Towards the CESM3 ocean component

Gustavo Marques
gmarques@ucar.edu

In collaboration with: Alper Altuntas, Frank Bryan, Keith Lindsay, Ian Grooms, Gokhan Danabasoglu, Mike Levy, and Bill Large

CESM OMWG, February 8, 2024

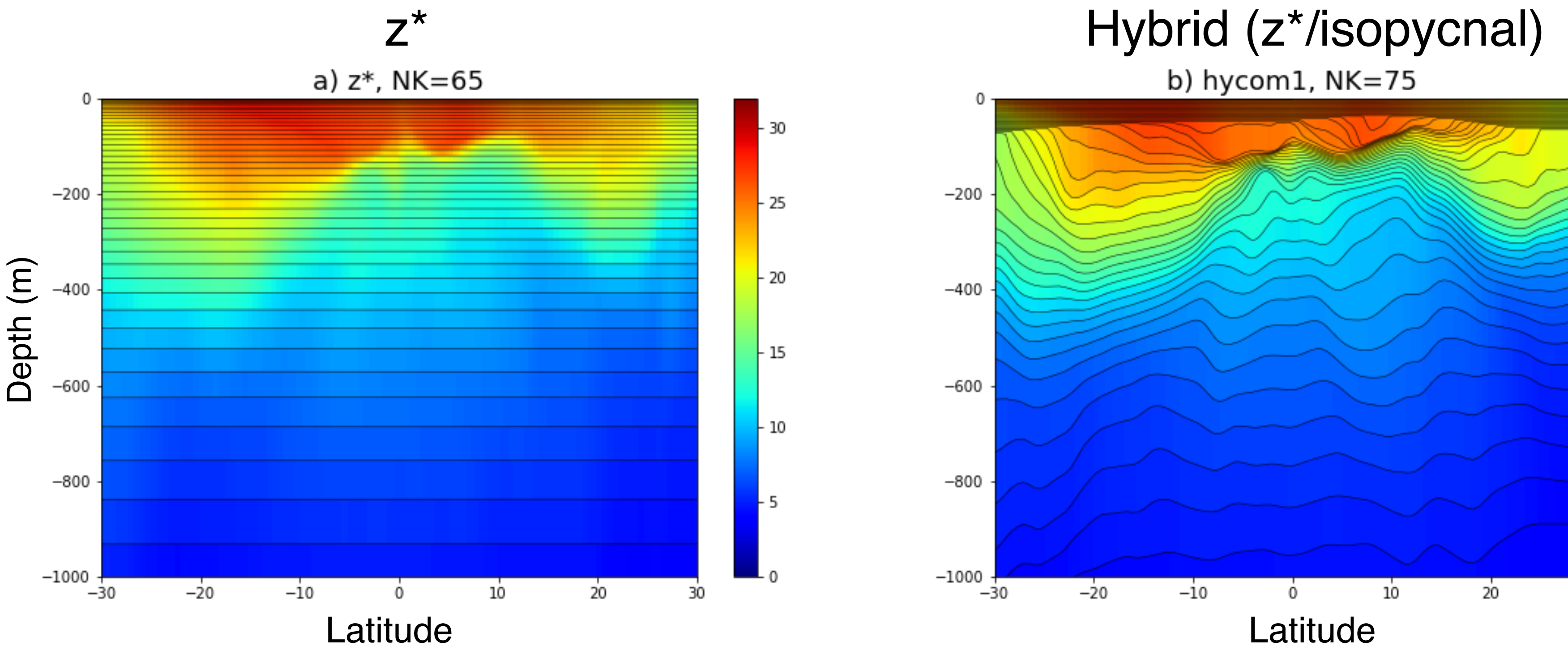
This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

CESM "workhorse" configurations

	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 vert. mode optimized, 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)
Advection	3rd order upwind	Horiz. PPM, Vert. ALE w/ 3rd order remapping
Other params	Overflow, estuary box model	**subgrid scale EOS correction**, **geothermal**, estuary box model

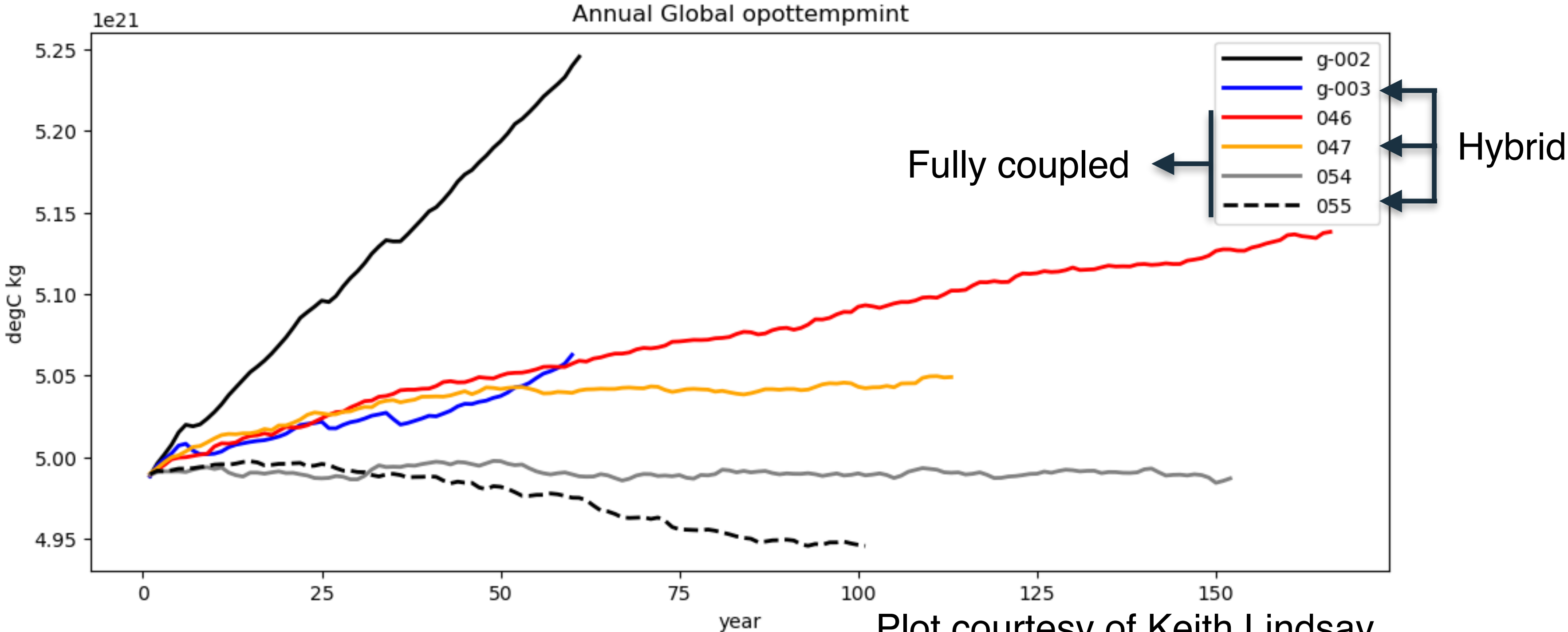
Vertical coordinates

Potential temperature transects across prime meridian:



Contours are layer interfaces and colors are potential temperature.

