Representing the mesoscale horizontal diffusion of tracers within the boundary layers of general vertical coordinate ocean models

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

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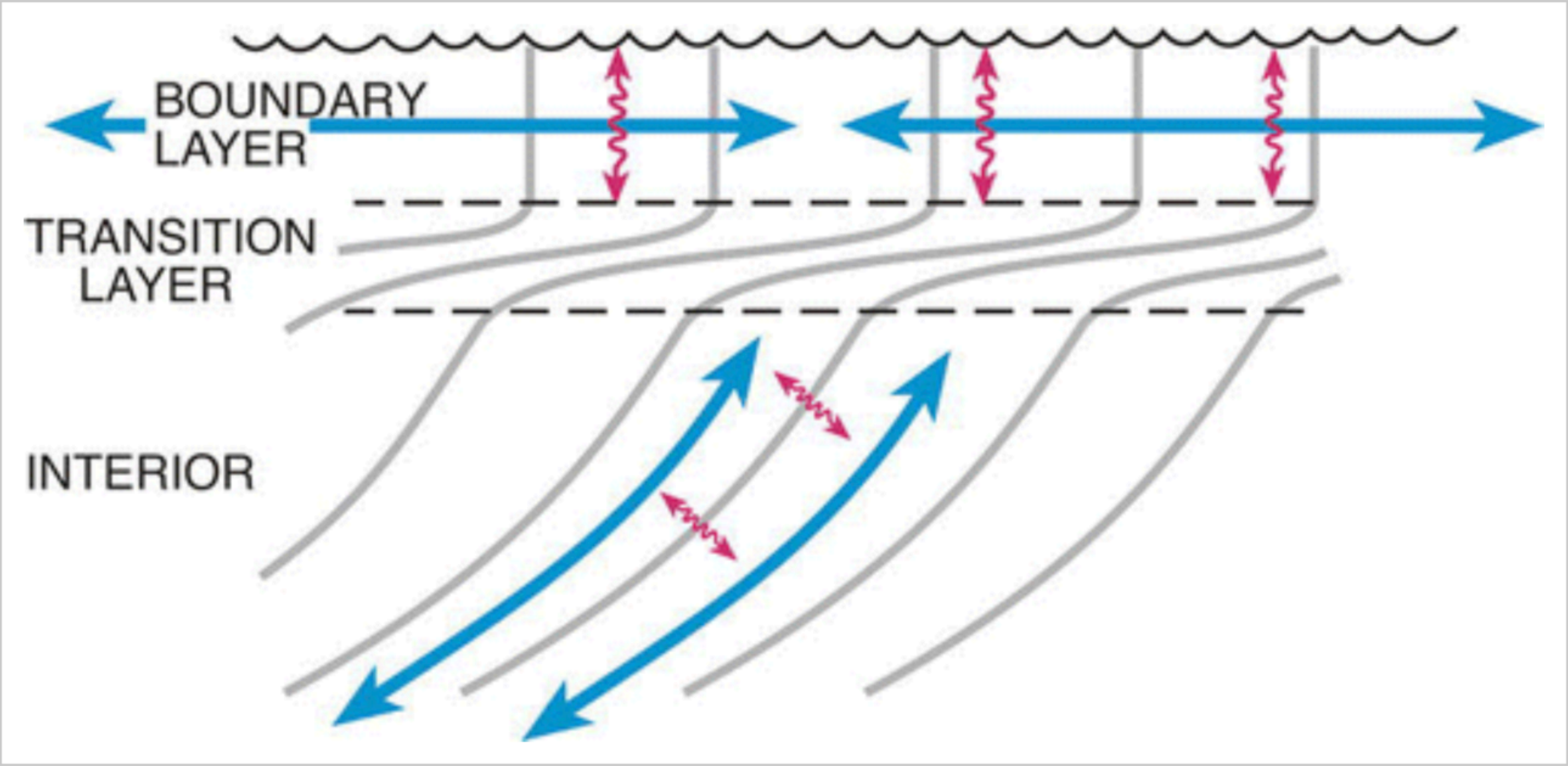
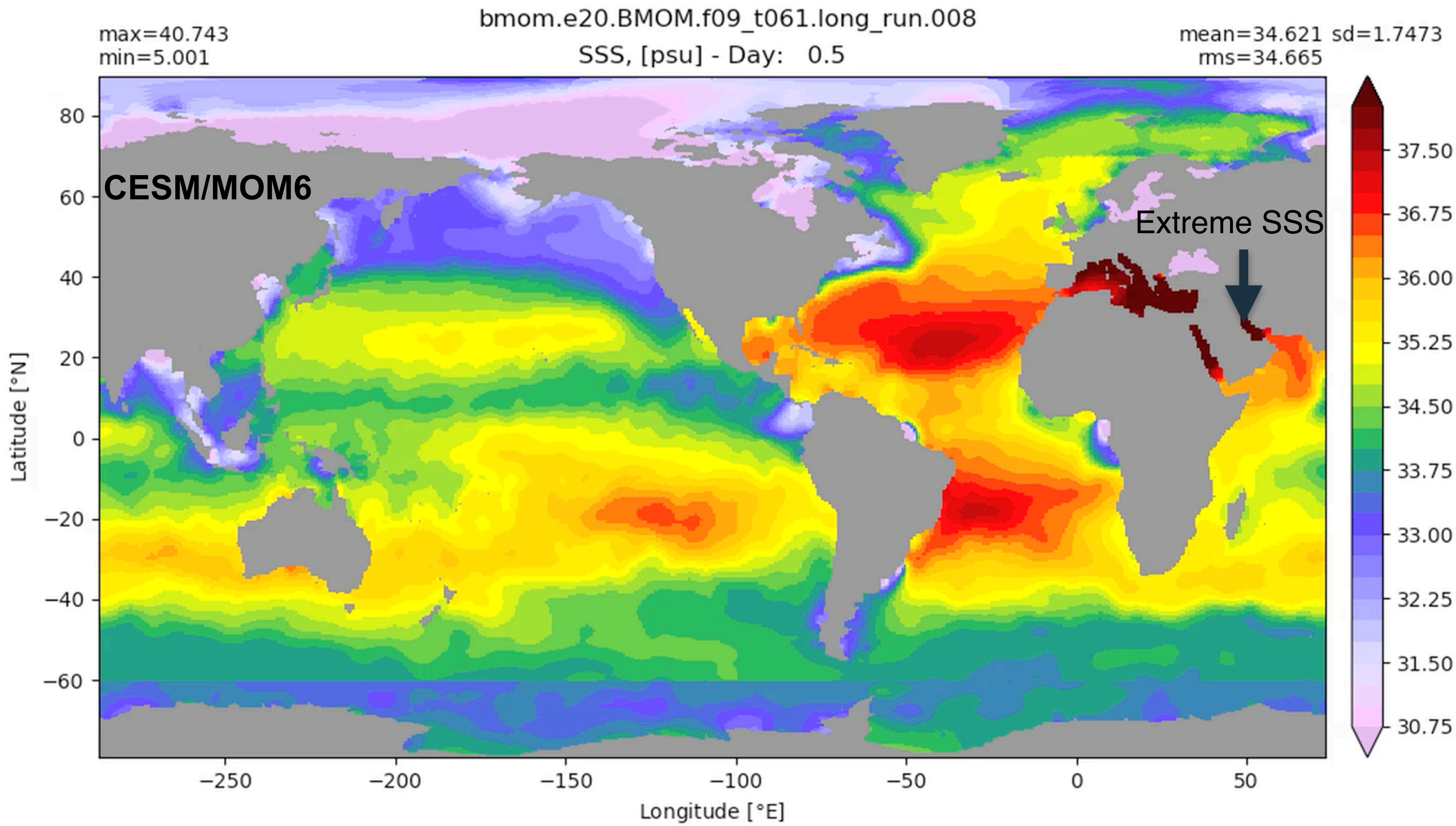
Motivation

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

Lateral

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

Neutral

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

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)
- **Pressure reconstruction**: purely diabatic mixing using ALE reconstructions

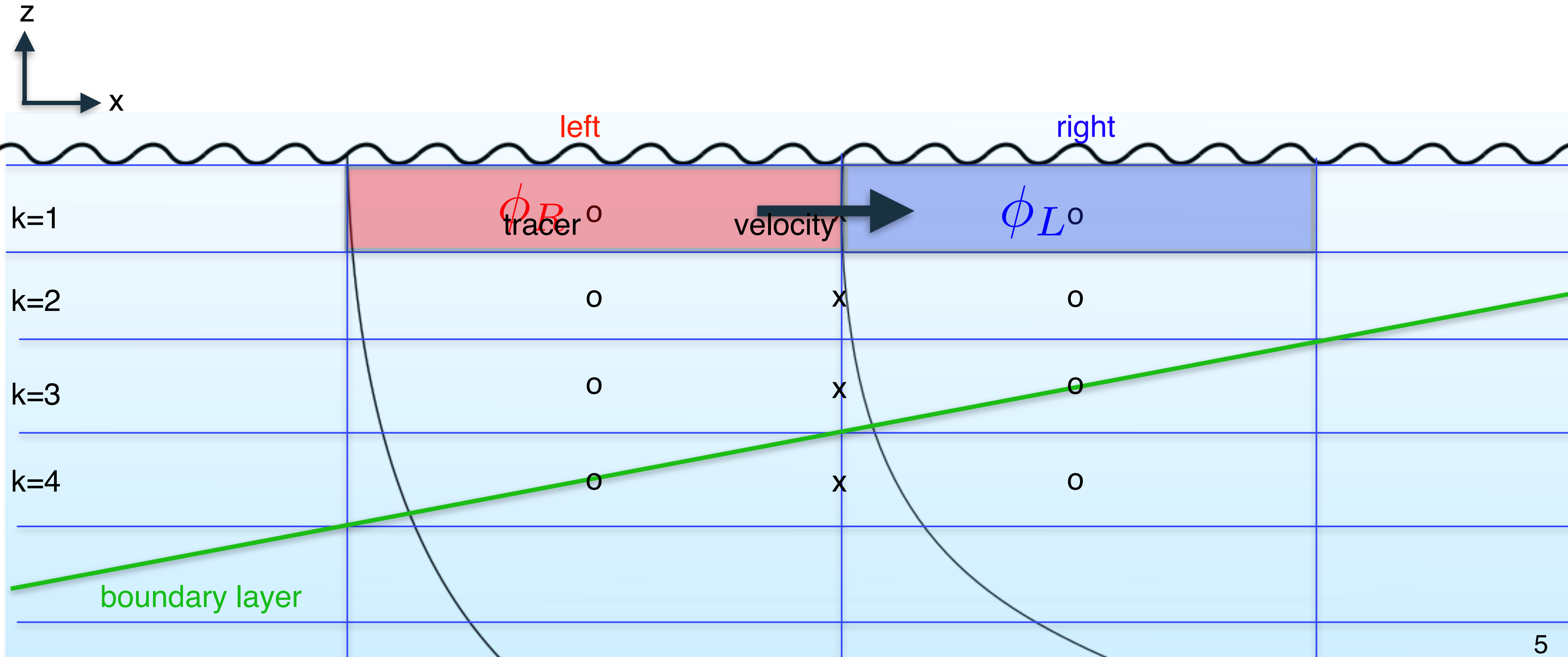
Method #2: Layer by layer approach

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

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, special care at k_min = min(4,3)



