An adaptive vertical coordinate for ocean models

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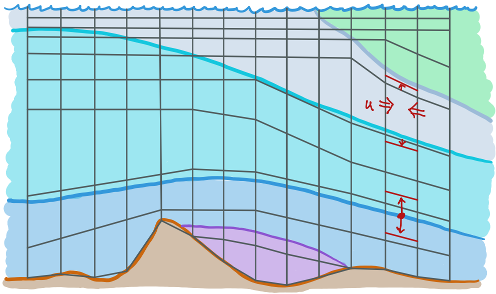
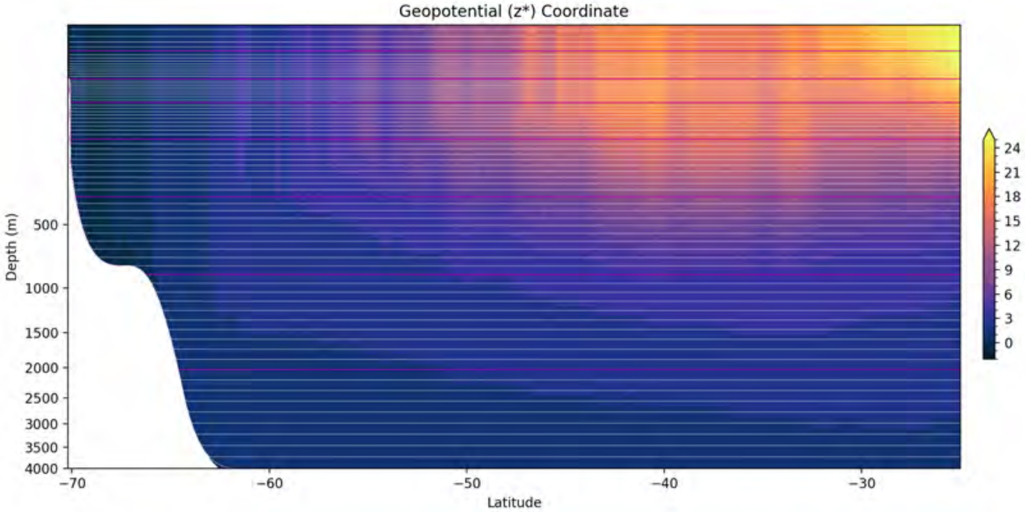
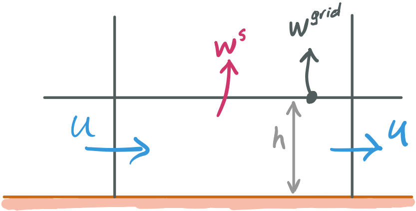


Geopotential (quasi-Eulerian) Vertical Coordinates (z^*)



MOM6 uses Arbitrary Lagrangian Eulerian (ALE) Coordinates



Example: Lowest grid cell in a 1-D model!
Divide w into cross-surface & grid components:

$$w = w^{\mathrm{s}} - w^{\mathrm{grid}}$$

Evolve layer thickness $h \to h^{\mathrm{new}}$ over timestep Δt

Quasi-Eulerian (z^*)