Global integrated temperature (forced and fully coupled)

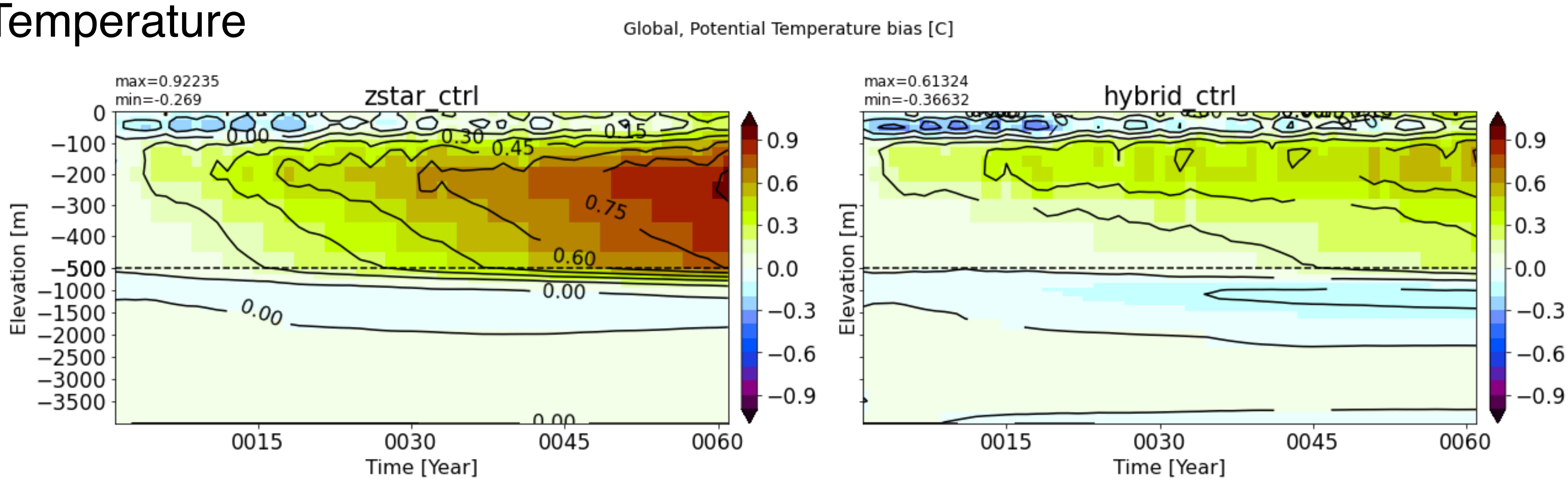


Plot courtesy of Keith Lindsay

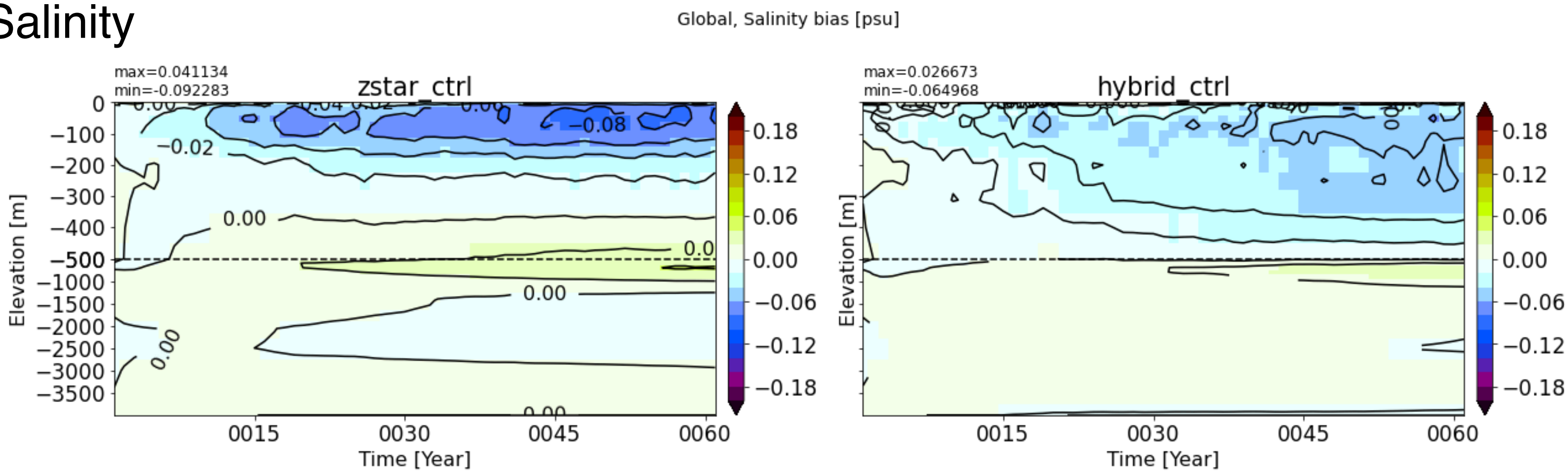
Hybrid cools relative to zstar (03/02, 47/46, 55/54). If we go with hybrid in CESM3, need to account for this in F compset RESTOM tuning.

Global T and S drifts (1 JRA cycle)