Method #1: Bulk approach

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

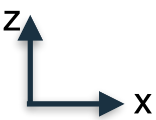
2) calculate bulk (thickness weighted) tracer averages, $\overline{\phi}$

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

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

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

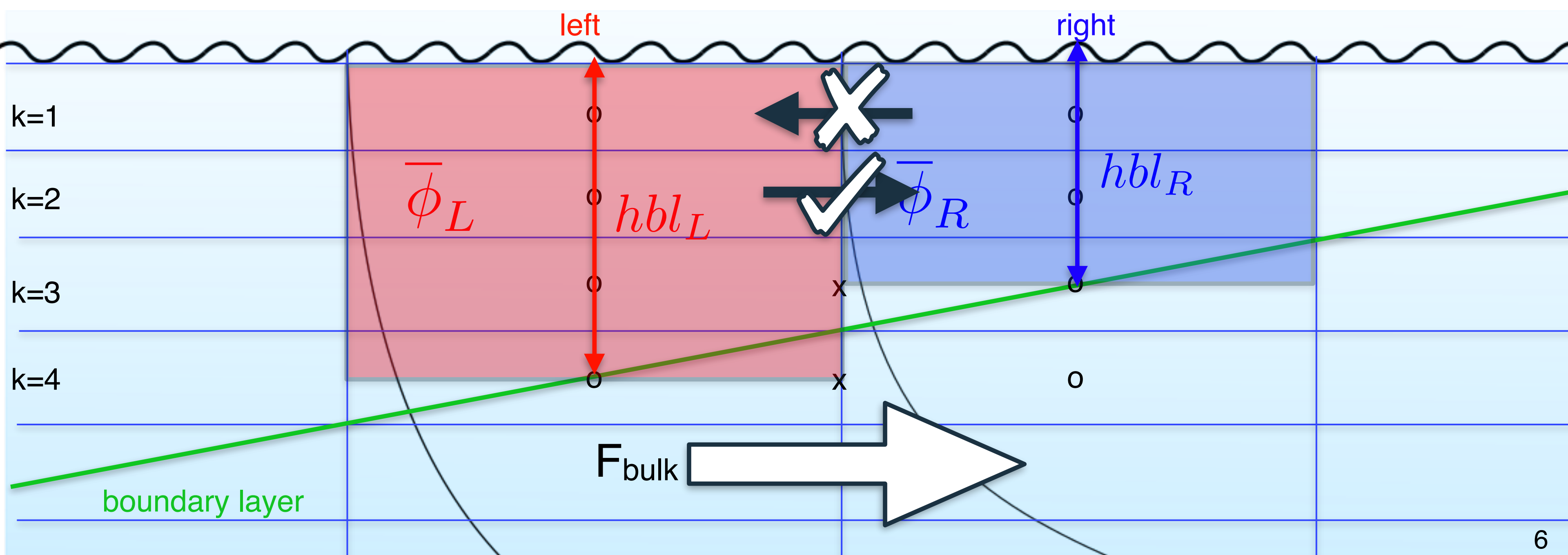
h_u is the harmonic mean of thicknesses at each layer, special care at k_min = min(4,3)

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



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.

