University of St Andrews

# Online tracer-coordinate diagnostics in MOM6

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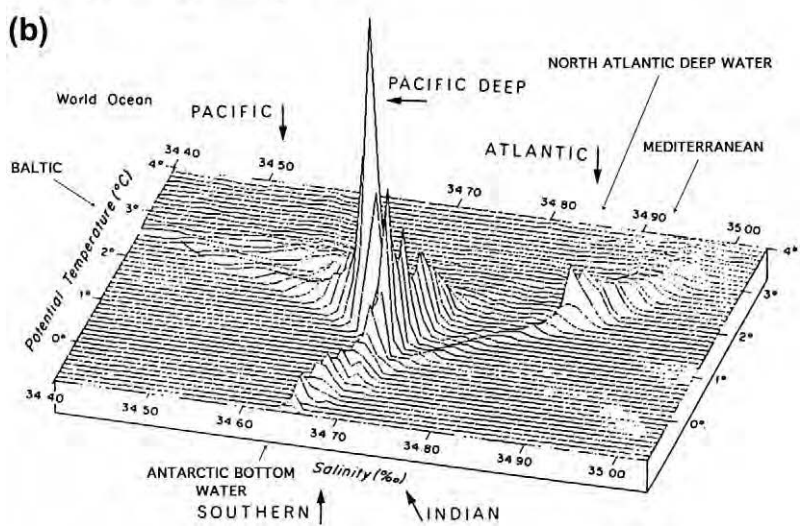
# Motivation

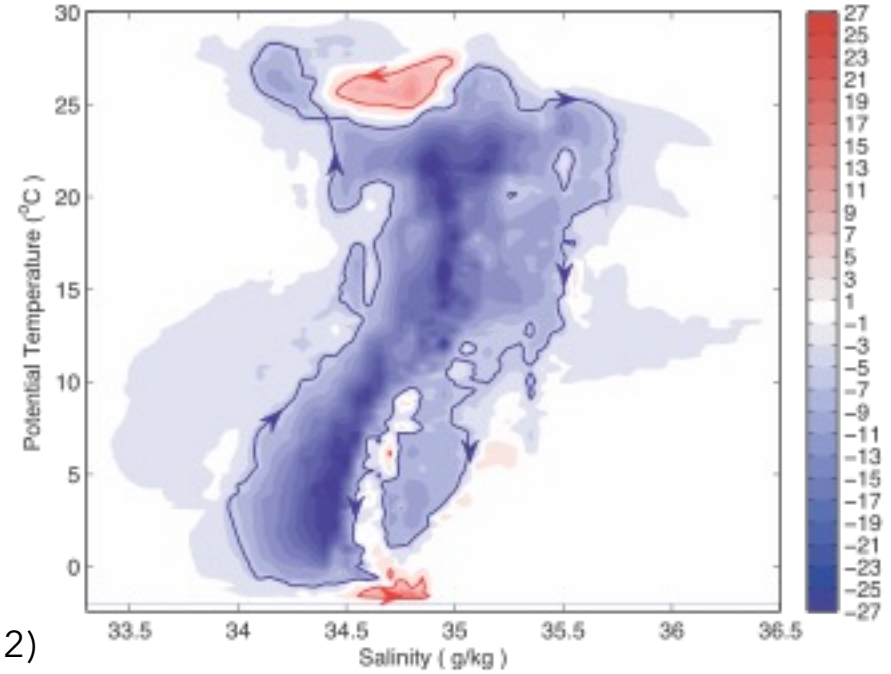
Evaluating ocean circulation in **tracer coordinates** goes back to the earliest days of oceanography.

Properties such as **temperature** and **salinity** tag ocean watermasses.

These watermasses evolve in response to **boundary forcing** and **ocean dynamics**.




Talley, Descriptive Physical Oceanography; from Worthington (1981)




Zika *et al.* (2012)

# Why use tracer coordinates for ocean model diagnostics?

A watermass framework allows **process-level understanding** of ocean dynamics.

A powerful tool for understanding **ocean model processes and biases**, aiding development.

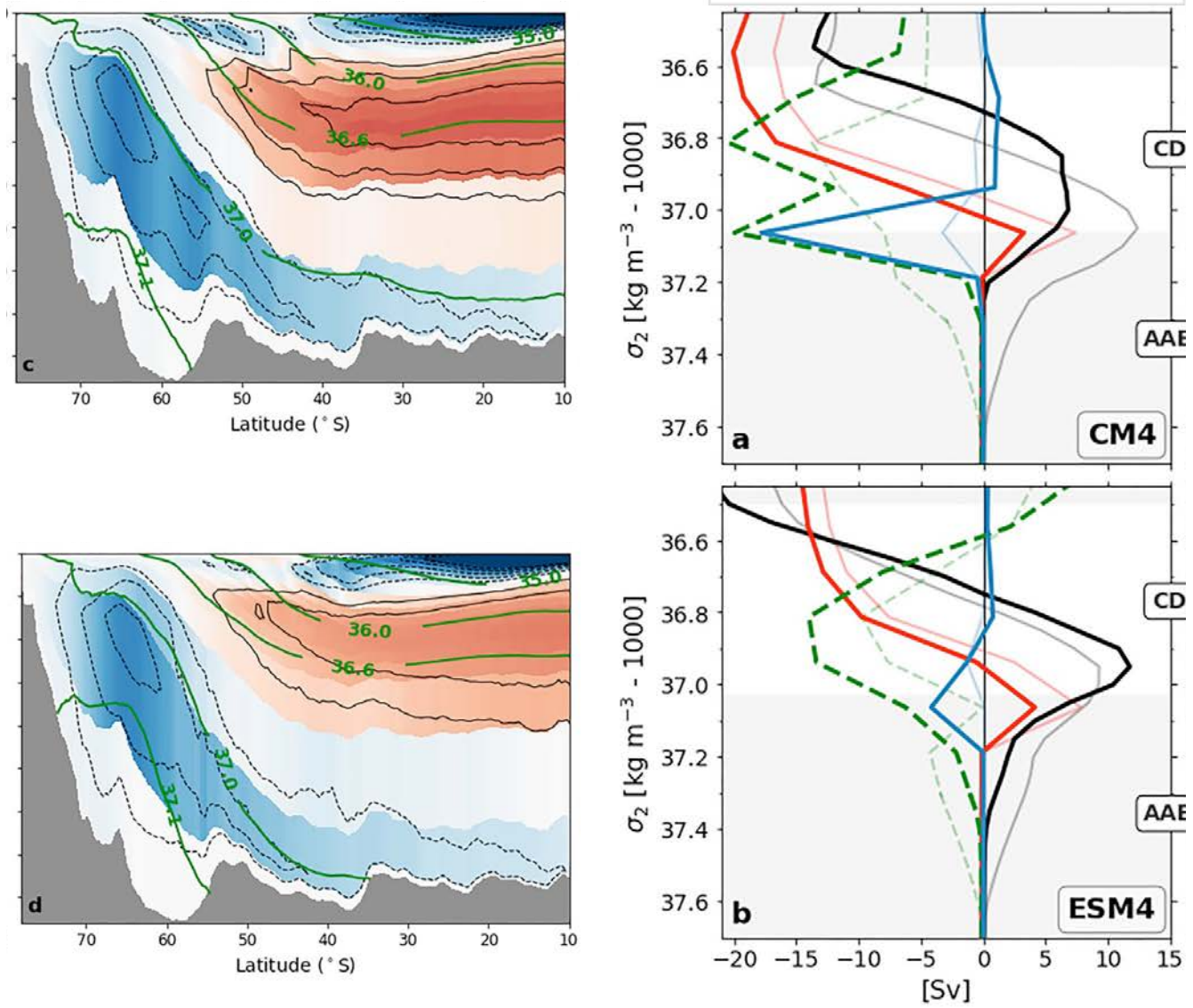
# Antarctic Bottom Water response to freshwater forcing

AABW **response diverges** between two models, apparently associated with **interior ocean mixing processes.**