Temperature



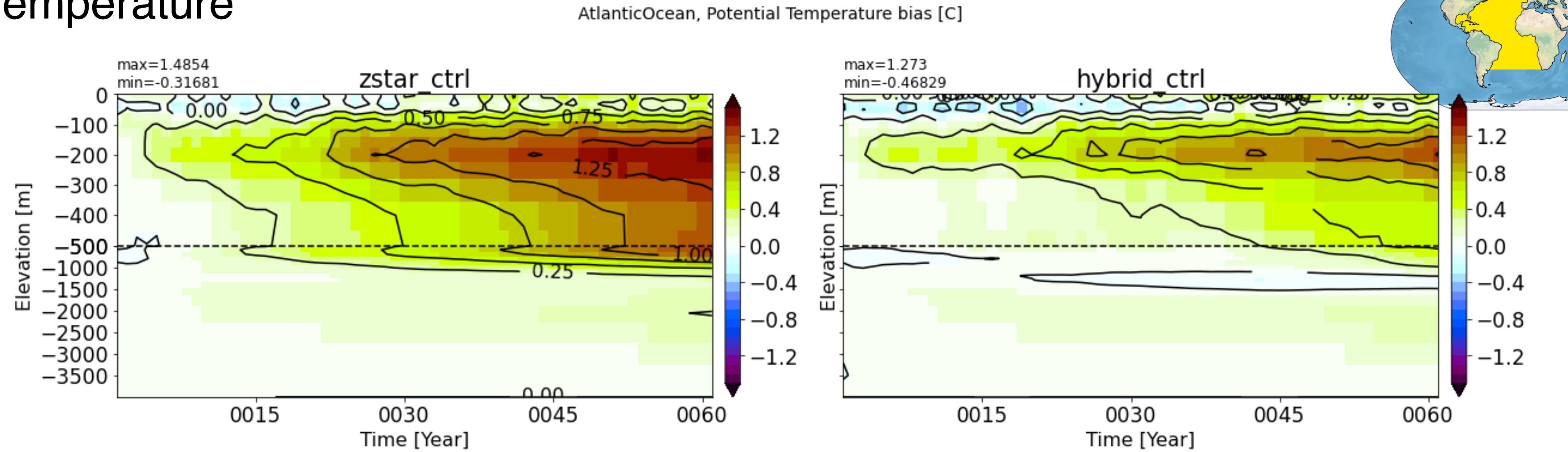
Salinity



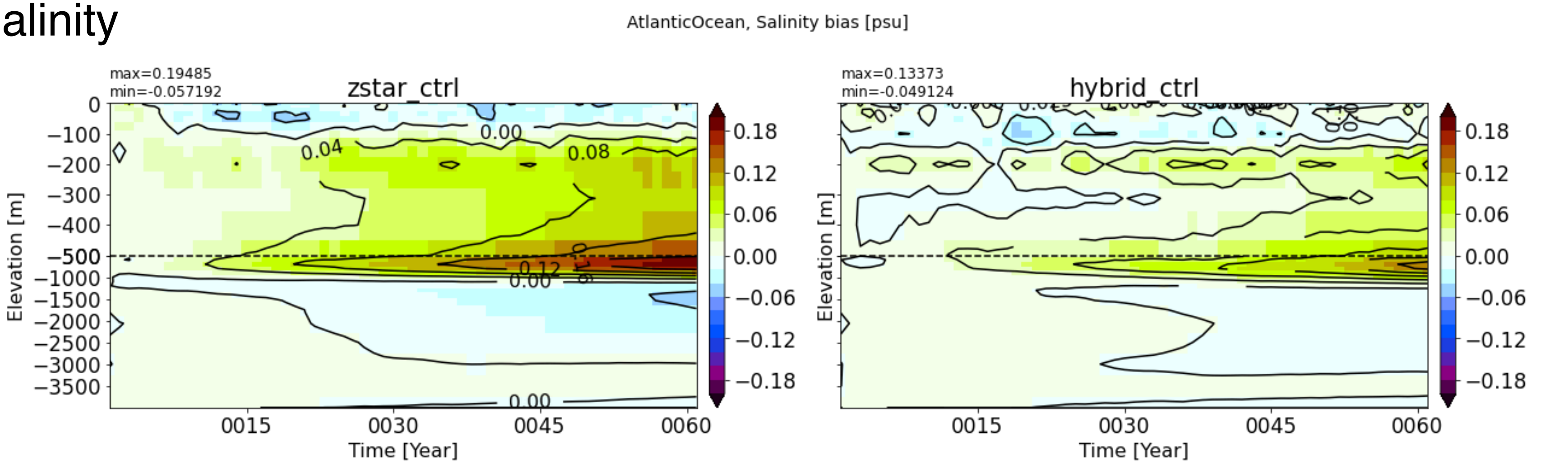
Zstar is warmer and fresher near the surface (above 500 m);
Hybrid is cooler and saltier at depth (below 500 m).

Atlantic T and S drifts

Temperature



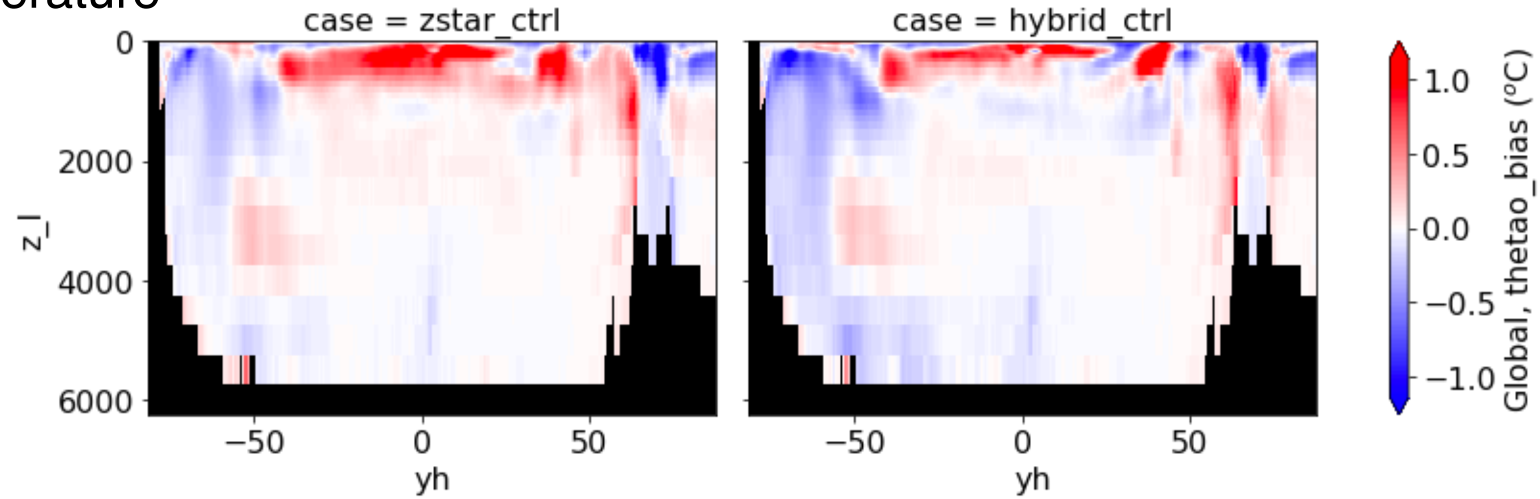
Salinity



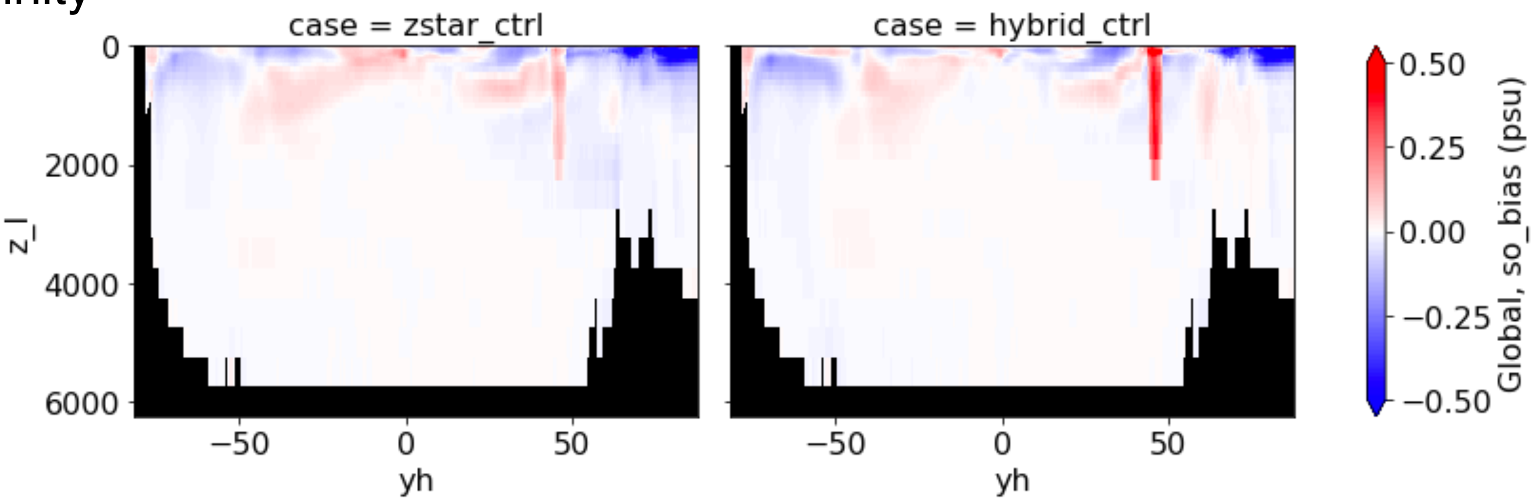
Zstar is warmer everywhere; bias due to Med Sea overflow worse in zstar.