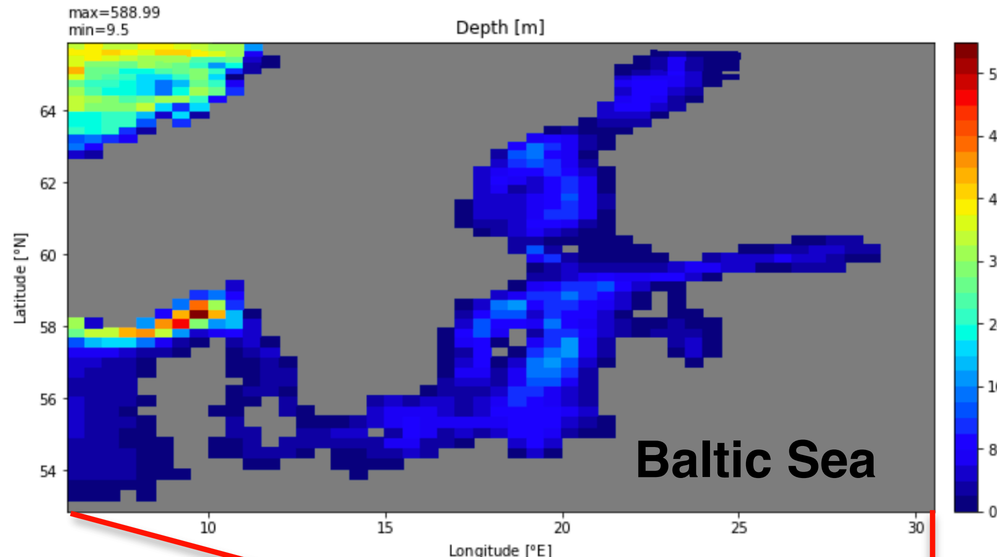
```

- Follows MOM6 code style guide
- dOxyGenized
- 19 unit tests (so far)
- Dimensional consistency testing (TODO, waiting for Bob’s talk)
- Diagnostics: diffusive flux (x,y; 2D and 3D), tracer tendencies (2D and 3D)

Proof of concept using the Baltic test case

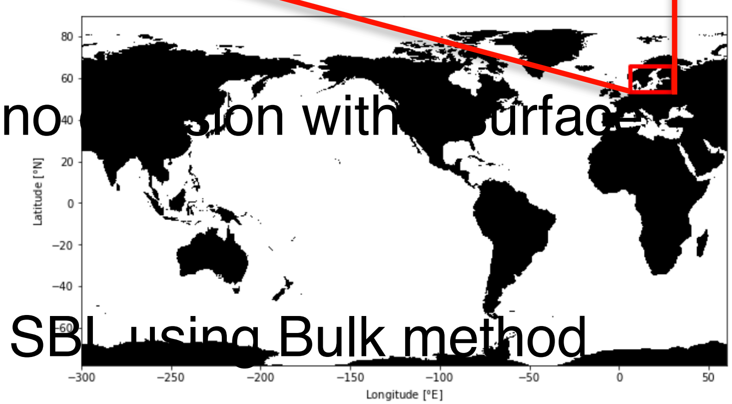
MOM6-examples/ice_ocean_SIS2/Baltic_OM4_05/

- Active ocean/sea ice (MOM6/SIS2); CORE2
- Nominal 0.5 degree
- Hybrid vertical coordinate (HYCOM-like)
- Setup similar to OM4p5 exp. (Adcroft et al, 2019)
- Tracer diffusivity = 200 m^2s^{-1}
- Run for 10 years

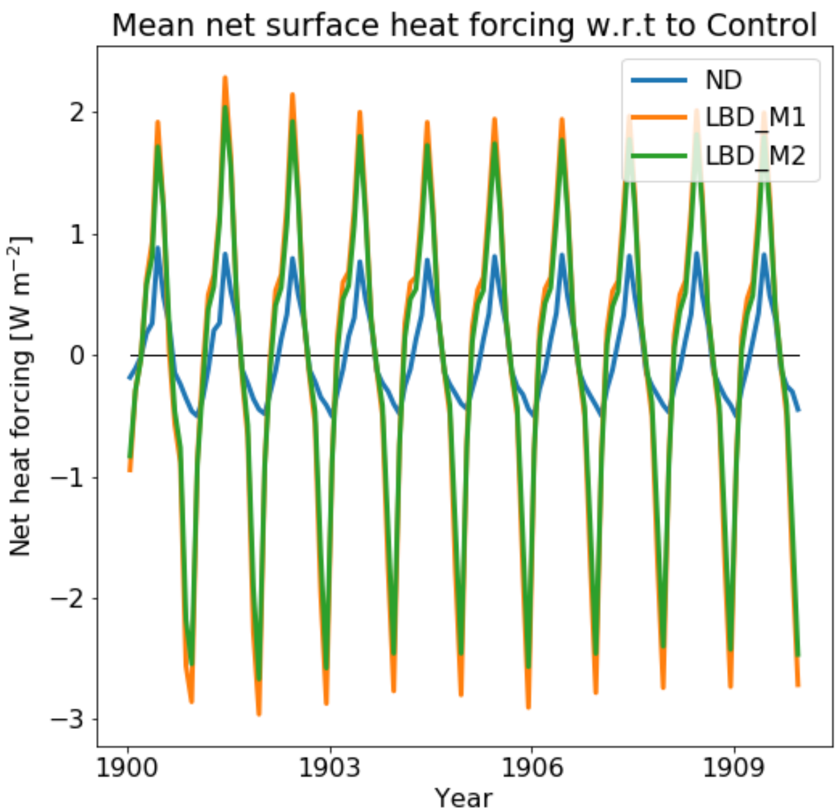


