Numerical tracer mixing in the COSIMA model suite

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Climate Change Research Centre

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Introduction

Numerical mixing – artificial diffusion of tracer gradients arising from discrete advection

Contributes to model biases – **"the models mix too much".** Interior diapycnal diffusivity is small ($<10^{-5} m^2 s^{-1}$), spurious numerical mixing can often be larger.

Difficult to quantify in realistic models – typically studied in idealized contexts

<u>This study:</u>

- Numerical mixing estimated across ACCESS-OM2 suite
- Sensitivity to resolution and physical parameterizations.

We do not:

- Test sensitivity to advection schemes (take MDPPM as given)
- Precisely decompose isopycnal vs. diapycnal components

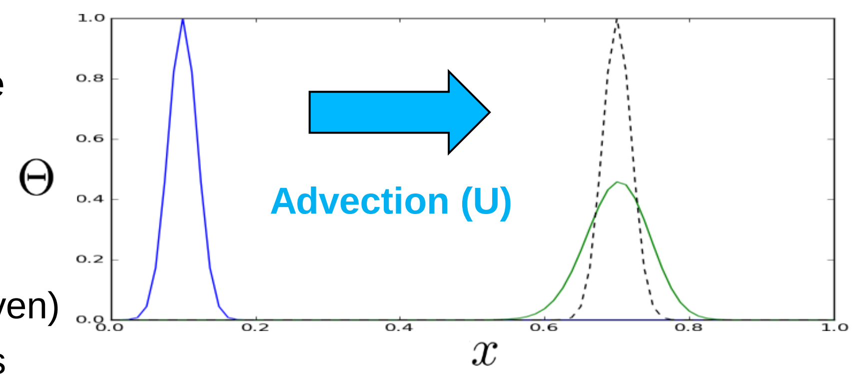
Continuous 1D Advection:

$$\frac{\partial \Theta}{\partial t} = -U \frac{\partial \Theta}{\partial x}$$

Discrete analog (centered-space, forward-time):

Numerical Diffusion

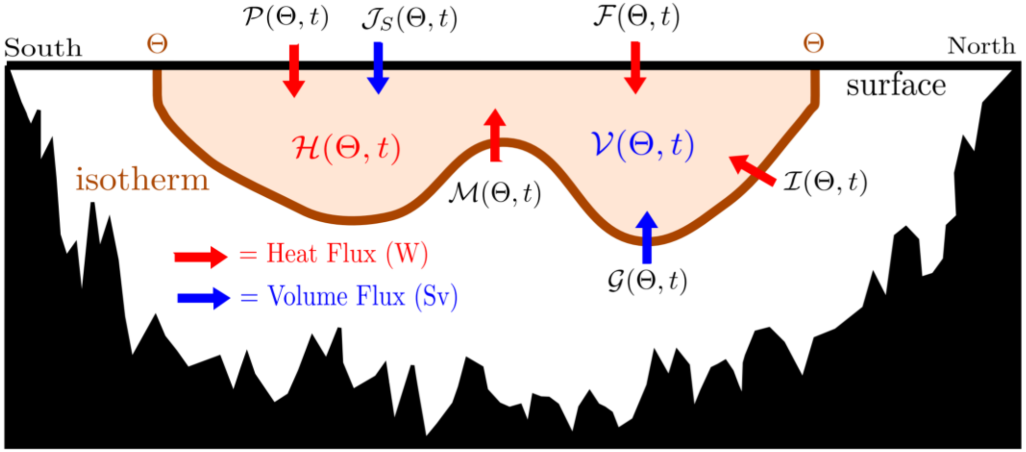
$$\frac{\partial \Theta}{\partial t} = -U \frac{\partial \Theta}{\partial x} + \boxed{U^2 \frac{\Delta t}{2} \frac{\partial^2 \Theta}{\partial x^2}} + \mathcal{O}((\Delta x)^2, (\Delta t)^2)$$