$$w^{\mathrm{grid}} \approx 0$$

$$w^{\mathrm{s}} = -w^{\mathrm{grid}} - \partial_x(hu)$$

$$h^{\mathrm{new}} = h + w^{\mathrm{grid}}\Delta t$$

ALE with Vertical Lagrangian Remap

$$w^{\mathrm{grid}} = -\partial_x(hu)$$

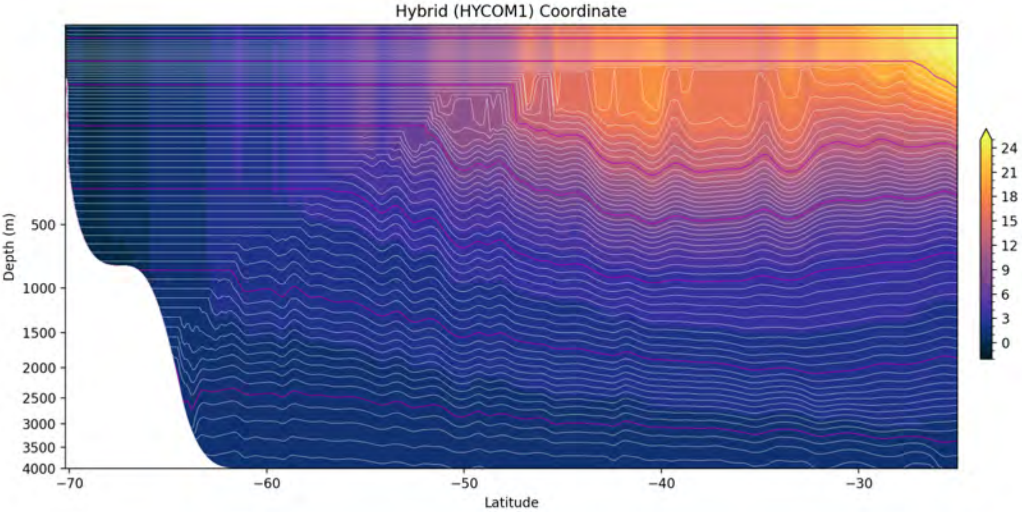
$$h^{\dagger} = h + w^{\mathrm{grid}}\Delta t$$

$$h^{\mathrm{new}} = h^{\mathrm{target}}$$

$$w^{s} = -(h^{\mathrm{target}} - h^{\dagger})/\Delta t$$

See Griffies et al. (2021) for details.

Hybrid z^*-Isopycnal Coordinates

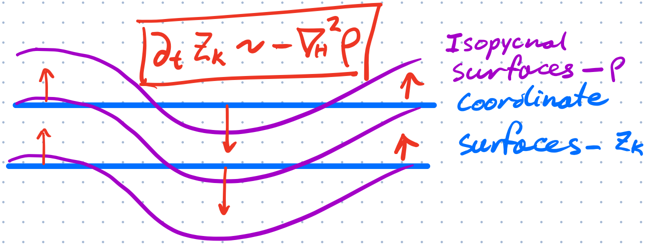


Towards an Adaptive Coordinate

Case 1:

- Stratified fluid
- Want coordinate surfaces aligned with isopycnals

Towards an Adaptive Coordinate



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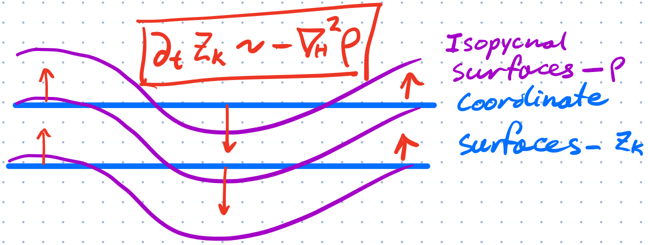
Towards an Adaptive Coordinate

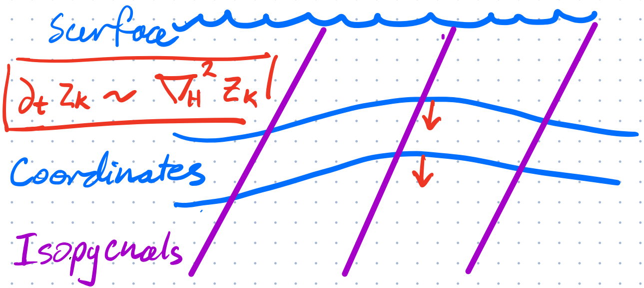


Case 1:

- Stratified fluid
- Want coordinate surfaces aligned with isopycnals

Case 2:

- Steeply sloping isopycnals
- Want coordinate surfaces aligned with z



Adaptive Grid (AG) Coordinates

We propose an evolution equation for coordinate interface height of layer k, z_k:

$$\partial_t z_k = -\nabla_H \cdot \Bigg(\underbrace{\omega_\sigma \frac{\kappa \nabla_H \sigma}{\sqrt{(\partial_z \sigma)^2 + (\nabla_H \sigma)^2}}}_{\text{density adaptivity}} + \underbrace{\omega_z \kappa \nabla_H z_k}_{\text{lateral smoothing}} \Bigg) + \underbrace{\tau_r^{-1} (z_k^* - z_k)}_{\text{vertical restoring}} + \underbrace{F_{\text{con}}}_{\text{convective adjustment}}$$

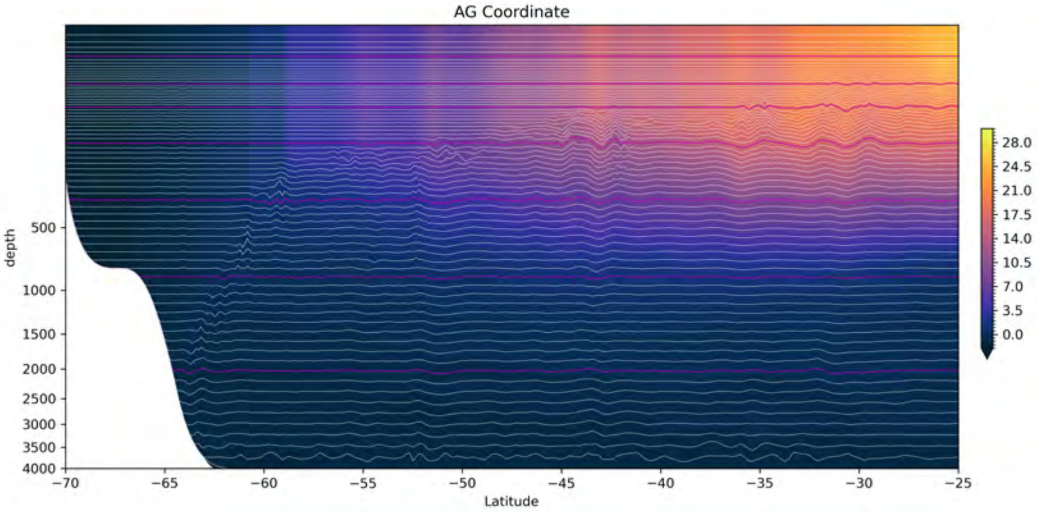
- **Density Adaptivity:** Orients the coordinate interface to reduce along-layer density gradients. Creates coordinates in stratified regions that locally approximate isopycnals.
- **Lateral Smoothing:** When density surfaces are too steep, smoothing switches on. It acts to smooth the interface height to produce geopotential-like interfaces.
  The switch is controlled by isopycnal slope, S:

$$\omega_\sigma = \begin{cases} 1, & \text{if } S \leq S_{\text{max}} \\ 0, & \text{if } S > S_{\text{max}} \end{cases}$$

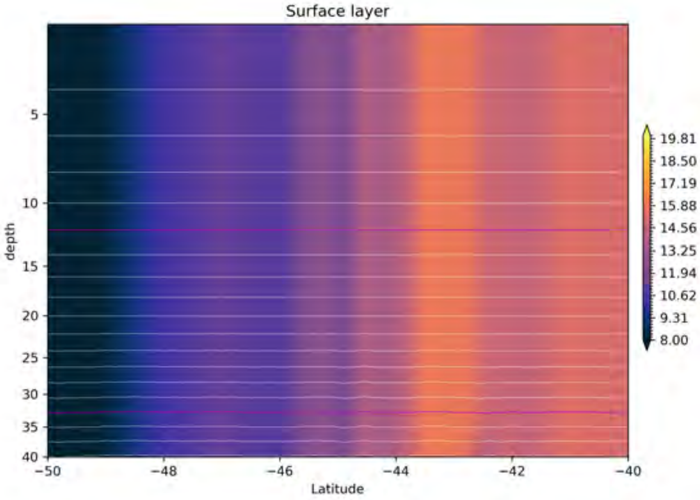
with a 5-gridpoint lateral smoothing of ω_σ, & $\omega_z = 1 - \omega_\sigma$.

