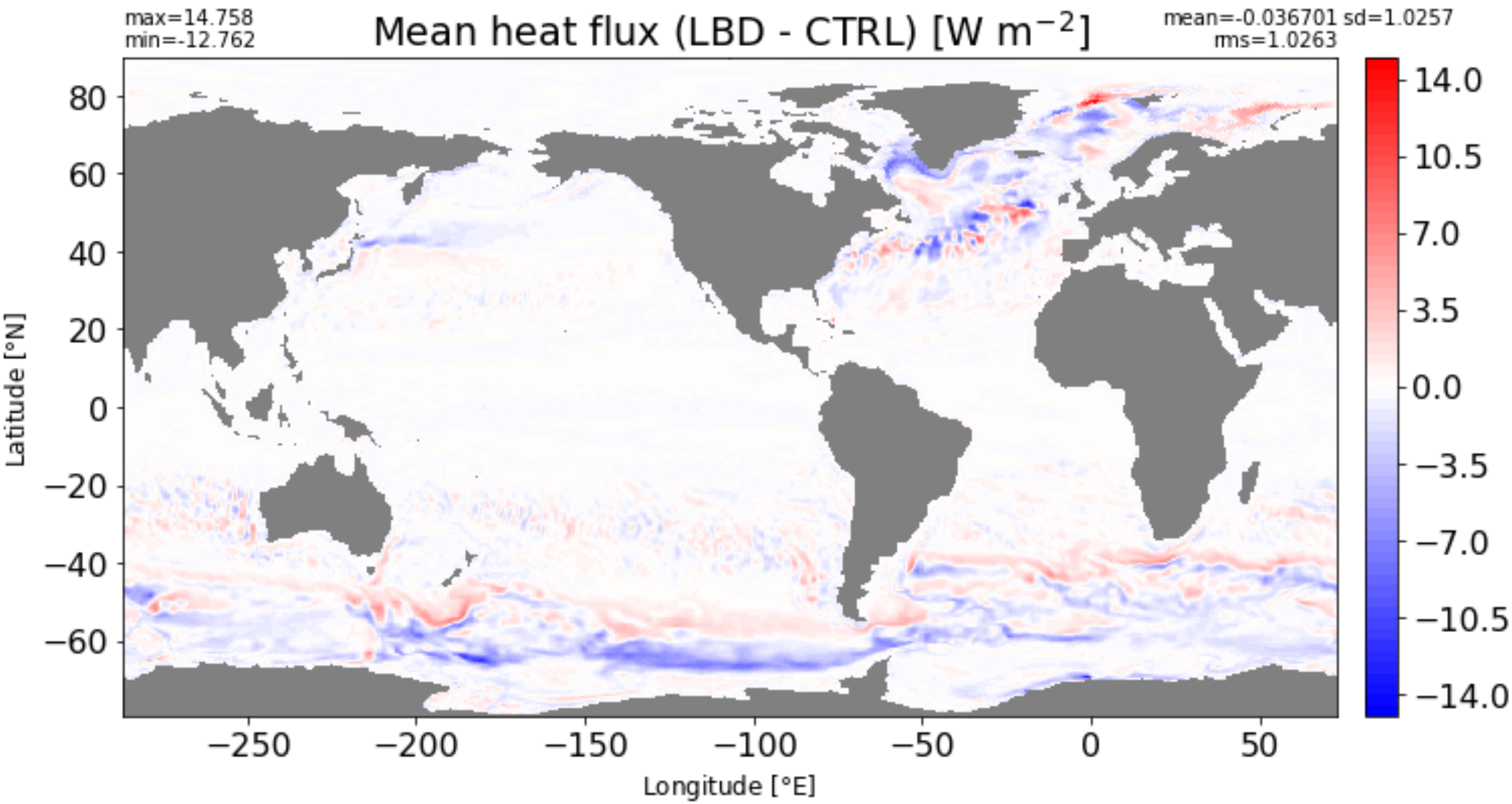
AMOC time series



Global mean potential temperature



Mean net surface heat forcing (LBD - CTRL)



Surface heat flux = SW + LW + **LAT** + **SEN** + MASS_HEAT + FRAZIL + ICE_HEAT

Summary

- A method for applying lateral diffusive tracer fluxes due to mesoscale eddies within the surface boundary layer (SBL) have been implemented in a general vertical coordinate ocean model (MOM6)

- Proof of concept using simple two-column cases and tested in global ice-ocean setup (CESM/MOM6), both using z*

Adding lateral diffusion in the SBL leads to:

- Overall deepening of the SBL → small reduction in the total ocean heat content

- Although impact on climate relevant metrics (PHT and MOC) is not substantial, overall solution is improved

- Still a lot to be done!