Global zonally-average T and S biases (last 30 years)

Temperature



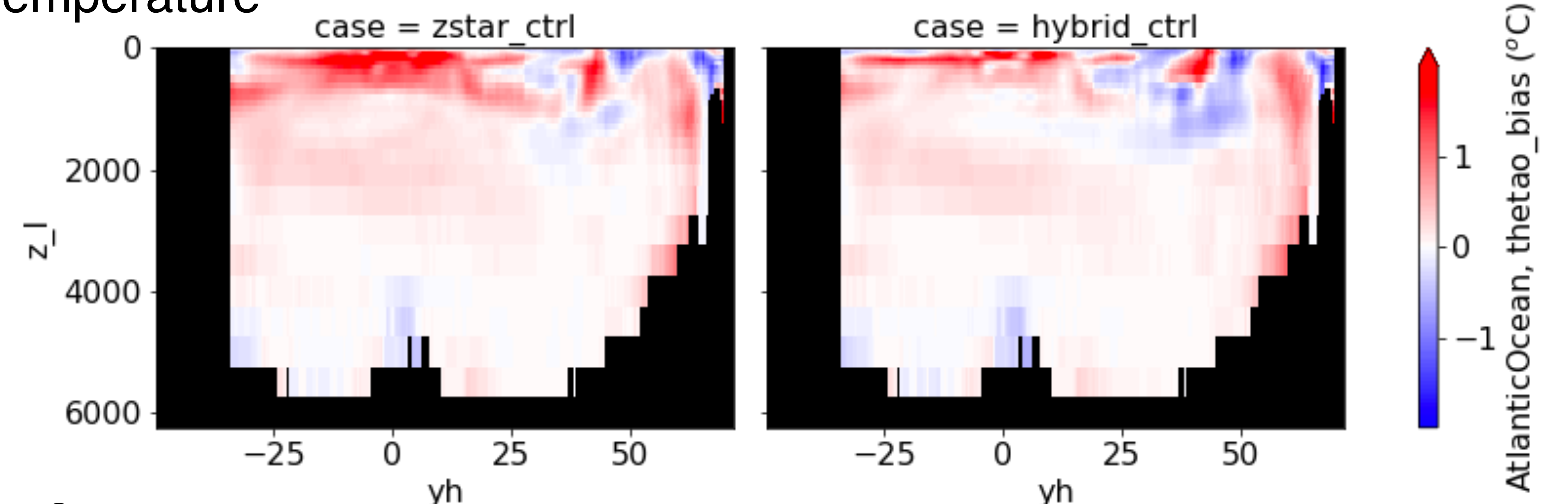
Salinity



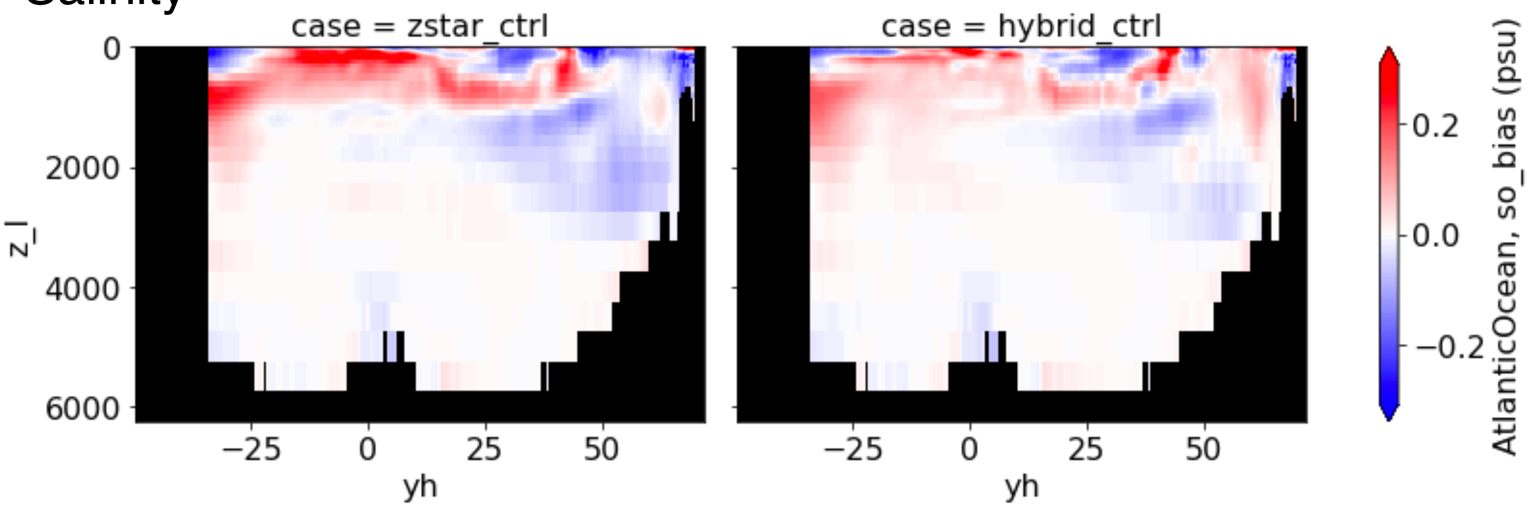
Zstar is warmer in the Equator; Hybrid is colder in the Southern Ocean. Larger salinity bias in the Black Sea in hybrid.

Atlantic zonally-average T and S biases (last 30 years)

Temperature



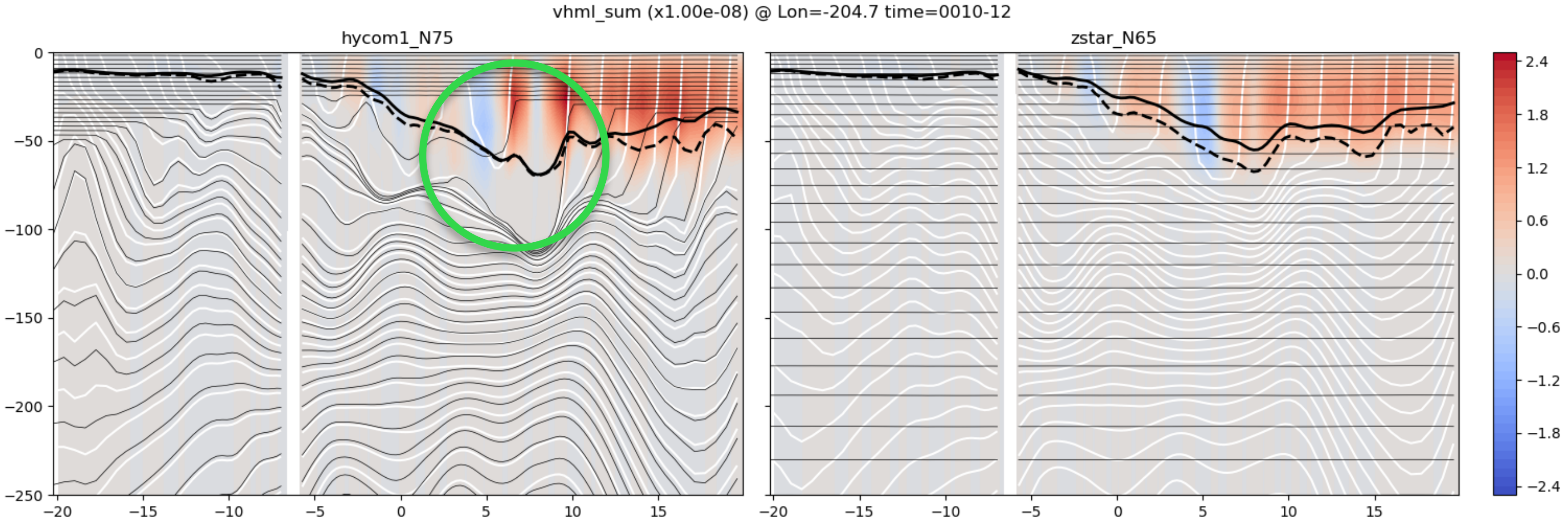
Salinity



Zstar is warmer and saltier in the Equator.

