Status of MOM6 towards CESM3 Release & Discussion

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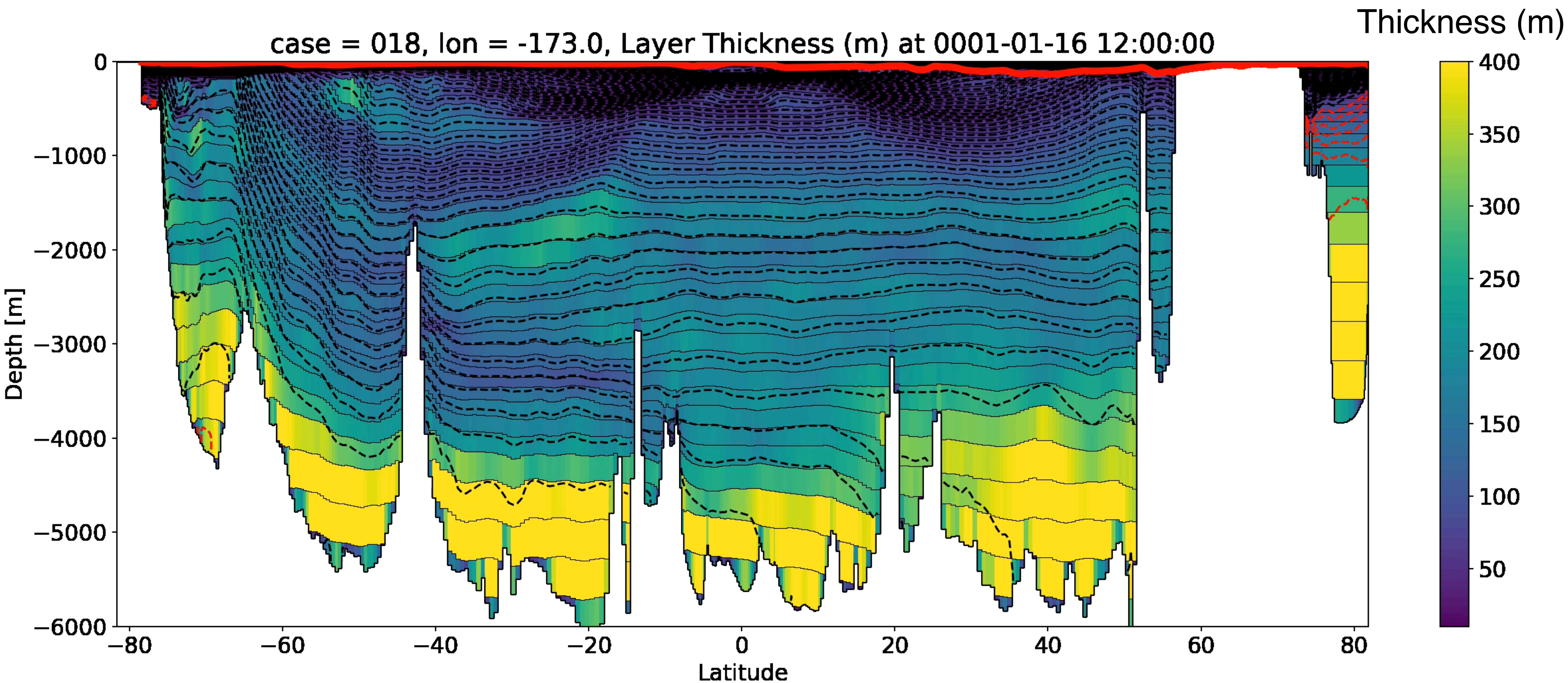
CESM "workhorse" configurations and choice of physics

	POP2	MOM6
H. Grid	1.125° dipole w/ equatorial refinement	0.66° tripole w/ equatorial refinement
V. Grid	z-coord., dz = 10 m @ surface, 60 levels	z*-coord. or **hybrid*** (z*/isopyc) or dz = 2.5 m @ surface, 65-75 levels
Freshwater B.C.	Constant volume, virtual salt flux	Variable mass, natural B.C
V. Mixing	CVMix-KPP + Langmuir	CVMix-KPP + **wave processes****
GM+Redi	Marshall N^2 scaling	MEKE+GEOMETRIC scaling + **Vertical structure in Redi***+ **backscatter****
Mixed Layer Eddies	Fox-Kemper et al. (2010), L_f = 5 km	Fox-Kemper et al. (2010), L_f = 1 km + **Bodner et al. (2023)****
H. Viscosity	Anisotropic Laplacian	Isotropic Laplacian + Biharmonic, via MEKE
Solar penetration	Ohlmann (2003)	Manizza (2005), **Ohlmann (2003)****
Advection	3rd order upwind	Horiz. PPM, Vert. ALE w/ 3rd order remap. + **KE-conserving correction****
Other params	Overflow, estuary box model	**subgrid scale EOS correction***, **geothermal***, **estuary box model*****

*** new defaults** **** current evaluations** ***** will not be included in CESM3**

Loss of resolution with old hybrid (z*/isopycnal) configurations

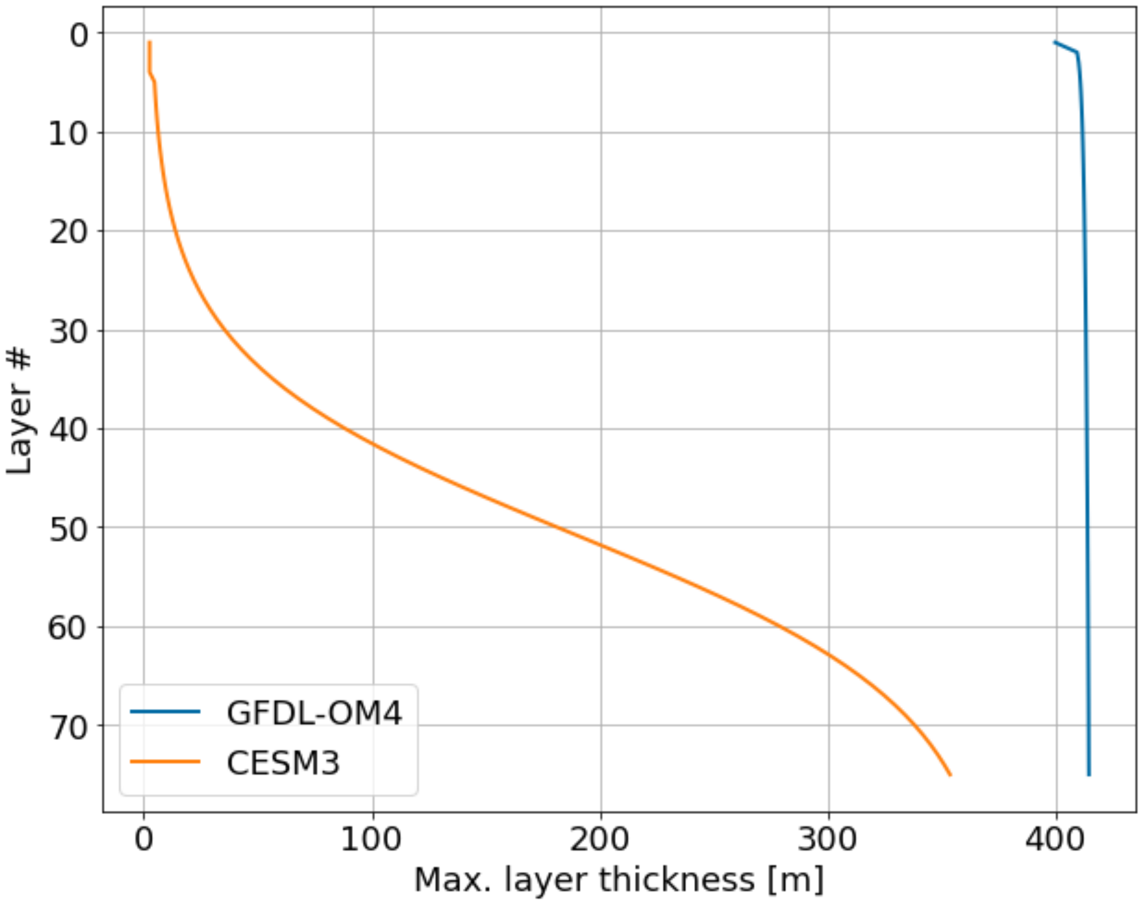
Transect across Pacific Ocean for an old forced control. Example of where hybrid was not working properly.



Light contours are interfaces, and colors are layer thicknesses (m). Dashed contours are positions of the target densities (σ_2) in the HYCOM1 coordinate (dashed red are 10 most dense values). The solid red is the mixed layer depth.