Method: Heat budget analysis in temperature coordinates

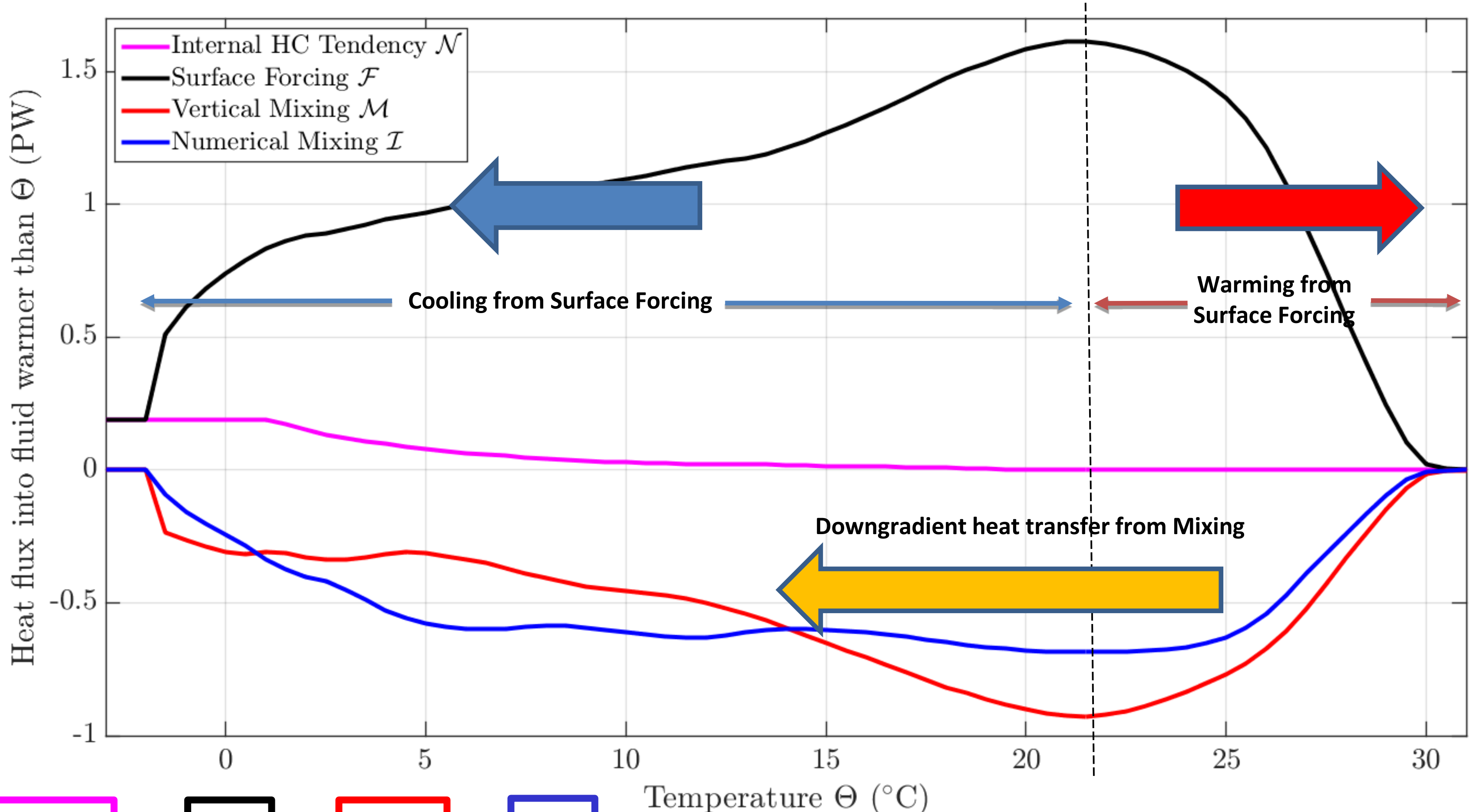
Heat budget of the seawater warmer than Theta:

$$\underbrace{\frac{\partial \mathcal{H}}{\partial t}(\Theta,t)}_{\text{Tendency}} = \underbrace{\mathcal{F}}_{\text{Forcing}} + \underbrace{\mathcal{M}}_{\text{Vertical}} + \underbrace{\mathcal{R}}_{\text{Redi}} + \underbrace{\mathcal{I}}_{\text{Numerical}} + \underbrace{\mathcal{G}\Theta\rho_0 C_p}_{\text{Diathermal Advection}}$$



- Diathermal advection removed by combining with the volume budget – *integrated, more robust*.
- F, M and R calculated by ***online*** binning Eulerian budget into temperature coordinates. dH/dt tracked using snapshots.
- Numerical mixing (I) calculated by residual

Global Diathermal Heat Budget in MOM025 Control



$$\frac{\partial \mathcal{H}_I}{\partial t} = \mathcal{F} + \mathcal{M} + \mathcal{I}$$

Warm-to-cold heat transport driven as much by numerical as vertical mixing

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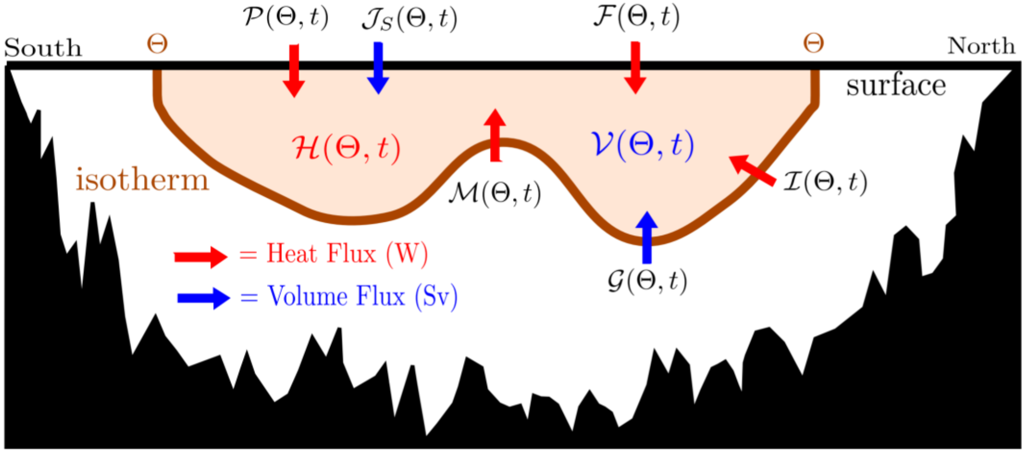