**Tesdal *et al.* (2023) *JGR-O***

CM4

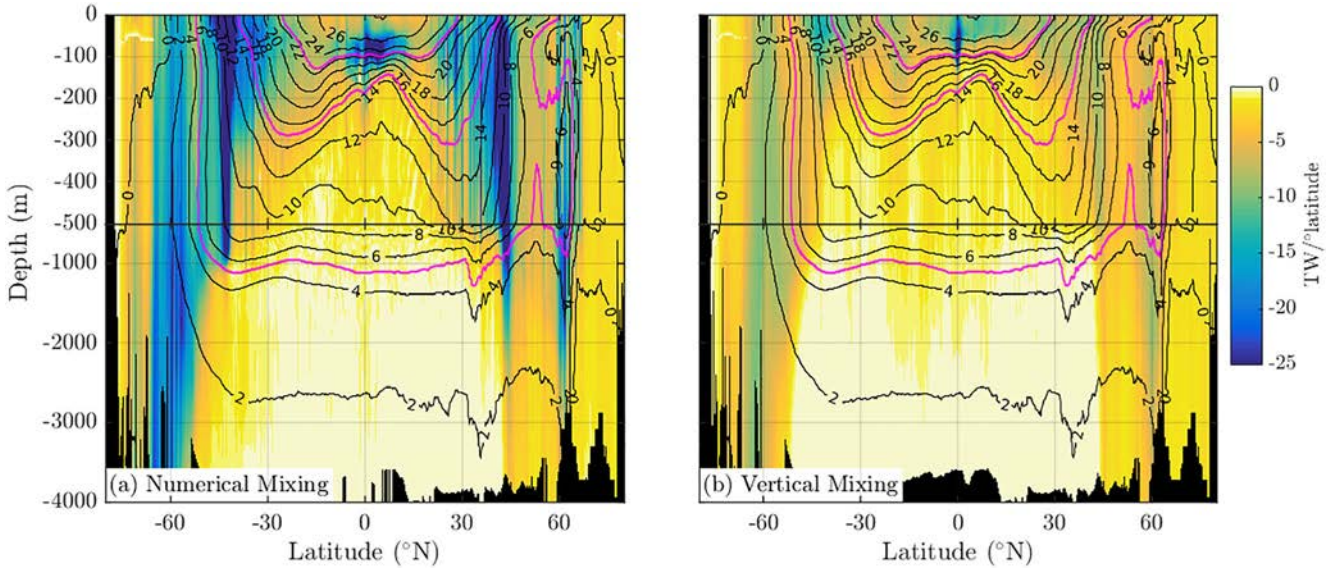
ESM4



# Diagnostic of numerical mixing

Accurate **budgets in temperature coordinates** reveal heat flux and watermass transformation rates due to **numerical mixing**.

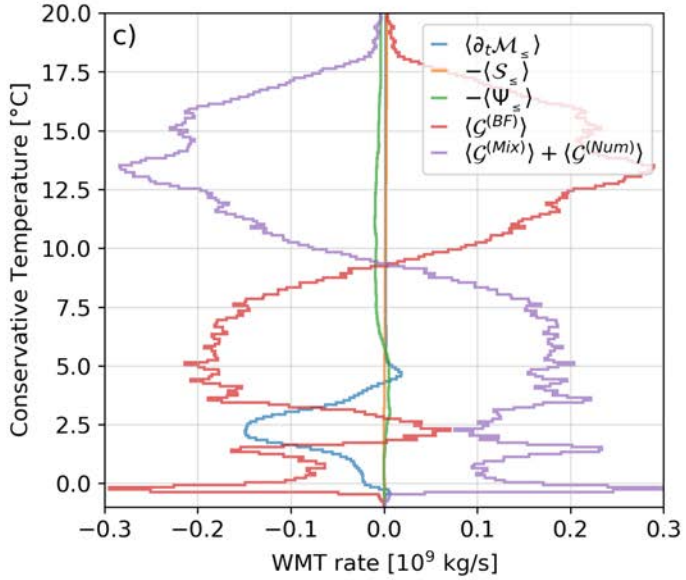
**Holmes *et al.* (2021) *JAMES***




Numerical mixing

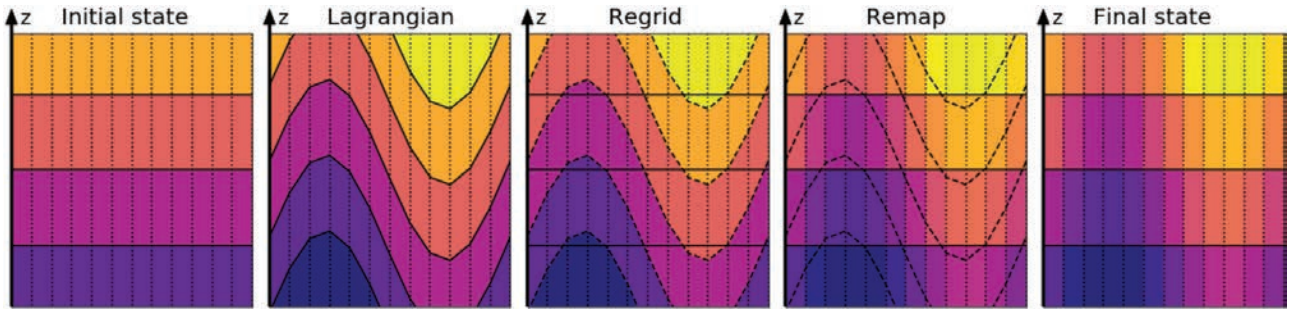
Explicit vertical mixing

**Drake *et al.* (in revision) *JAMES***



# Potential for online remapping in MOM6

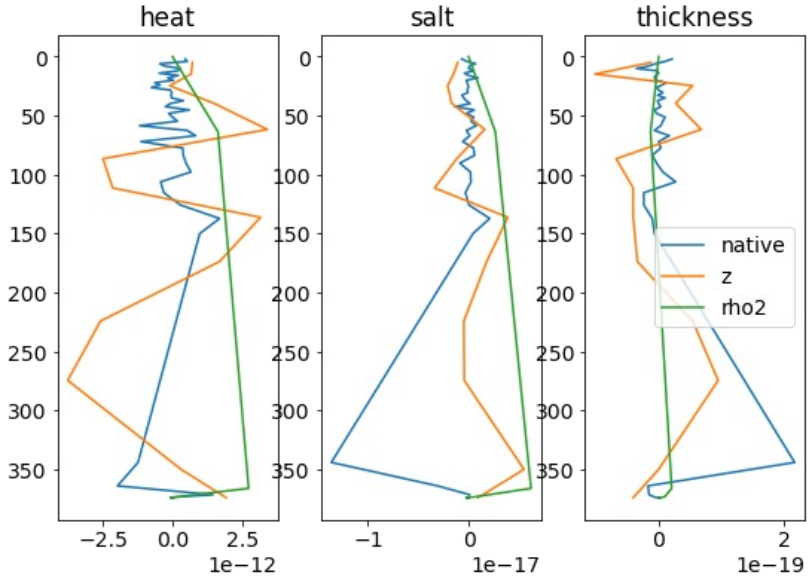
Can the **regrid-remap architecture** of MOM6 be leveraged to perform **accurate online remapping** to a coordinate defined by any arbitrary tracer?




Griffies *et al.* (2020)

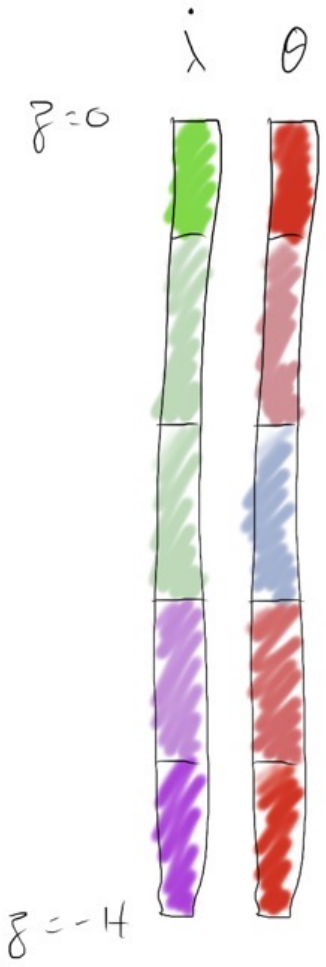
Diagnostic remapping already exists for z* and ρ
Strict requirement to be monotonically increasing with depth
What about tracers with non-monotonic and/or decreasing profiles?