Future work

- Test the new method using additional vertical coordinates
- Enable LBD in the bottom boundary layer
- 3D tracer diffusivities

Thank you!

Bulk method

1) vertical indices containing boundary layer (k=4,3)

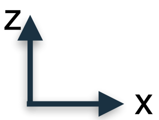
2) calculate bulk (thickness weighted) tracer averages, $\overline{\phi}$

3) calculate 'bulk' diffusive flux

$$F_{bulk} = -\kappa_u \times h_{eff} \times (\overline{\phi}_R - \overline{\phi}_L)$$

h_{eff} is the harmonic mean:

$$h_{eff} = \frac{2 \times (hbl_L \times hbl_R)}{hbl_L + hbl_R}$$



4) decompose F_{bulk} onto individual layers

$$F_{layer}(k) = F_{bulk} \times h_{frac}$$

$$h_{frac} = h_u(k) \times \frac{1}{\sum(h_u)}$$

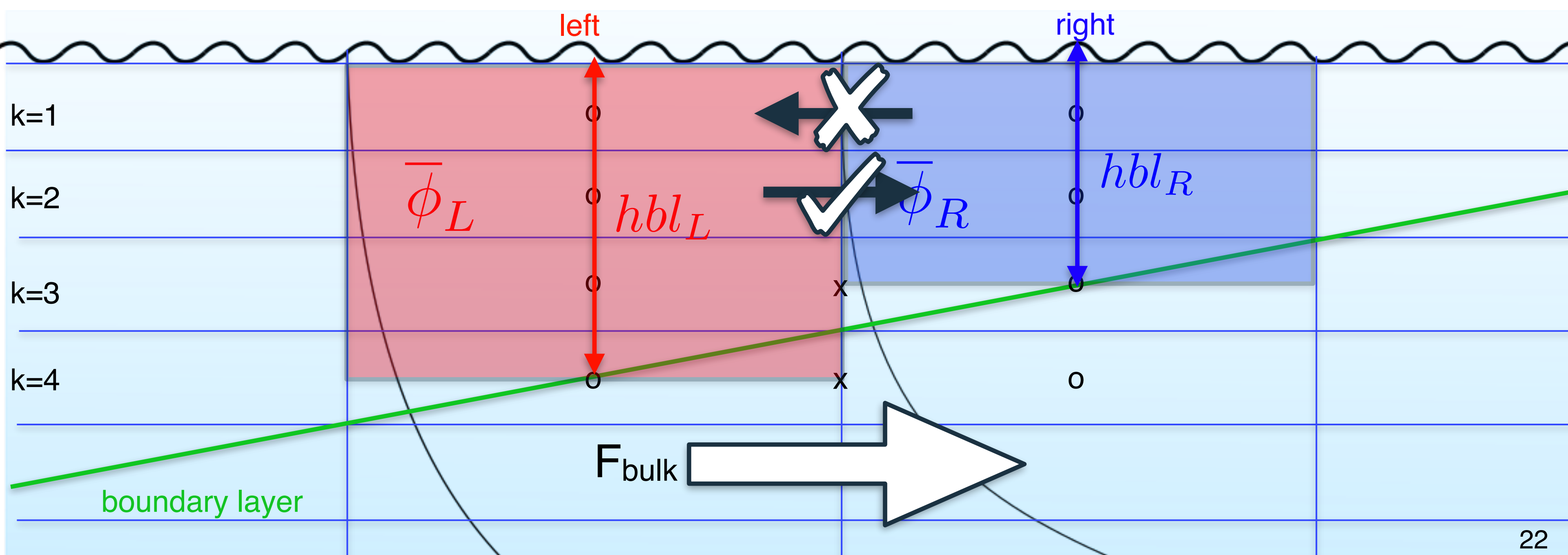
h_u is the harmonic mean of thicknesses at each layer, special care at k_min = min(4,3)

