

Online tracer-coordinate diagnostics in MOM6

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STEPHEN GRIFFIES + OTHERS

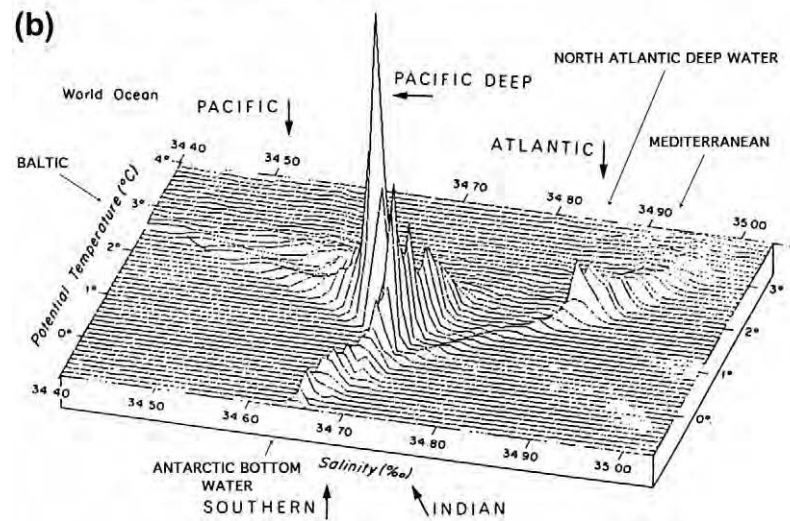


Motivation

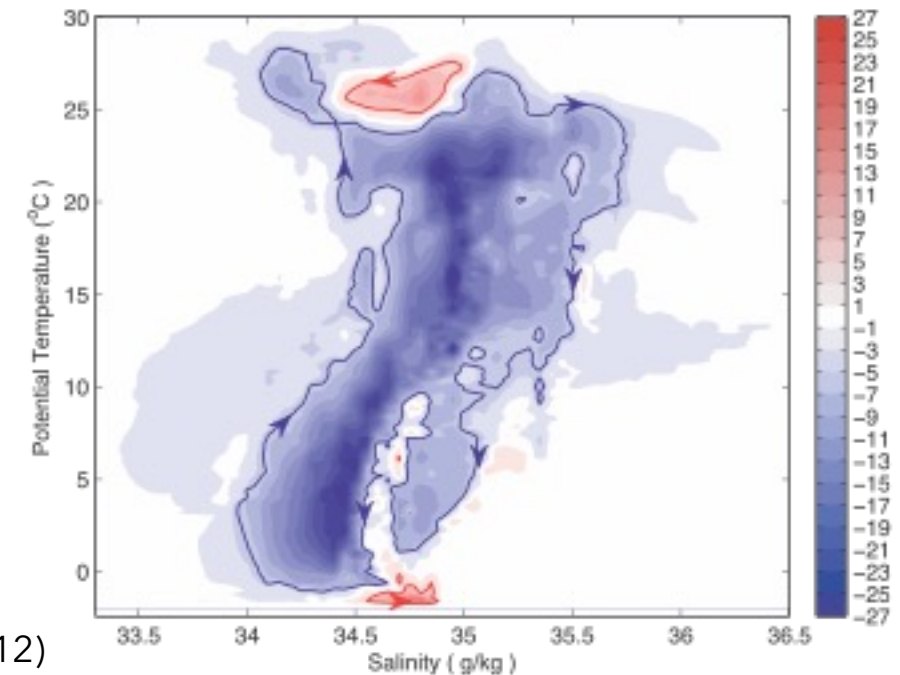
Evaluating ocean circulation in **tracer coordinates** goes back to the earliest days of oceanography.

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?

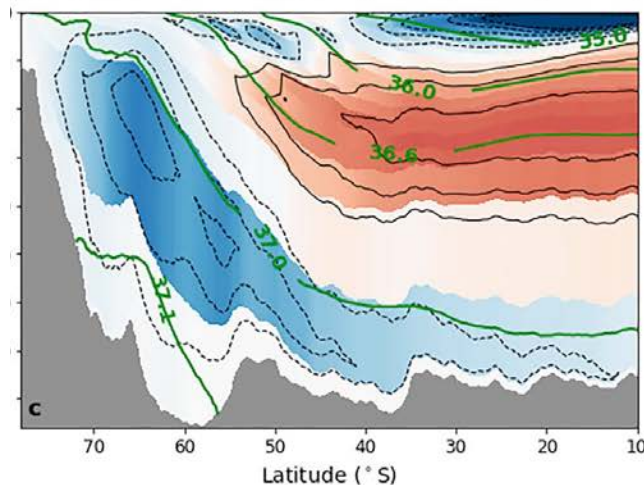
A watermass framework allows **process-level understanding** of ocean dynamics.

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

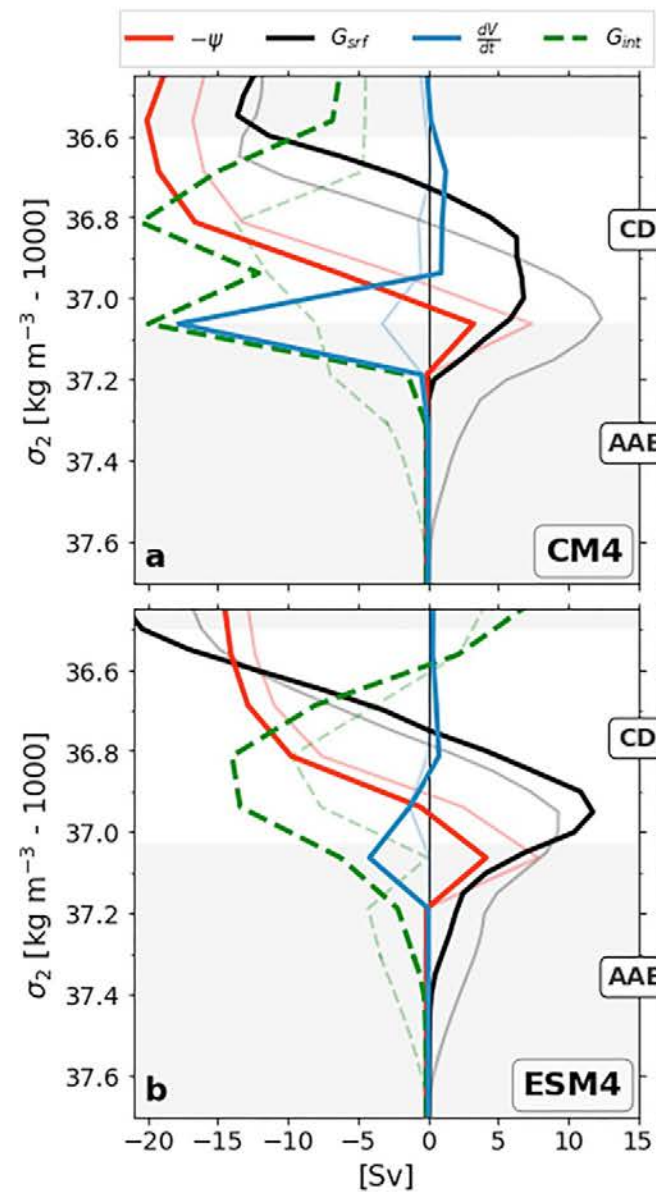
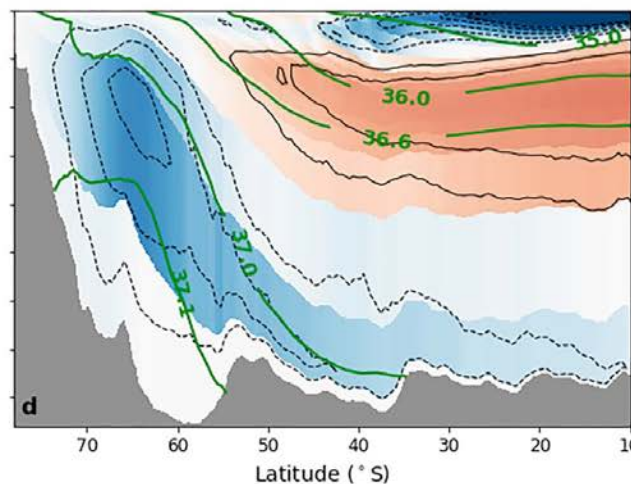
Antarctic Bottom Water response to freshwater forcing