- Temperature
- Salinity
- Oxygen
- Ideal Age

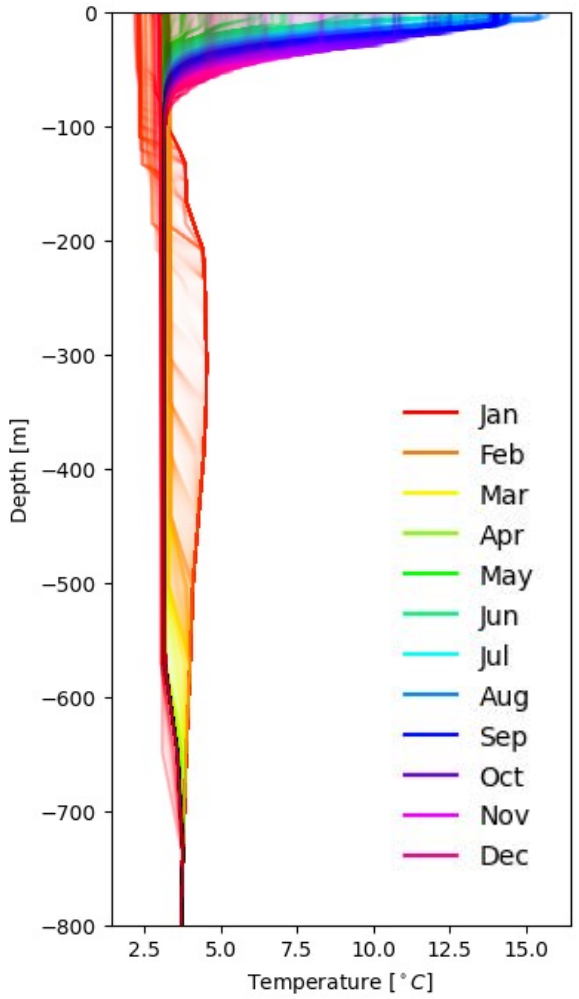


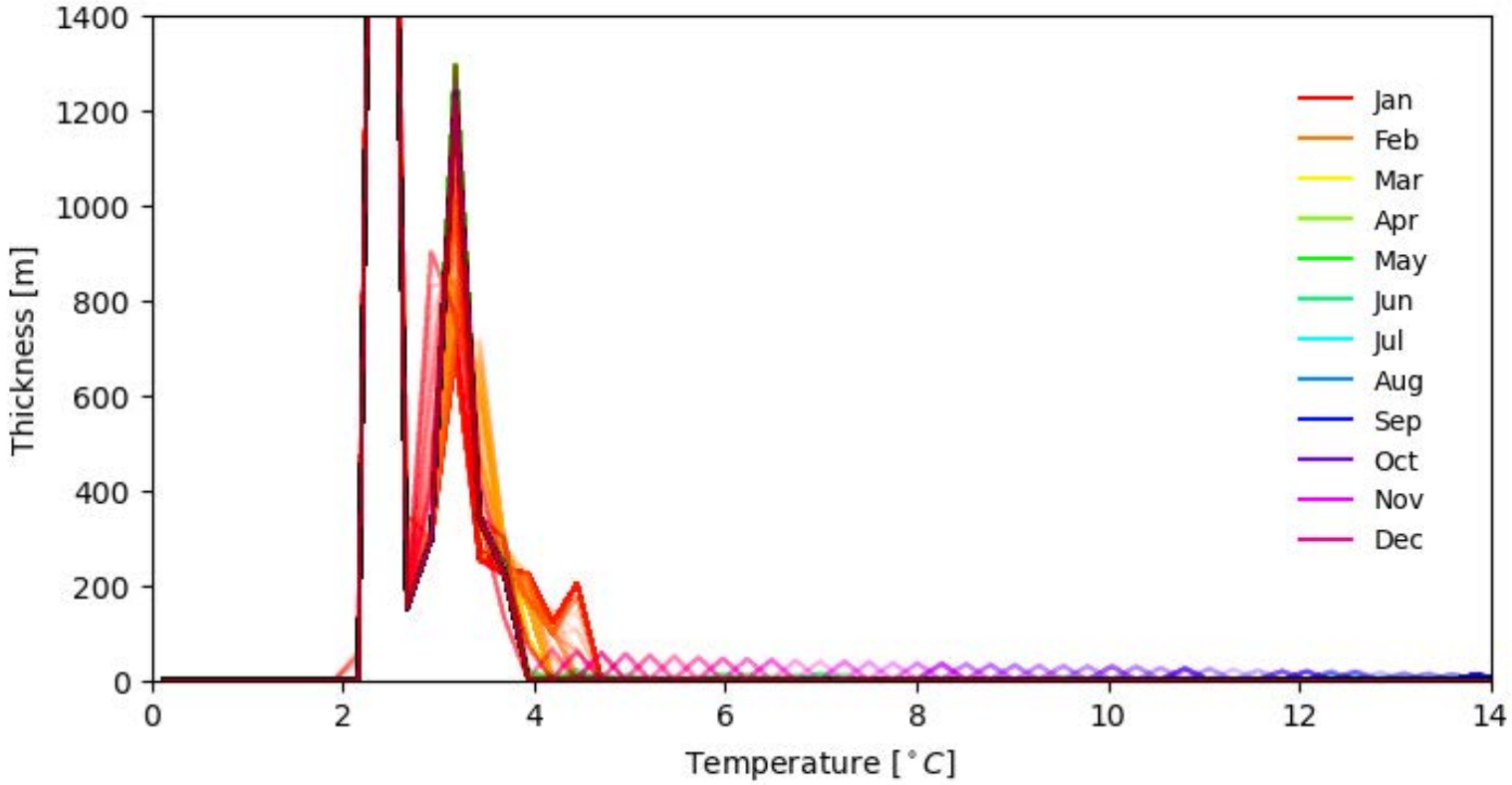
# Online remapping in MOM6

Defining **a matrix of weights** mapping source to target grids.

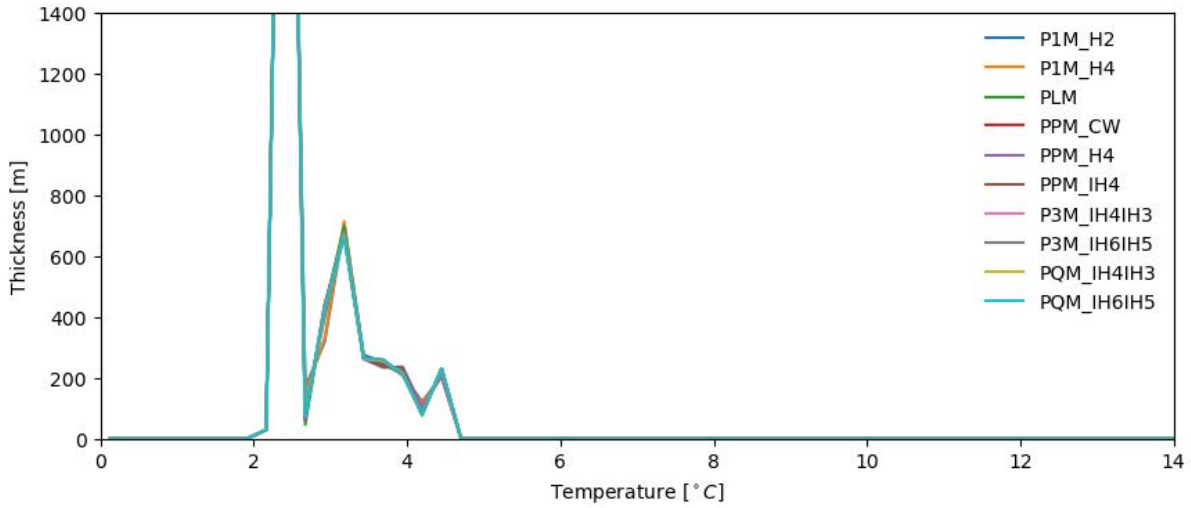


# Evolution of watermasses in a **vertical column** subject to boundary forcing

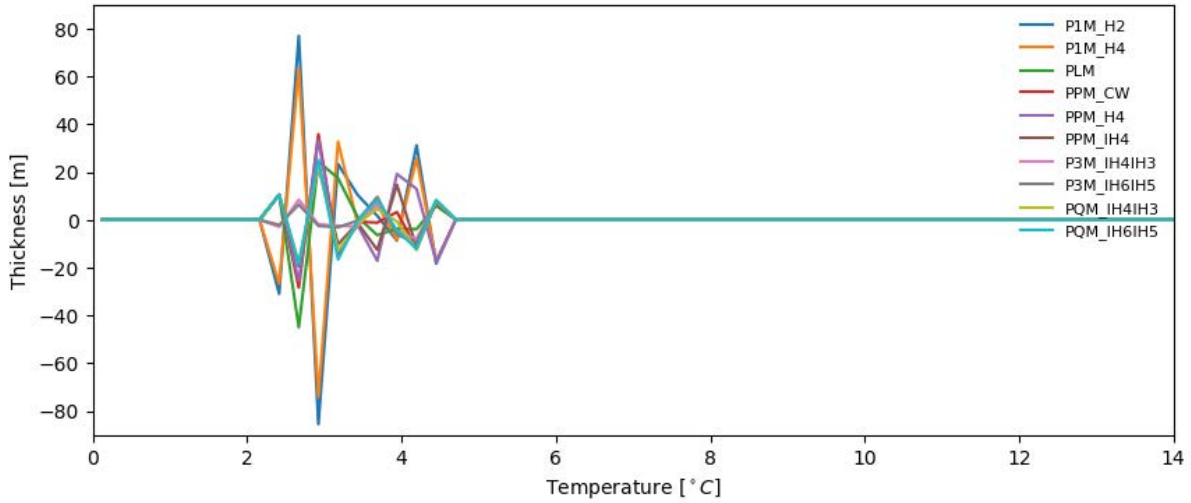


MOM6 has a number of **interpolation schemes** that impact interface depth, and therefore layer thickness