(Gibson, 2019; Gibson et al., In Prep)

Adaptive Grid (AG) Coordinates



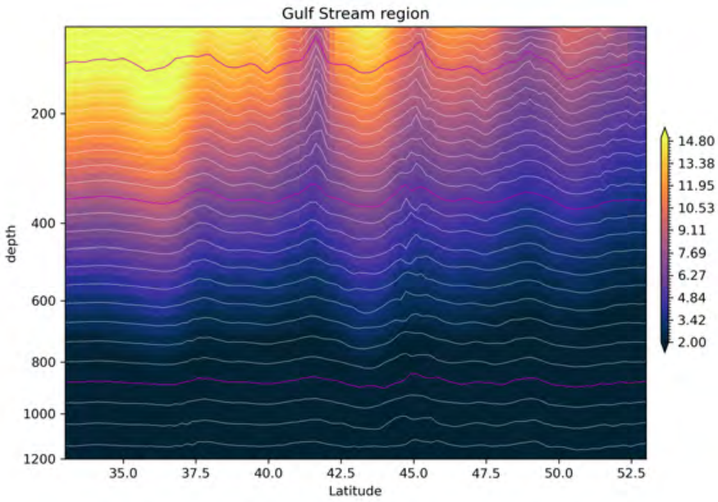
Adaptive Grid (AG) Coordinates



Surface region

- Vertical isopycnals
- Lateral smoothing dominates
- Geopotential-like coordinate surfaces

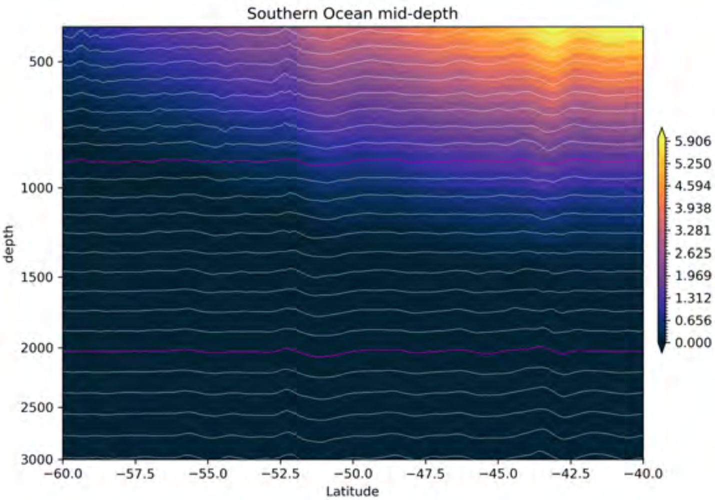
Adaptive Grid (AG) Coordinates



Eddying regions

- Stratified, with eddies
- Density adaptation dominates
- Isopycnal-like coordinate surfaces