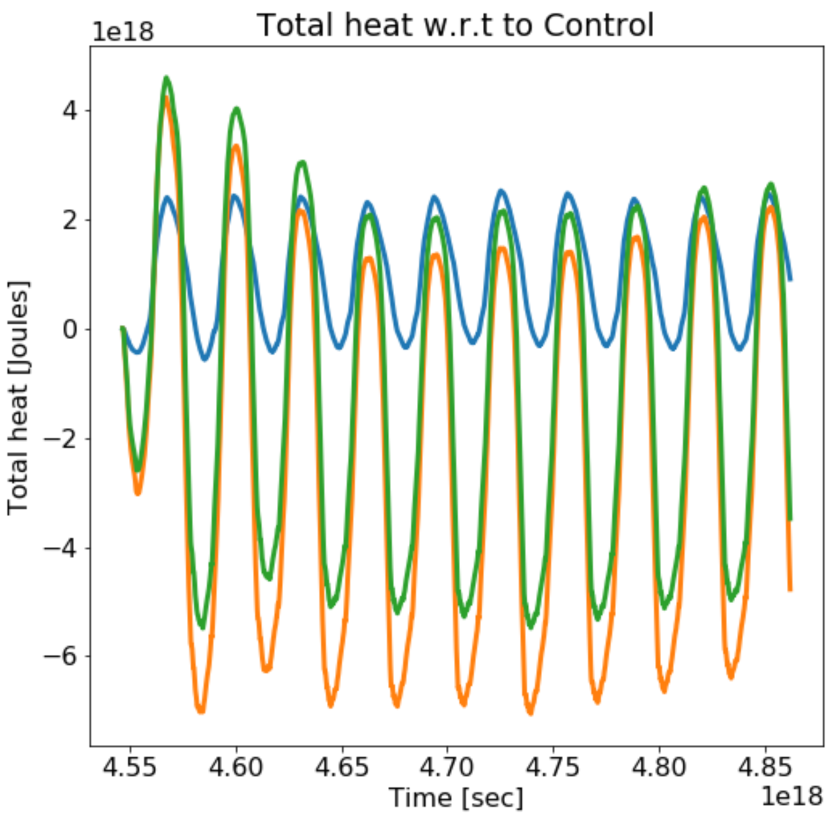
Experiments

- **Control**: neutral diffusion in the interior only, no diffusion within surface boundary layer (SBL)
- **Neutral diffusion**: including within SBL
- **LBD_M1**: neutral in the interior, lateral in the SBL using Bulk method
- **LBD_M2**: neutral in the interior, lateral in the SBL using layer method



Net surface heat forcing and ocean heat content



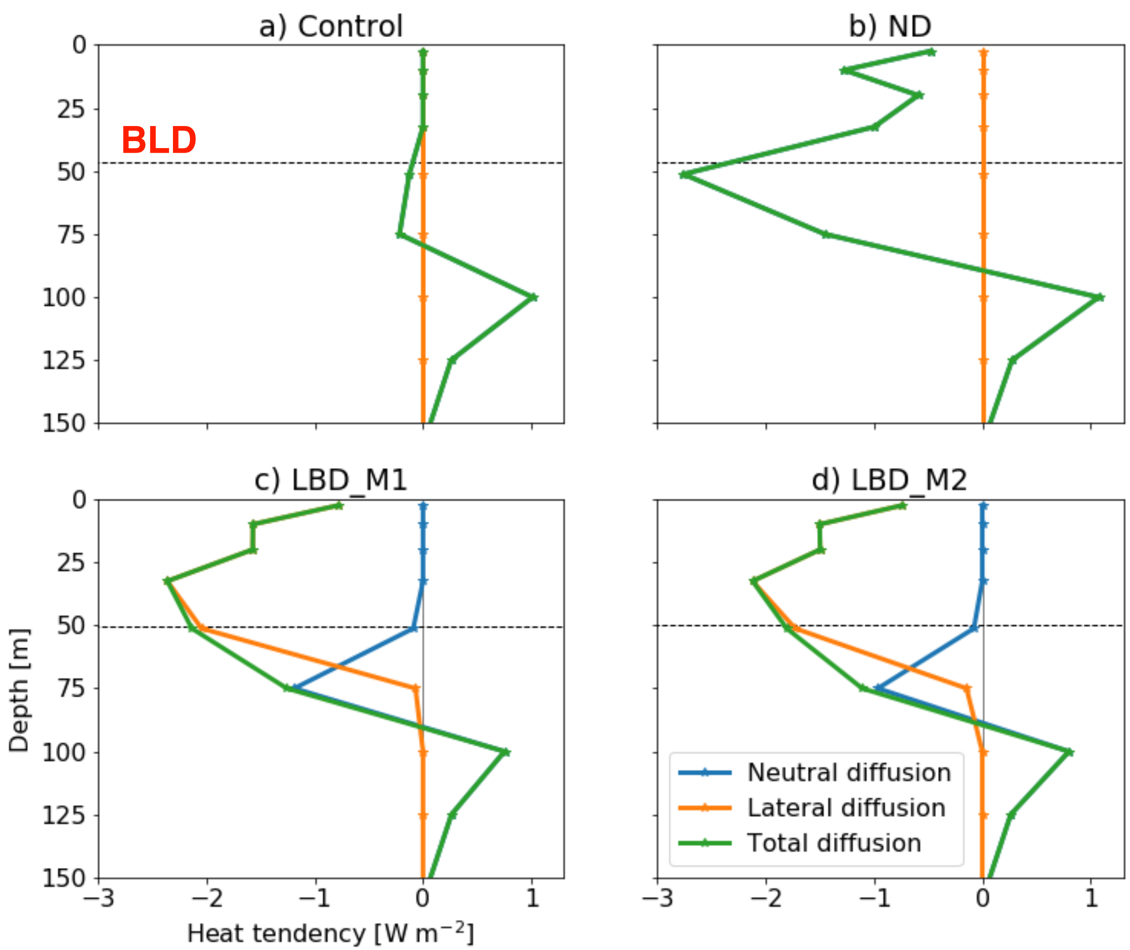


Lower ocean heat content in the LBD experiments

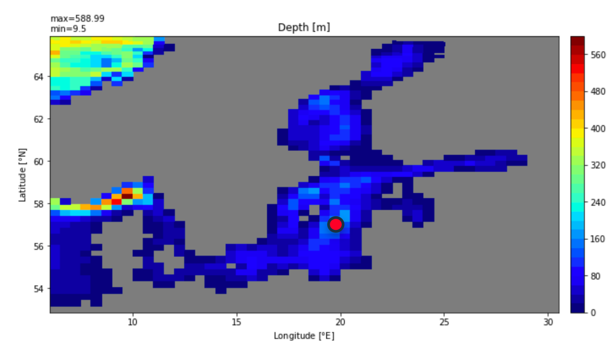
Instantaneous heat tendency contribution: fixed point

$$\partial_t \theta = \ldots + \nabla_h \cdot (\kappa_l \cdot \nabla_h \theta) + \nabla \cdot (\kappa_n \cdot \nabla \theta)$$