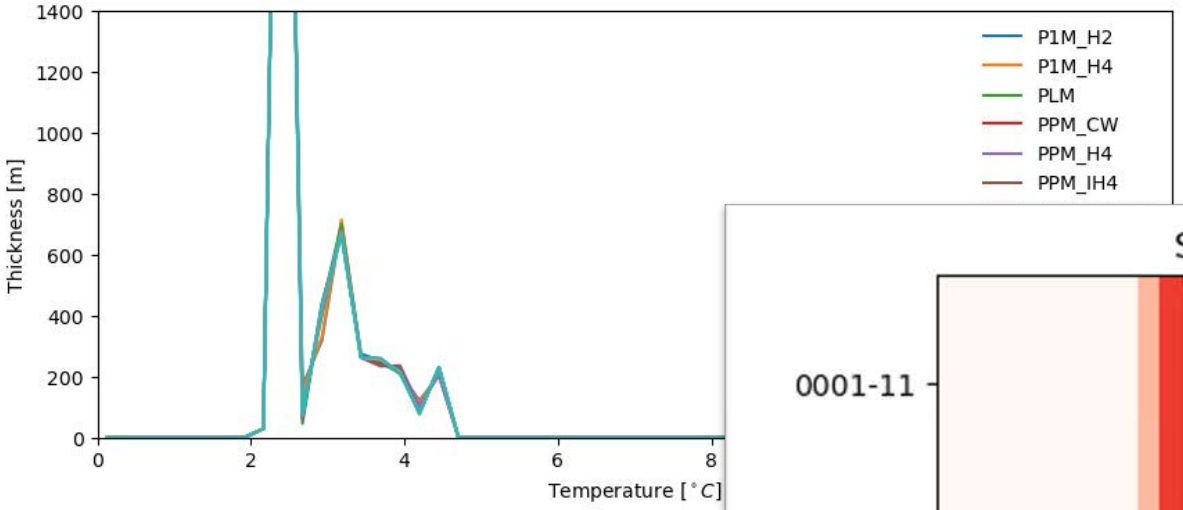



Layer thickness for different interpolation schemes

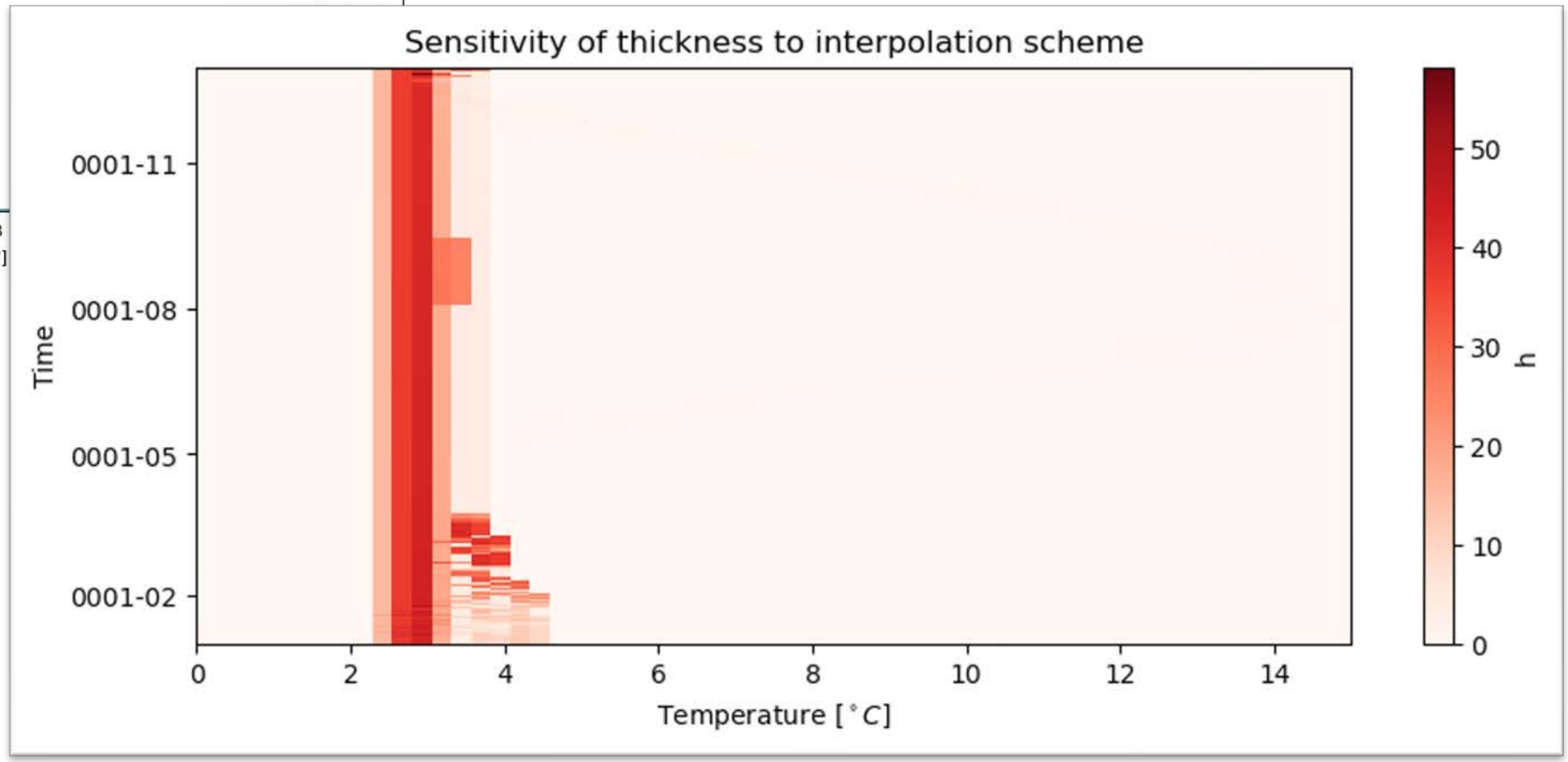



Anomaly relative to mean

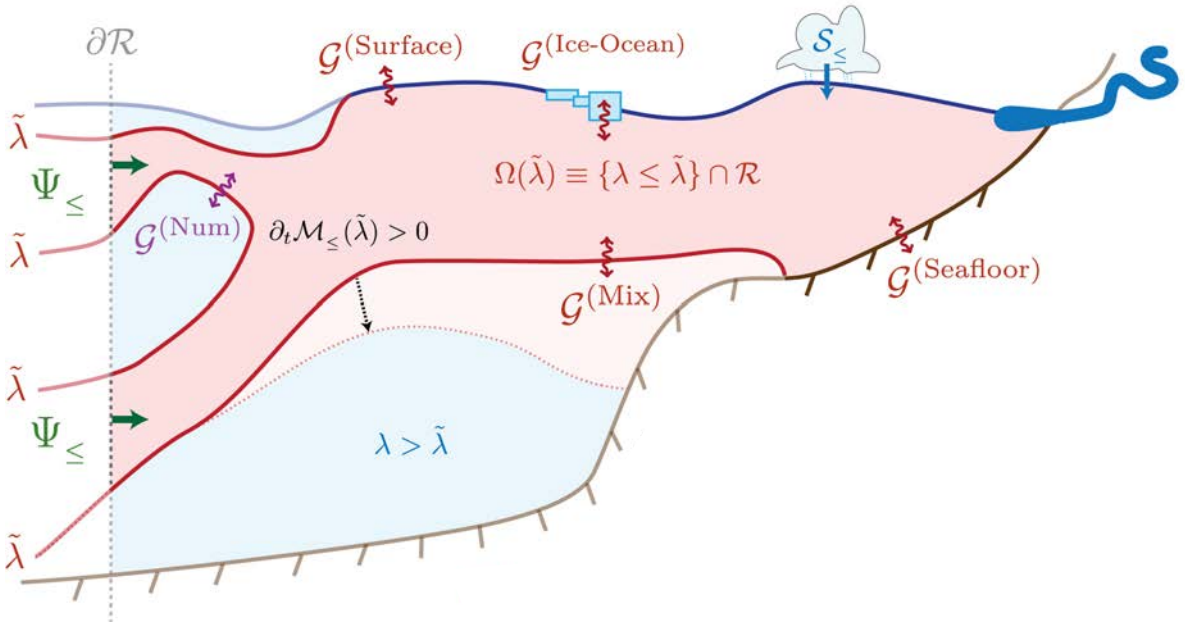
MOM6 has a number of **interpolation schemes** that impact interface depth, and therefore layer thickness