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

CM4



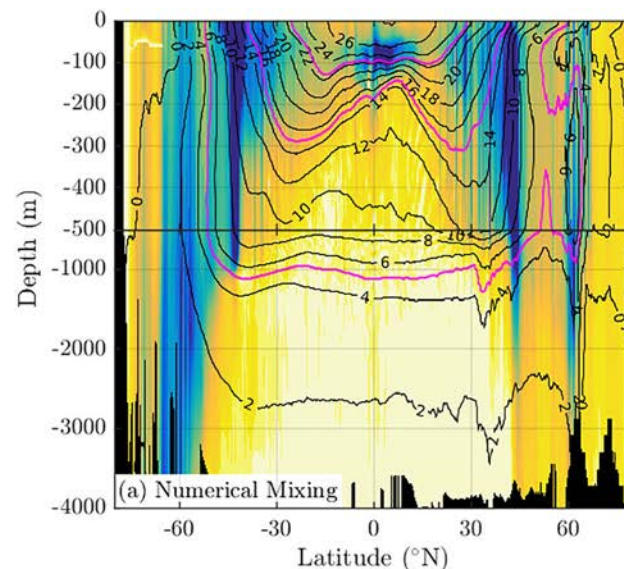
ESM4



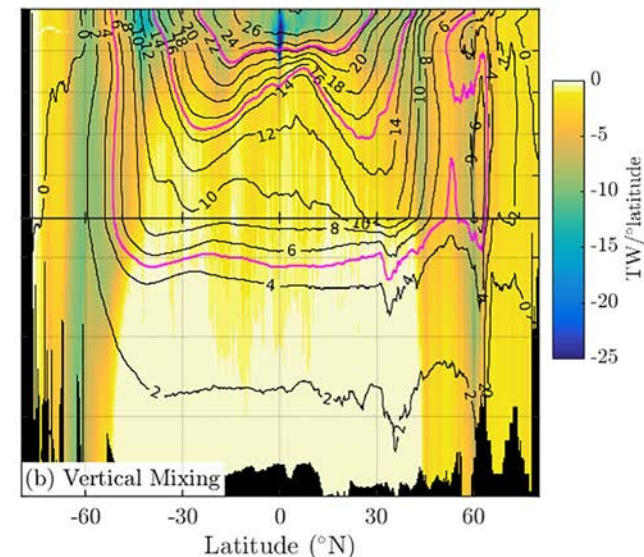
Diagnostic of numerical mixing

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

Holmes et al. (2021) JAMES

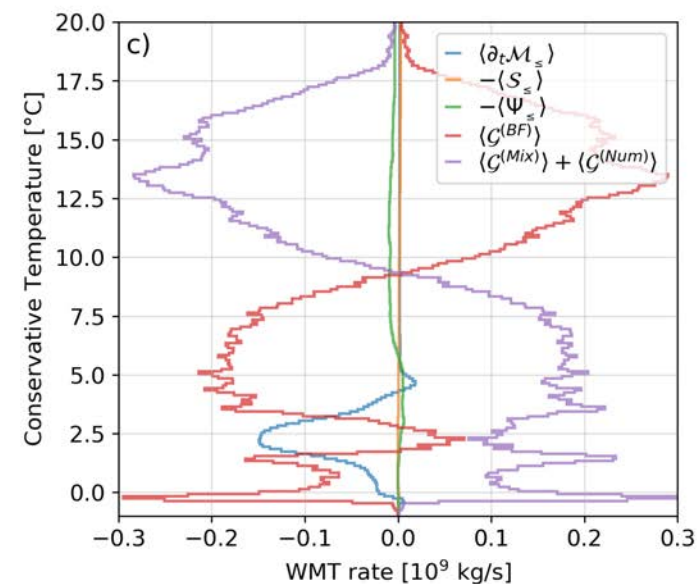


Numerical mixing



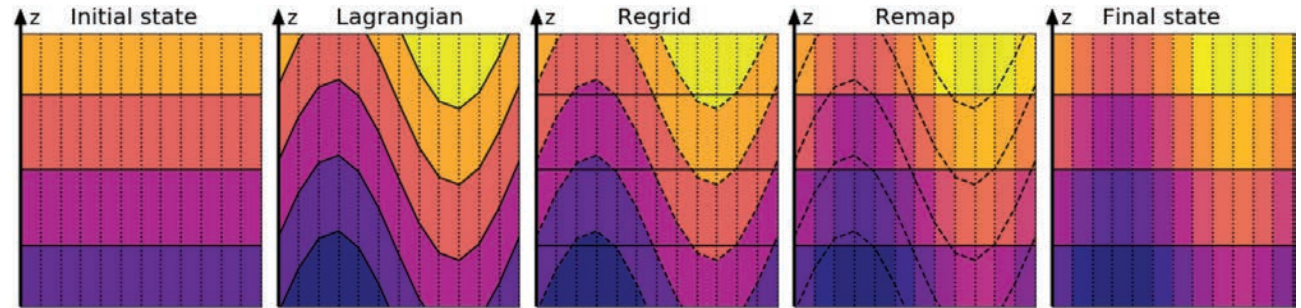
Explicit vertical mixing

Drake et al. (in revision) JAMES



Potential for online remapping in MOM6

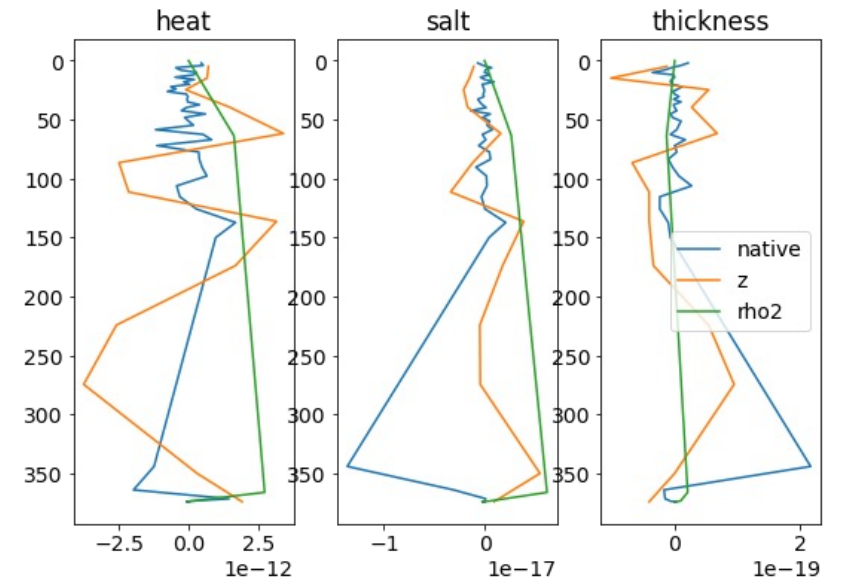
Can the **regrid-remap architecture** of MOM6 be leveraged to perform **accurate online remapping** to a coordinate defined by any arbitrary tracer?