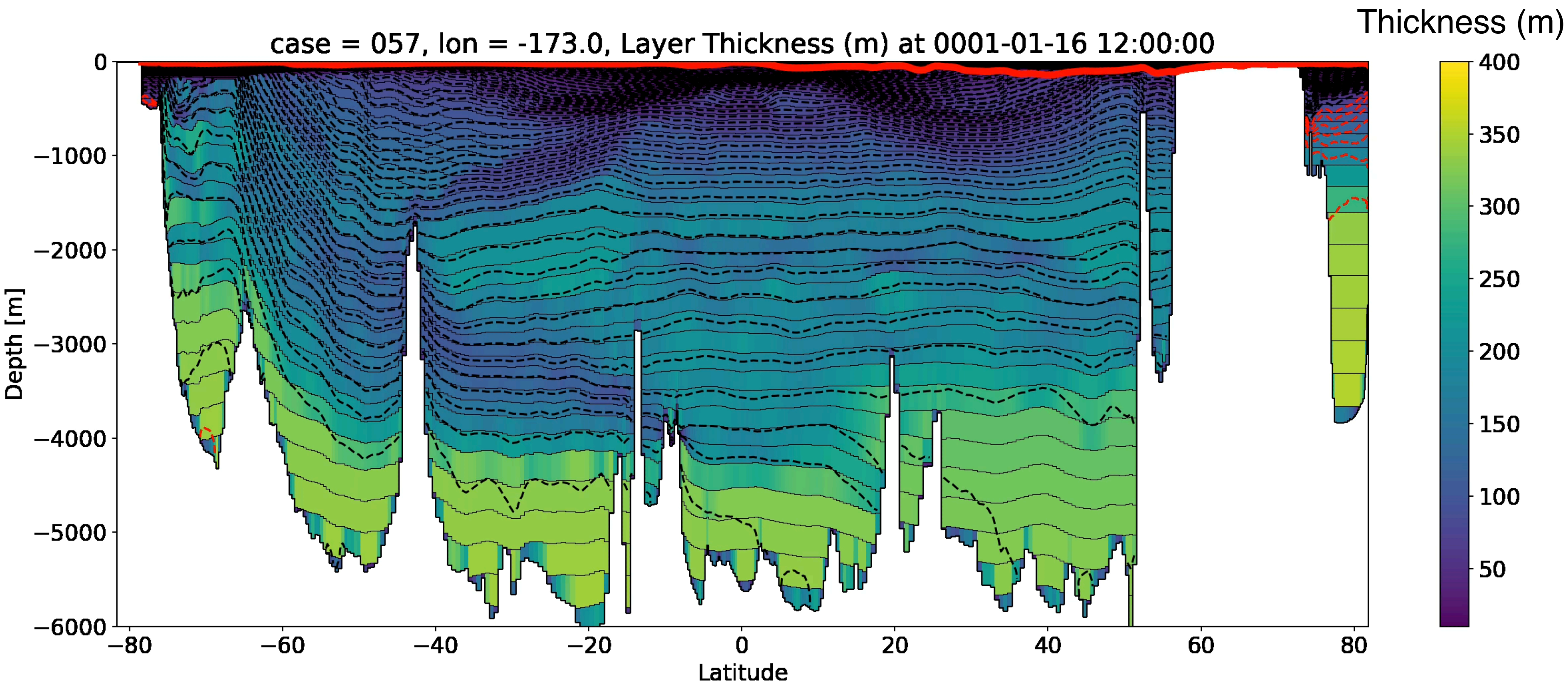
Improvements in the HYCOM1 settings

Maximum layer thickness is defined using a hyperbolic tangent function + manual tweaks.



Layer thicknesses with new HYCOM1 settings

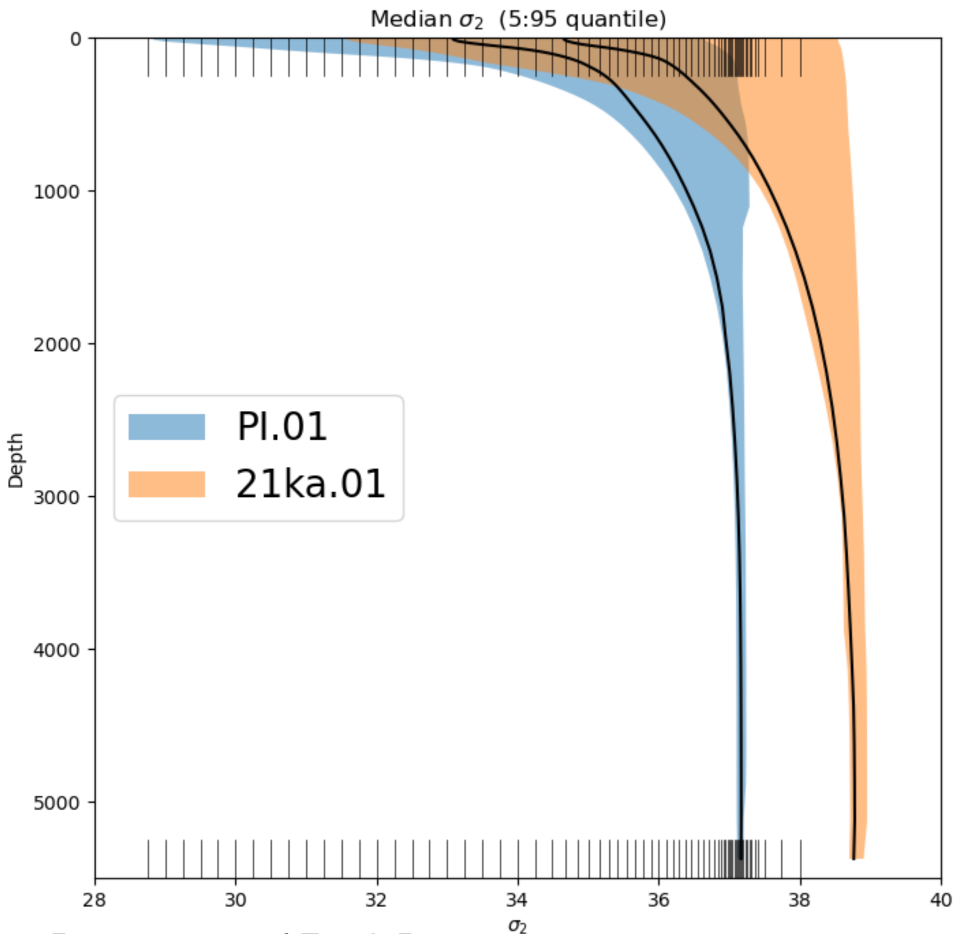
Loss of vertical resolution is no longer an issue.



Light contours are interfaces, and colors are layer thicknesses (m). Dashed contours are positions of the target densities (σ_2) in the HYCOM1 coordinate (dashed red are 10 most dense values). The solid red is the mixed layer depth.

Current HYCOM1 settings in other climates

Pre-Industrial vs. Last Glacial Maximum (LGM)



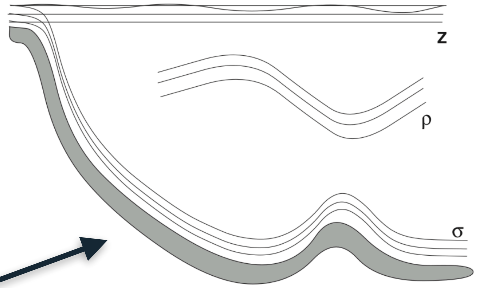
Plot courtesy of Frank Bryan

- PI ✓
- Historical ✓
- SSP5-8.5 - (2000 - 2300) ✓
- Last Millennium Ensemble ✓
- Pliocene ?
- Eocene ✗
- Last Glacial Maximum ✗

Current CESM3 target densities do not work for LGM simulations. It's possible to shift targets towards denser values. OMWG will work with PWG to address this.

Decision to go forward with a hybrid vertical coordinate

- OMWG has decided to use a hybrid vertical coordinate (HYCOM1) in CESM3;



Griffies et al. (2000)

Rational for choosing hybrid:

Pros

- Best of all worlds - level near the surface and isopycnal in the interior;
- Less spurious mixing → mitigate thermocline warm bias;
- Better overflows;
- Stronger AMOC.

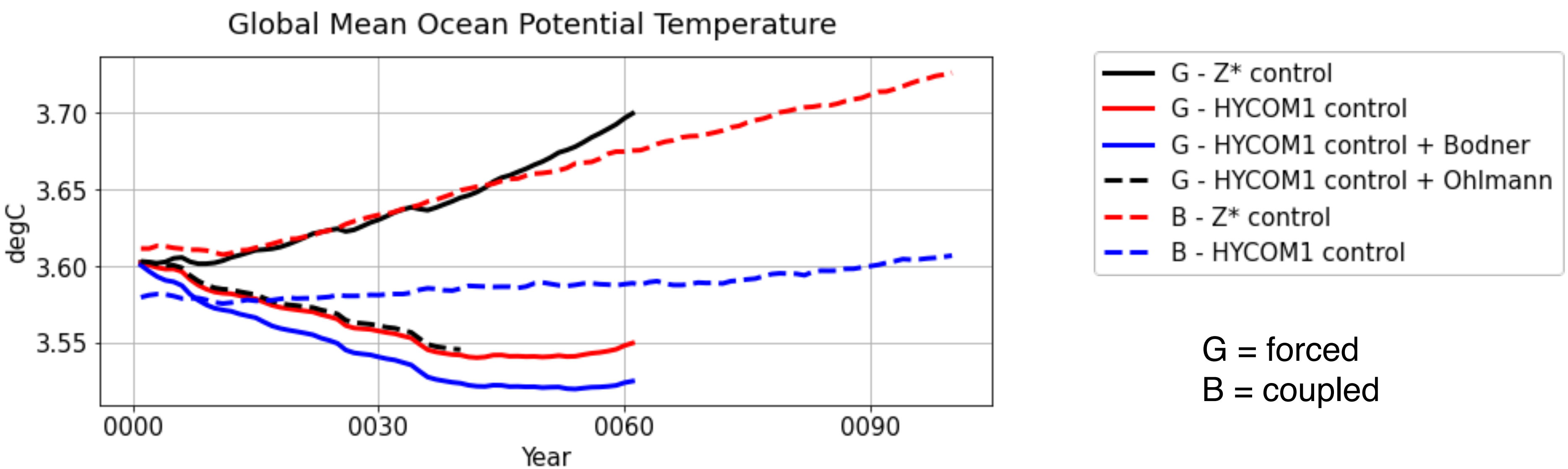
Cons

- ~~Loss of upper-ocean resolution;~~
- Less intuitive to configure;
- Still learning how to adapt it to other climate regimes.

Addressing concerns:

- Ability to output in many vertical coordinates (z, σ_0, σ_2, native, etc);
- We recognize this might pose a challenge for modeling some climate regimes. OMWG is working with other WGs to find solutions.