Limit tracer flux:

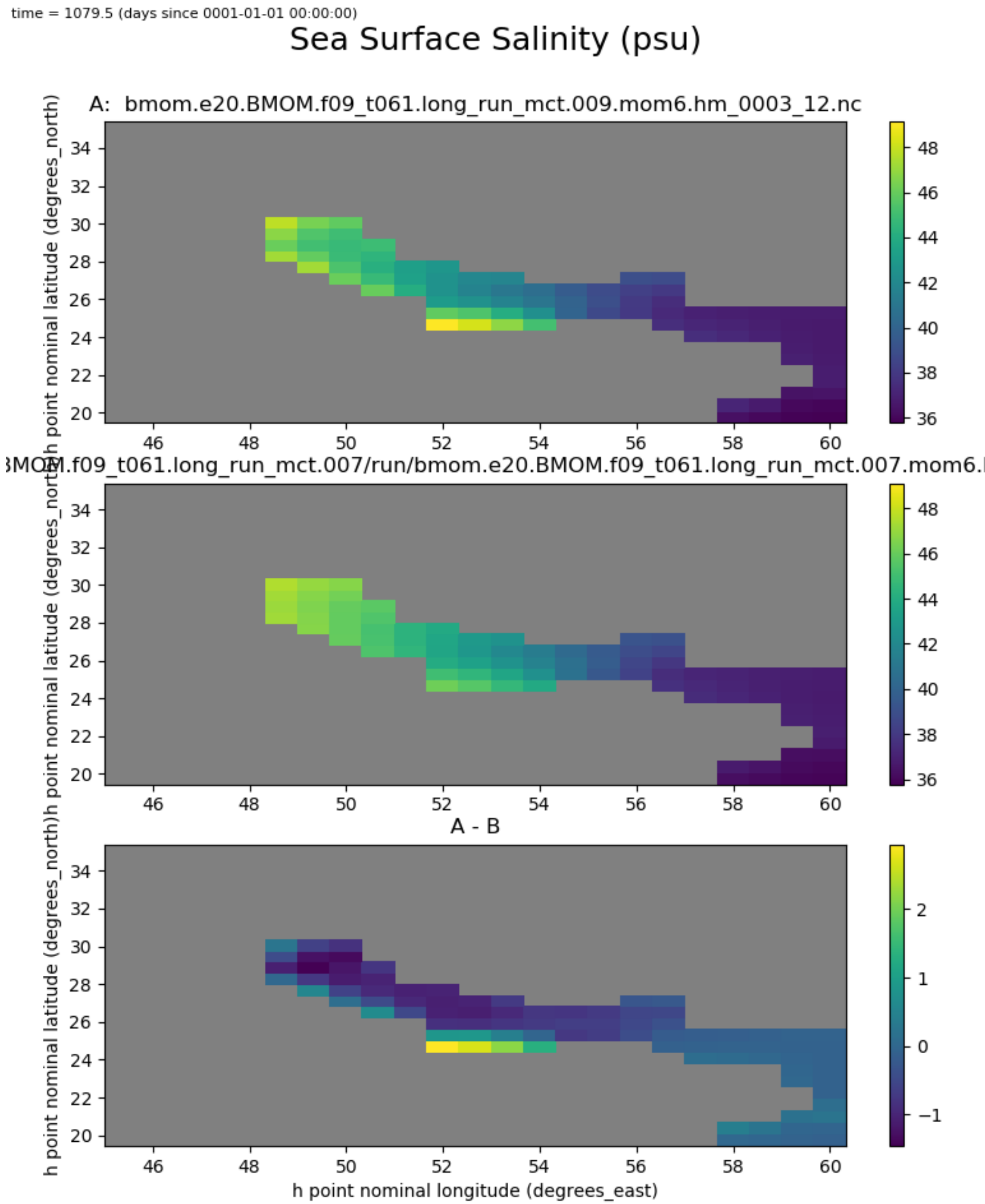
$$F_{max}(z) = -0.2 \times [V_R(k) \times \phi_R(k)] - [V_L(k) \times \phi_L(k)]$$

only apply flux if it is down-gradient

V = cell volume



SSS reduction in a fully-coupled run



Out-of-the-box

LBD (layer by layer)

Difference