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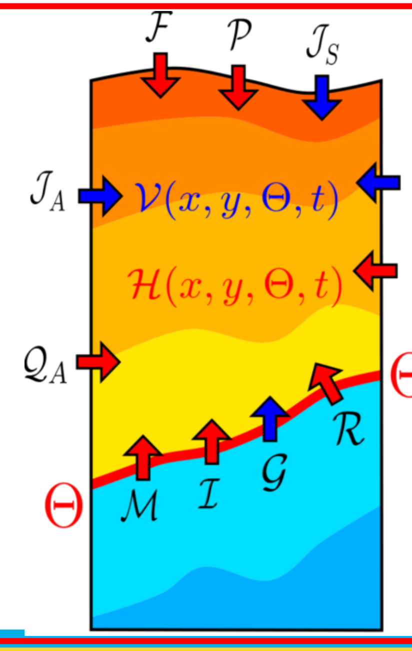
Spatial Structure

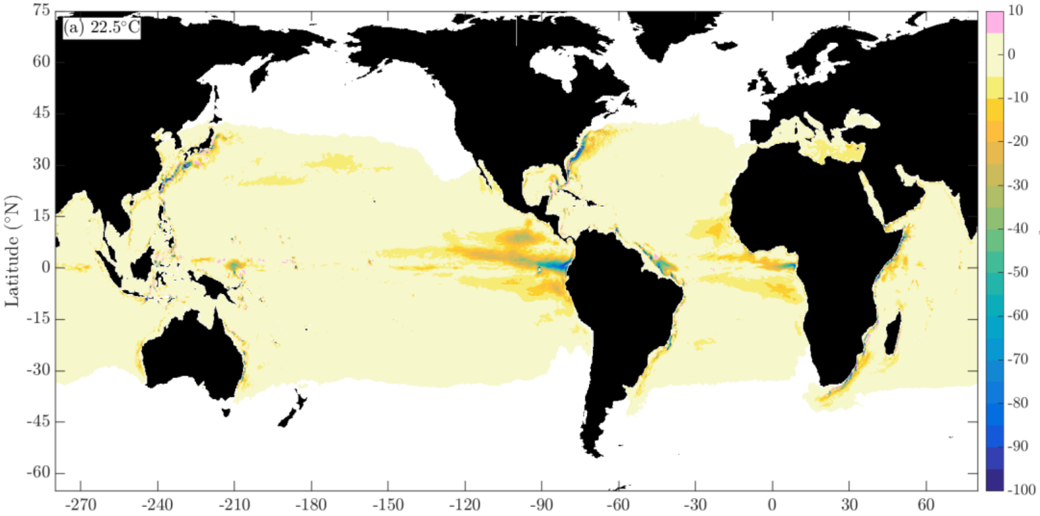
Can be estimated by generalizing to a single fluid column by including temperature-binned lateral volume (J) and heat (Q) fluxes

However – more approximations needed.

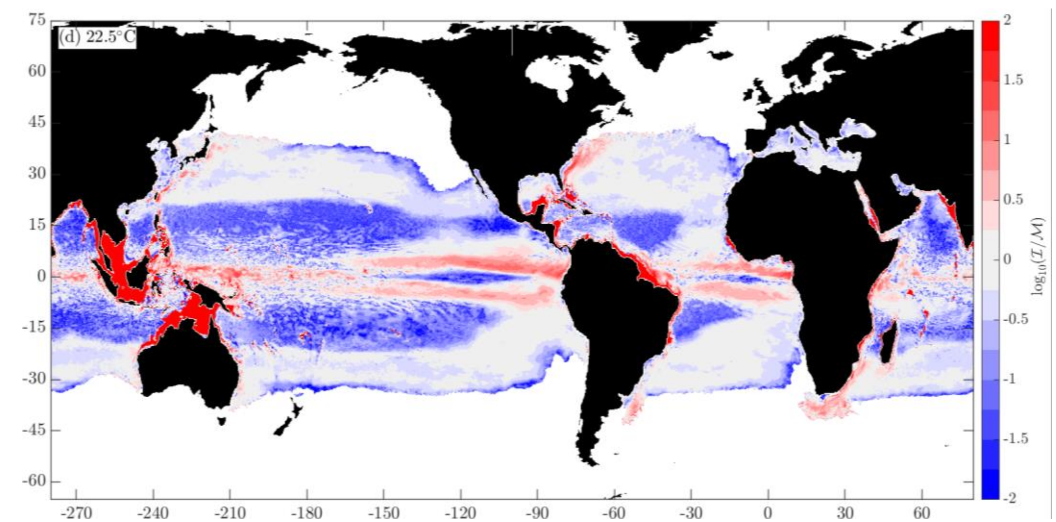


MOM025 Control results -> Warm temperatures

Heat flux due to numerical mixing through 22.5ºC isotherm:



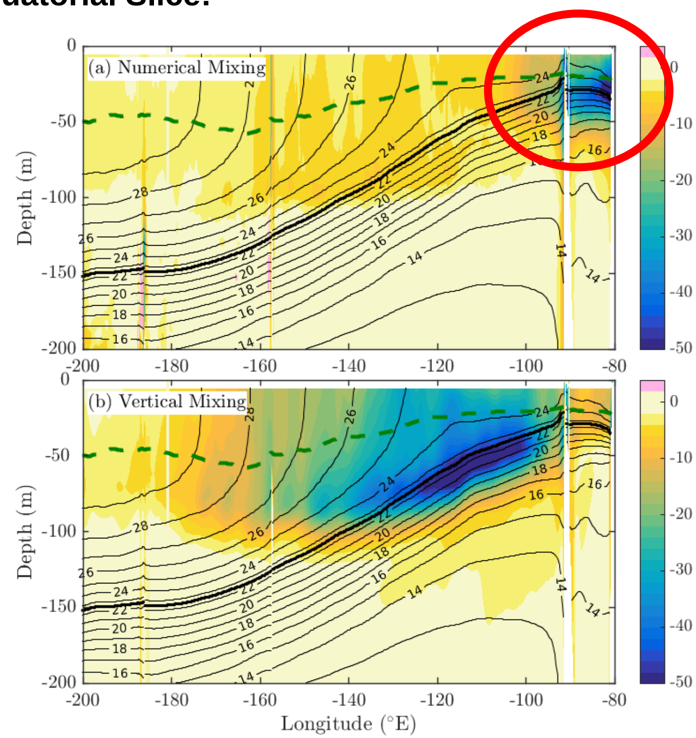
Ratio of numerical mixing to vertical mixing:



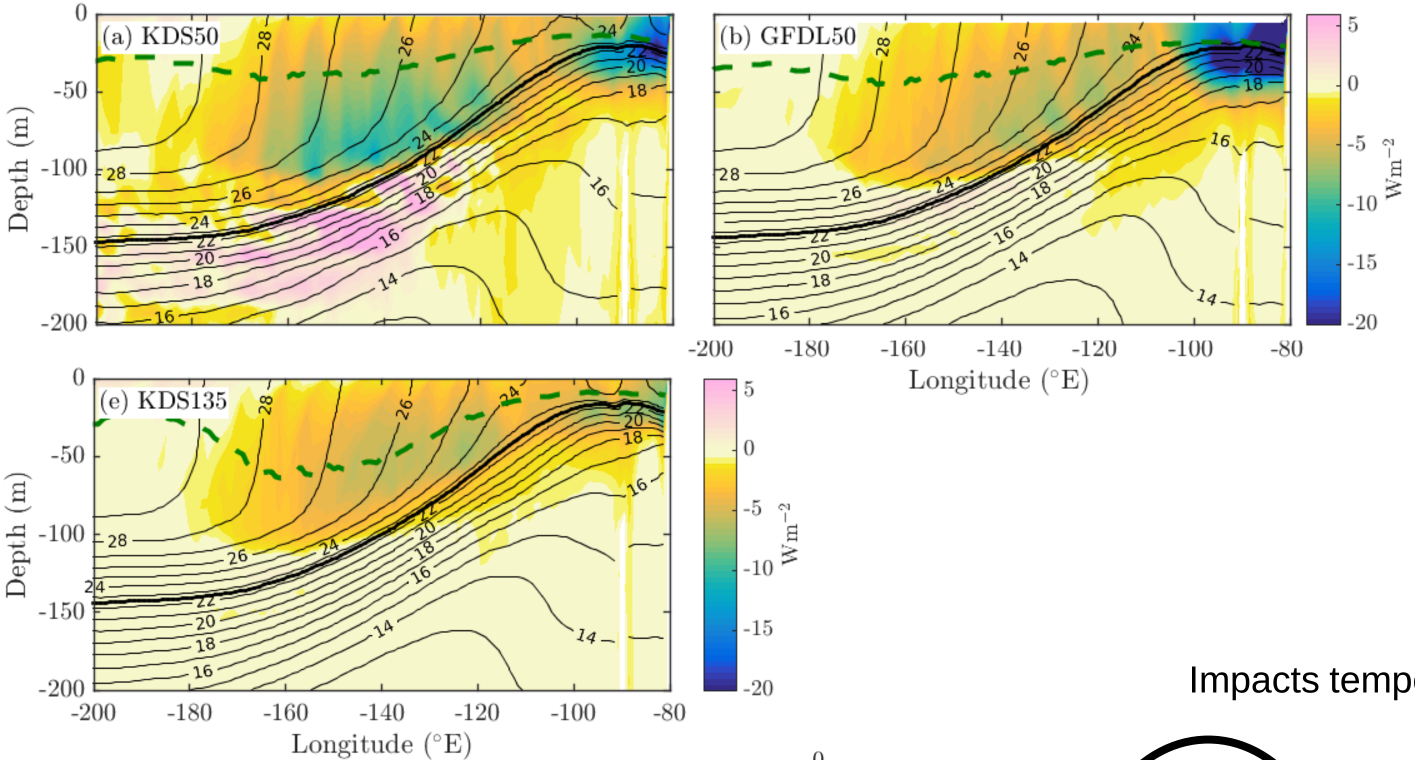
Note: Background diffusivity = $10^{-5} m^2 s^{-1}$
($10^{-6} m^2 s^{-1}$ near Equator)