Lateral diffusion + Neutral diffusion = Total diffusion



Location of profiles



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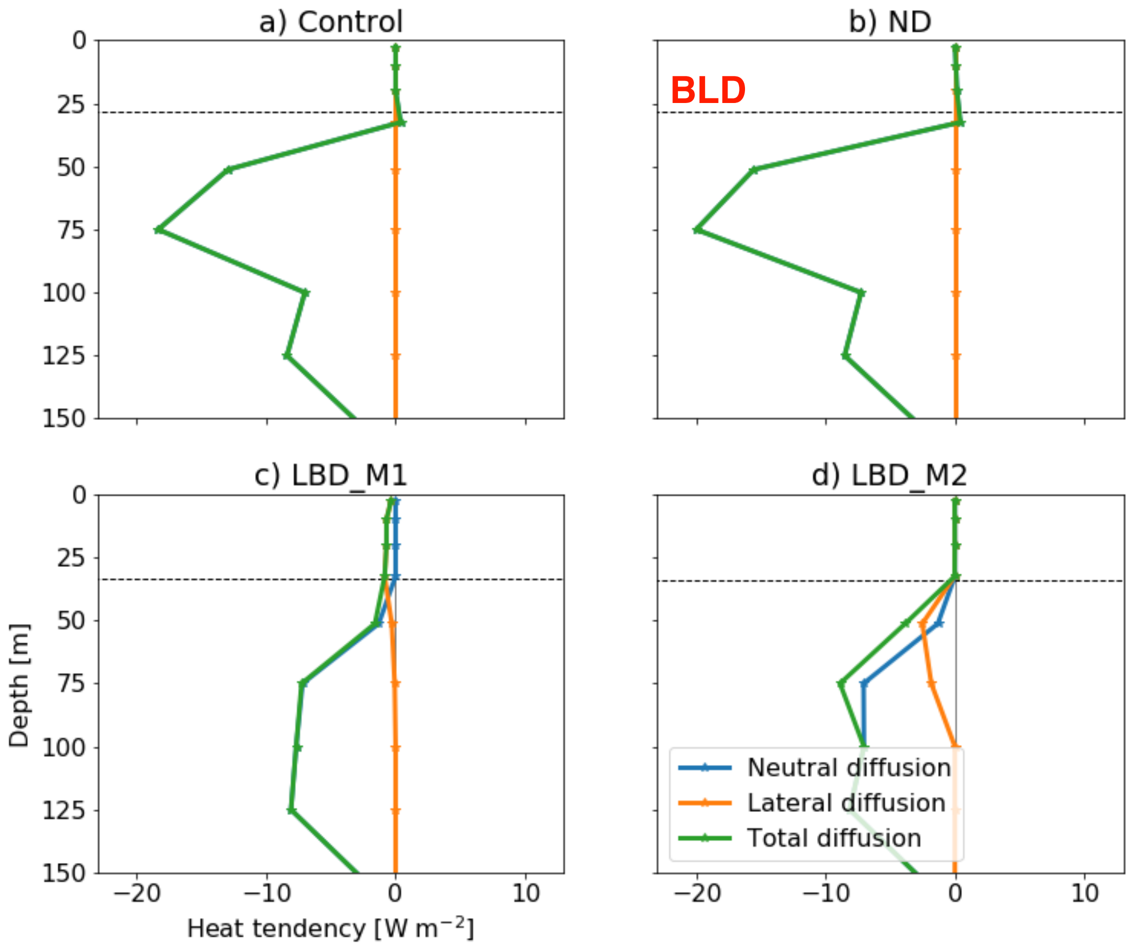

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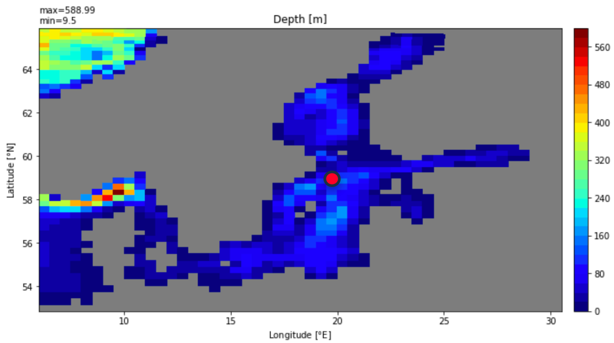
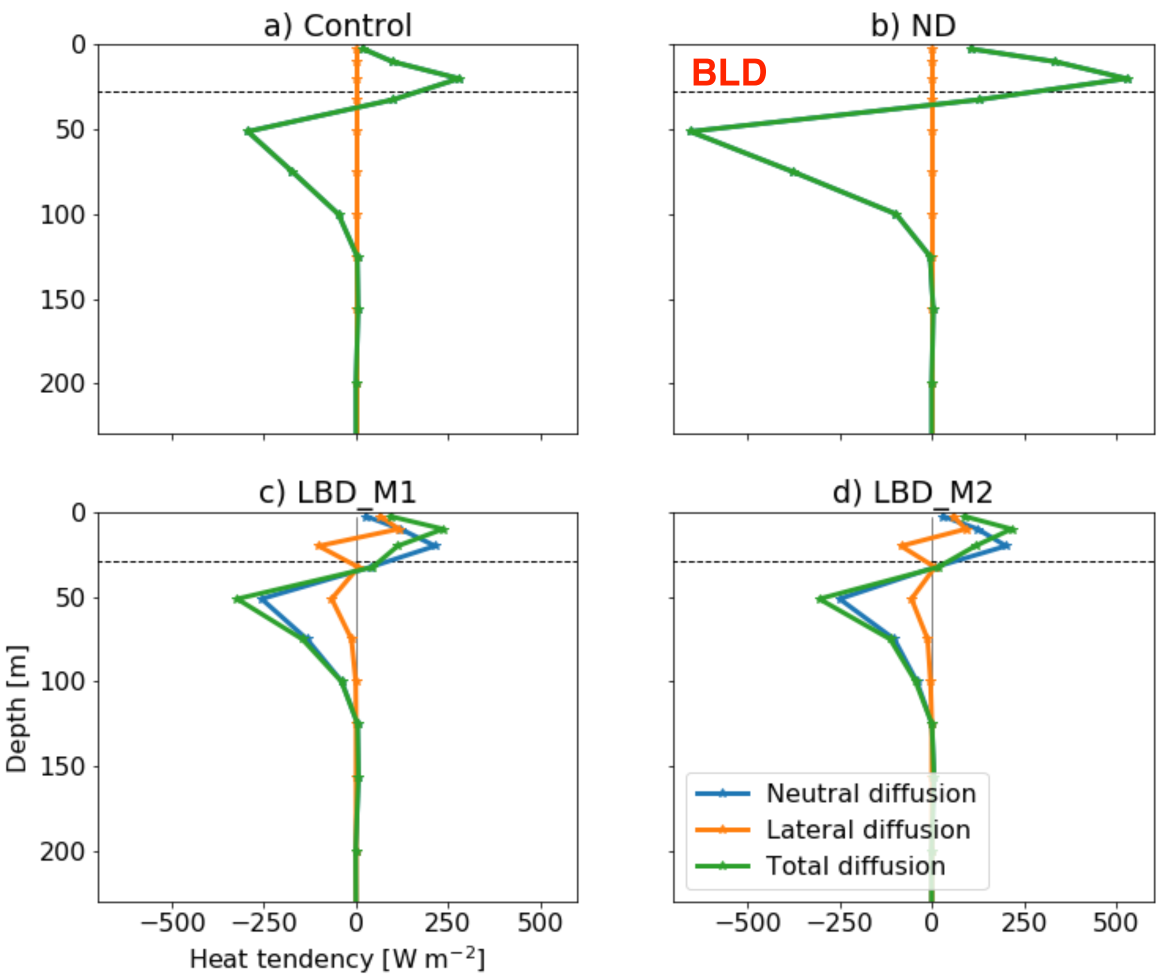


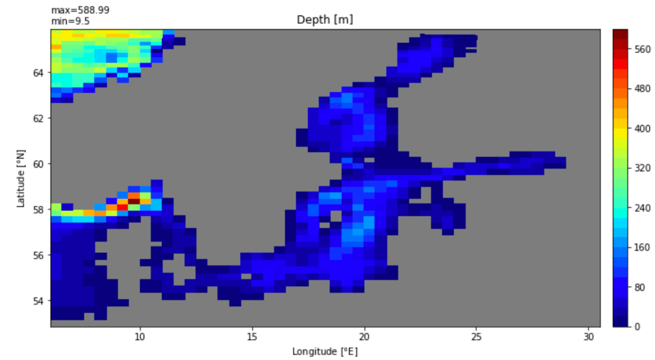
Instantaneous heat tendency contribution: horizontal sum

$$\partial_t \theta = \ldots + \nabla_h \cdot (\kappa_l \cdot \nabla_h \theta) + \nabla \cdot (\kappa_n \cdot \nabla \theta)$$

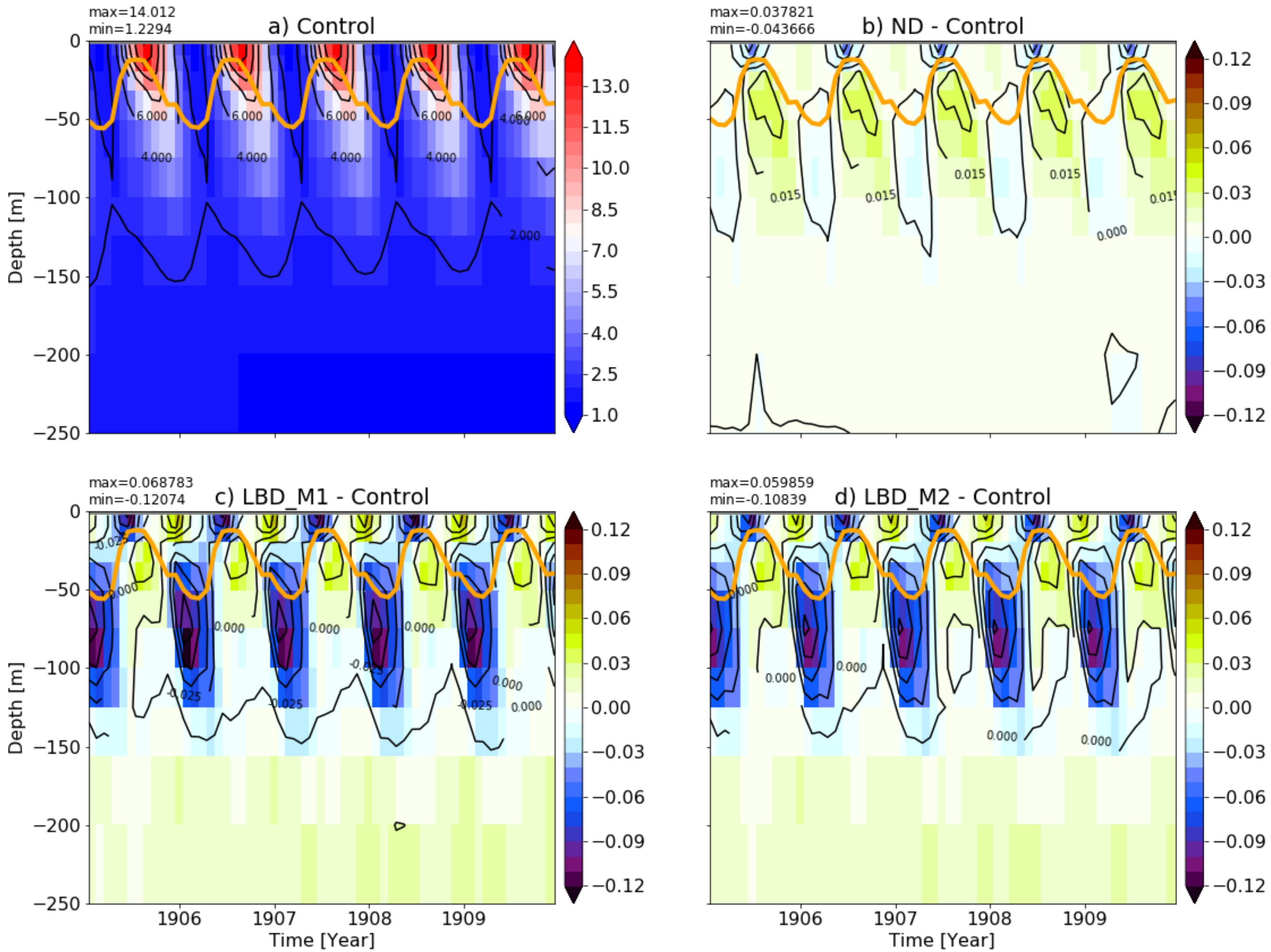
Lateral diffusion + Neutral diffusion = Total diffusion