Global mean temperature (forced and coupled)



G = forced
B = coupled

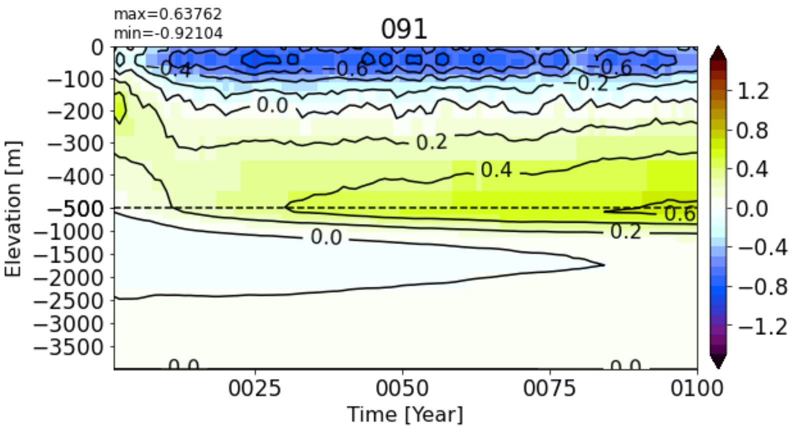
HYCOM1 cools relative to Z*.

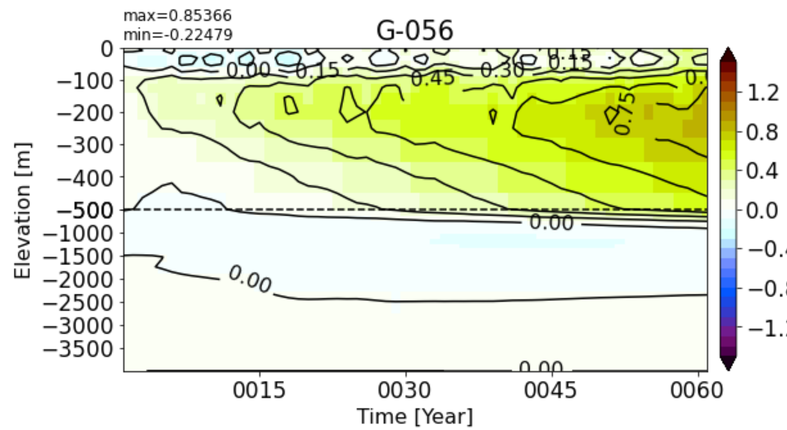
Global temperature drift

Coupled

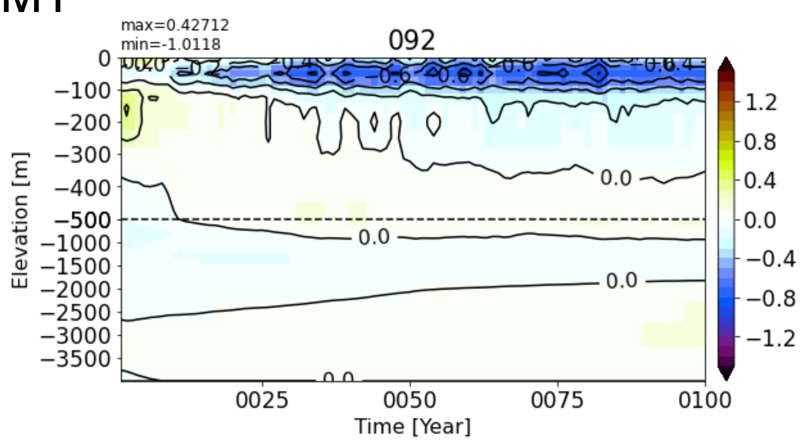
Forced

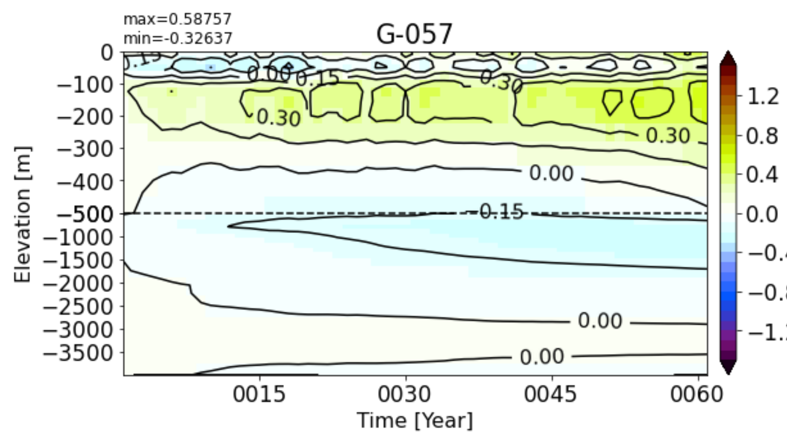
Z*





HYCOM1





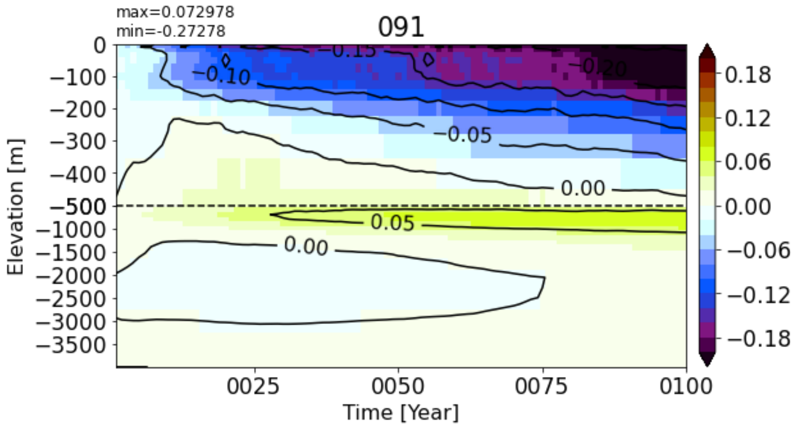
Z* is warmer below ~ 200 m.

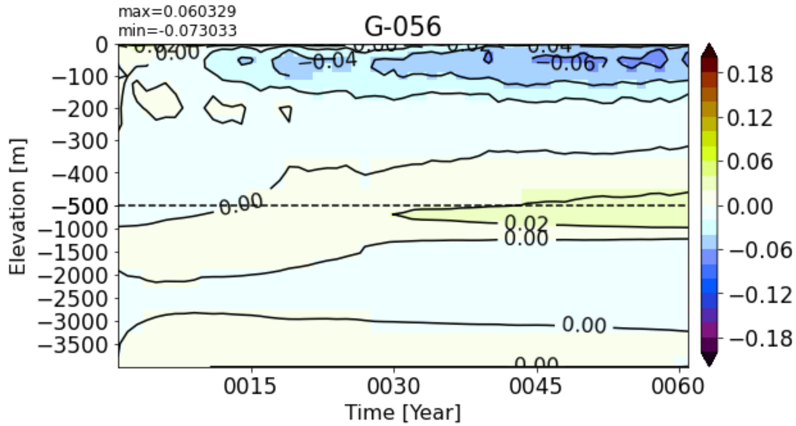
Z* is warmer below ~ 100 m.