Griffies *et al.* (2020)

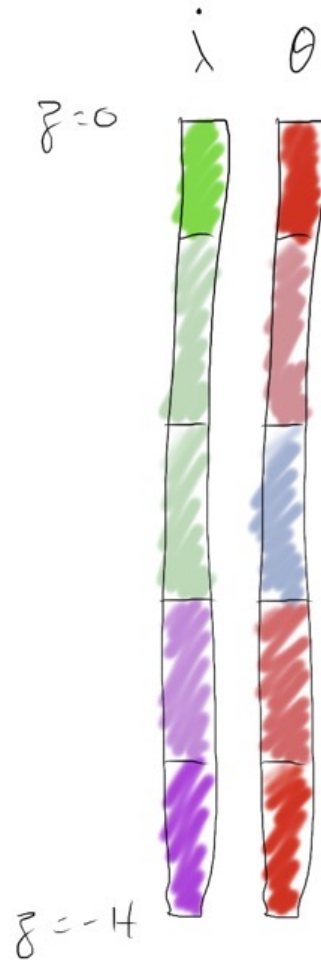
Diagnostic remapping already exists for z^* and ρ
Strict requirement to be monotonically increasing with depth
What about tracers with non-monotonic and/or decreasing profiles?

- Temperature
- Salinity
- Oxygen
- Ideal Age

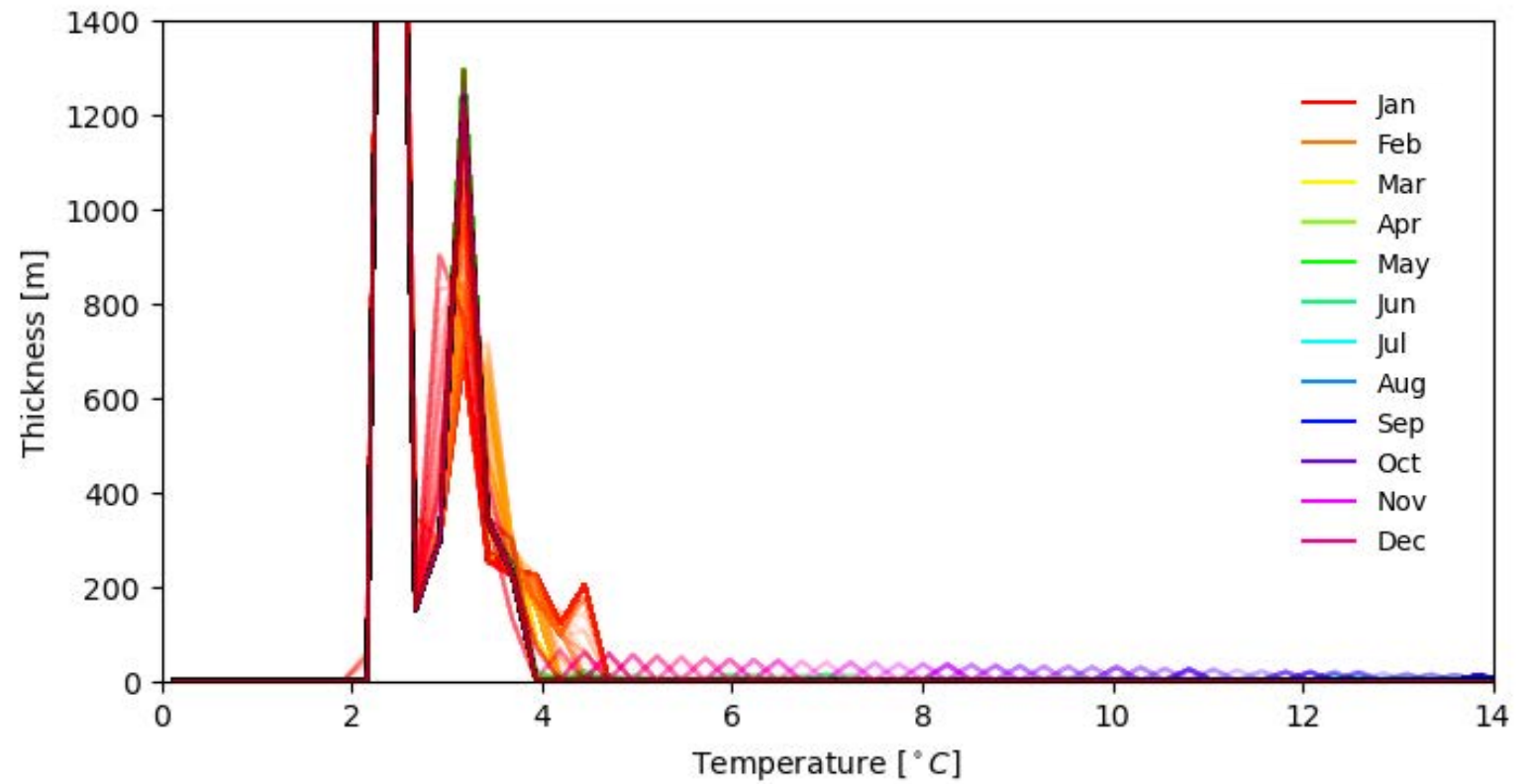
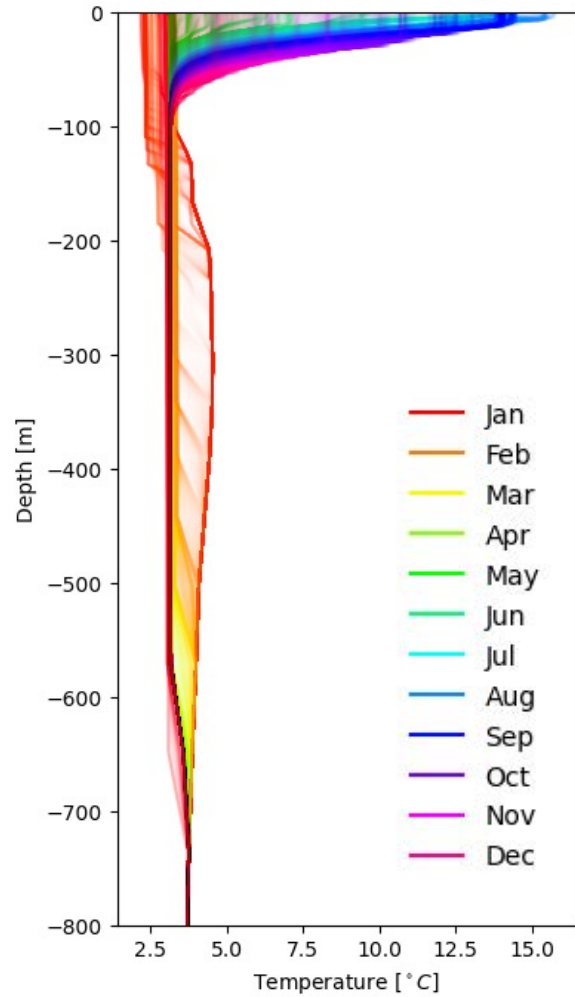