Loss of resolution in hybrid

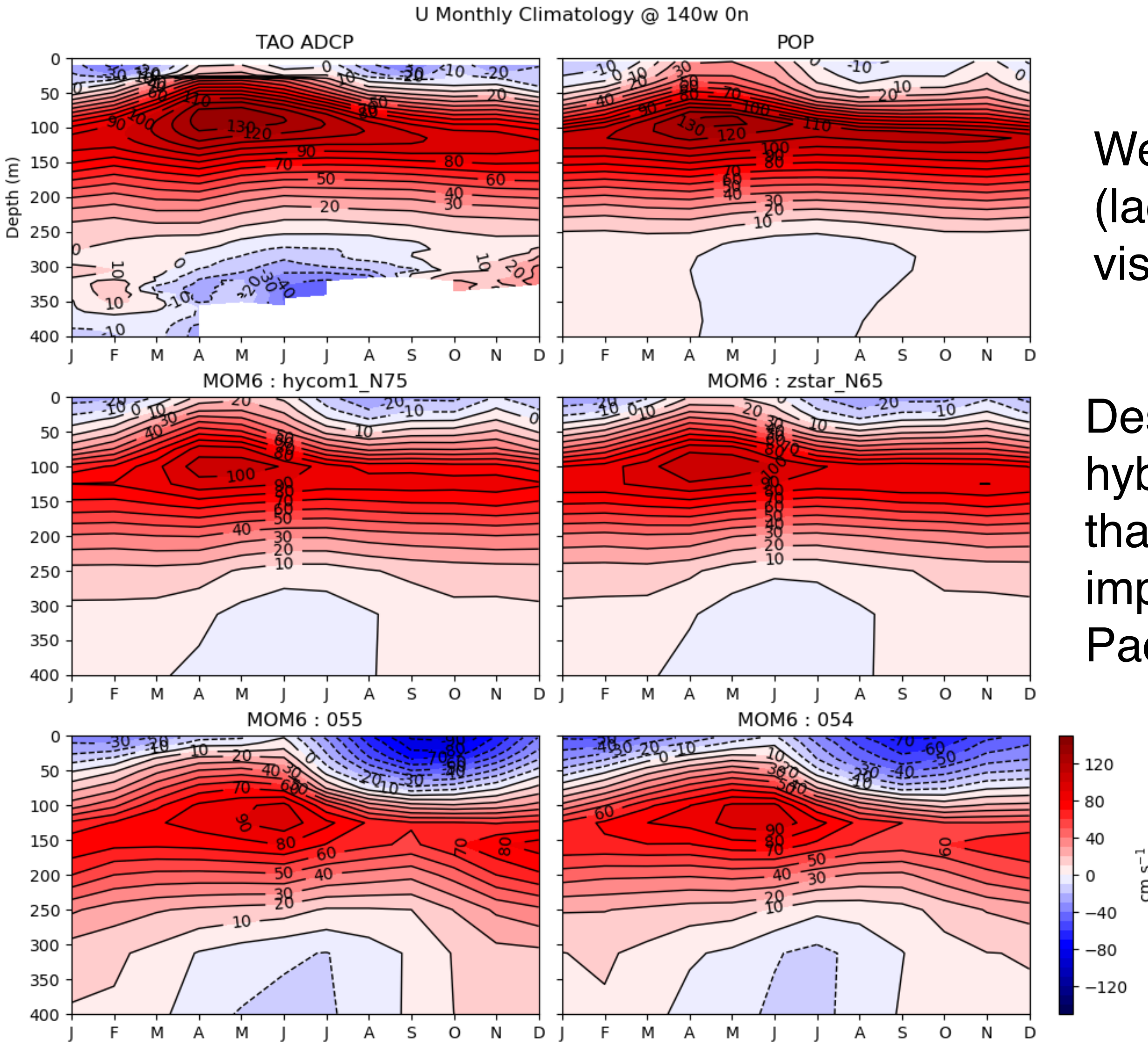
Example of where hybrid (hycom1) is not working properly.



Plot courtesy of Frank Bryan

It is interacting with the physics via MLE.

Equatorial under current



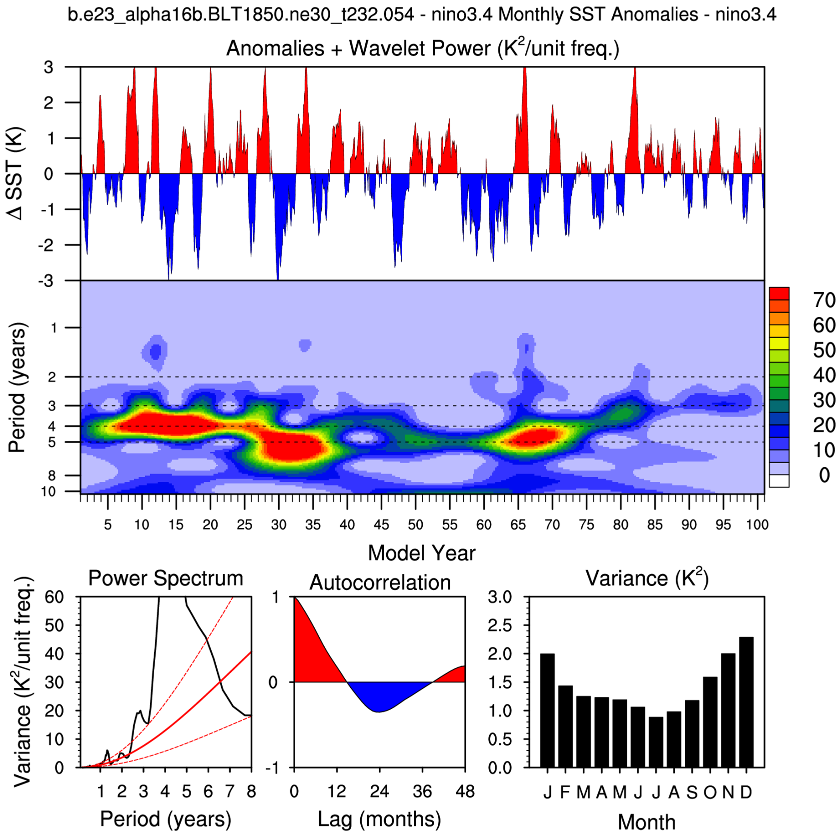
Weaker EUC in MOM6 (lack of anisotropic viscosity?);

Despite problems we see in hybrid layer thicknesses, that does not strongly impact EUC in central Pacific.