Global salinity drift

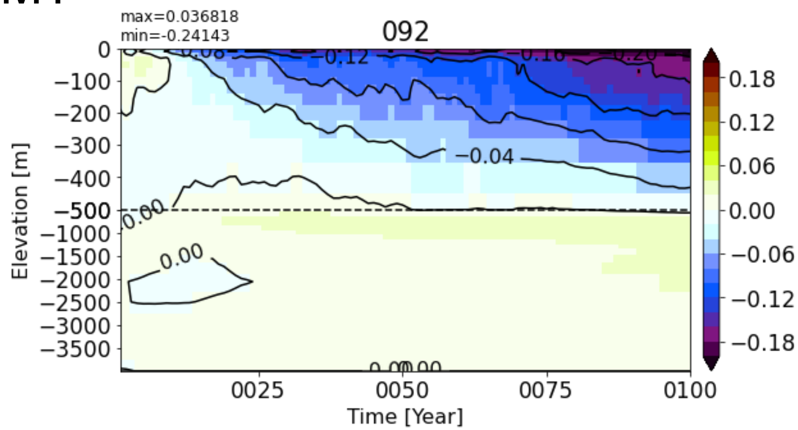
Coupled | Forced

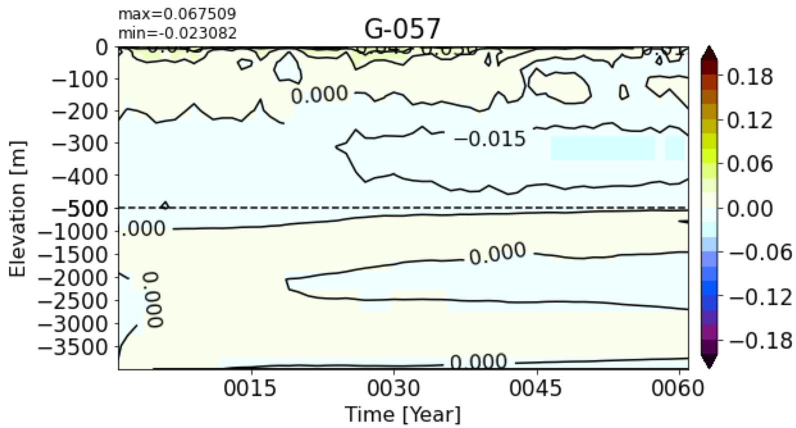
Z*





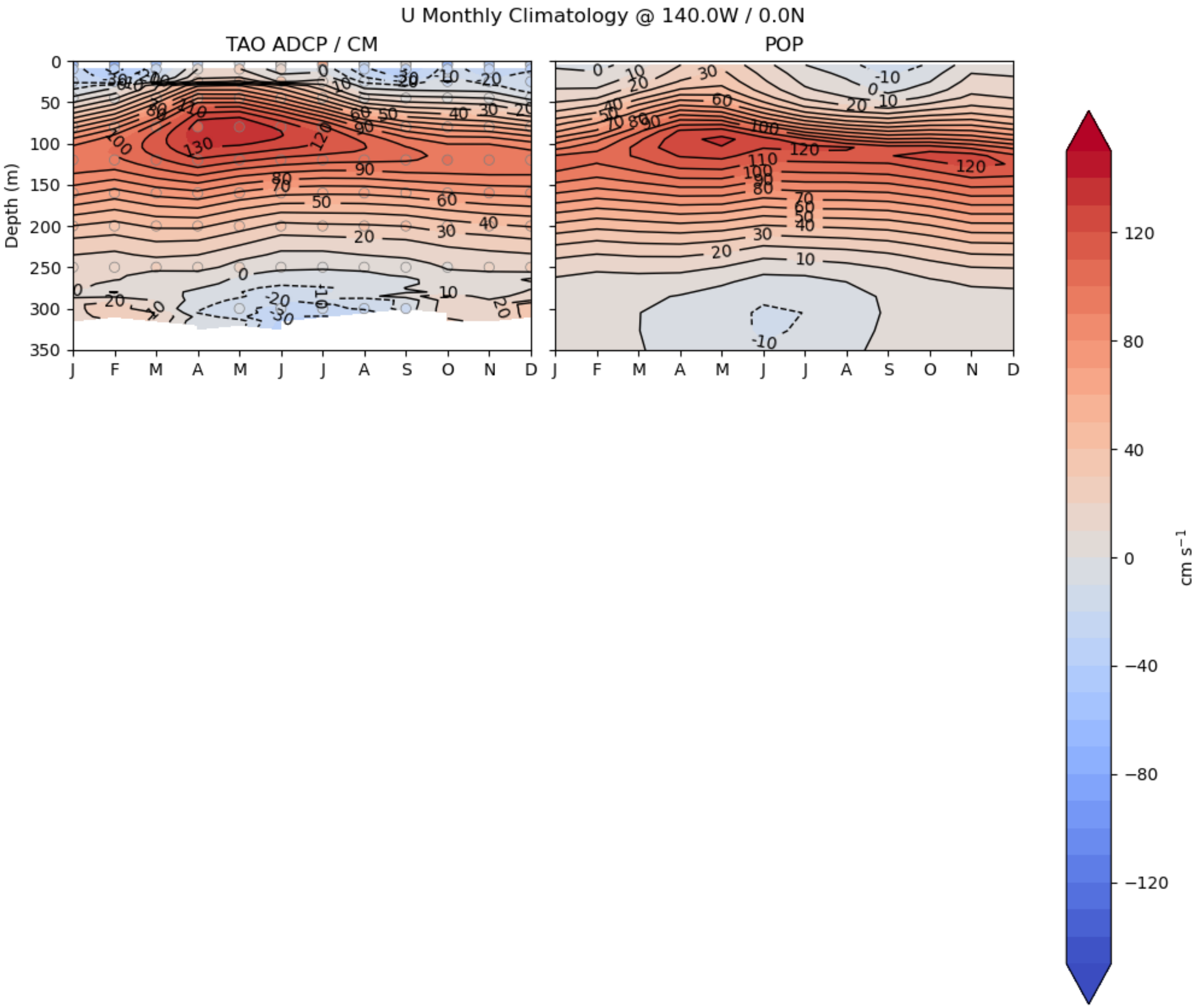
HYCOM1





Z* is fresher near the surface. Below 500 m, Z* is saltier.

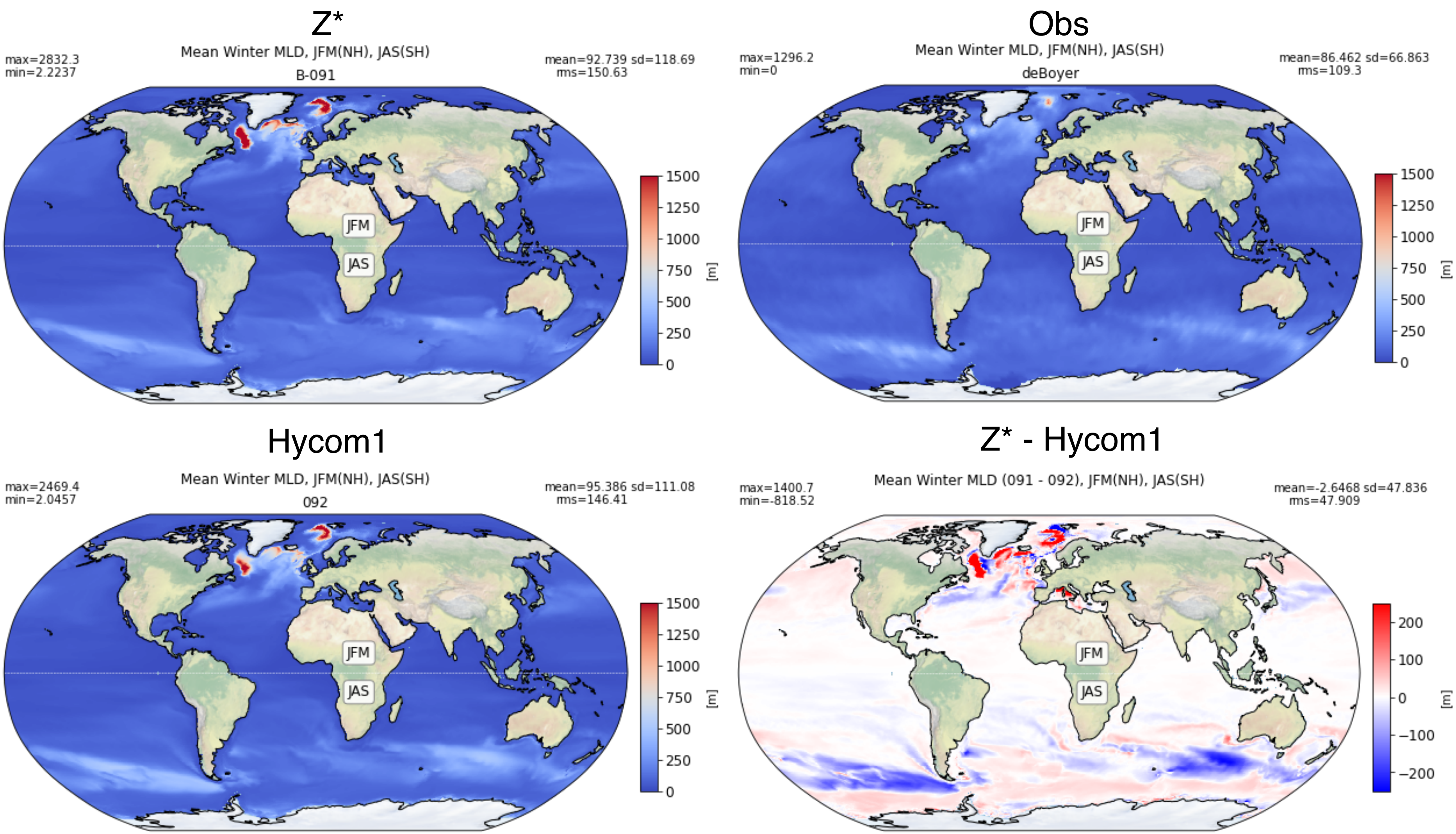
Pacific Equatorial Undercurrent



- We were overwriting the background visc/diff and this was leading to Prandtl #s of ~200 below the EUC;
- Setting background (KV and KD) to zero and max. thicknesses in new runs;
- Very little difference between Z*and HYCOM1 in new runs;
- The EUC is slightly deeper in MOM6.

Many thanks to Deepak Cherian for discovering this issue and proposing a solution!

Winter mixed layer depth (m) - coupled cases



Hycom1 overestimates MLDs in the Southern Ocean;
Z* overestimates MLDs in the North Atlantic.

MLE length scale scheme from Bodner et al (2023)

Modifying the Mixed Layer Eddy Parameterization to Include Frontogenesis Arrest by Boundary Layer Turbulence

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Streamfunction implemented in GCMs:

$$\boldsymbol{\Psi} = C_e \frac{\Delta s}{L_f} \frac{H^2 \nabla_H \overline{b}^z \times \mathbf{z}}{\sqrt{f^2 + \tau^{-2}}} \mu(z). \quad (6)$$

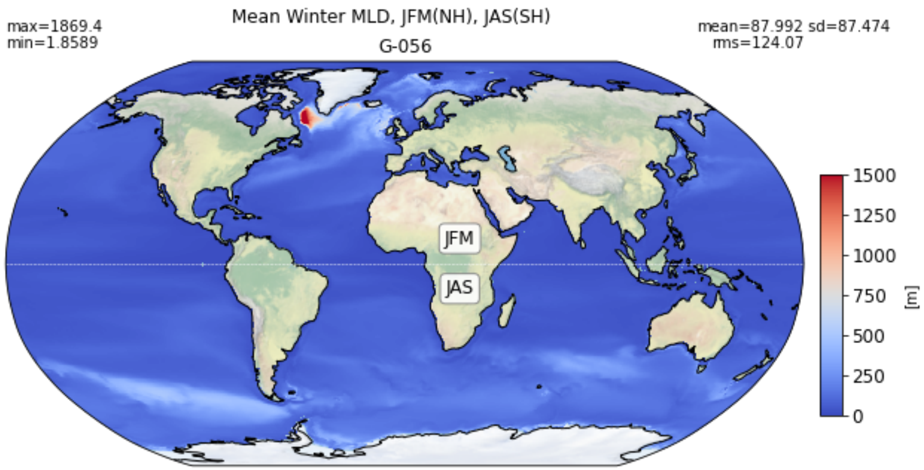
We have been using L_f = 1 km in CESM/MOM6. L_f is a function of the ocean state when BODNER=True.