Online remapping in MOM6

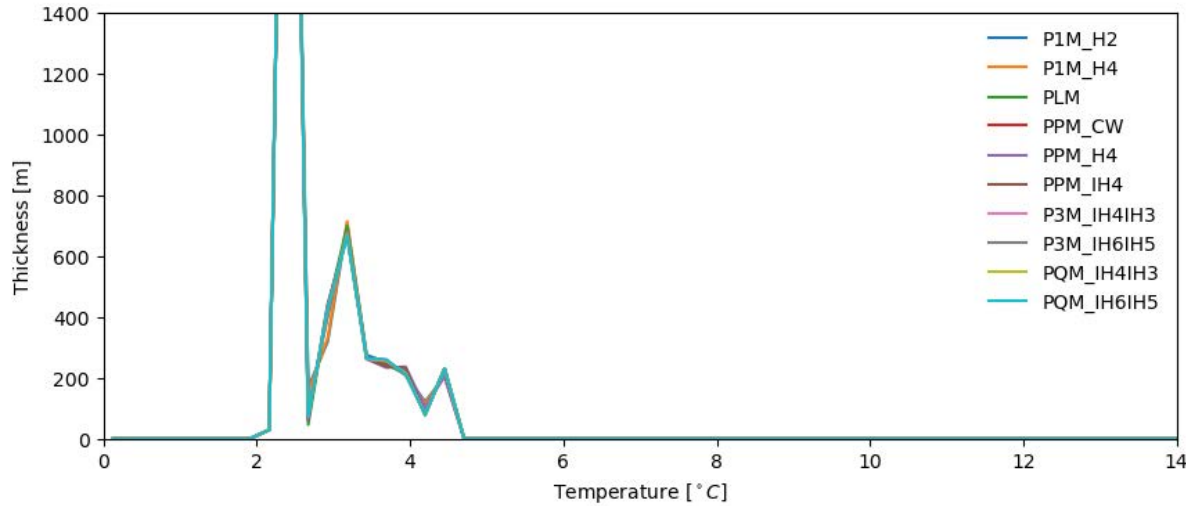
Defining **a matrix of weights** mapping source to target grids.



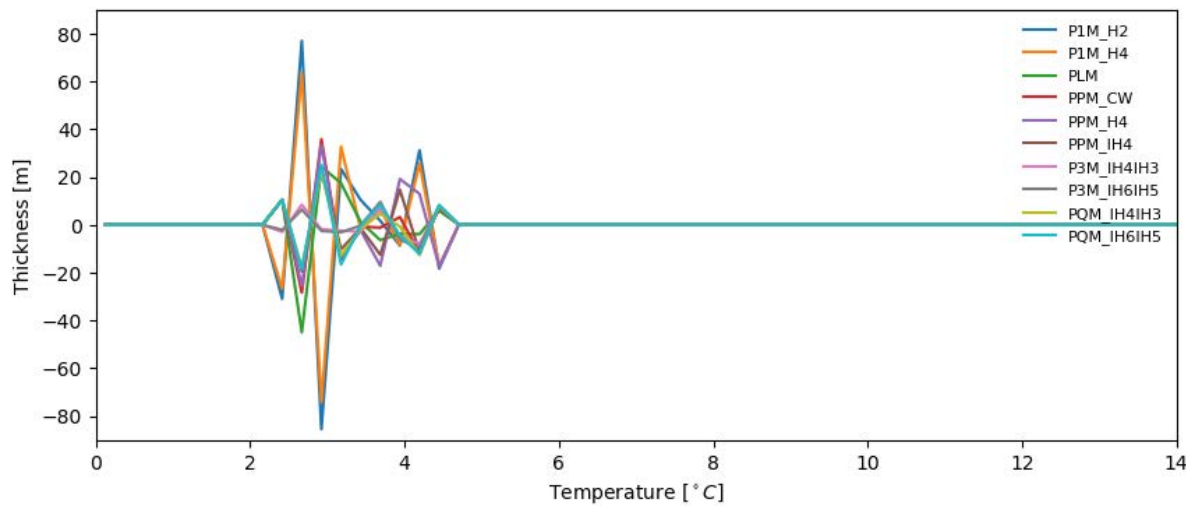
Evolution of watermasses in a **vertical column** subject to boundary forcing