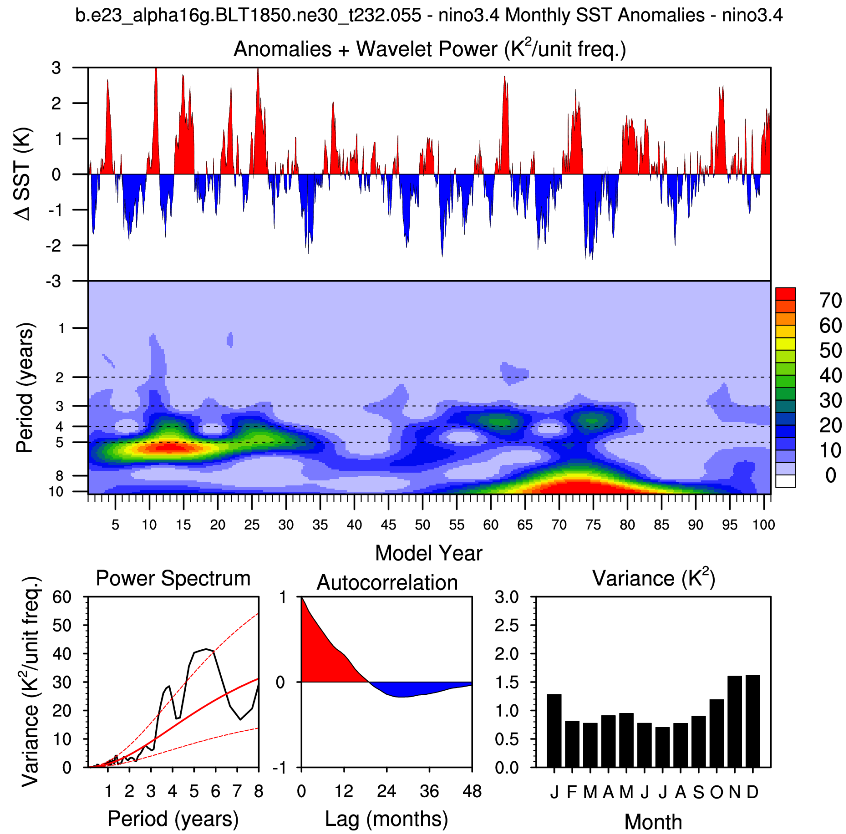
Plot courtesy of Frank Bryan

ENSO (nino3.4) in fully coupled cases (zstar vs hybrid)

zstar



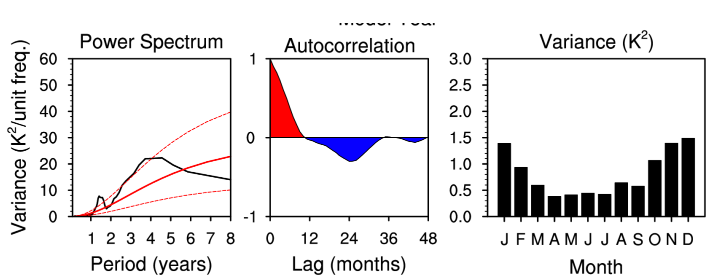
hybrid



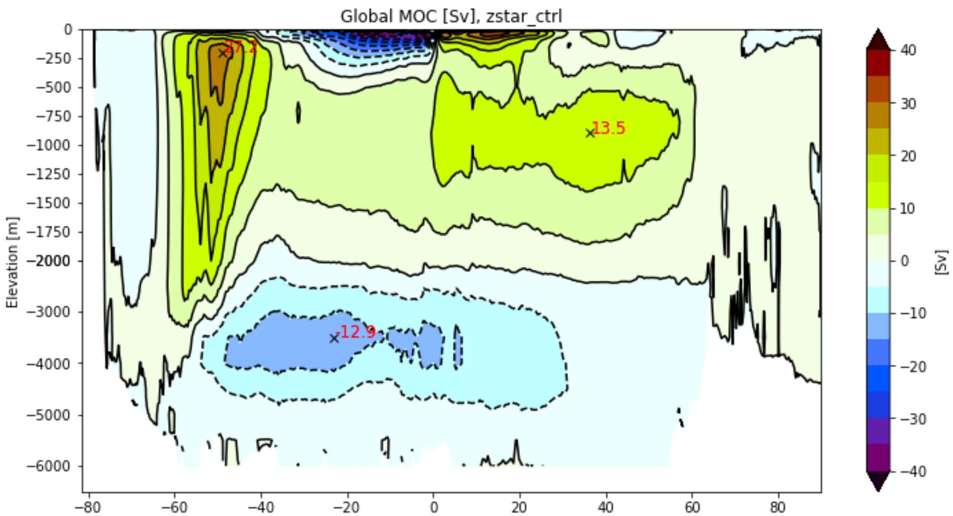
Plots courtesy of Rich Neale

HadISST

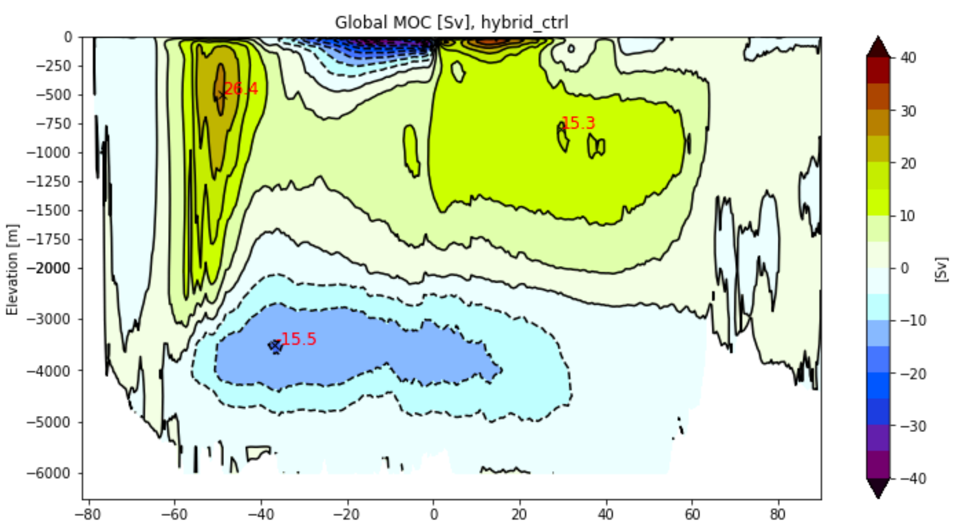
Hybrid looks good!



Global meridional overturning circulation [Sv]