- C_L ~ O(Ri)
- u_* frictional velocity
- h boundary layer depth
- w_* turbulent convective velocity
- f Coriolis parameter
- m_* nondim 0.5
- n_* nondim 0.066

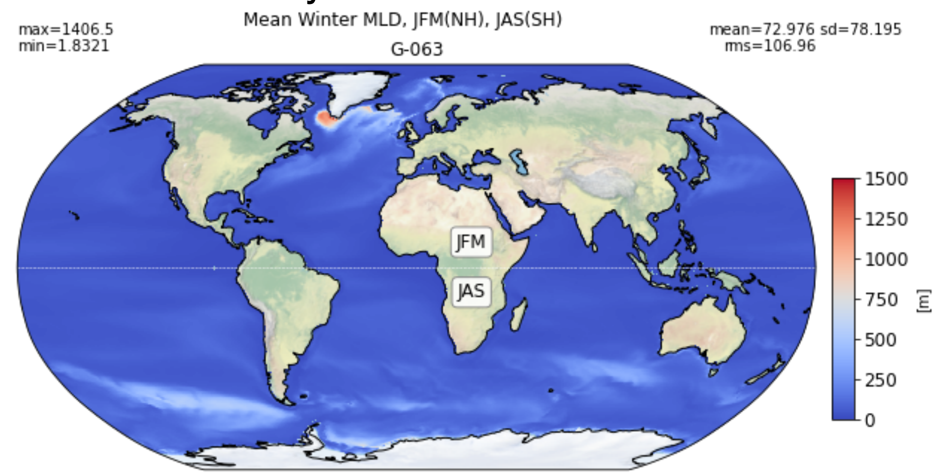
$$L_f = C_L \frac{(m_* u_*^3 + n_* w_*^3)^{2/3}}{f^2} \frac{1}{h}, \quad (24)$$

Winter mixed layer depth (m) - forced cases

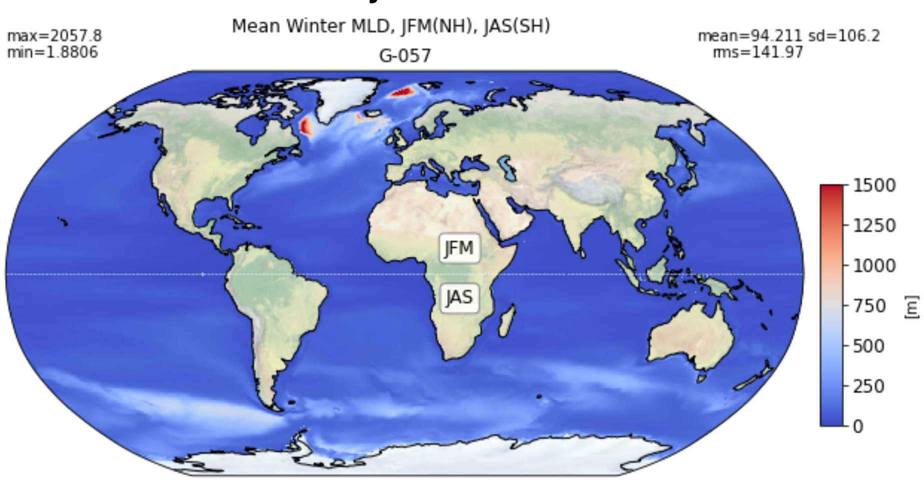
Z*



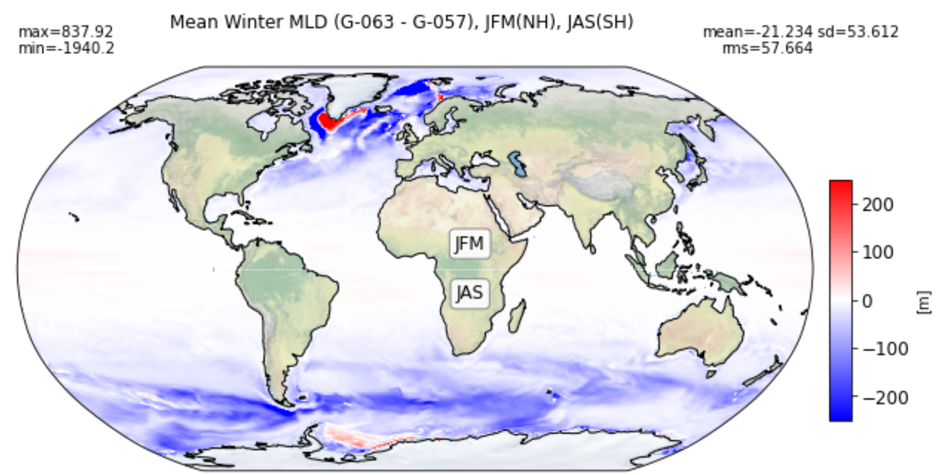
Hycom1 + Bodner



Hycom1



(Hycom1 + Bodner) - Hycom1

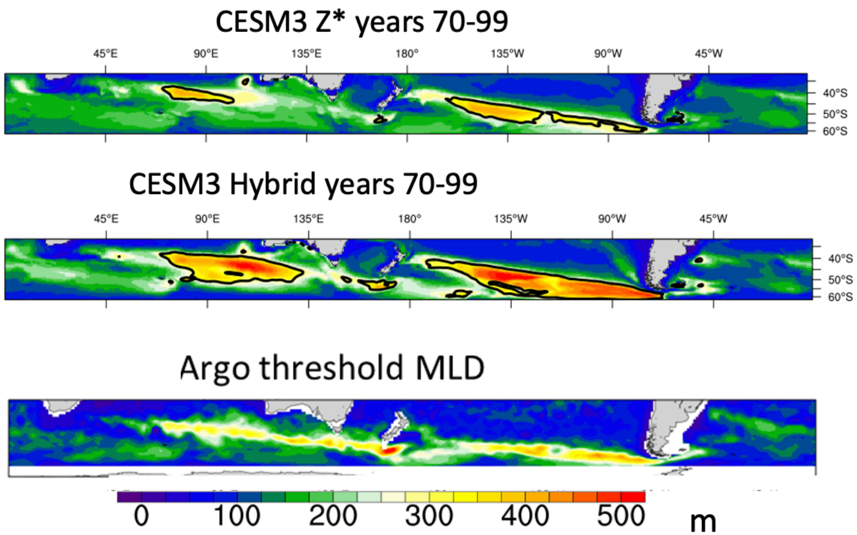


Hycom1 + Bodner helps reduce biases in the Southern Ocean, but move Lab. Sea convection to the southern tip of Greenland.

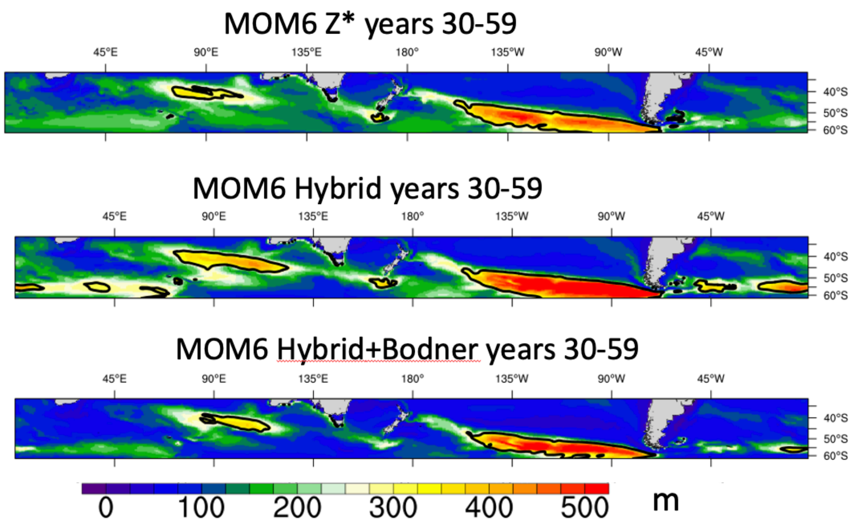
Winter mixed layer depth (m) - SubAntarctic region

Winter=JAS. MLD = where density is 0.03 kg m^{-3} greater than surface value.

Coupled



Forced



Plots courtesy of Justin Small

Hycom1 + Bodner helps reduce biases in the Southern Ocean.

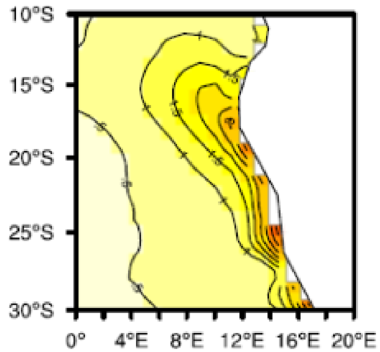
Eastern Boundary Upwelling Systems – SST bias