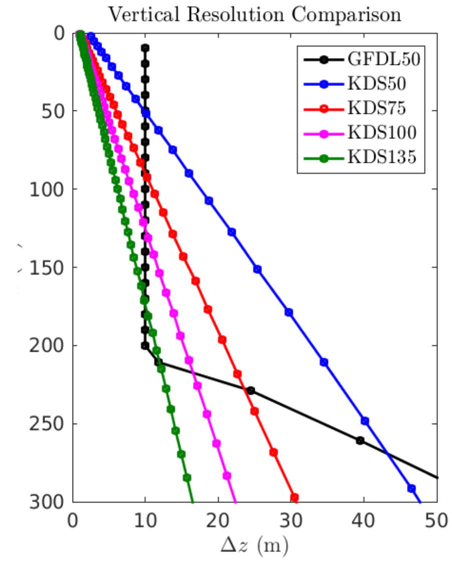
High grid-scale vertical temperature gradients

Equatorial Slice:

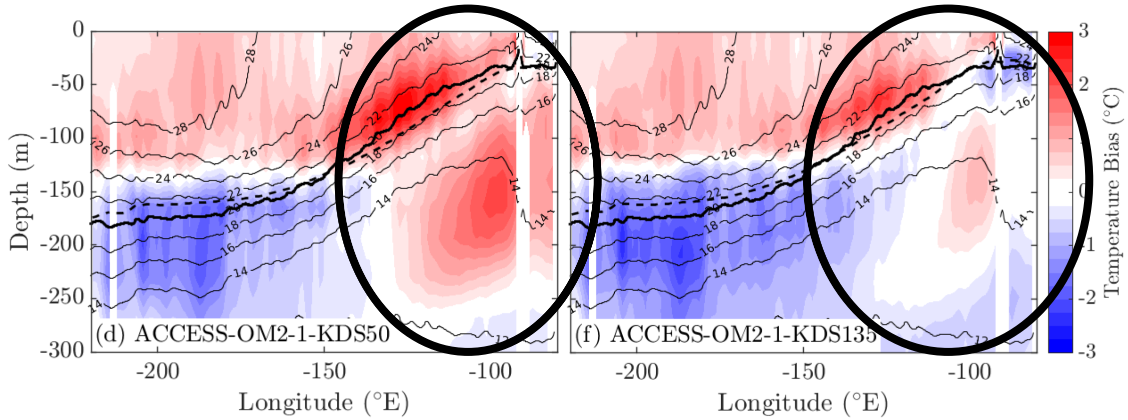


Sensitivity to vertical resolution in ACCESS-OM2-1





Impacts temperature structure

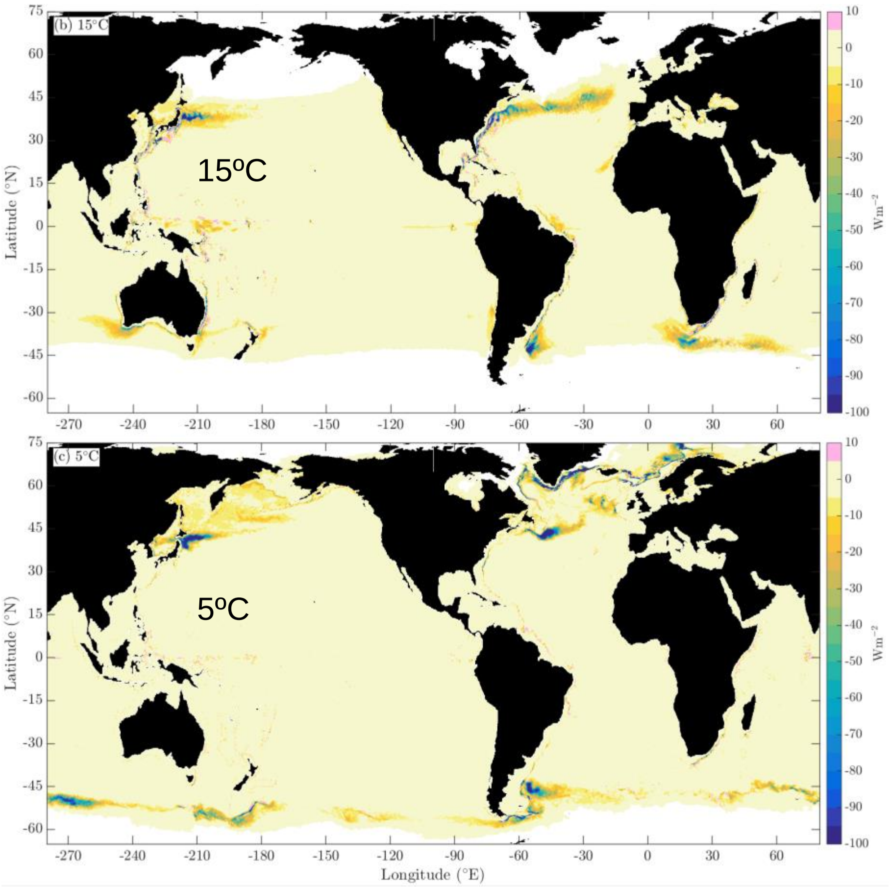