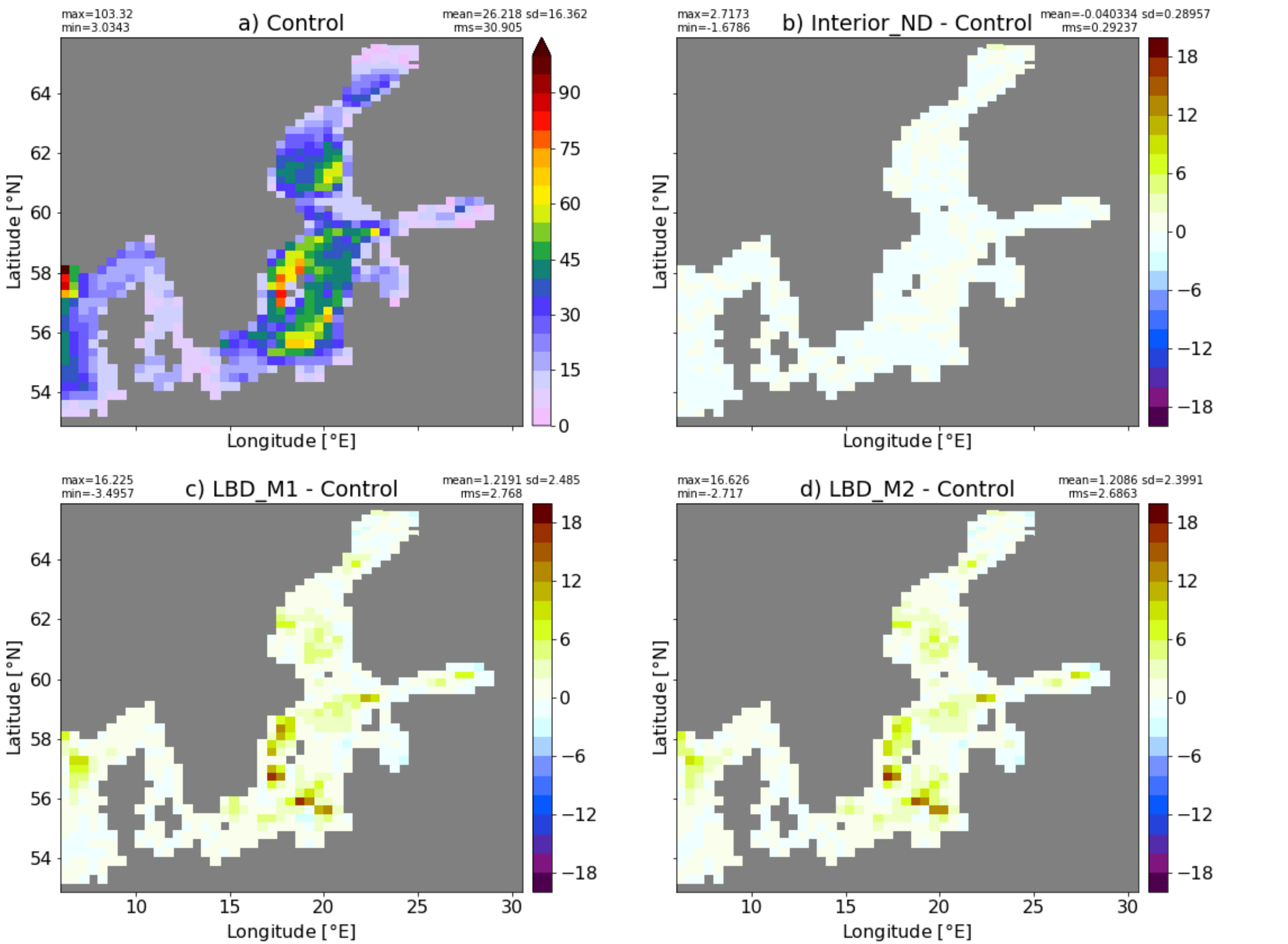
Profiles = sum over Baltic



Horizontal mean potential temperature (depth vs time)

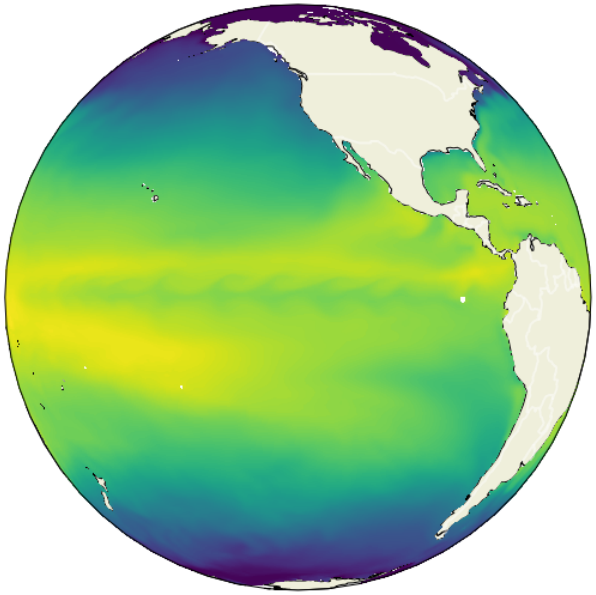


Mixed layer depth: Winter (JFM, year 9)



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 (KPP, shear, DD, convection)
- GM and tracer diffusivity = 800 $m^2 s^{-1}$



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

Experiments

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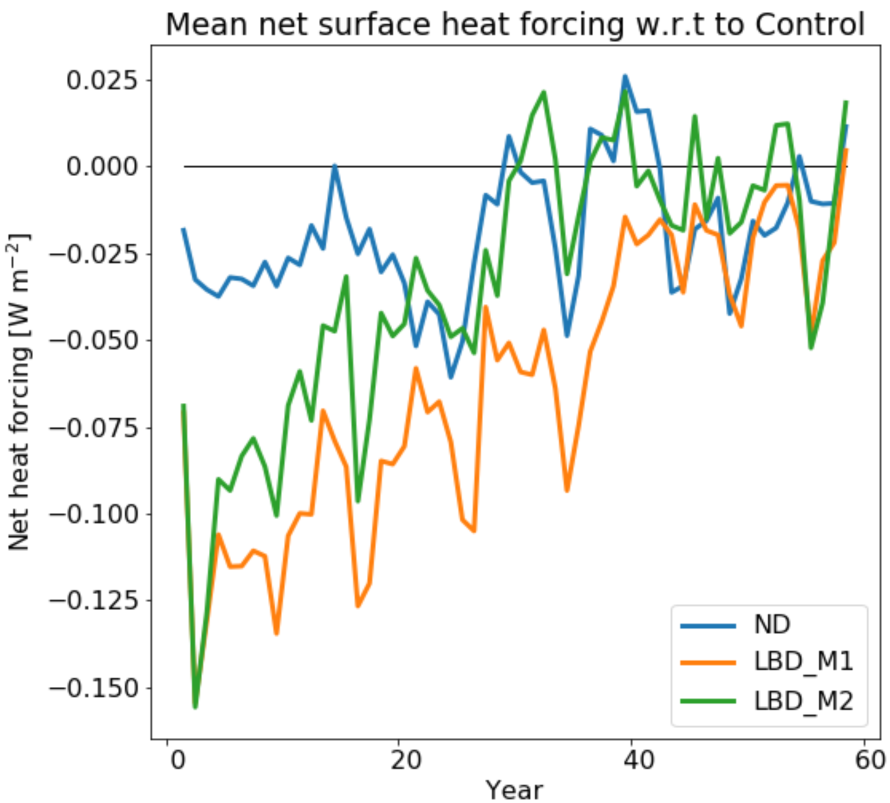
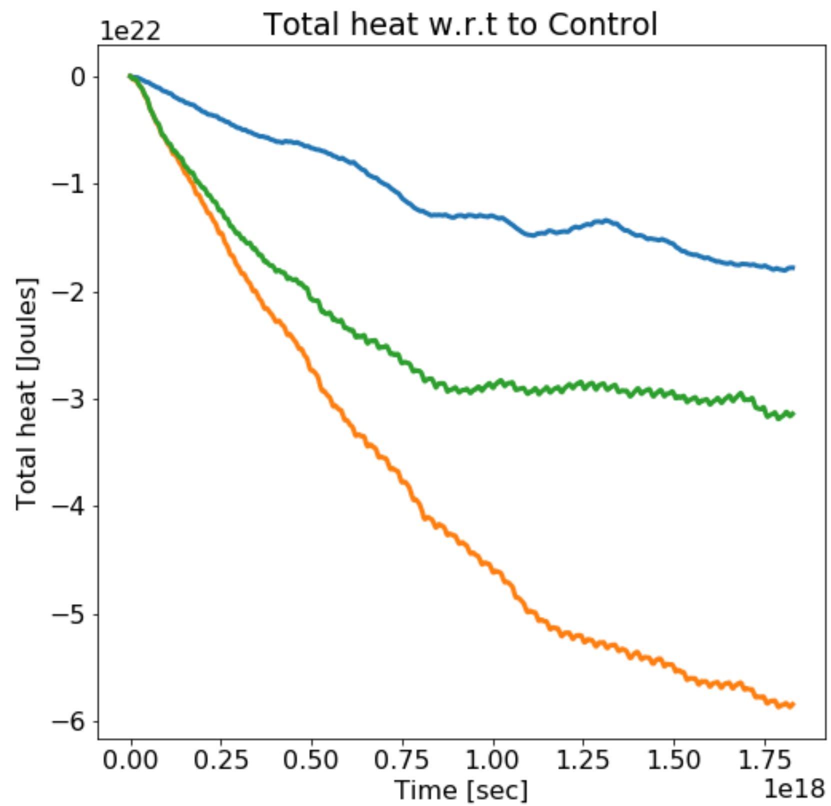
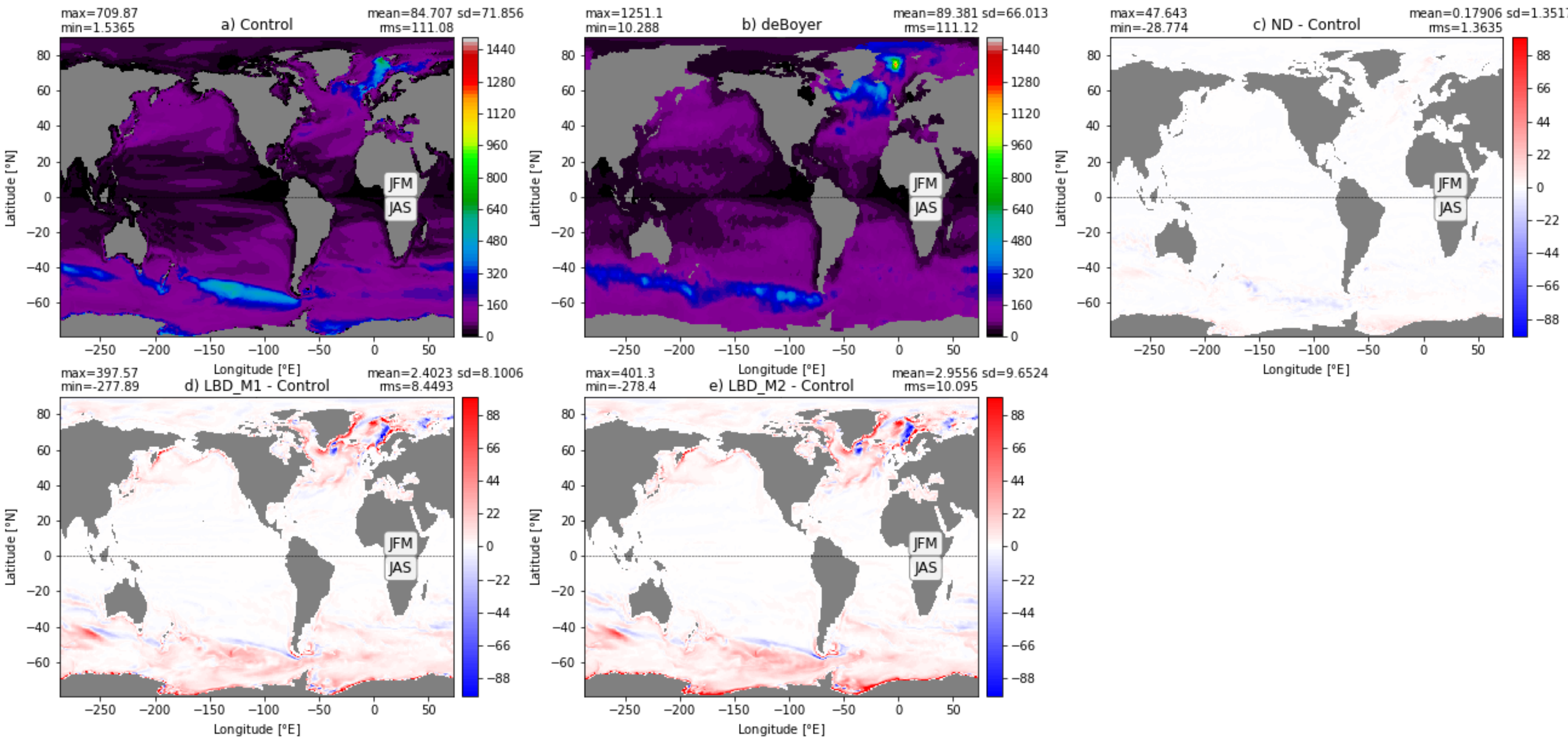
Net surface heat forcing and total heat