**Standard deviation of anomaly**



# Watermass transformation in a **downslope gravity flow**




$$\partial_t \mathcal{M}_{\leq} = \Psi_{\leq} + \mathcal{S}_{\leq} - \mathcal{G}^{(\mathrm{BF})} - \mathcal{G}^{(\mathrm{Mix})} + \mathcal{E}$$

$$\mathcal{G}^{(\mathrm{T})} \equiv \frac{\partial}{\partial \tilde{\lambda}} \int_{\Omega(\tilde{\lambda},t)} \rho \, \dot{\lambda} \, \mathrm{d}V$$

$$\mathcal{E} \equiv \mathcal{G}^{(\mathrm{Spurious})}$$

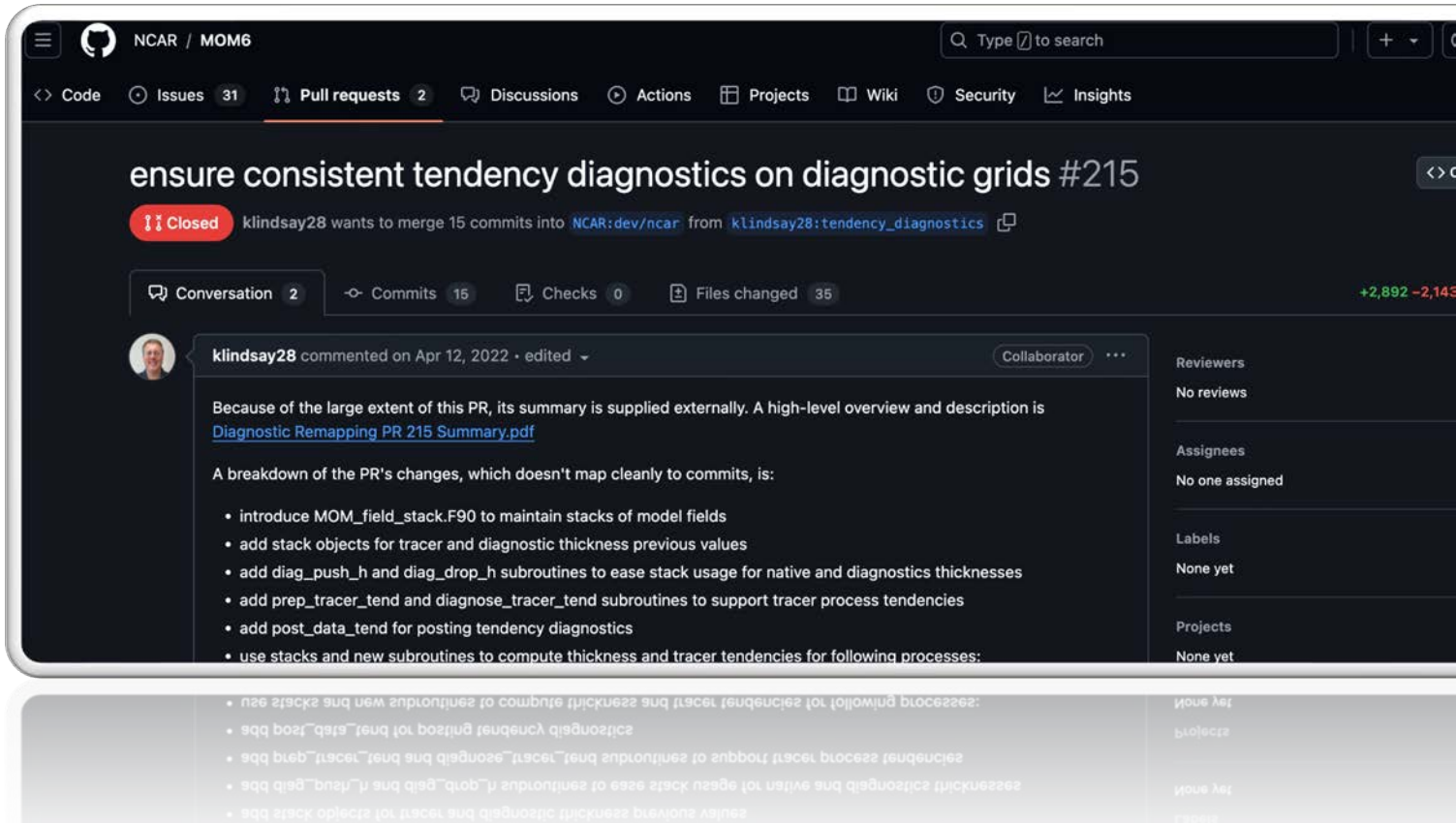
*Drake et al. (in revision)*
*Paper preprint for JAMES* (https://osf.io/rntyp)

# Tracer budget closure in remapped coordinates

Some diagnostics require accurate **tracer budget closure** within layers, e.g. heat budget within temperature layers.

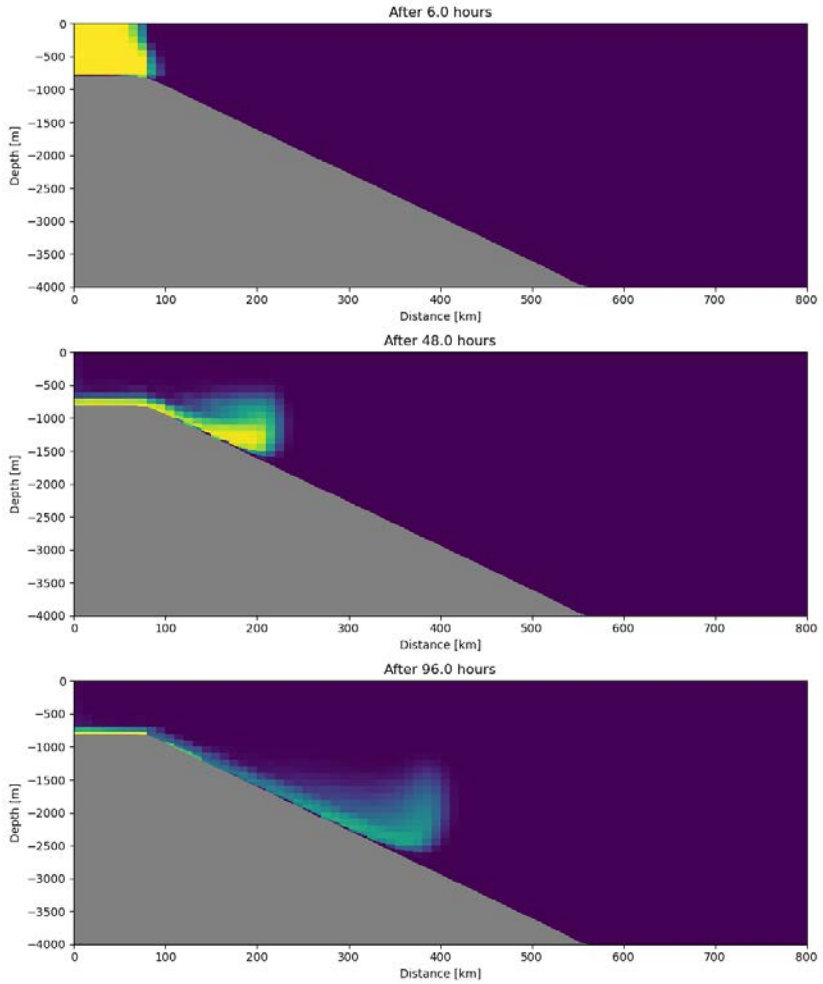
Problems persist in implementing this, due to **timing of remapping** relative to **timing of processes**.

$$\frac{\Lambda_{t_1}|_\theta - \Lambda_{t_0}|_\theta}{t_1 - t_0} \neq \sum_i \dot{\Lambda}_i|_\theta$$