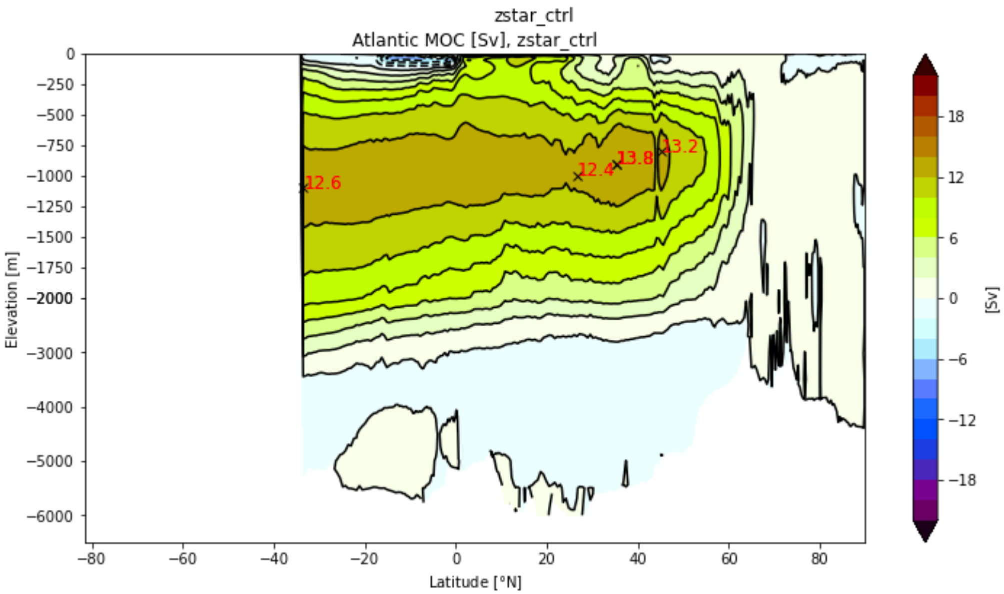


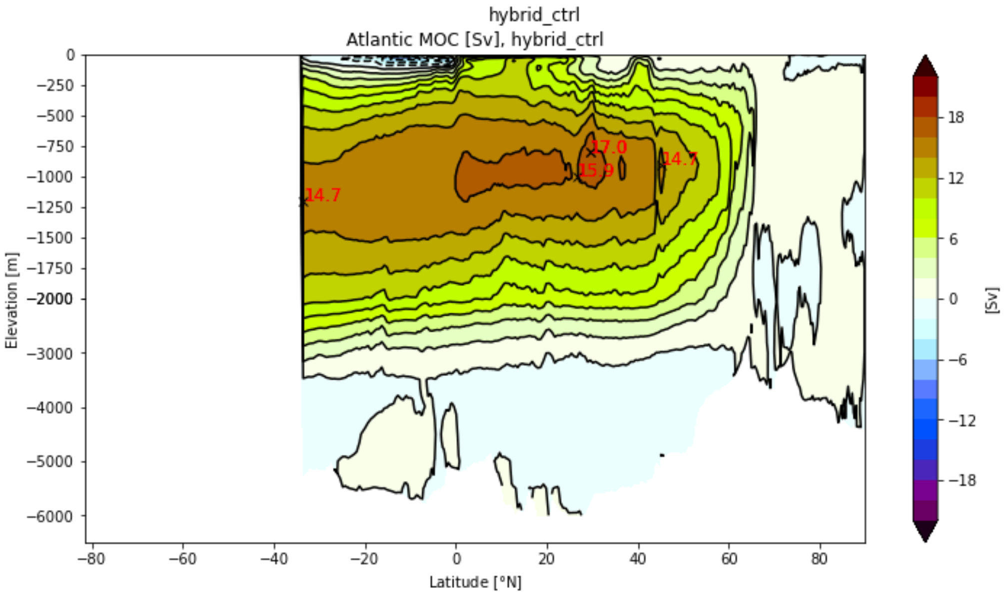
Average over last 30 years



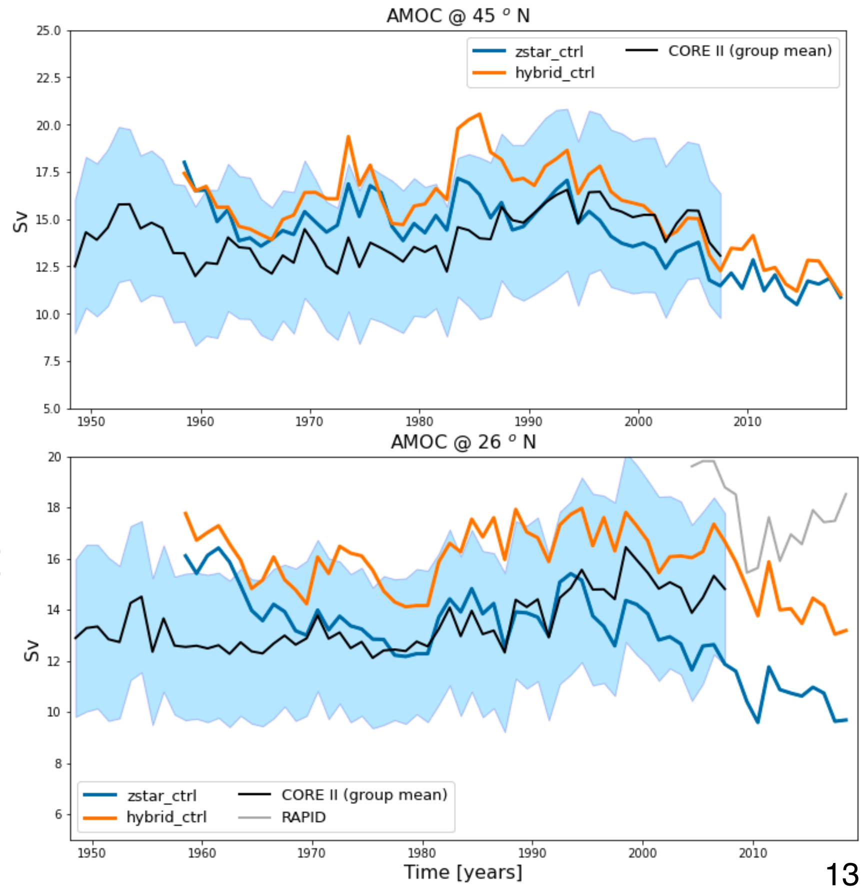
Overall similar MOC structure in zstar and hybrid. Stronger circulation in hybrid.

Atlantic meridional overtuning circulation [Sv]