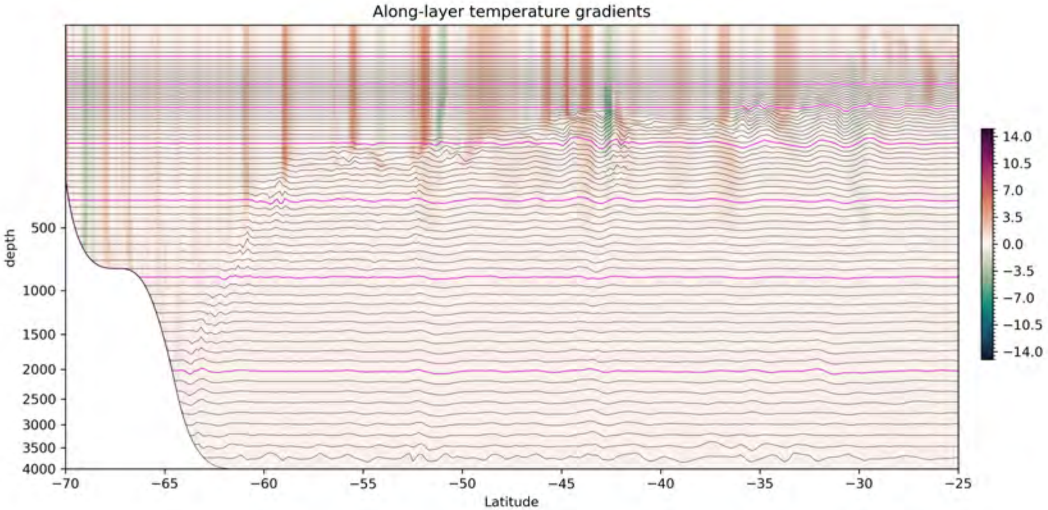
Adaptive Grid (AG) Coordinates



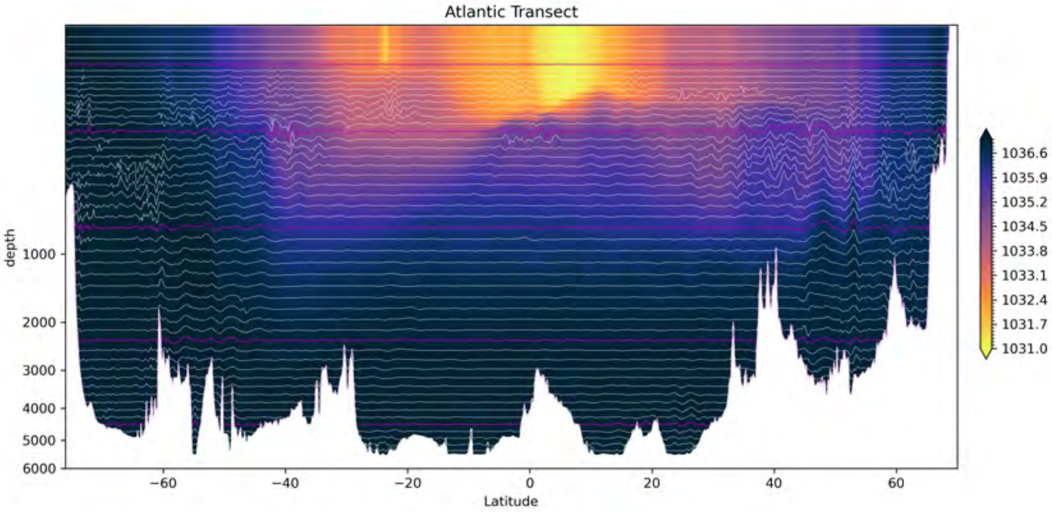
Large-scale isopycnal slopes

- Stratified, with eddies and a large-scale slope
- Density adaptation can "see" eddies, but not the large-scale structure
- Less Isopycnal-like than expected . . . Closer to $\tilde{z}$ than isopycnal?
- Perhaps this is OK??