# **Example**: Watermass transformation in a **downslope gravity flow**

## Temperature




0 °C

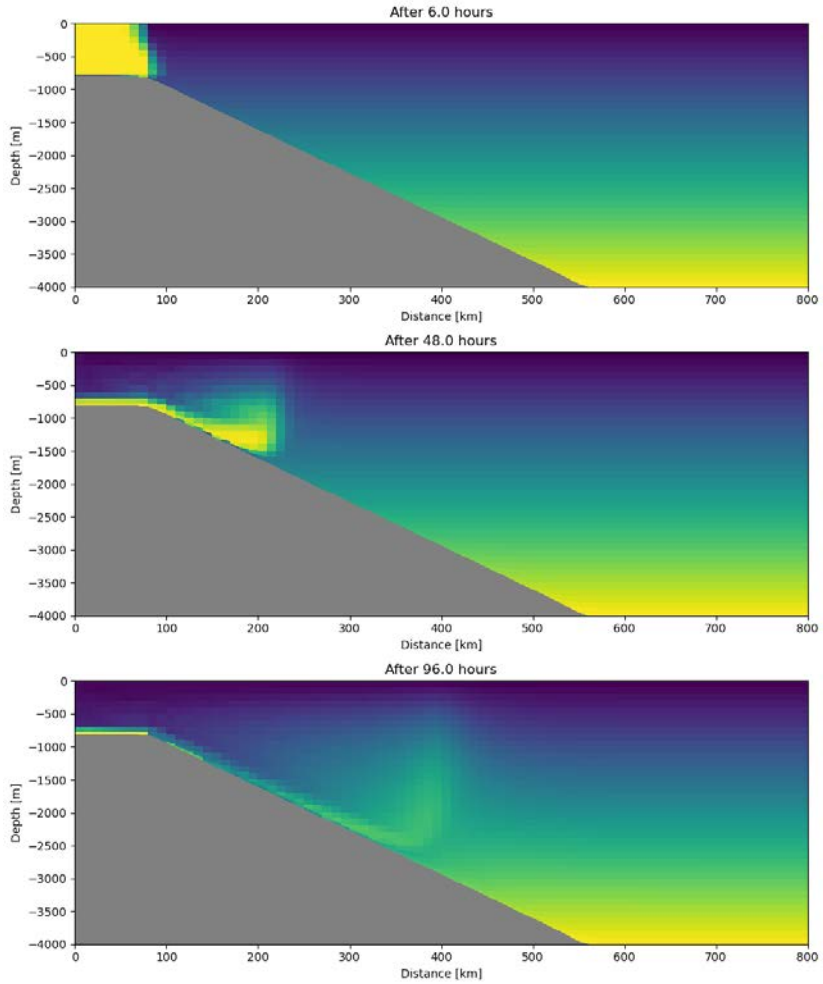
1 °C

*After 6 hours*

*After 48 hours*

*After 96 hours*

## Salinity

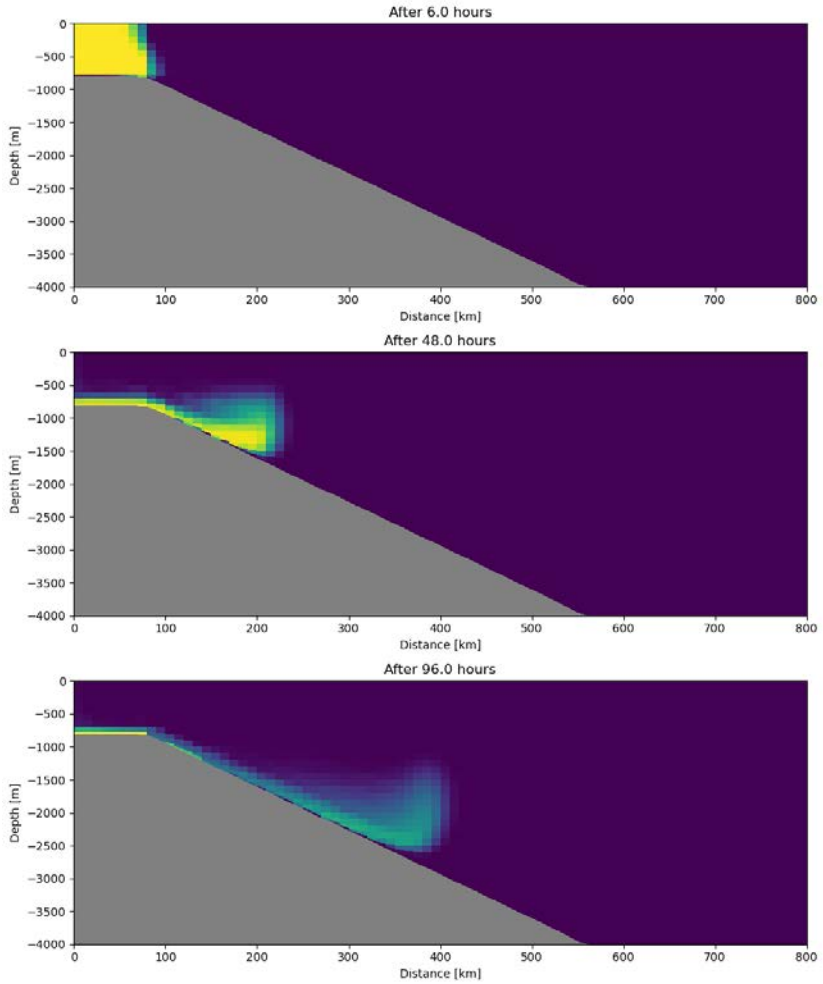



32 gkg$^{-1}$

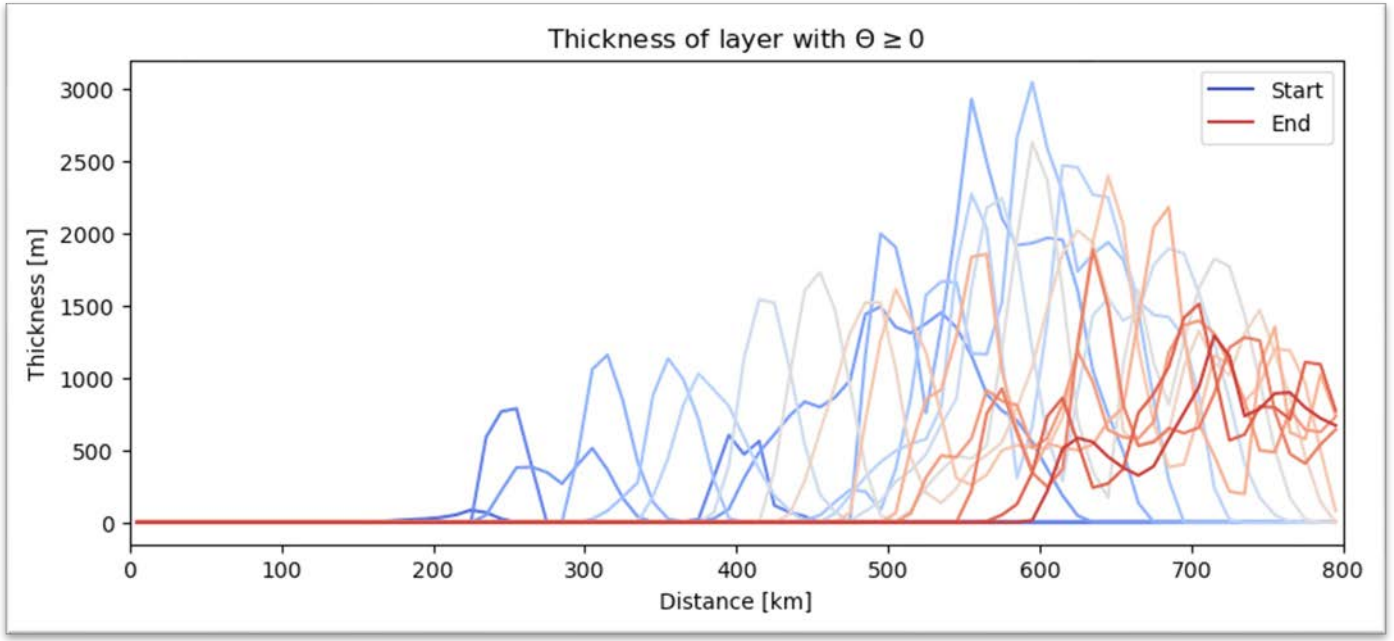
35 gkg$^{-1}$

# **Example**: Watermass transformation in a **downslope gravity flow**

## Temperature

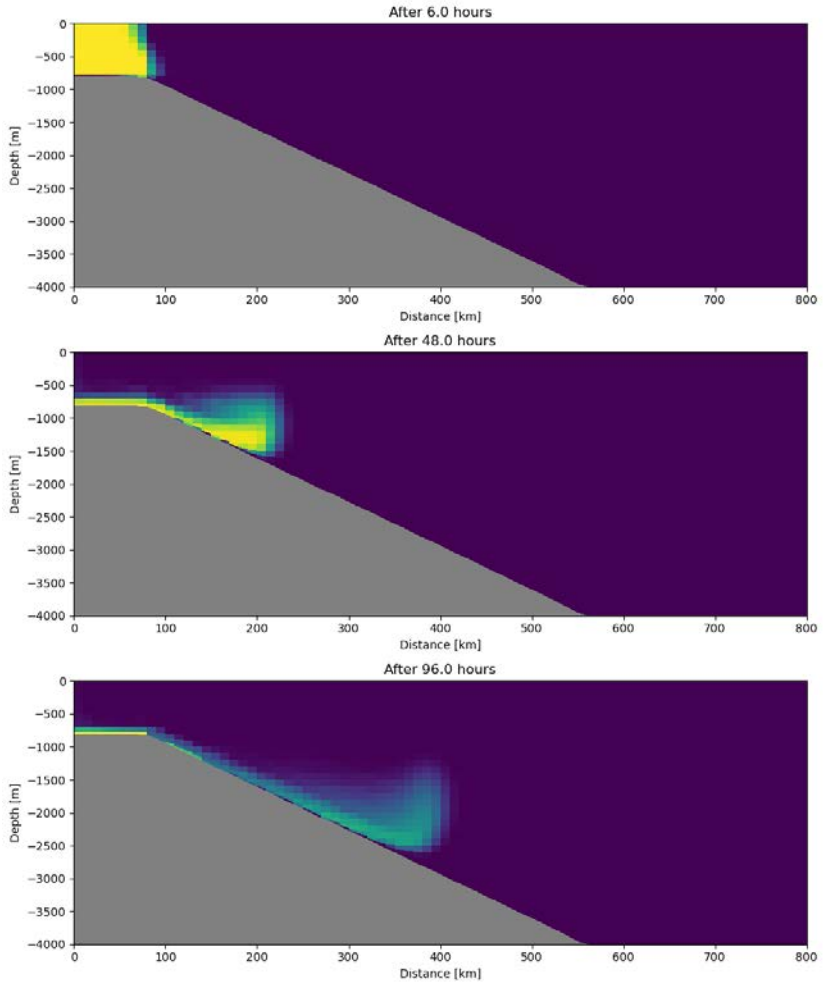