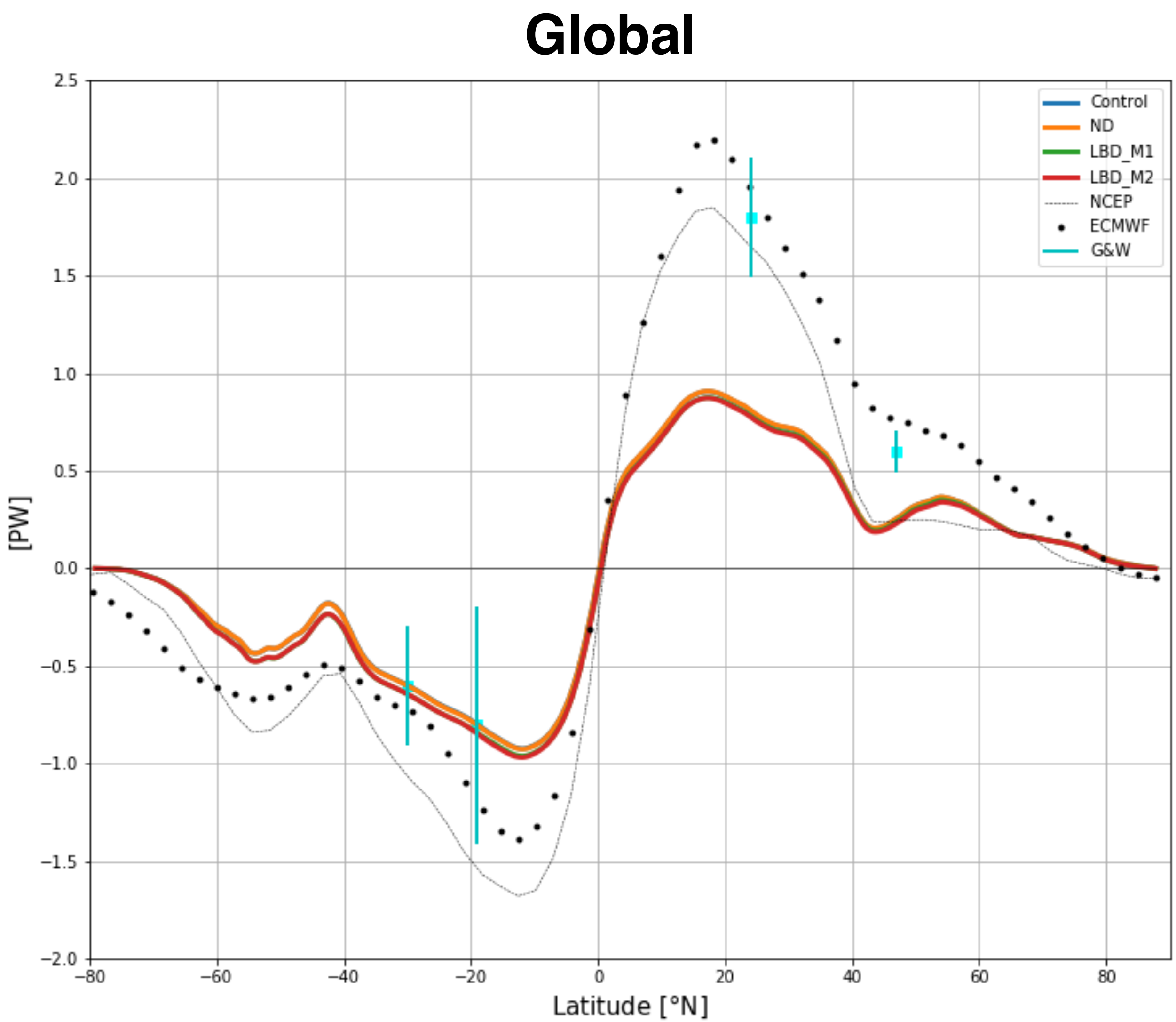




Mixed layer depth: Winter (JFM, last 20 years)

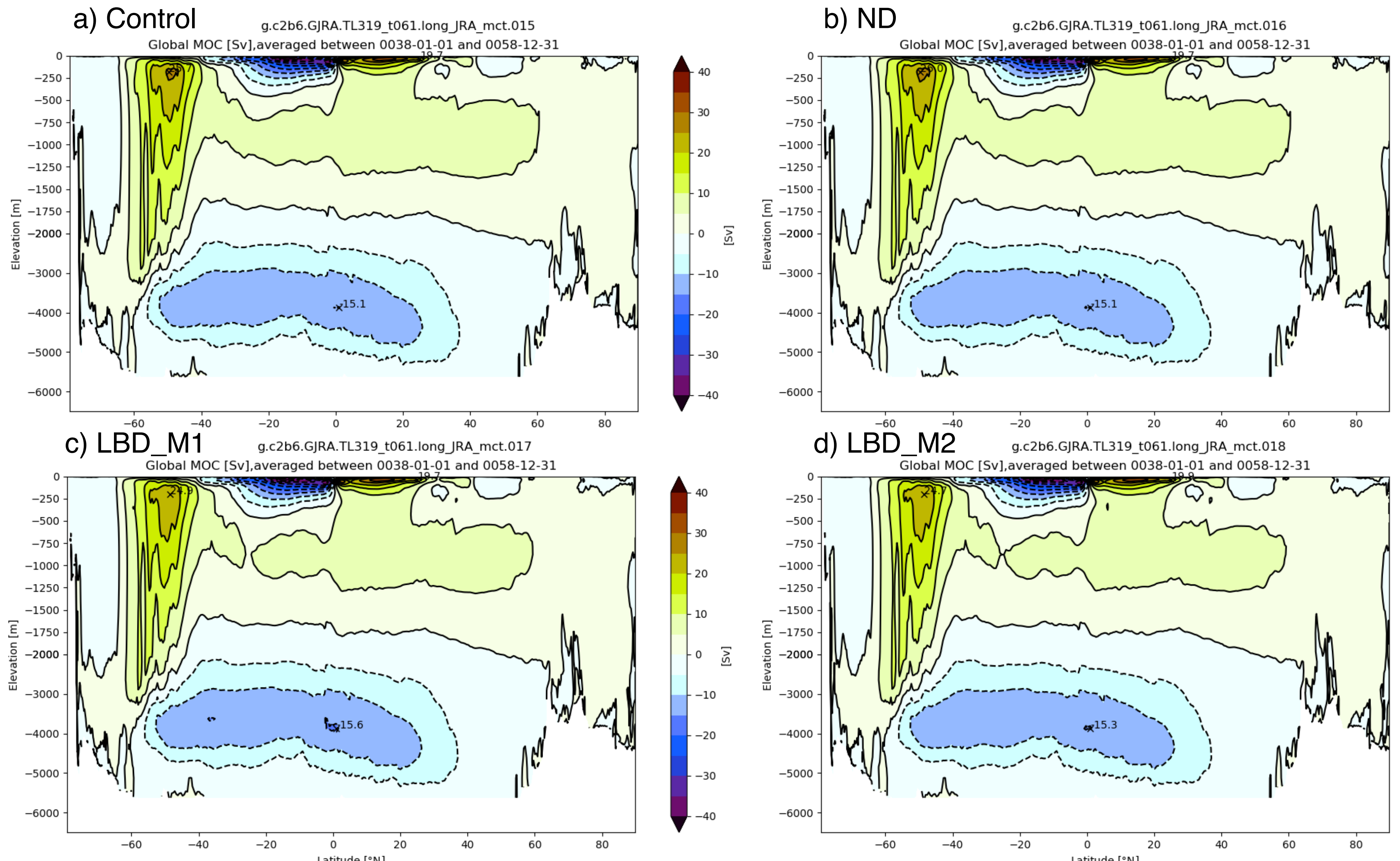


Poleward heat transport (mean last 20 years)



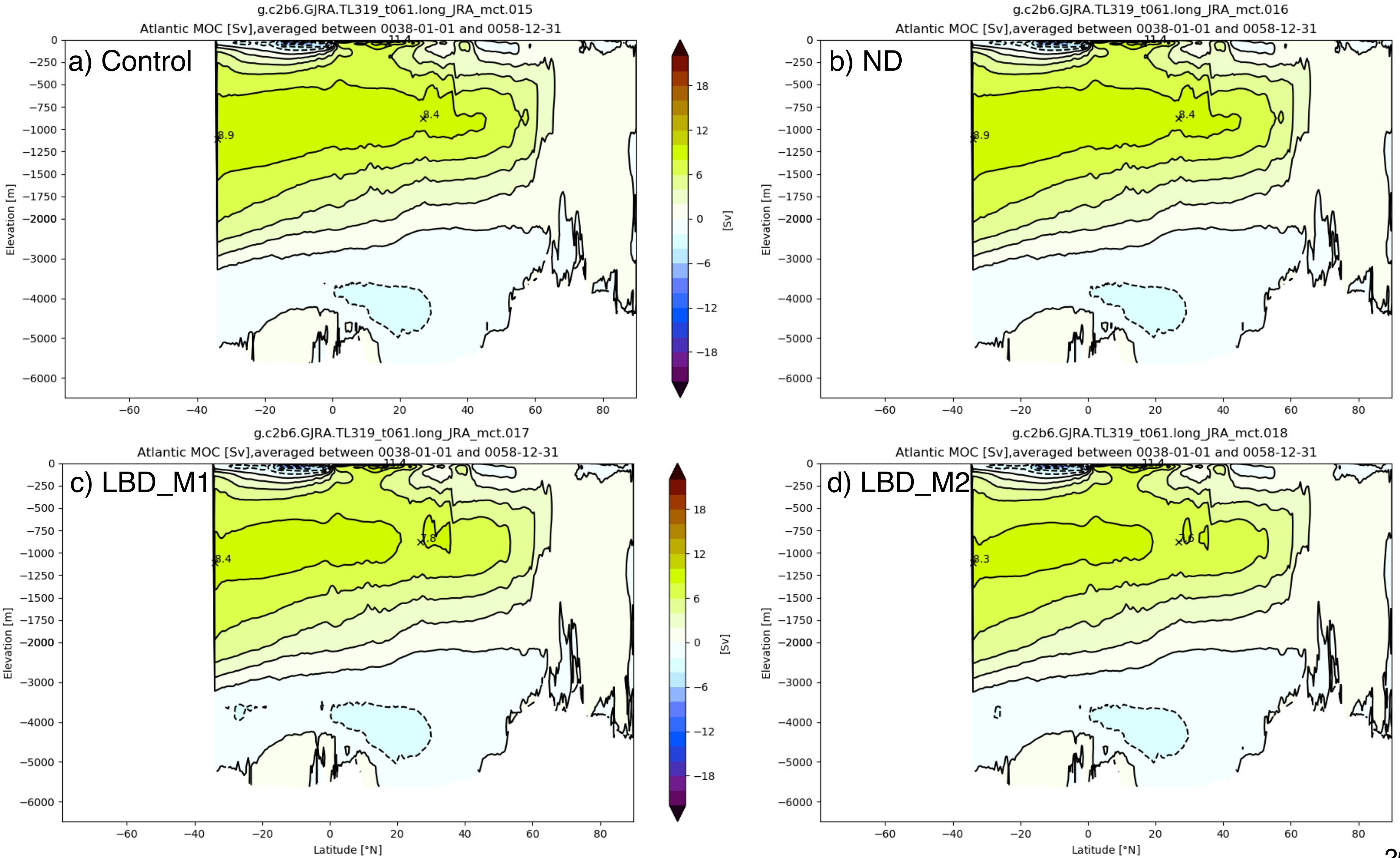
Meridional Overturning Circulation (mean last 20 years)

Global

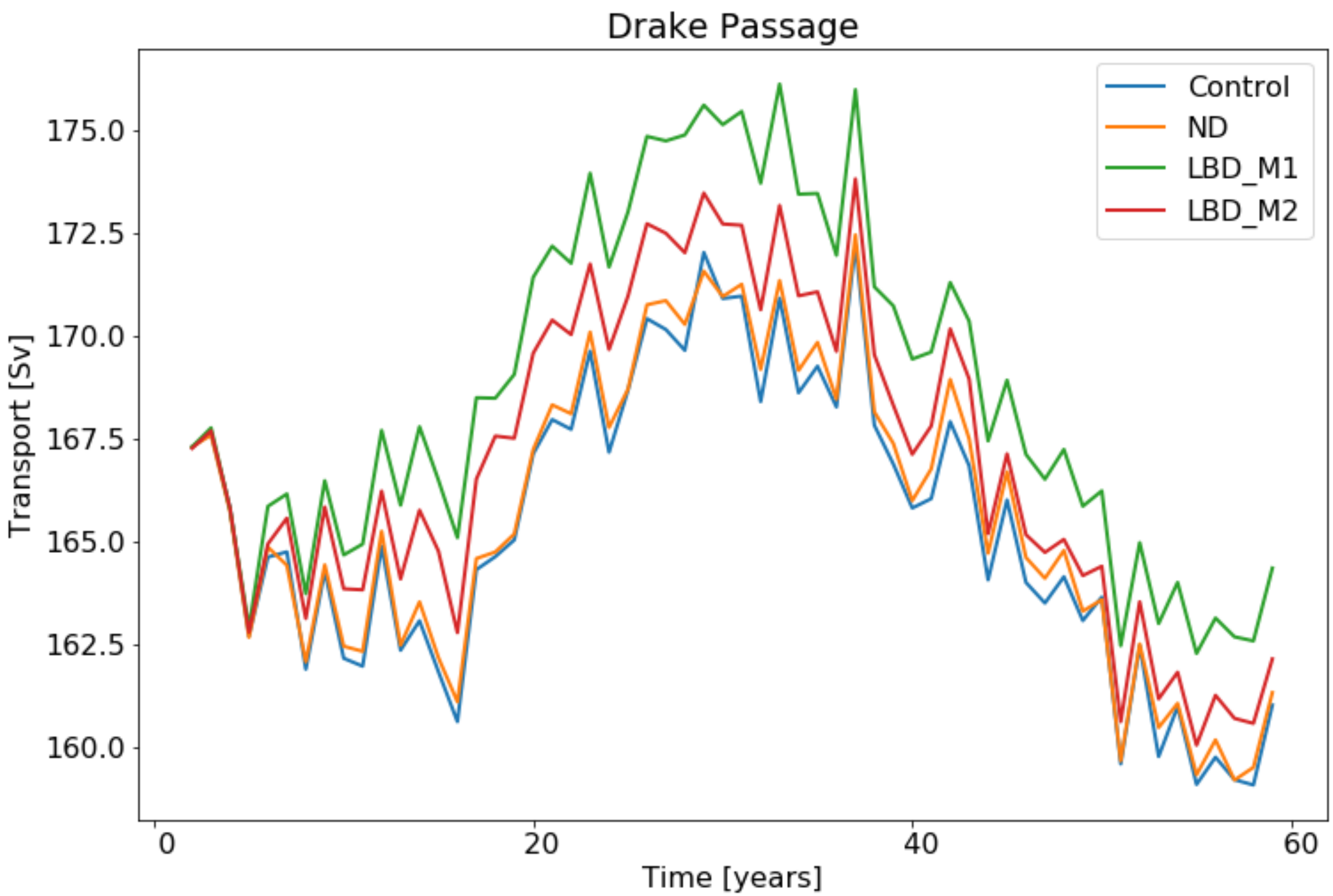


Meridional Overturning Circulation (mean last 20 years)

Atlantic



Volume transport in the Drake passage



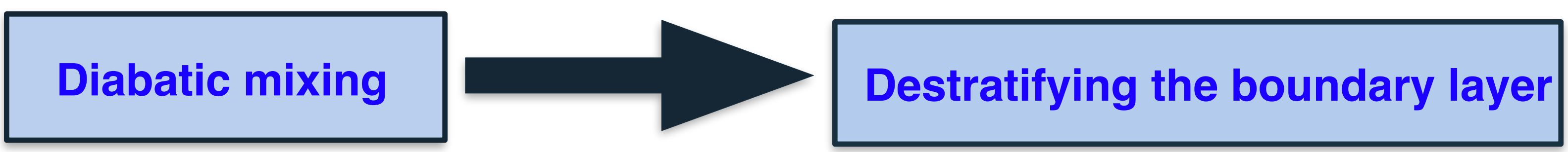
Summary

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

- Tested using “idealized” (Baltic test, hybrid and z*) and global (CESM/MOM6, z*) experiments

- Both methods lead to qualitatively similar results:
  - Overall deepening of the surface boundary layer

Hypothesis



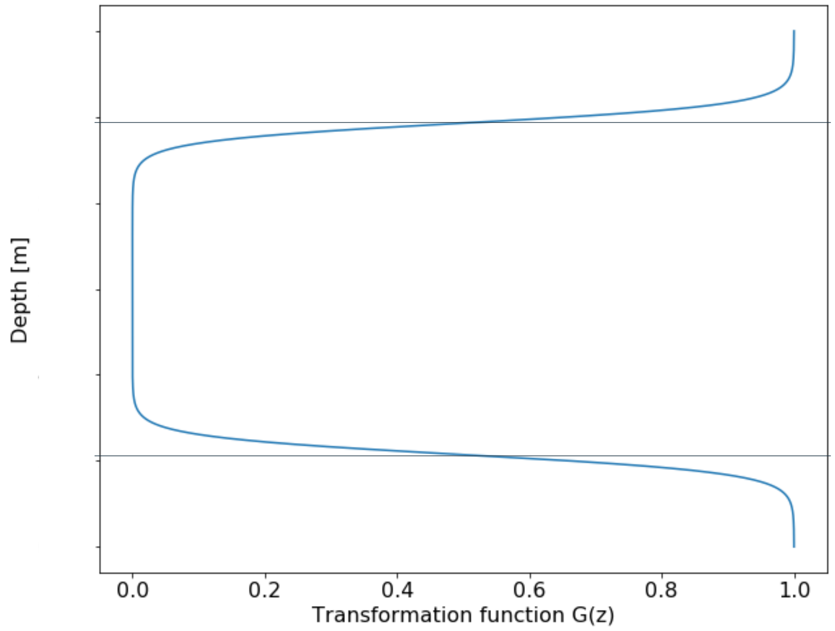
  - Reduction in the total ocean heat content

- Still a lot to be done!

Future work

- Enable LBD in the bottom boundary layer

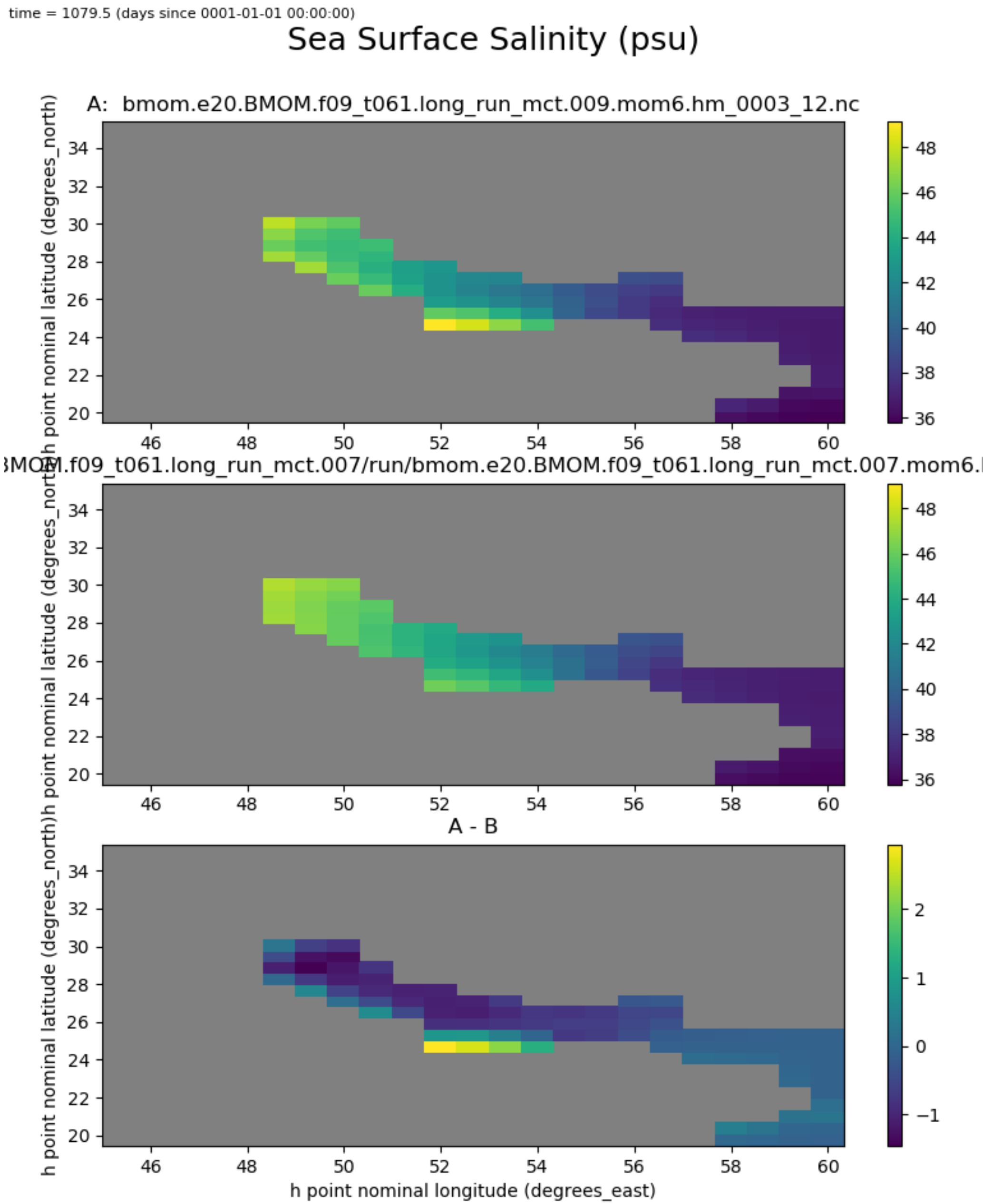
- Transformation function $D_T = G(Z) \times D_L + [1 - G(Z)] \times D_N$



- 3D tracer diffusivities

Thank you!

SSS reduction in a fully-coupled run

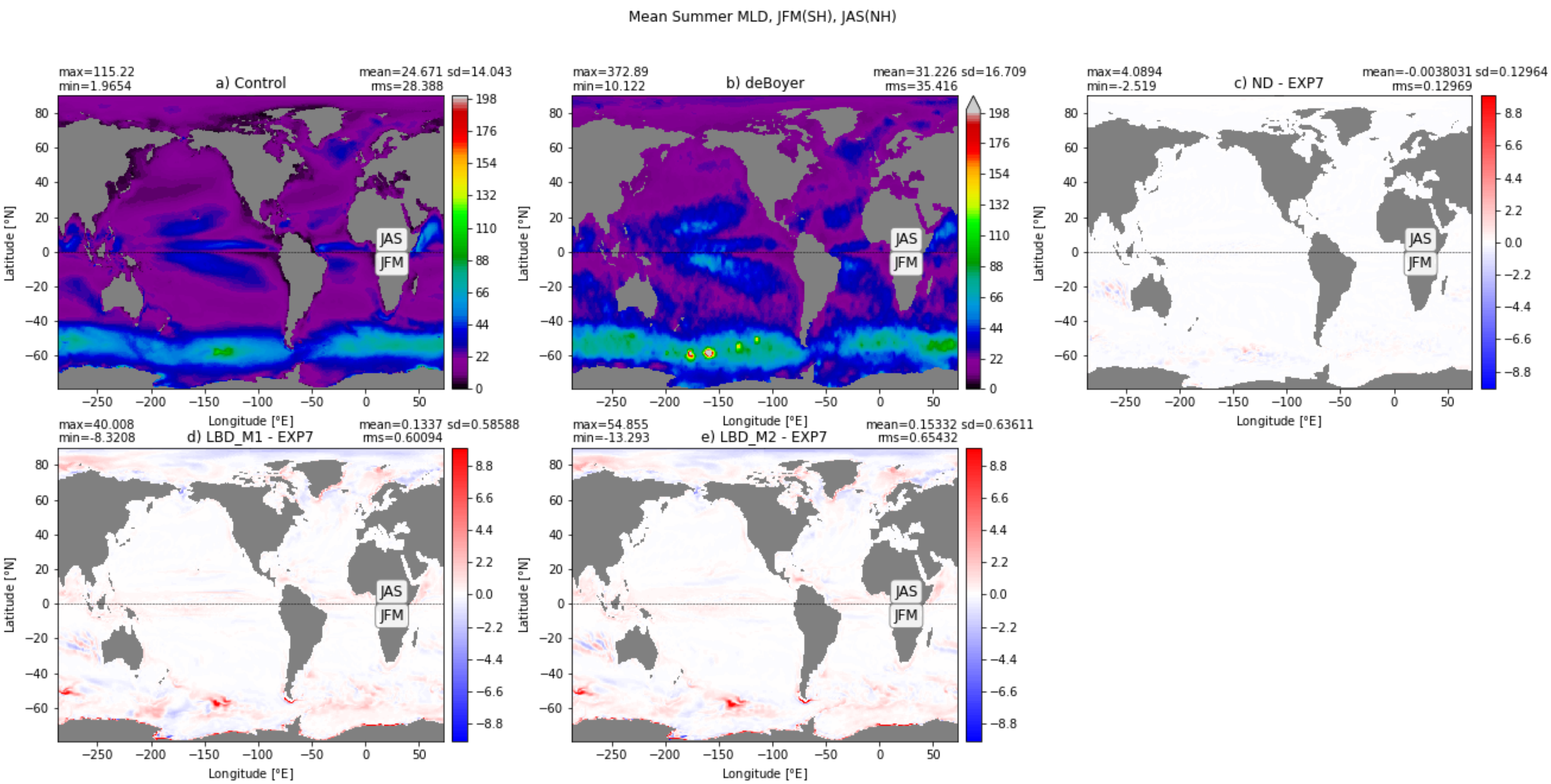


Out-of-the-box

LBD Method # 2

Difference

Mixed layer depth: Summer (JAS, last 20 years)



Tracer flux limiter

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