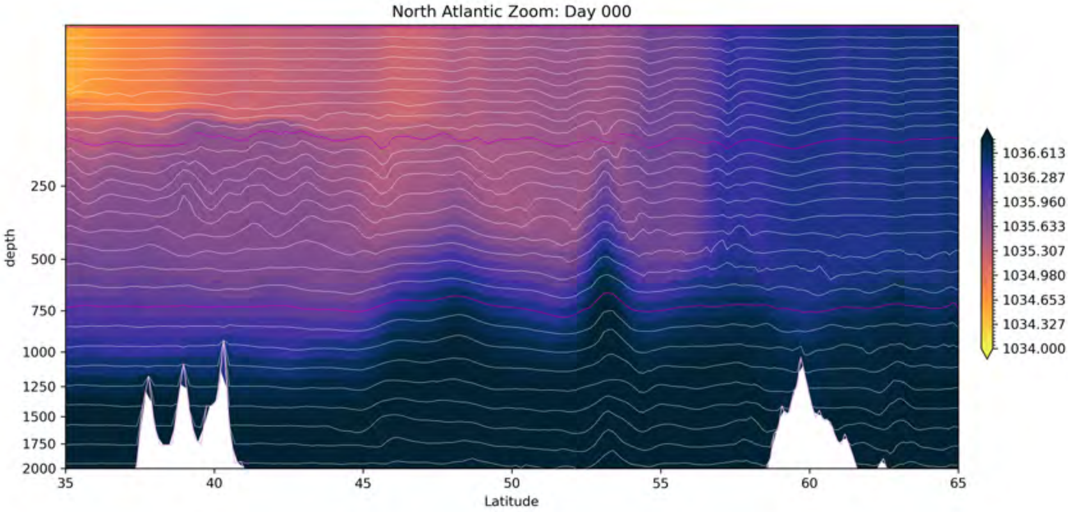
Adaptive Coordinates – Lateral Temp Gradients



Adaptive Coordinates – in a global model (proto-ACCESS-OM3)



Adaptive Grid (AG) Coordinates



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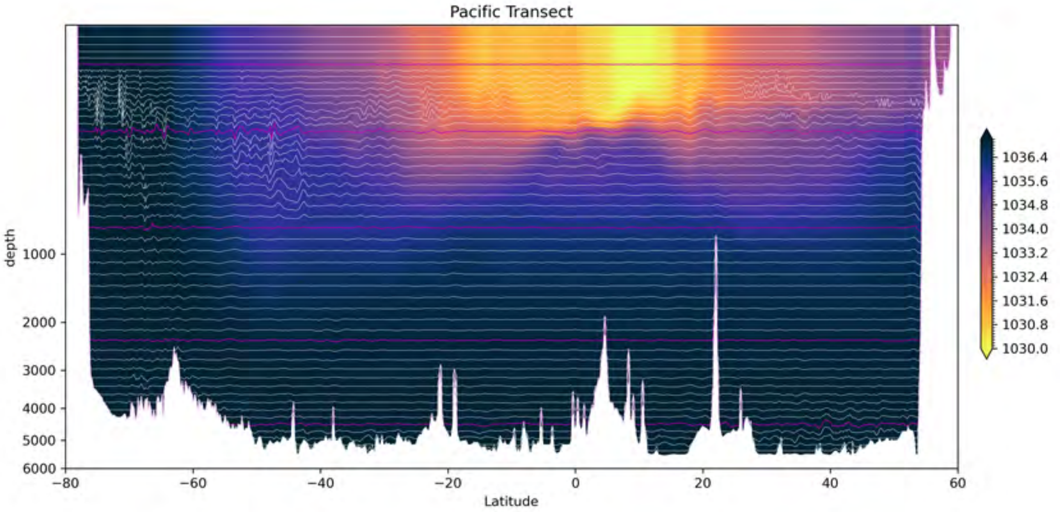

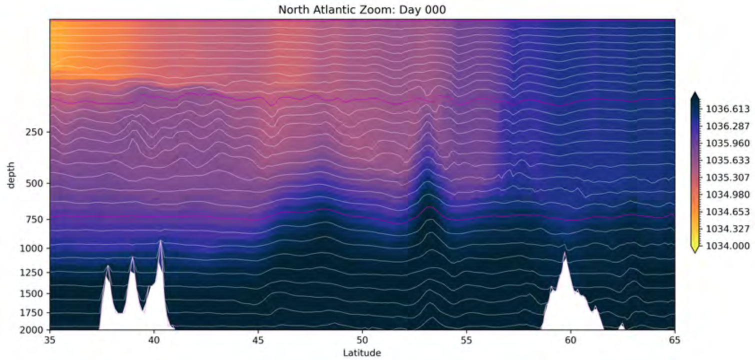

Summary

- AG Coordinate runs and is stable
- Qualitatively good in both idealised and global configurations
- Needs more testing
- Needs more quantitative assessment