## Thickness of layer warmer than 0°C

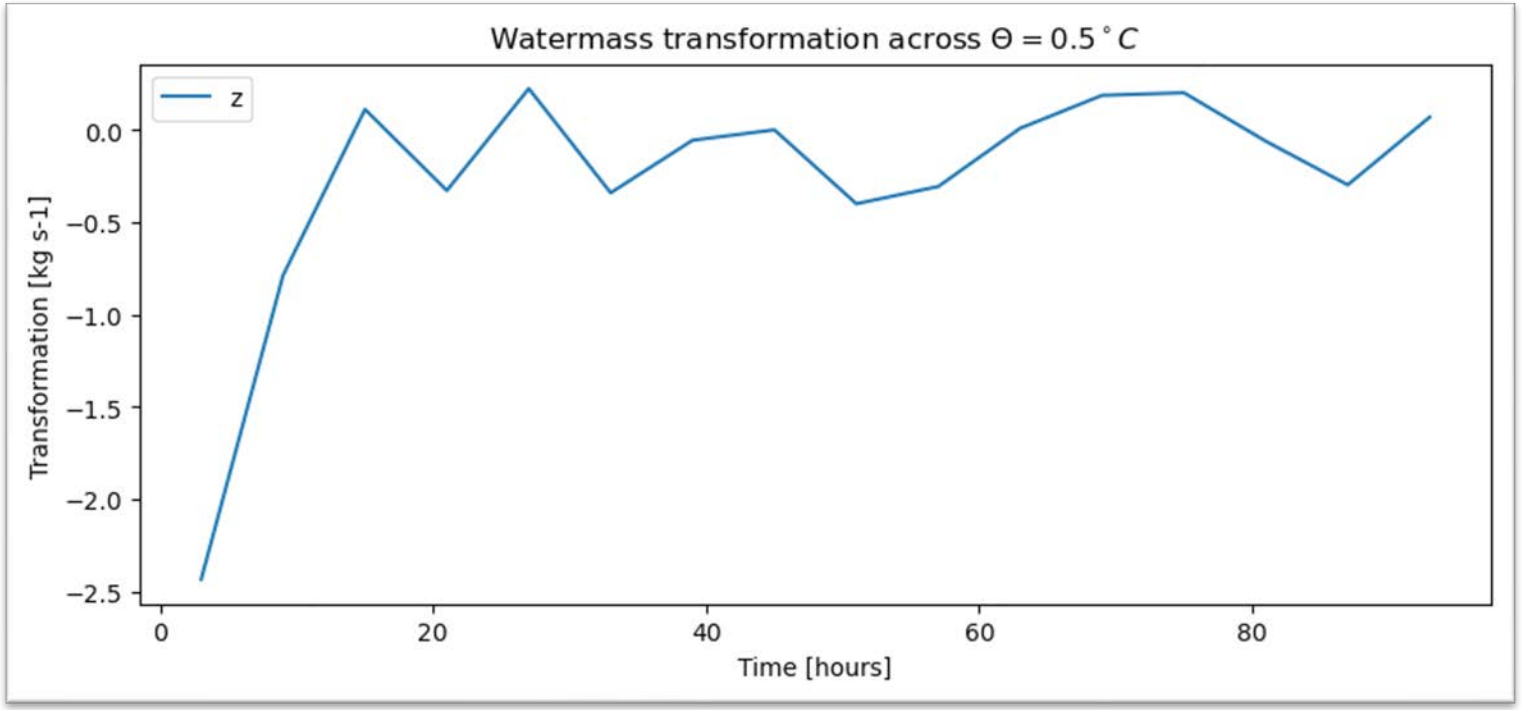


# **Example**: Watermass transformation in a **downslope gravity flow**

**Temperature**



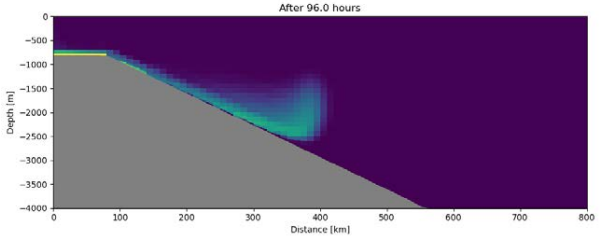

Watermass transformation due to **explicit vertical diffusion**



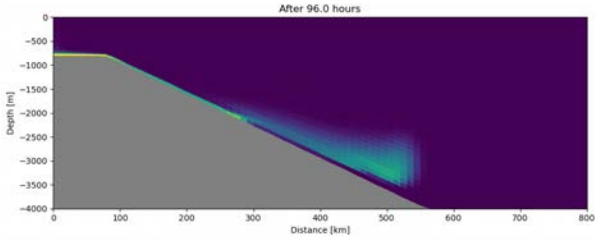
# **Example**: Watermass transformation in a **downslope gravity flow**