Benguela

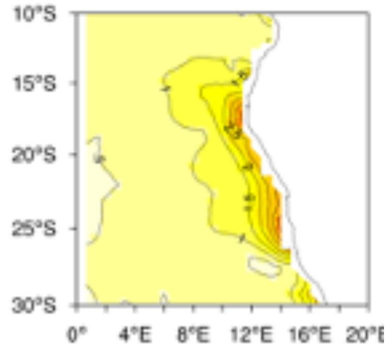
Plots courtesy of Justin Small

Forced

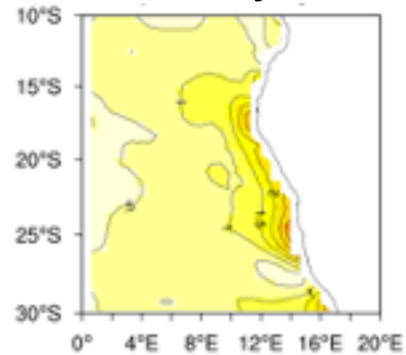
POP-LR



MOM6-Z*

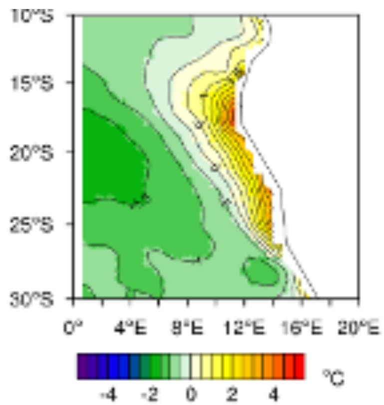


MOM6-Hycom1

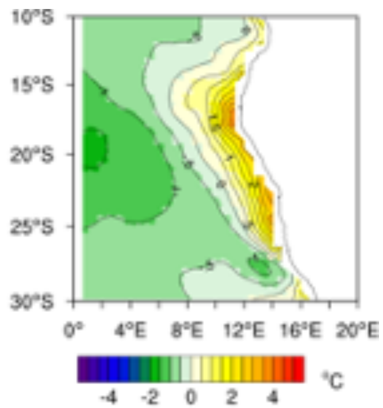


Coupled

MOM6-Z*



MOM6-Hycom1



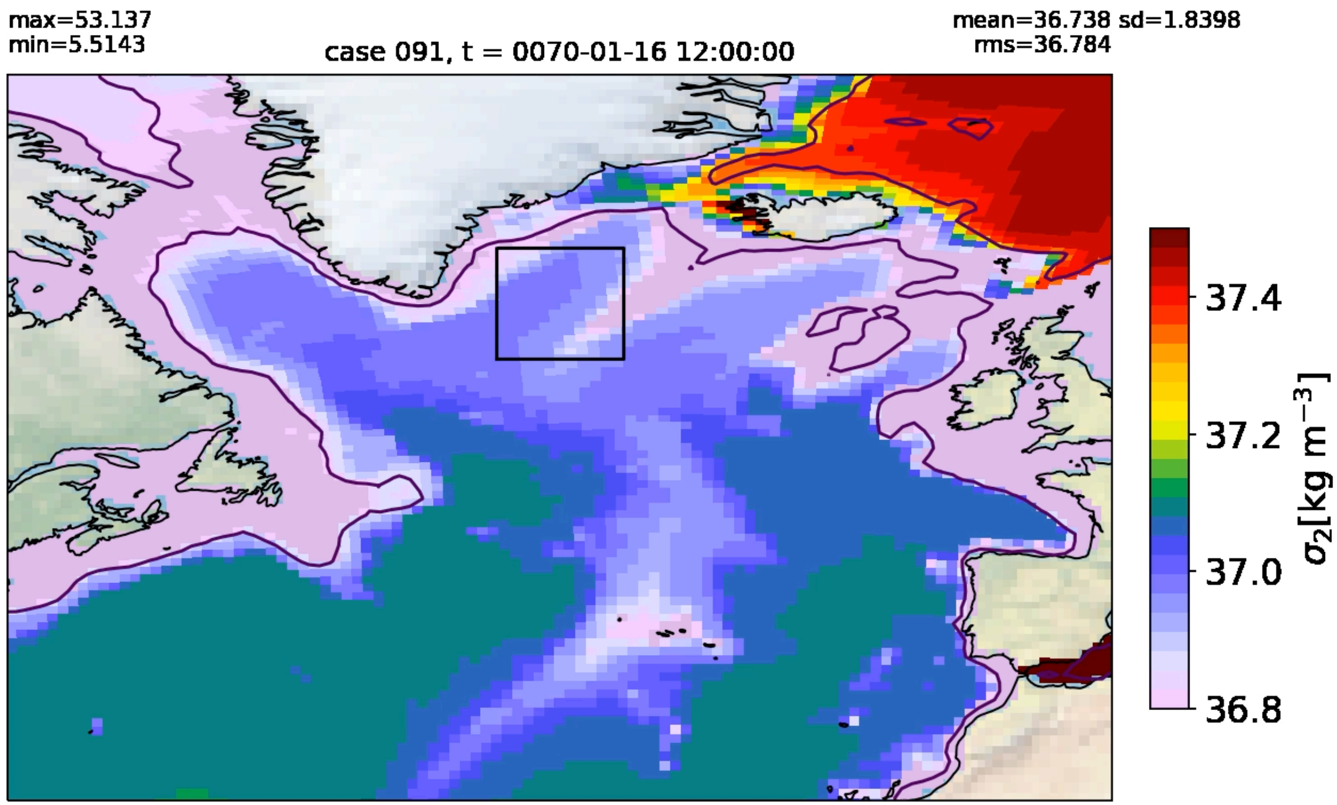
Forced MOM6 cases are a significant improvement over POP, probably because MOM6 grid (2/3°) is closer to JRA55 (1/2°) than POP.

Coupled cases are similar and typical of cases coupled to 1° ATM model.

Hybrid forced-case has slightly reduced bias relative to Z*.

Nordic overflows - Z*

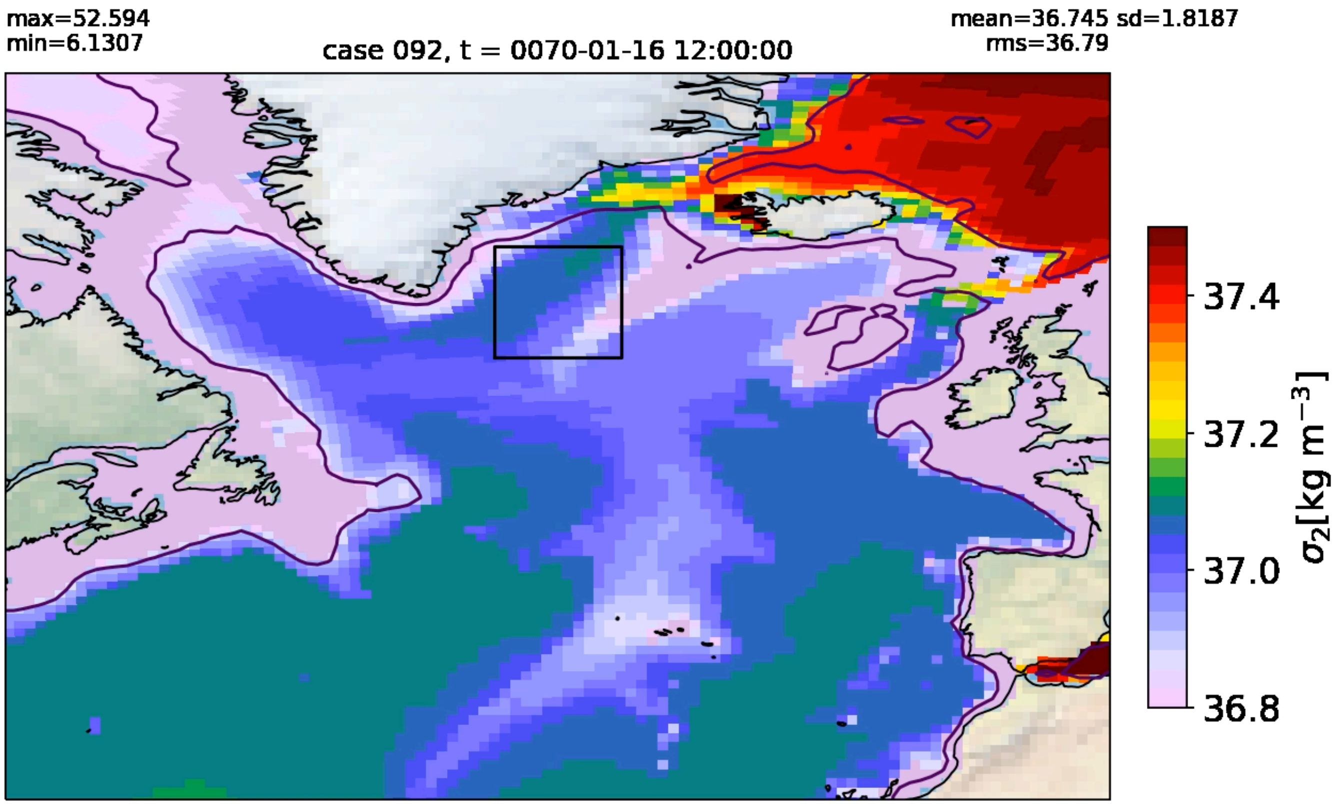
Mean density (σ_2) within 20 m from the bottom, case B-091



There is little indication of dense water export through the major straights and troughs.

Nordic overflows - HYCOM1

Mean density (σ_2) within 20 m from the bottom, case B-092



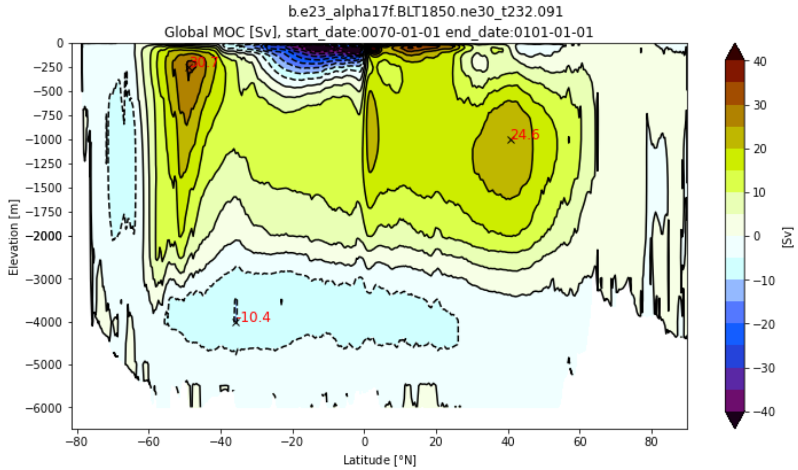
The export of dense water through the Denmark Strait and the Rockall Trough is clearly visible.