Changes not compensated by changes in vertical mixing.

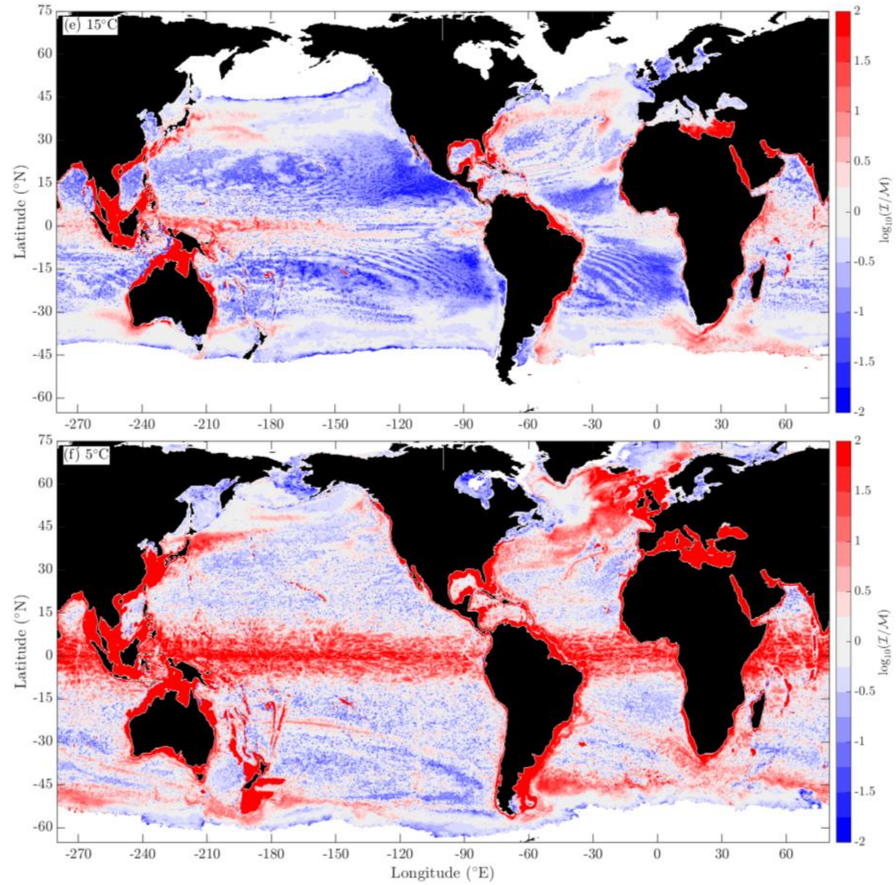
Sensitivity of numerical mixing at warm temperatures to vertical resolution and vertical diffusivity suggests it is ***spurious/diapycnal***.