**Temperature @ 96 hours**

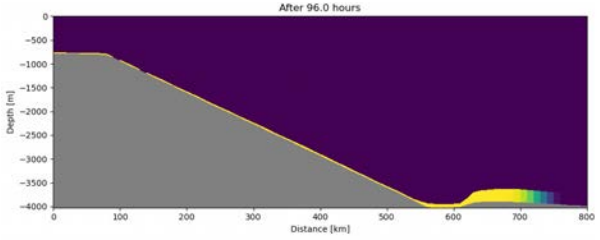
**z***



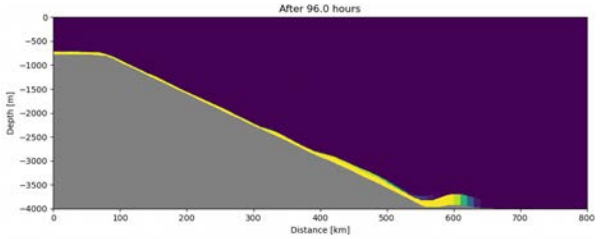

**σ**



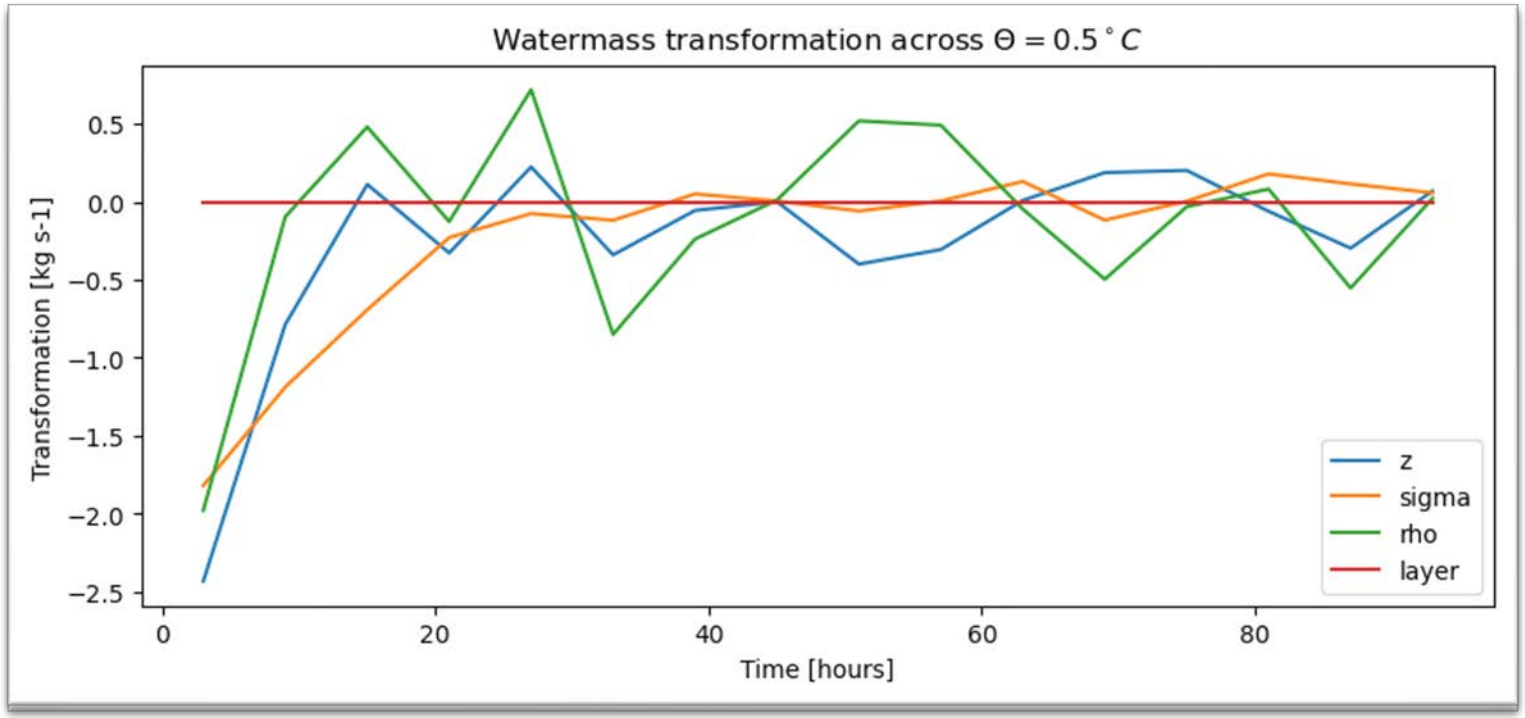

**$\rho_2$**




**layer**




Watermass transformation due to **explicit vertical diffusion**



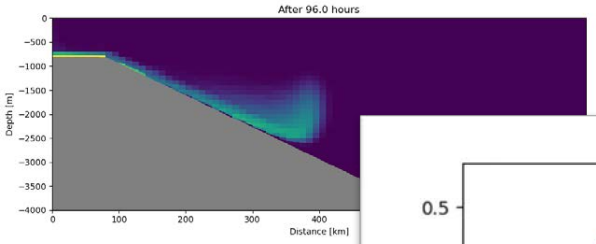
# Ongoing work

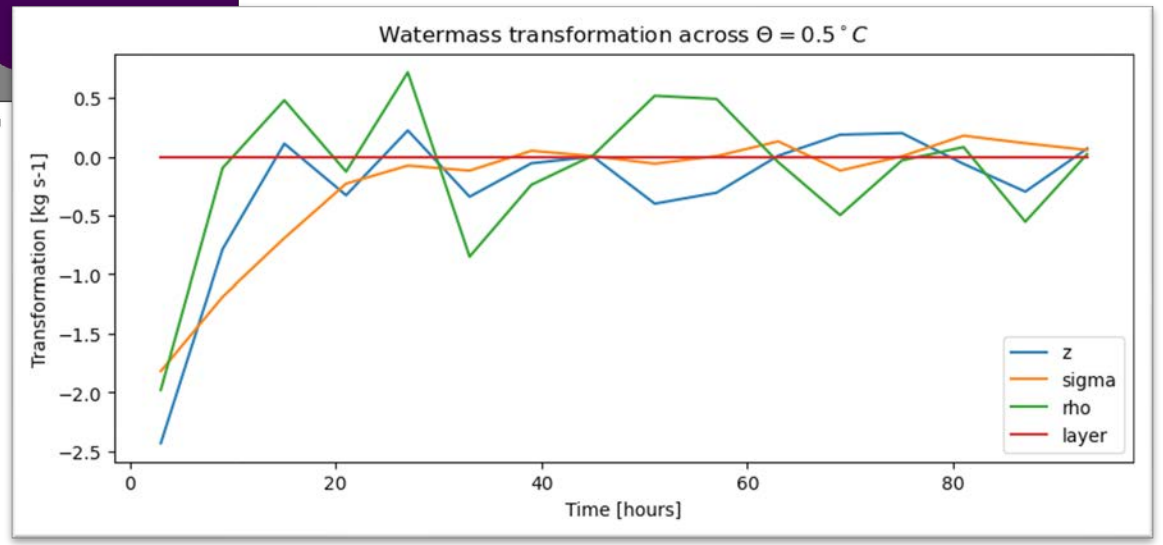
- Implement rigorous **budget closure for remapped diagnostics** in MOM6 (Keith Lindsay's PR)
- Improve **efficiency of weighted remapping** and merge into MOM6 main branch
- Implement **remapping to any tracer coordinate** --- currently only possible for temperature

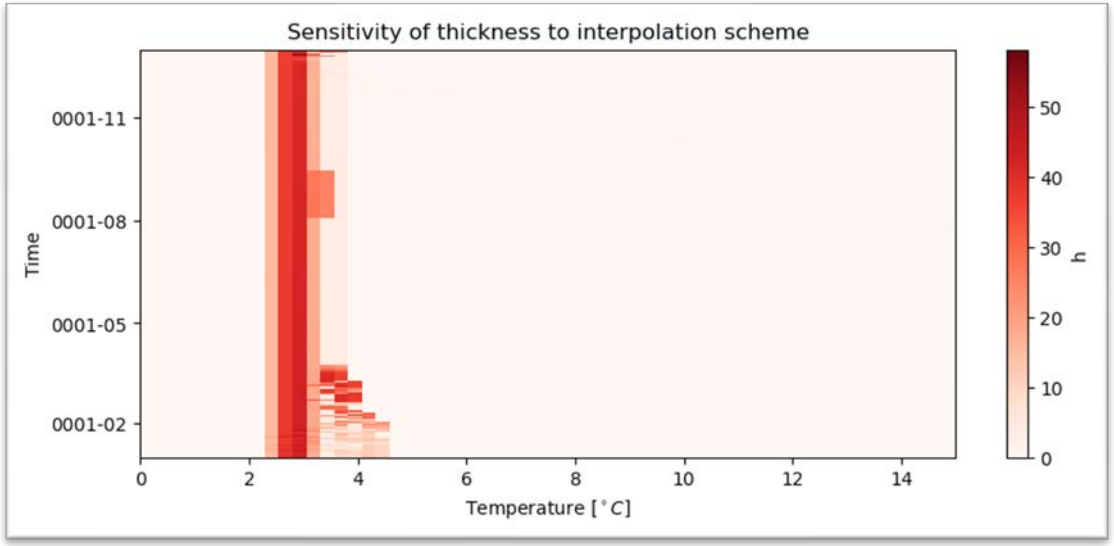
# Take-home messages

Tracer coordinates offer **powerful, complementary diagnostics** for understanding ocean **dynamics** and model **biases/sensitivities**.

**Online remapping** is required for accurate budget closure, but **irreducible uncertainty** persists.

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