Designing a HYCOM1 grid for CESM-MOM6

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We decided a year ago to use the 'hycom1' hybrid coordinate in MOM6 for CESM3.

The hycom1 coordinate uses three lists:

- z^* target depths z_k^{min}
- σ_2 target values σ_k
- Max layer thicknesses h_k^{max}.

It starts at the top ($k = 0$) and works down to find interfaces. It sets

$$z_k = \max\{z_k^{\text{min}}, z(\sigma_k)\}$$

where $z(\sigma_k)$ is the depth of the target σ_2 value. Max means deeper here.

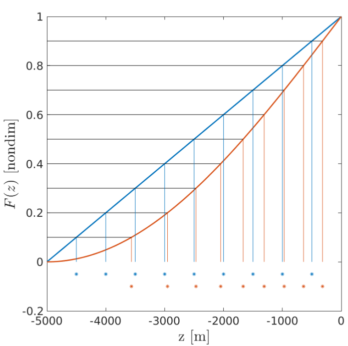
Then, if $z_k - z_{k-1}$ is too thick, it reduces z_k to accommodate the max thickness.

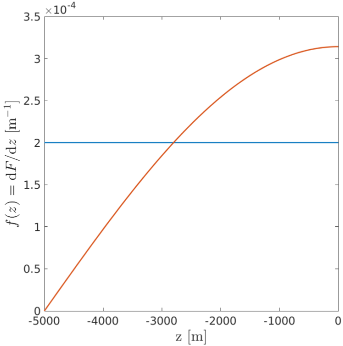
We have a hycom1 configuration with 75 layers that works pretty well for global PI-control and historical simulations.

How should we choose σ_k for other climates, e.g. paleo or future, or for regional configurations?

The isopycnal targets σ_k in our current configuration were chosen 'by hand,' as were the ones in OM4.

I will first develop a systematic way to set isopycnal targets, then will revisit the choice of z^* targets.





Left: Grid-distribution functions $F(z)$ and grids created using them. Right: The corresponding grid-density functions $f(z) = F'(z)$.

What is a good grid-density function?

Charney (1971) introduced a coordinate r with

$$\mathrm{d}r = N(z)\mathrm{d}z$$

Baroclinic modes and are approximately amplitude-modulated cosines in the Charney coordinate.

An equispaced grid in the Charney coordinate does a near-optimal job of resolving internal and Rossby wave modes (Robey & Grooms, 2024).

The Charney coordinate has a grid-density function proportional to $N(z)$.

Given a potential-density profile $\rho(z)$ we can find z levels and/or σ_2 levels that are equispaced in the Charney coordinate.

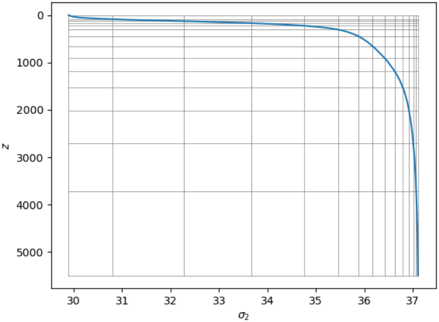
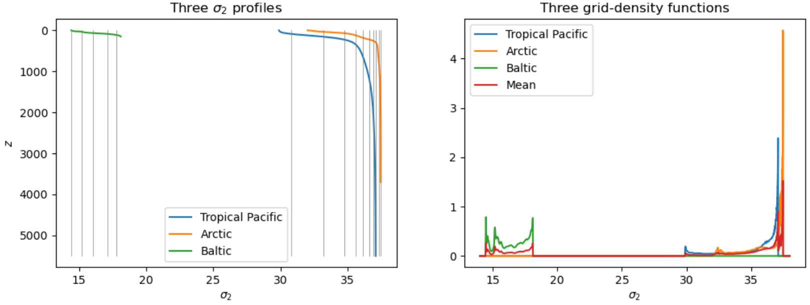


Figure shows a σ_2 profile from the tropical Pacific (WOA data) with fifteen z and σ_2 levels that are equispaced in the Charney coordinate.

The Charney coordinate is not an option in MOM6. For now I want *one* set of σ_2 values to use for *all* columns in the hycom1 coordinate.