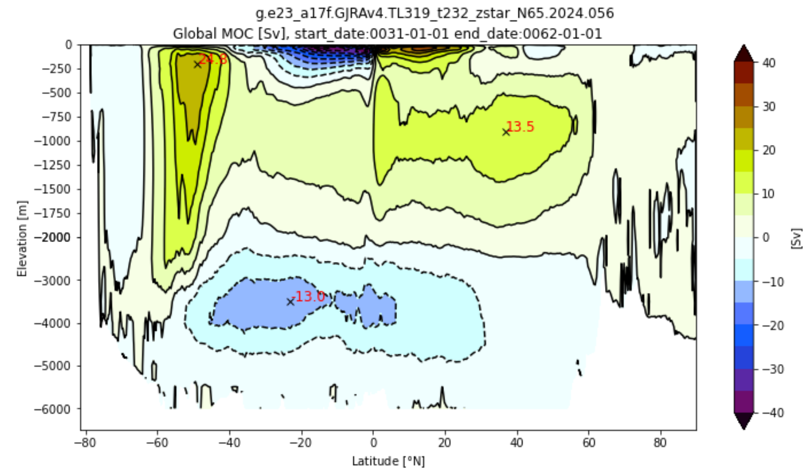
Global meridional overturning circulation [Sv]

Average over last 30 years

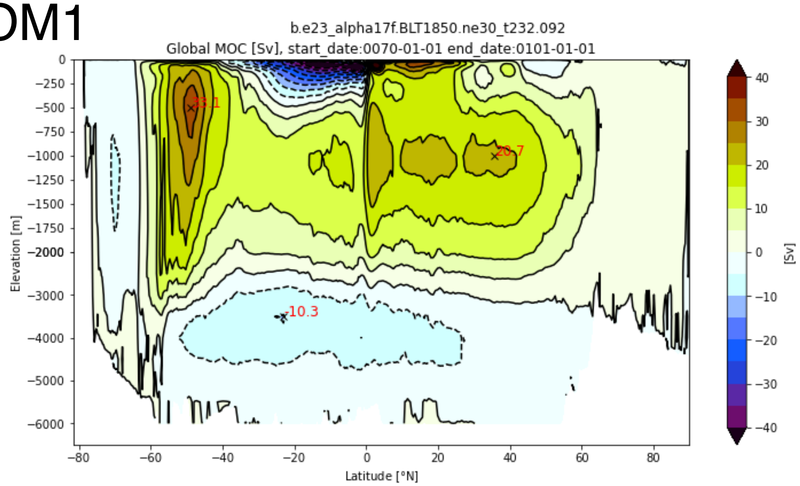
Coupled | Forced

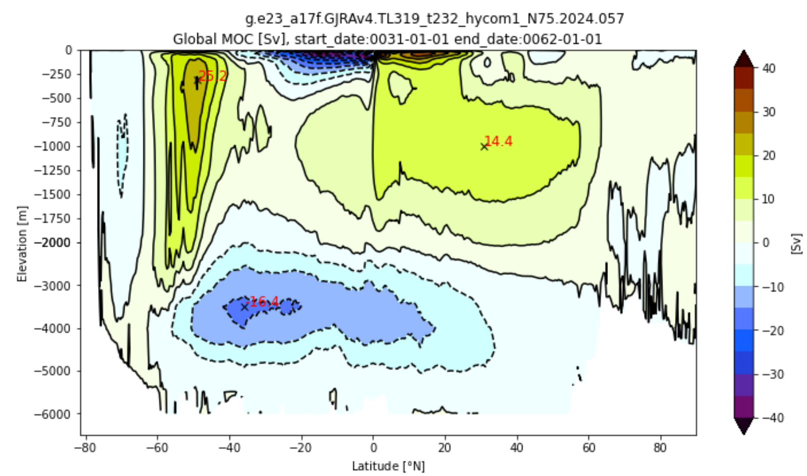
Z*





HYCOM1





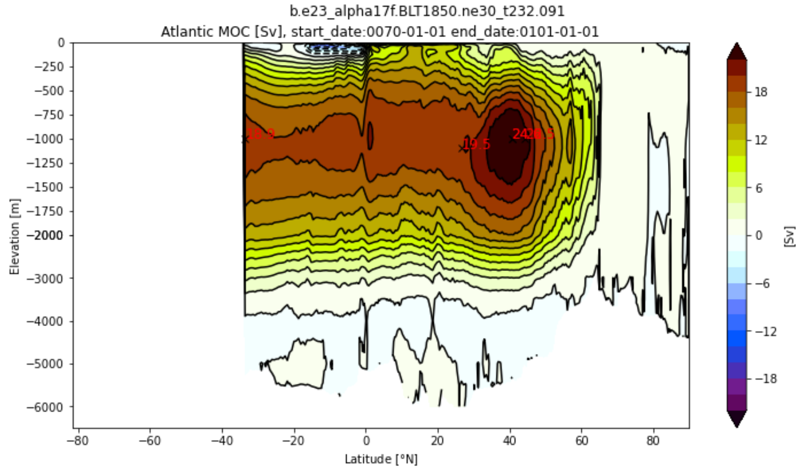
Overall similar MOC structure in Z* and HYCOM1.

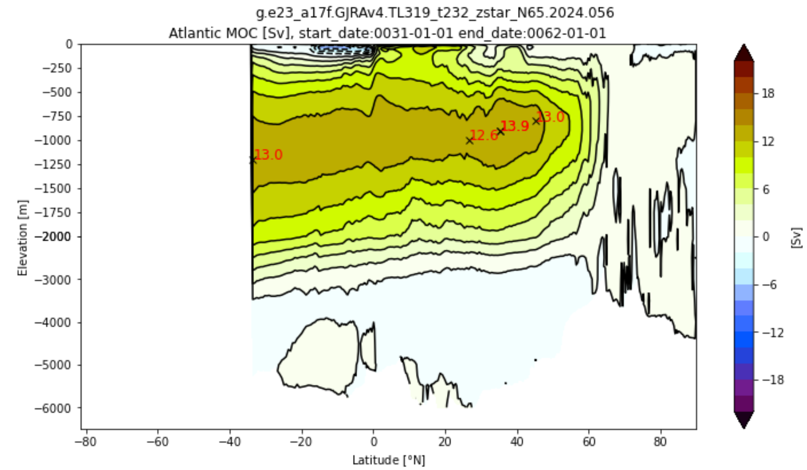
Atlantic meridional overturning circulation (AMOC) [Sv]