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

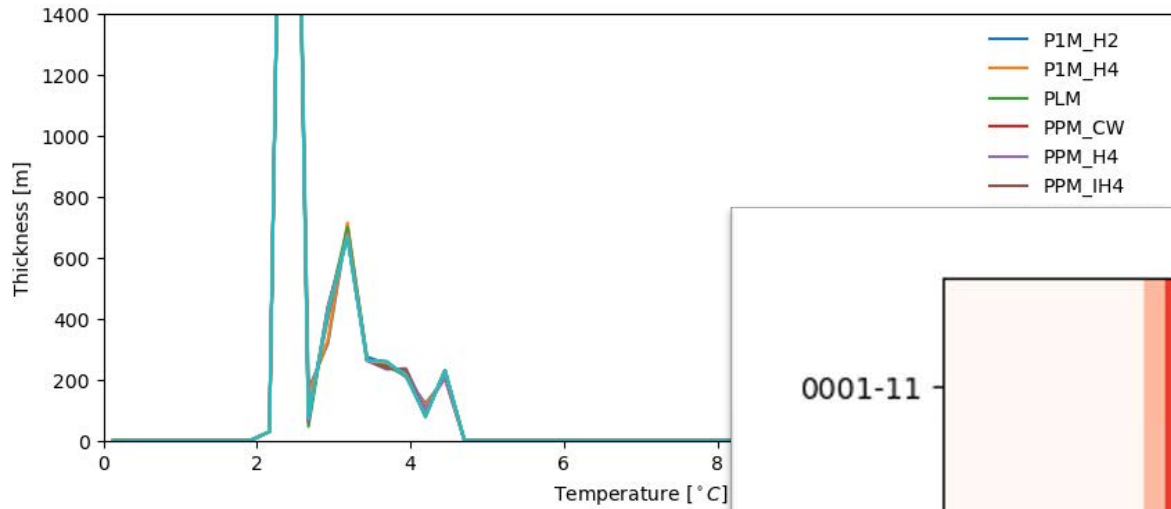


Layer thickness for different interpolation schemes

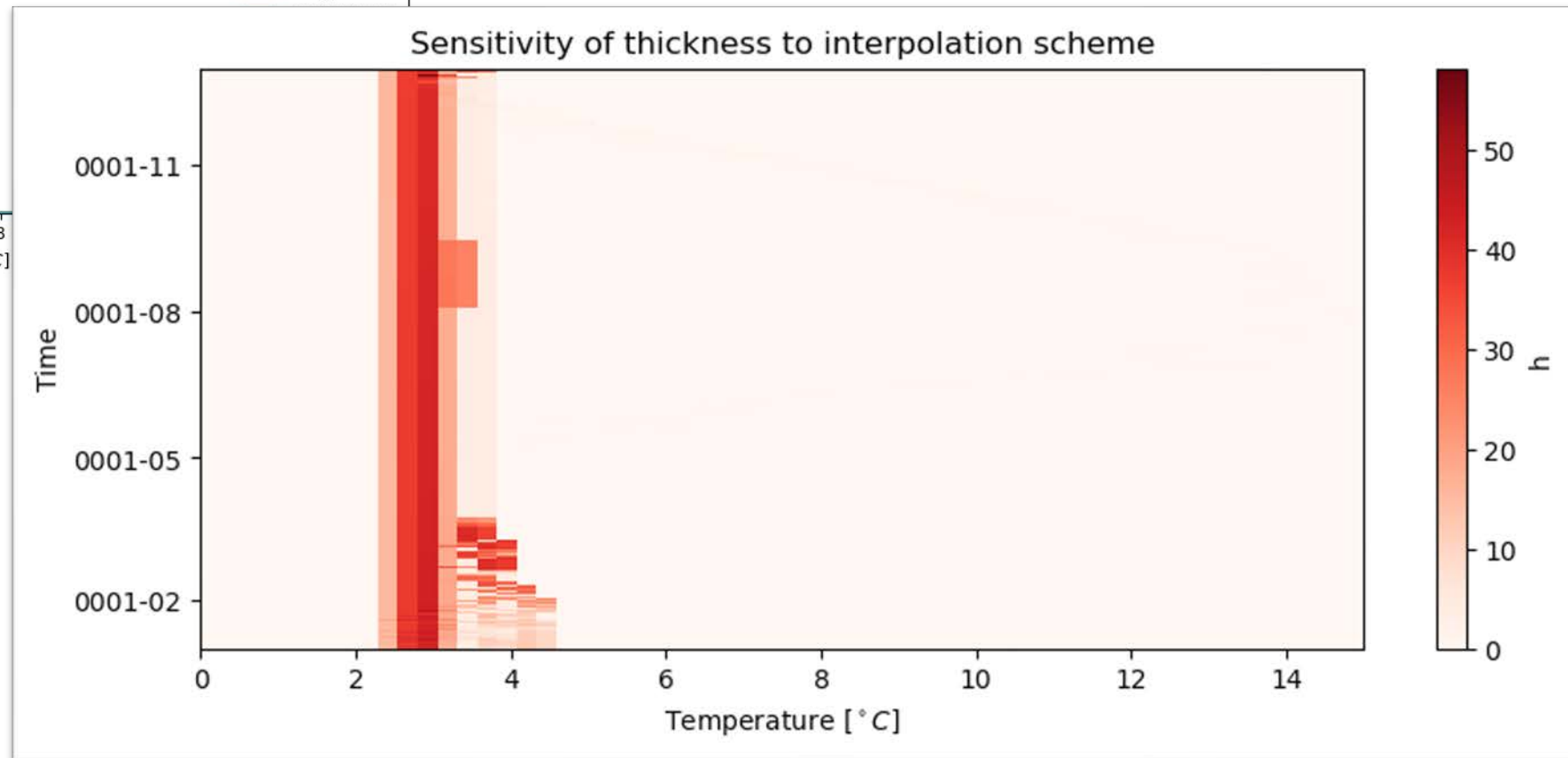


Anomaly relative to mean

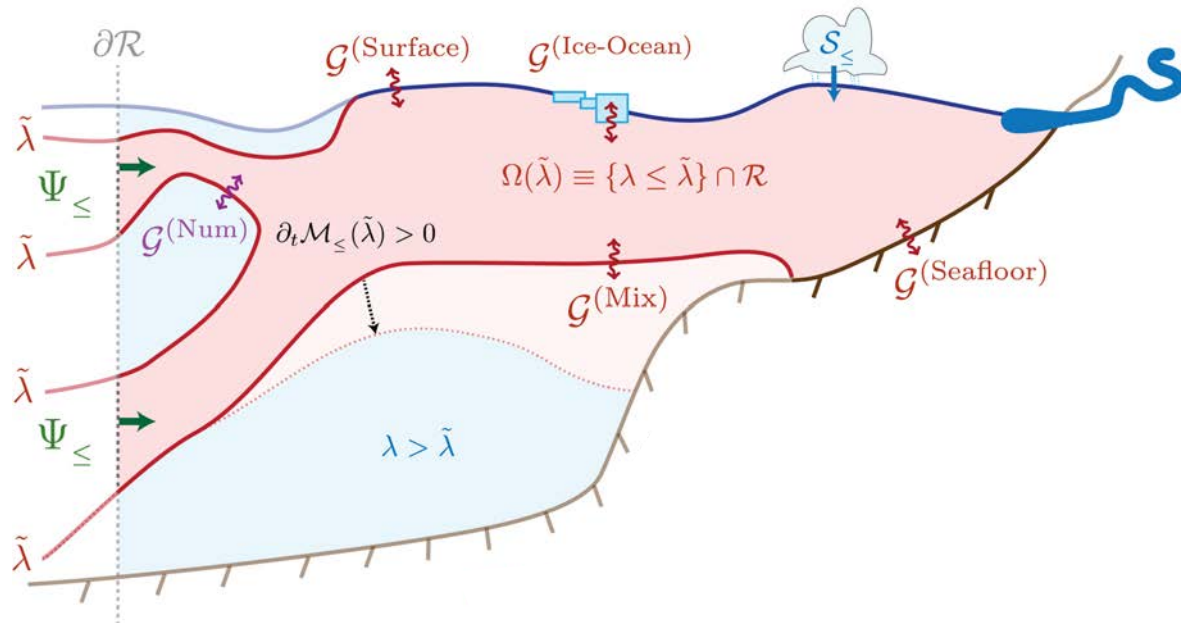
MOM6 has a number of **interpolation schemes** that impact interface depth, and therefore layer thickness



Standard deviation of anomaly



Watermass transformation in a **downslope gravity flow**



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

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

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

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**.

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

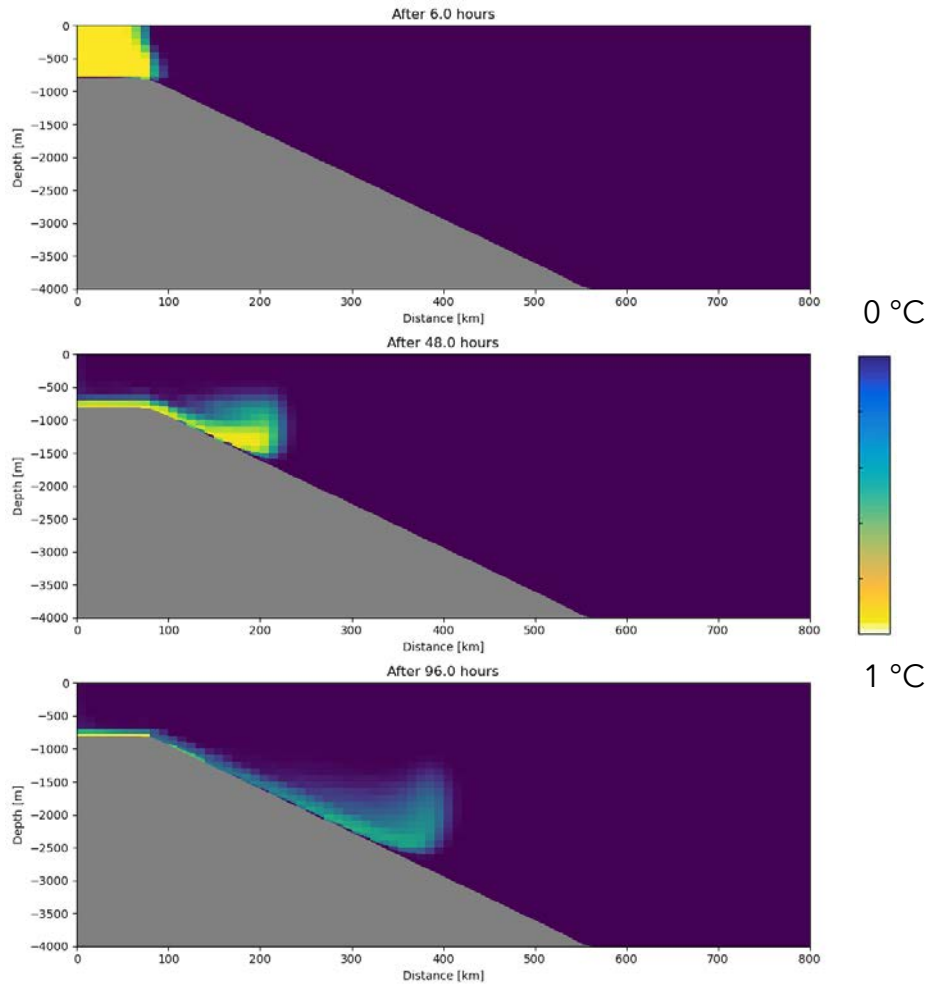
The screenshot shows a GitHub pull request page for the repository 'NCAR / MOM6'. The pull request title is 'ensure consistent tendency diagnostics on diagnostic grids #215'. It is marked as 'Closed' and shows that 'klindsay28' wants to merge 15 commits into 'NCAR:dev/ncar' from 'klindsay28:tendency_diagnostics'. The pull request has 2 conversations, 15 commits, 0 checks, and 35 files changed. A comment from 'klindsay28' dated April 12, 2022, explains that the PR summary is supplied externally and provides a link to a PDF summary. The comment also lists a breakdown of the PR's changes, which doesn't map cleanly to commits:

- introduce MOM_field_stack.F90 to maintain stacks of model fields
- add stack objects for tracer and diagnostic thickness previous values
- add diag_push_h and diag_drop_h subroutines to ease stack usage for native and diagnostics thicknesses
- add prep_tracer_tend and diagnose_tracer_tend subroutines to support tracer process tendencies
- add post_data_tend for posting tendency diagnostics
- use stacks and new subroutines to compute thickness and tracer tendencies for following processes:

The right sidebar shows 'Reviewers' (No reviews), 'Assignees' (No one assigned), 'Labels' (None yet), and 'Projects' (None yet).

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

Temperature

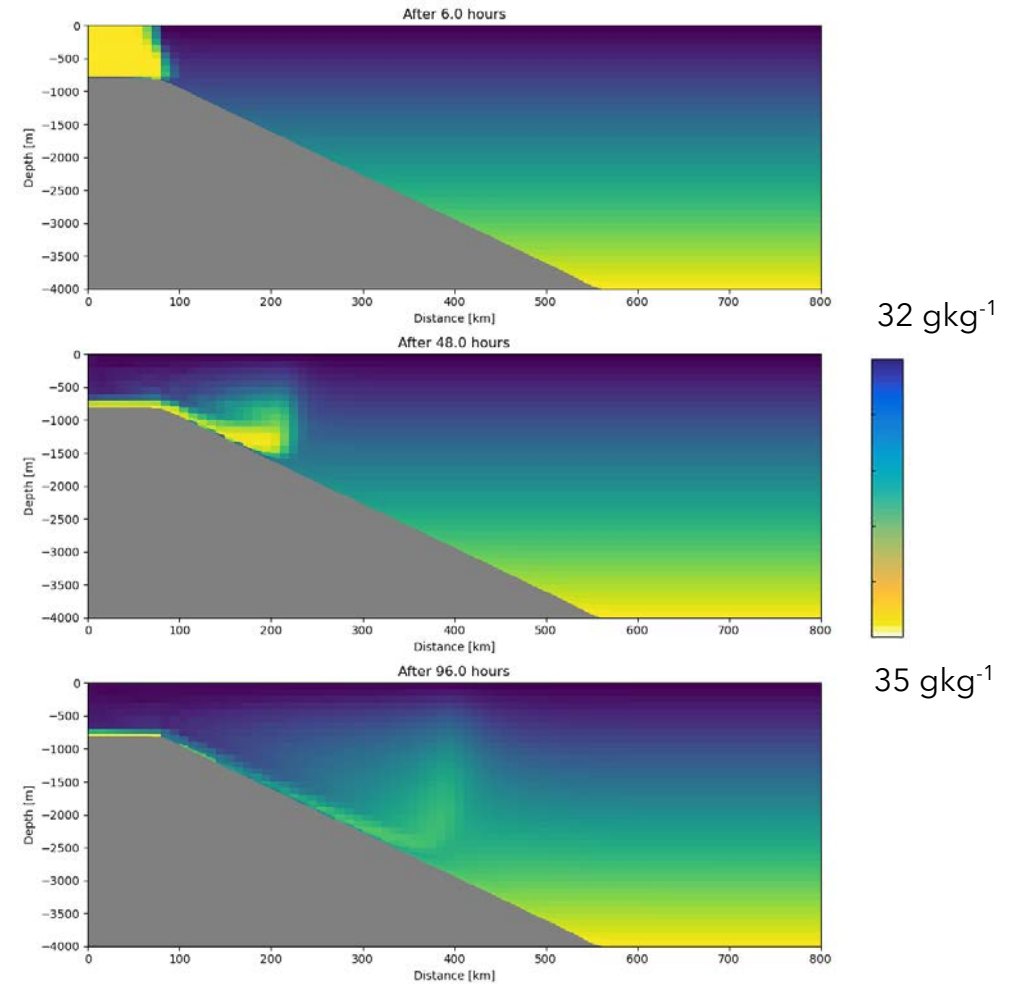


After 6 hours

After 48 hours

After 96 hours

Salinity

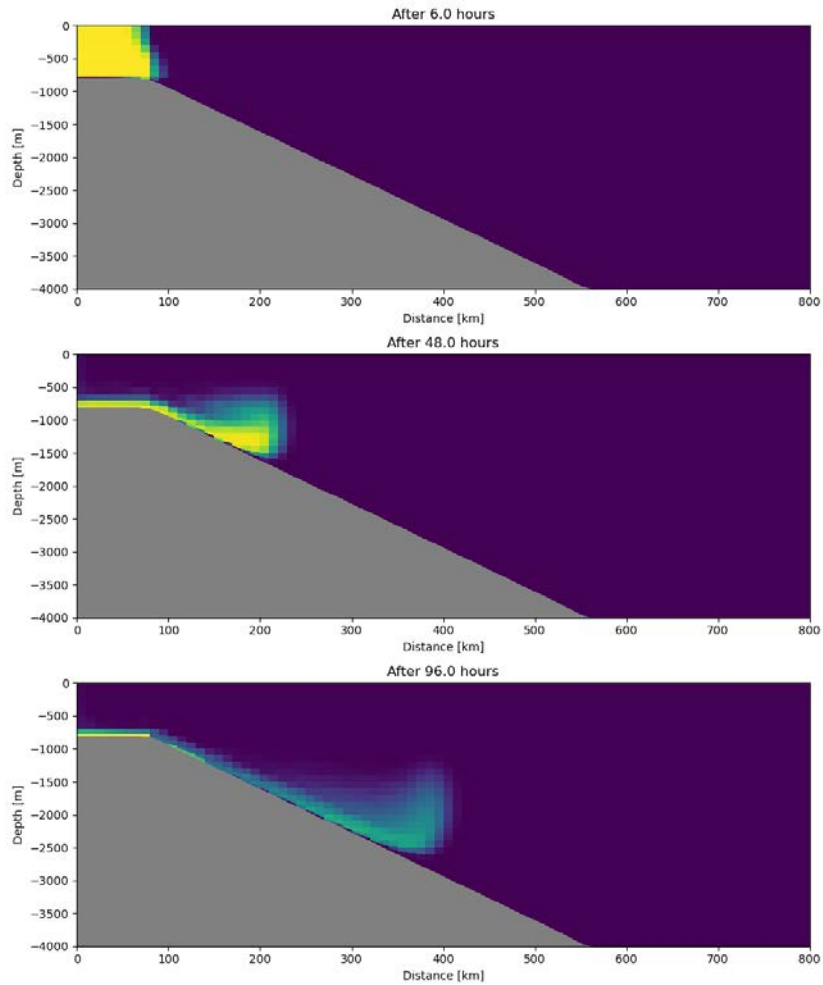


32 gkg^{-1}

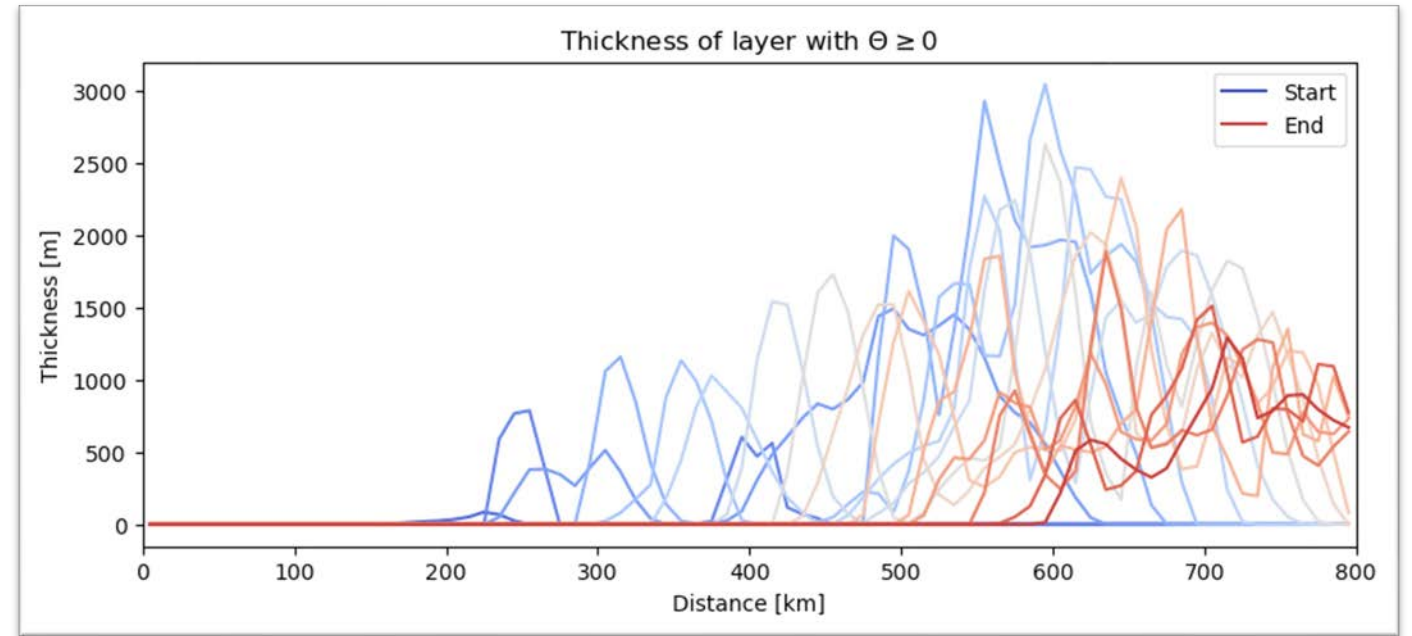
35 gkg^{-1}

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

Temperature

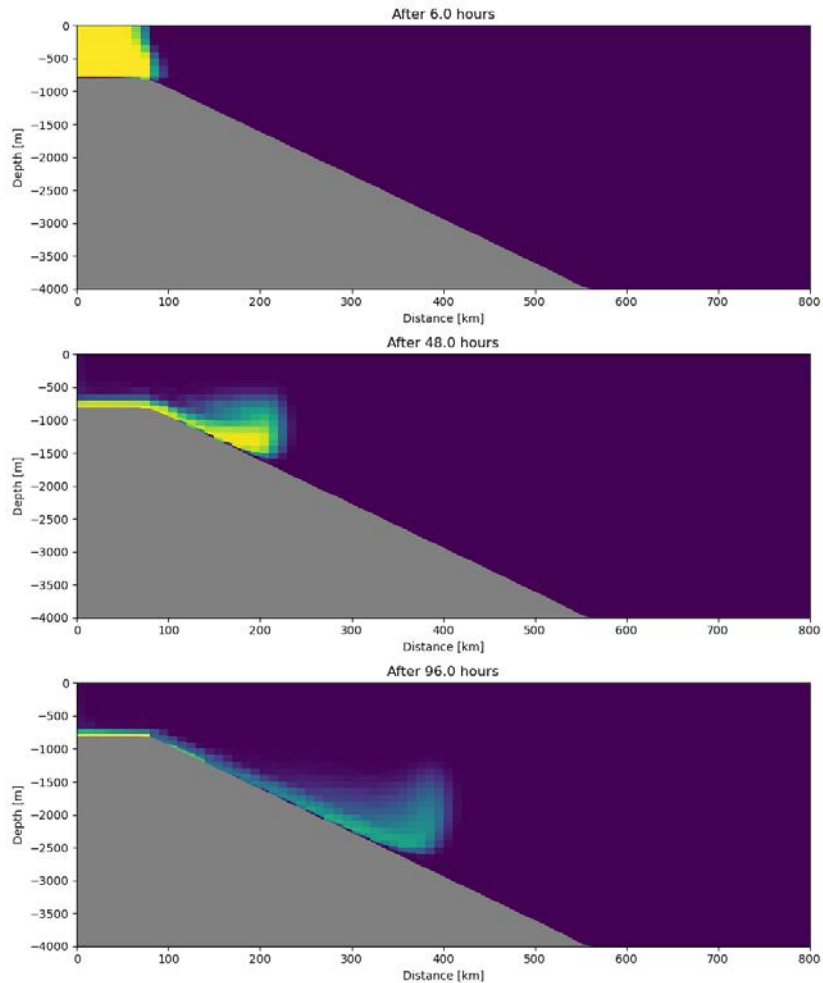


Thickness of layer warmer than 0°C

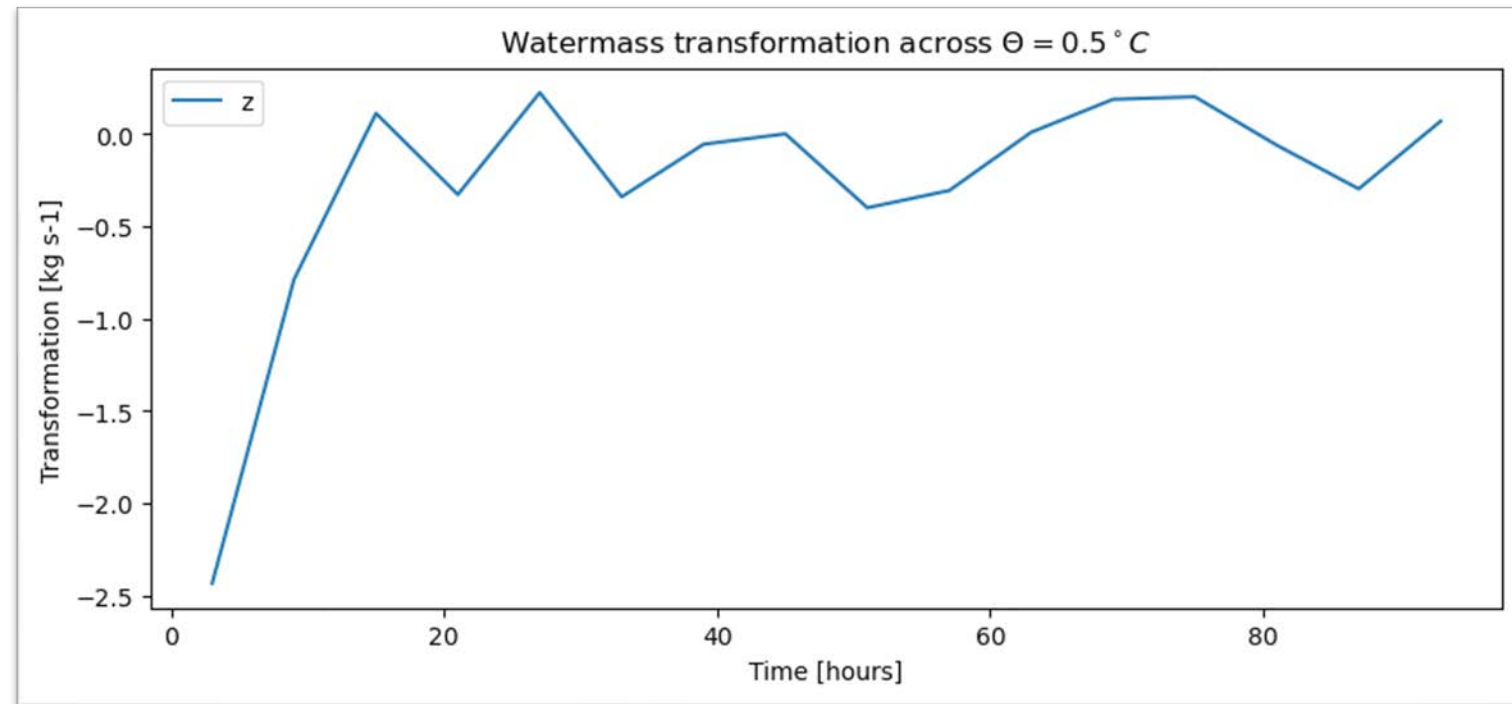