MOM025 Control results -> Cold temperatures

Numerical mixing



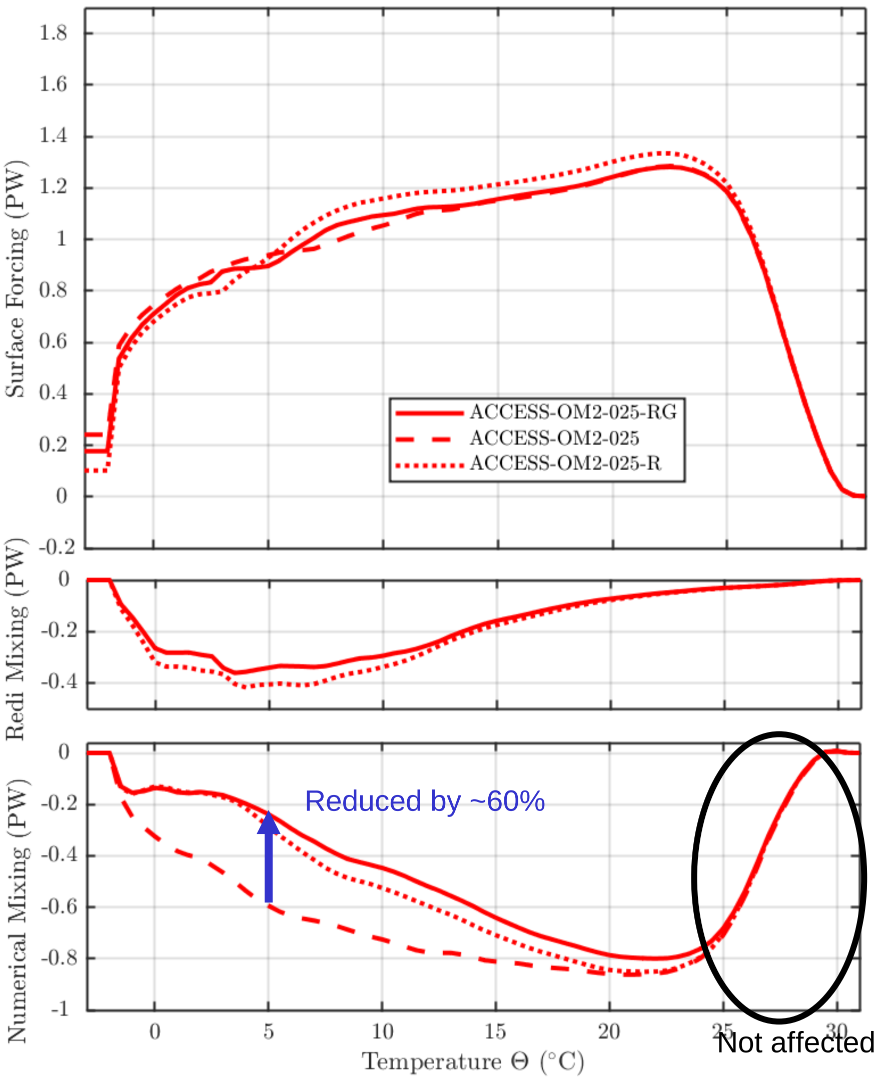
Ratio of numerical and vertical



Dominated by eddy-regions – boundary currents and ACC.

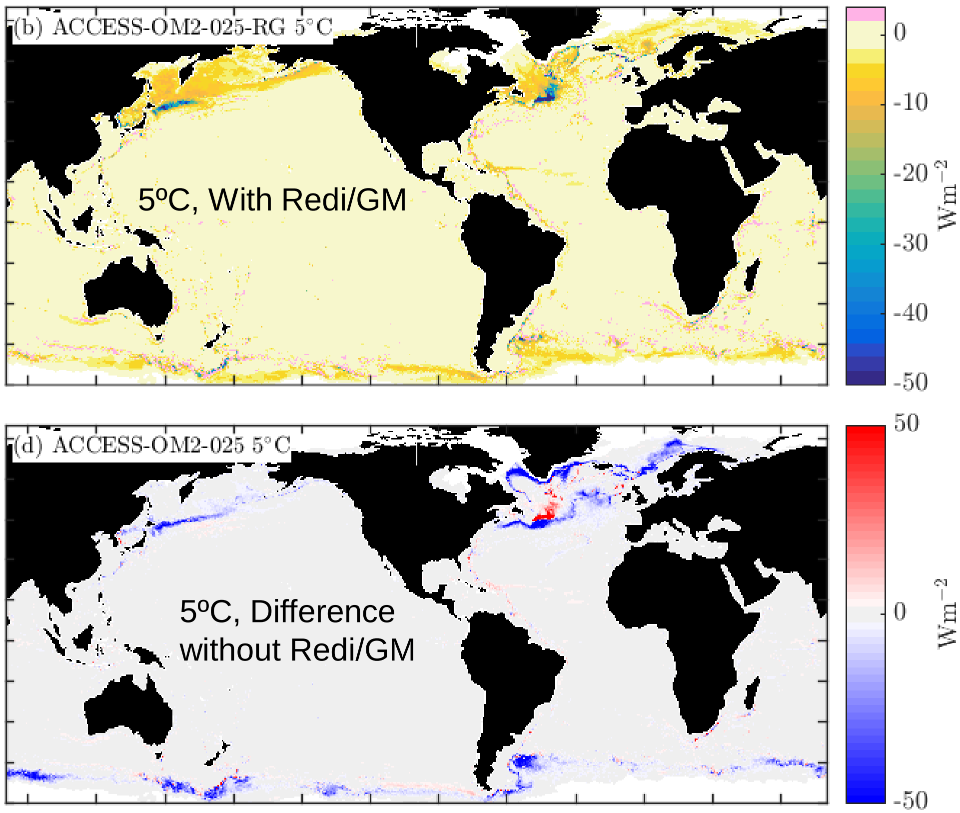
Does this mean that numerical mixing is mostly isopycnal in these regions?