How to combine the grid-densities that I get from different columns?

At each σ_2 there is a set of grid-density values. Use something like the the mean/median/max. The mean is below.



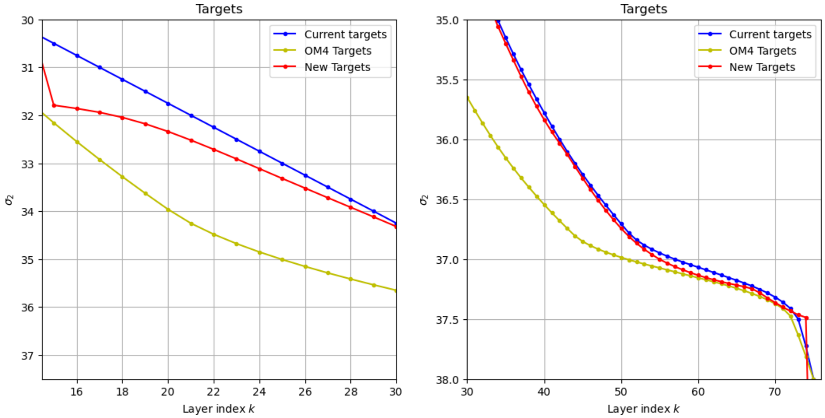
14 total layers: Arctic = 8 layers; Baltic = 5 layers; Trop Pac = 8 layers.

When using global data it would be interesting to explore other approaches like clustering.

I apply this approach to the WOA monthly climatology.

I use a surface-intensified (half-Chebyshev) spacing in the Charney coordinate to make sure that the main thermocline is well-resolved.

I use the p^{th} percentile rather than the mean or the max when combining the grid-density functions from all the columns.

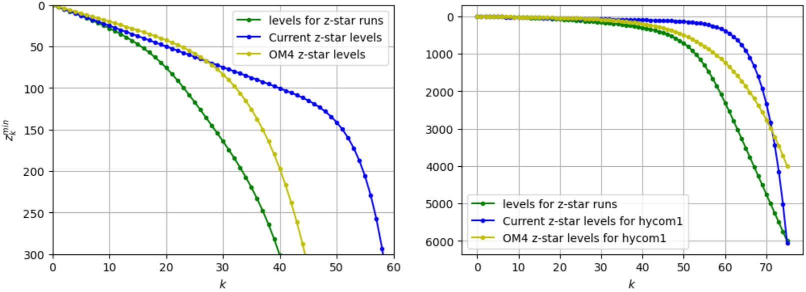


I automatically set max thicknesses to prevent thick layers near the surface but to allow thick/isopycnal behavior at depth.

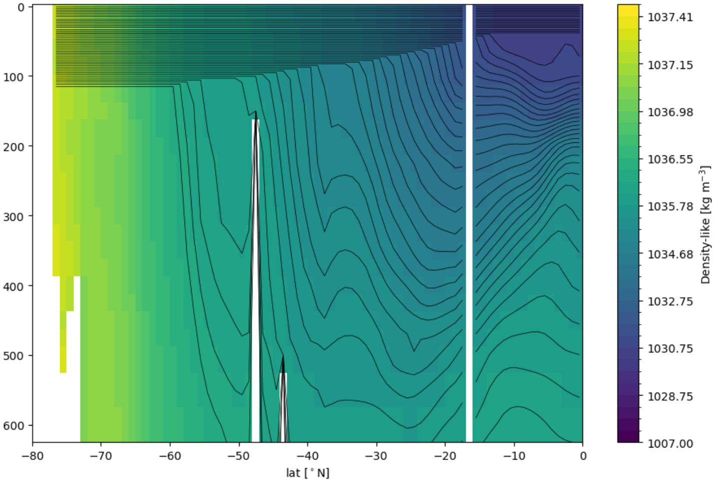
Considerations for designing the z^* part of the hycom1 coordinate.

We want a grid that is isopycnal as much as possible, to avoid spurious diapycnal mixing. But hycom1 only uses the isopycnal interface when that interface is **below** the target z^* interface.

The z^* interfaces in our current hycom1 configuration (and in OM4) are very shallow – lots of thin layers near the top – so that we use the isopycnal targets as much as possible.