Average over last 30 years

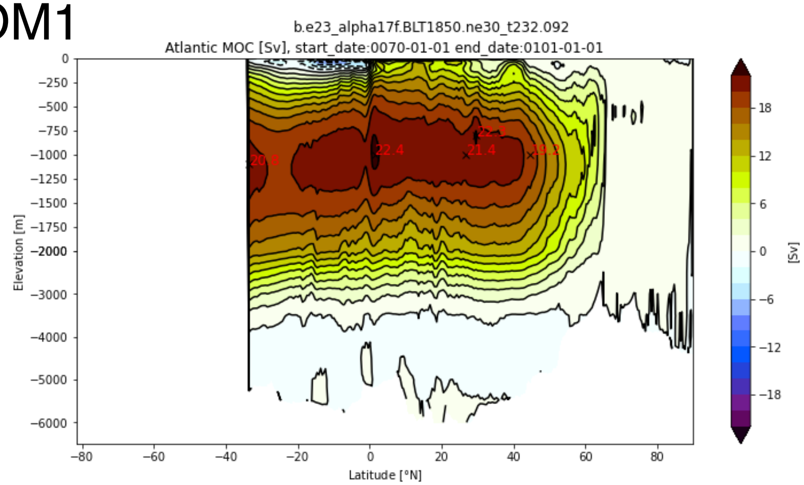
Coupled | Forced

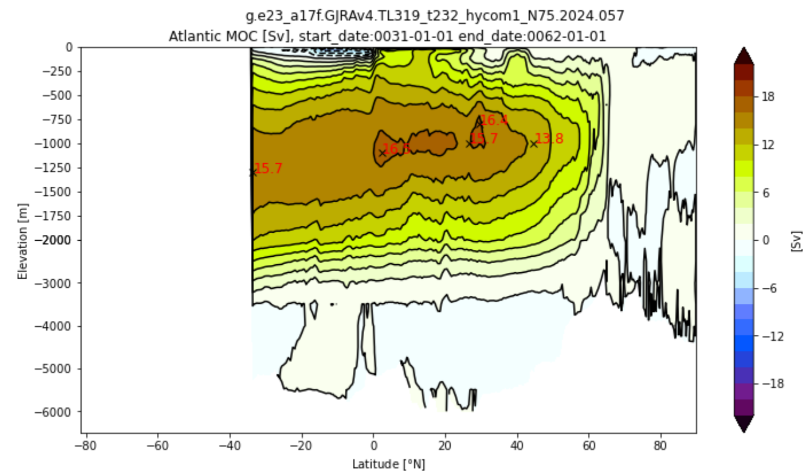
Z*





HYCOM1





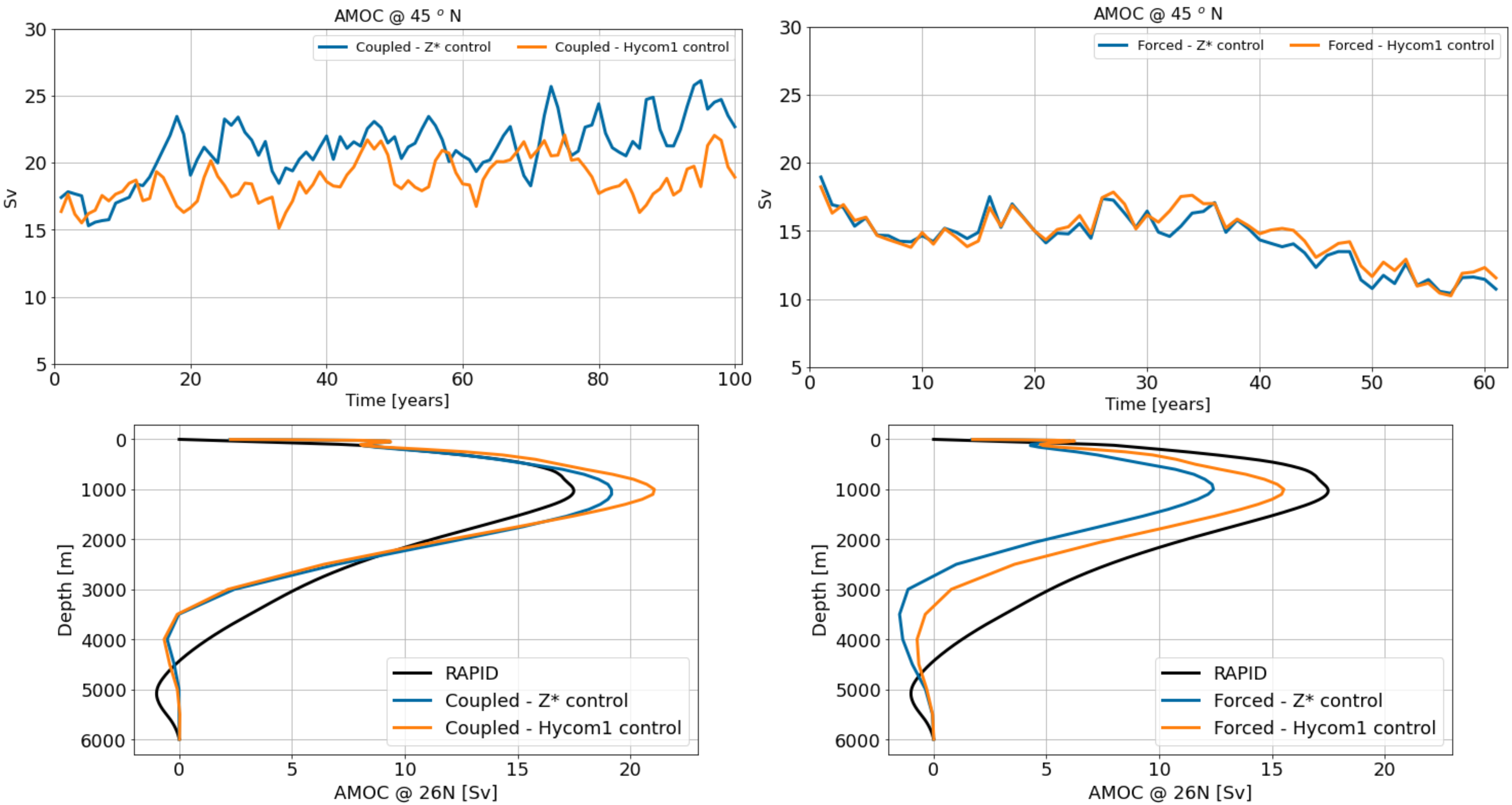
Stronger AMOC in coupled cases.

Overall, stronger AMOC with HYCOM1.

AMOC time series and profile @ 26 N

Coupled

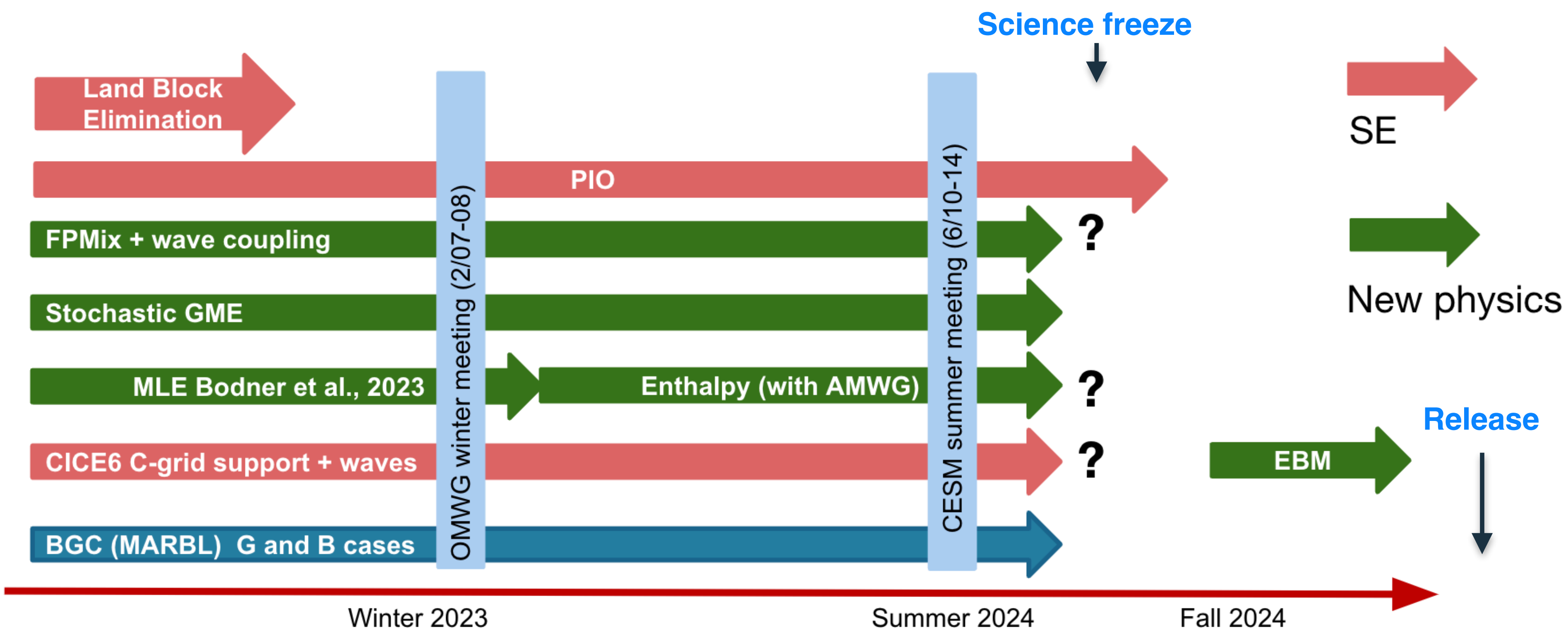
Forced



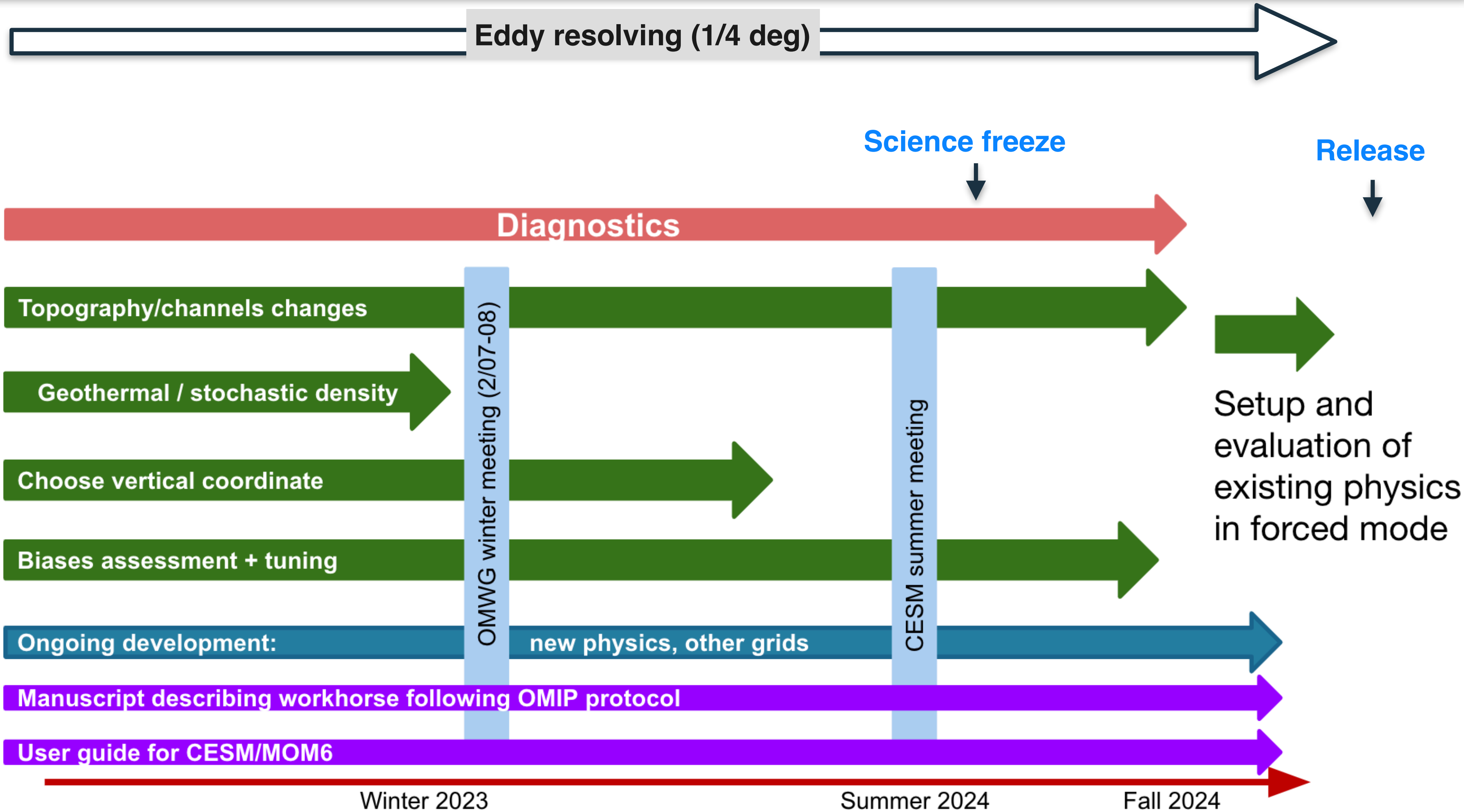
Overall, stronger AMOC with HYCOM1 in forced and coupled cases.
Differences at 26 N are larger in forced cases.

Towards CESM/MOM6 code base

Known bugs, bug fixes, etc (see full list @ https://github.com/NCAR/MOM6/issues and https://github.com/ESCOMP/MOM_interface/issues)



Tuning and model features



Discussions on model development and diagnostics:
https://github.com/NCAR/omwg_dev/discussions

Thank you

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