Sensitivity to neutral physics



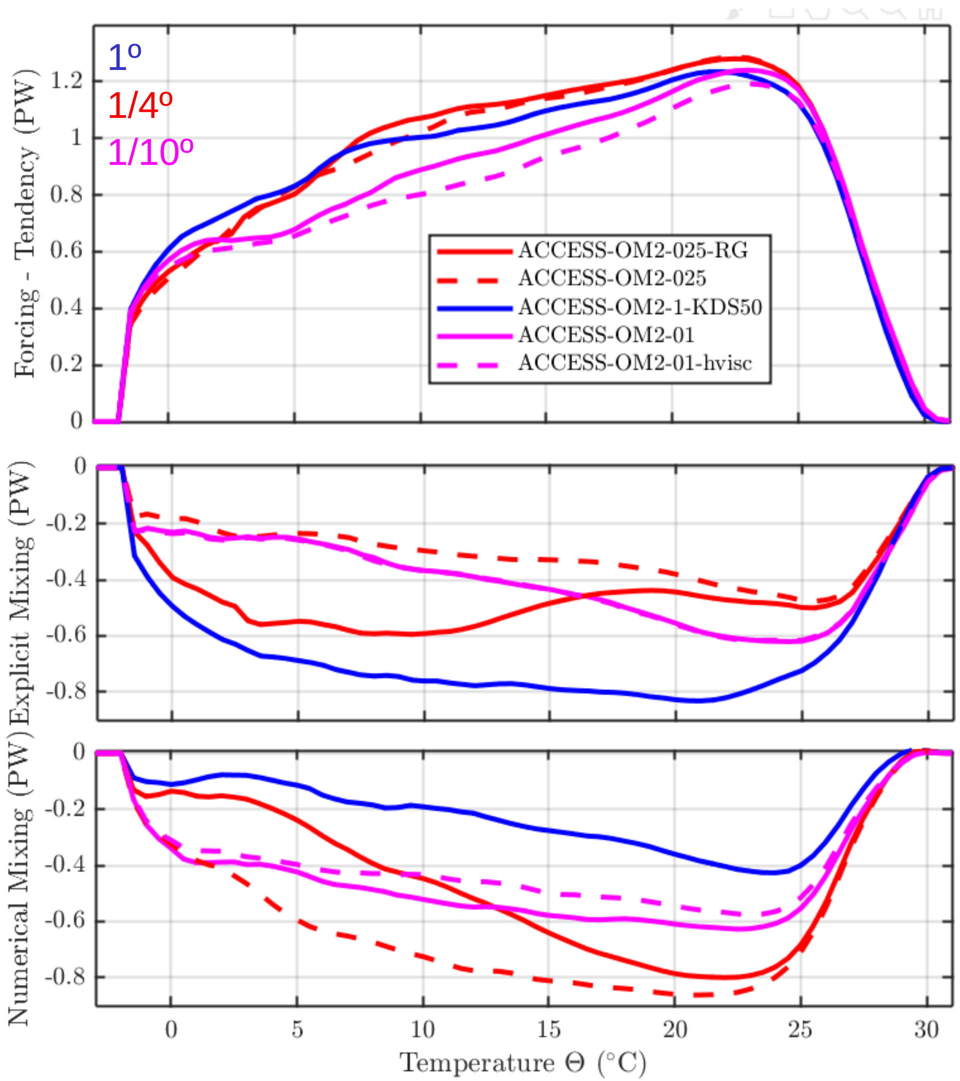
Adding along-isopycnal diffusion (~200m^2s^{-1}) reduces numerical mixing by ~60%. Diathermal budget suggests clean substitution.

However - there are significant mean state changes (Southern Ocean, Gulf Stream).



Note: Changes in vertical mixing negligible

Sensitivity to horizontal resolution and lateral viscosity



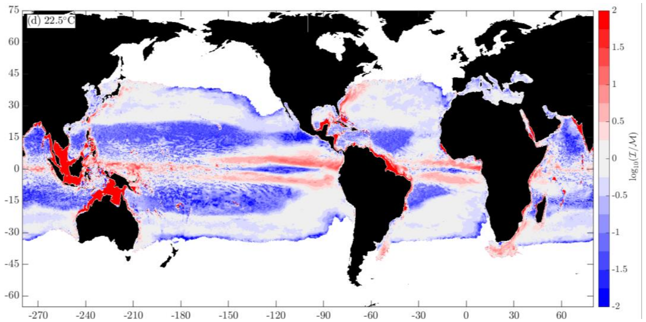
Generally, numerical mixing largest at 1/4º, followed by 1/10º and finally 1º.

Partially because of ***physical mixing differences across the resolutions*** – choices of mixing coefficients made partially in anticipation of numerical mixing.

Increasing Smagorinsky biharmonic viscosity from 2->3 in 1/10º reduces numerical mixing by 10-15%.

Spectral analysis (coming soon) will yield more insight…

Summary/conclusions/questions



<u>Key Conclusions:</u>

1) Numerical mixing drives a large fraction of global warm-to-cold heat transport.

2) Sensitivity to resolution and physical mixing schemes suggests:
   - warm/tropical numerical mixing is largely diapycnal
   - Cold/boundary current numerical mixing has a large isopycnal component.

<u>Open questions:</u>

1) Does numerical mixing constitute a valid representation of absent physical mixing?

2) Are the simulations adversely affected (more work needed – spectra, biases)?

Questions and suggestions welcome!