Example: Watermass transformation in a **downslope gravity flow**

Temperature



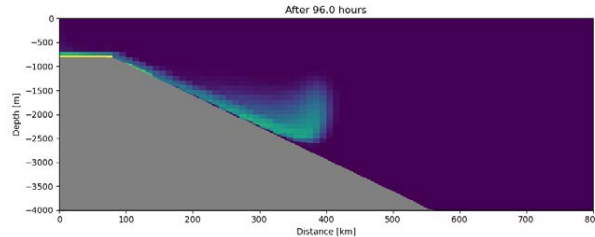
Watermass transformation due to **explicit vertical diffusion**



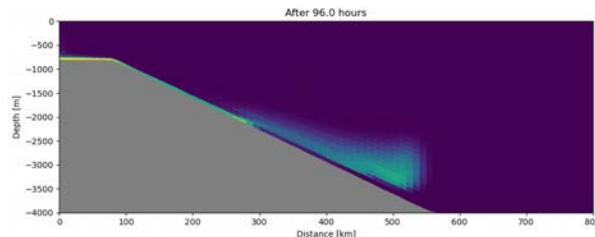
Example: Watermass transformation in a **downslope gravity flow**

Temperature @ 96 hours

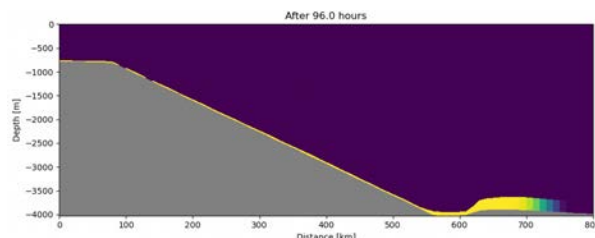
Z^*



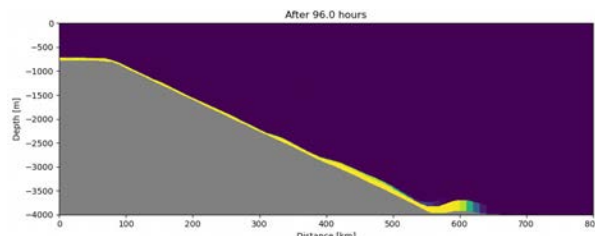
σ



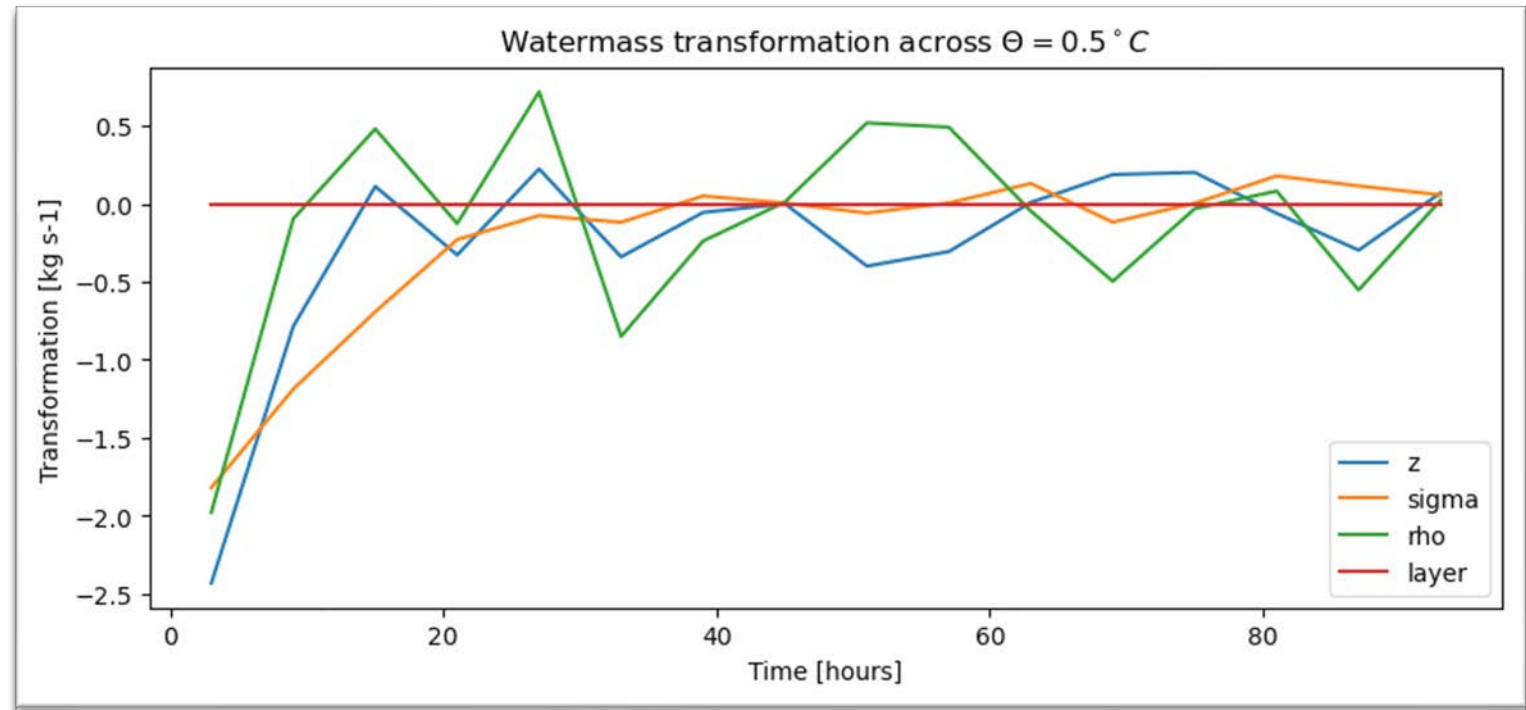
ρ_2



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.