Our z^* runs put about 30 points in the top 150 m. The OM4 hybrid coordinate puts 38 z^* points there, and our current hybrid config puts about 50 points there.



A section at the dateline (WOA data) showing where the first 46 interfaces would be in our current configuration, without max-thickness limiting. Some layers are too thick.

The hycom1 coordinate has an option to specify max thicknesses.

Max thickness is a function of k, not depth. Layer 42 needs to be thin near the surface at high latitudes, but we want it to be thick/isopycnal at depth in the tropics. How to enforce this?

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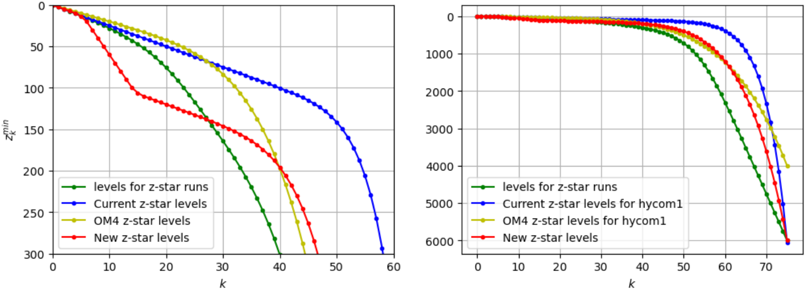
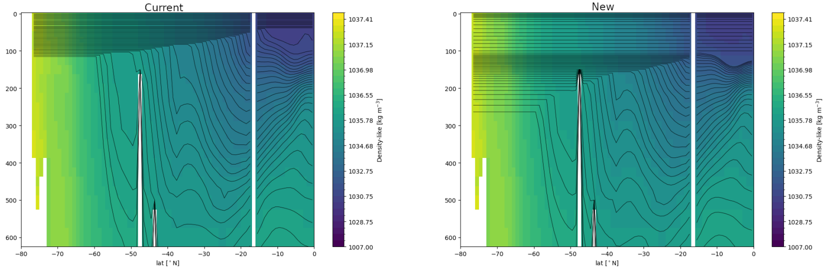
Change the z^* levels, not the max thicknesses:

Shallow z^* levels means lots of isopycnal behavior (good) but it also means thick layers near the surface (bad).

I make the z^* grid deeper to prevent thick layers near the surface, but not so deep that I lose isopycnal behavior.



Max 10 m thickness in the top 100 m (photic zone), followed by the usual shallow behavior to encourage isopycnal behavior below 100 m.

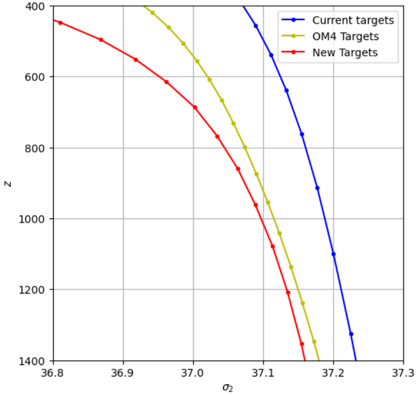


I can use $h_k^{\max}$ to prevent thick layers near the surface in the tropics.

I still have thick layers near the surface at high latitudes, but with the new grid those thick layers are (i) not as thick and (ii) not as close to the surface.

Dense water overflows the Greenland-Scotland ridge at depths $\sim 600 - 1{,}000$ m.

We need this to be isopycnal to avoid spurious mixing, otherwise we get a weak, shallow AMOC.



The plot shows $(\sigma_k, z_k^{\min})$ for three hycom1 configurations. Grids towards the upper right represent the overflows more isopycnally.

Gustavo will compare simulations using the old and new grid in his talk this afternoon. Mixed layers are improved, while AMOC is only a little worse (weaker, shallower).

I'm grateful for input from Alistair Adcroft, Frank Bryan, Gokhan Danabasoglu, Bill Large, Keith Lindsay, and Gustavo Marques.

I've already applied this method to create a grid for last-glacial-maximum simulations; evaluation is ongoing.

I'd like to use this to create grids for the regional configurations.