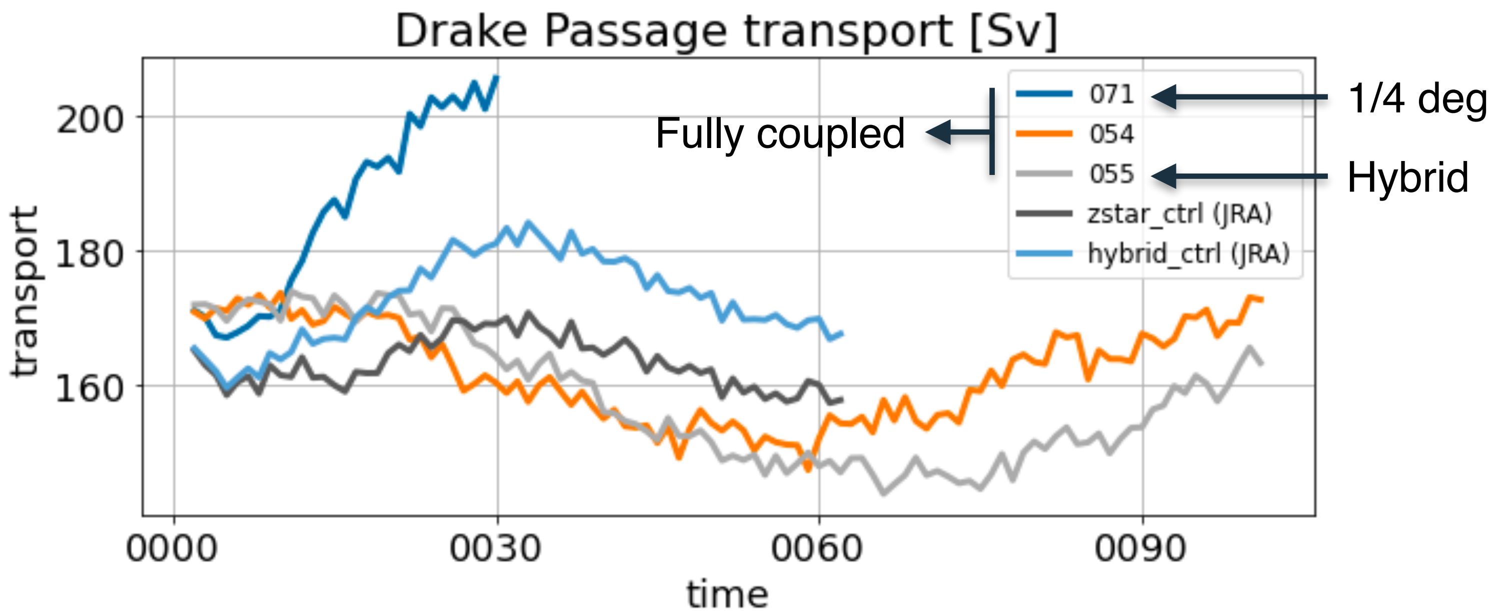




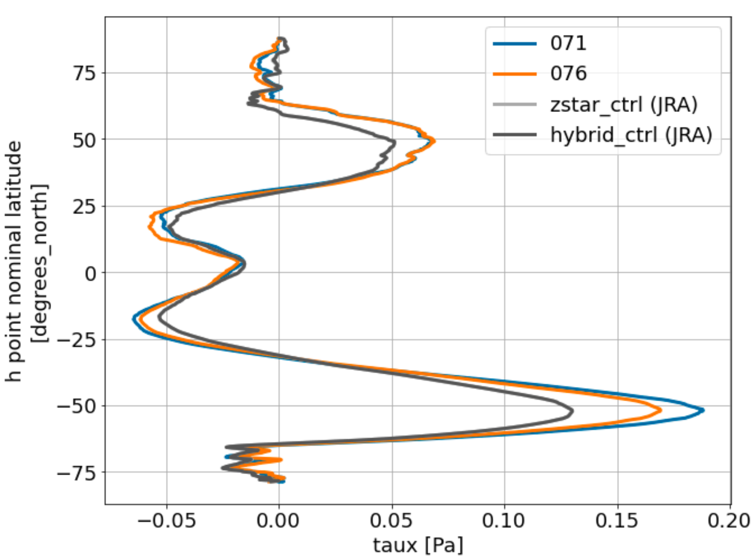
AMOC stronger in hybrid



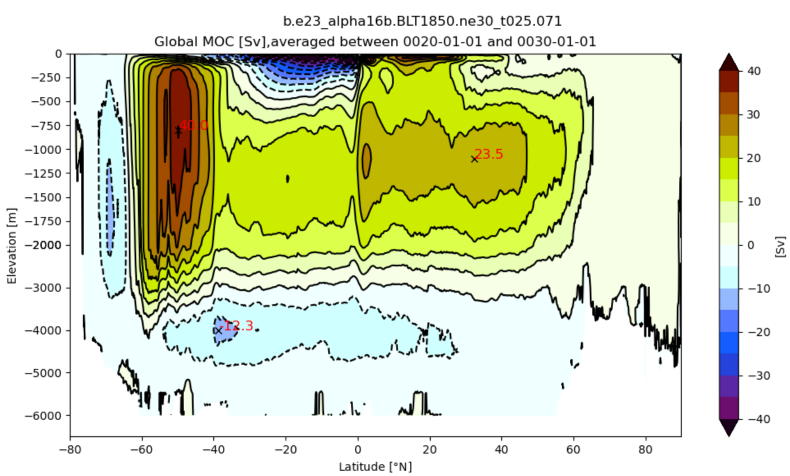
Drake Passage transport



Zonal average taux



Deacon cell is too strong in 1/4 deg fully coupled



Preliminary evaluation of length scale scheme from Bodner et al

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

ABIGAIL S. BODNER,[a] BAYLOR FOX-KEMPER,[a] LEAH JOHNSON,[b] LUKE P. VAN ROEKEL,[c] JAMES C. MCWILLIAMS,[d] PETER P. SULLIVAN,[e] PAUL S. HALL,[a] AND JIHAI DONG[f,g]

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

- 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

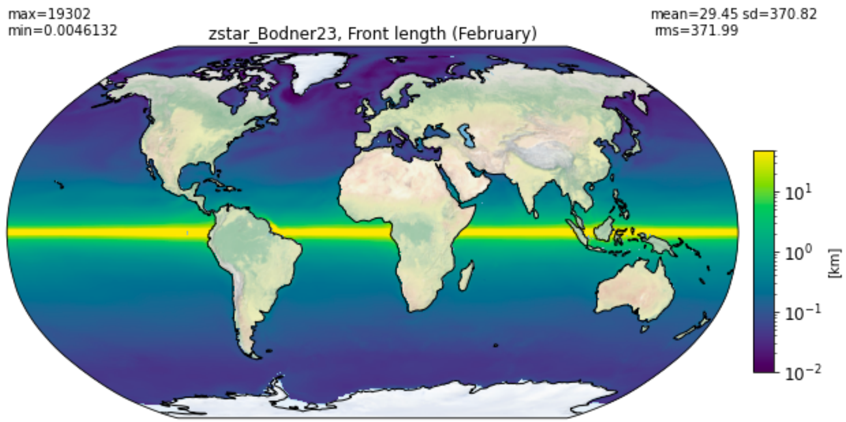
We have been using L_f = 1 km in CESM/MOM6

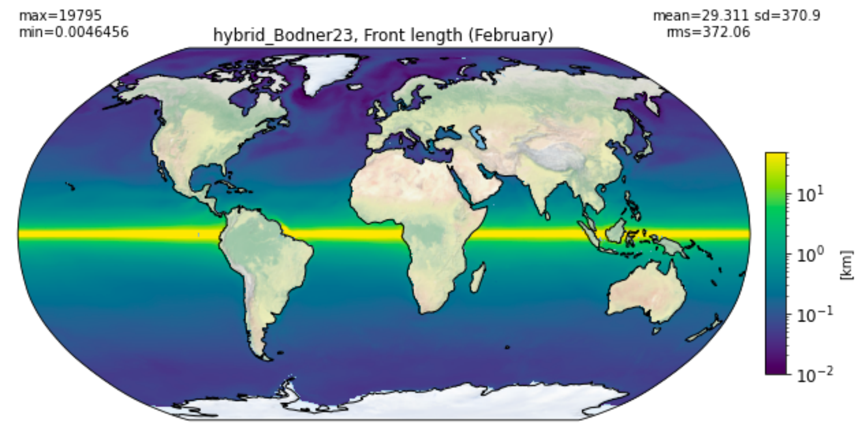
Streamfunction implemented in GCMs:

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

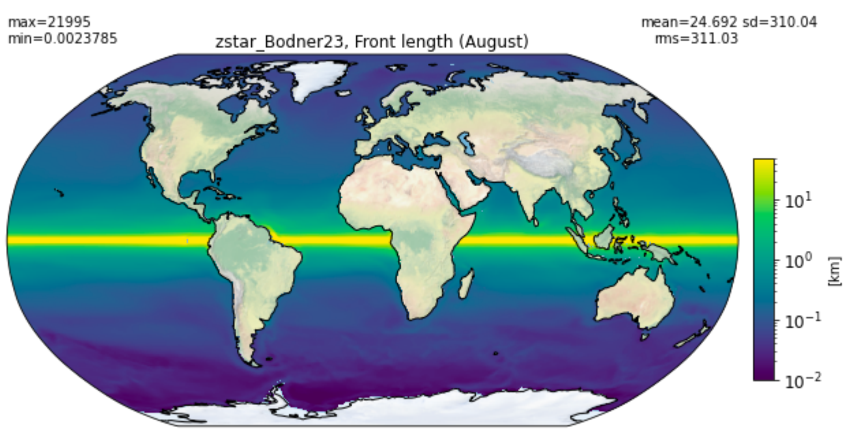
Global maps of L_f

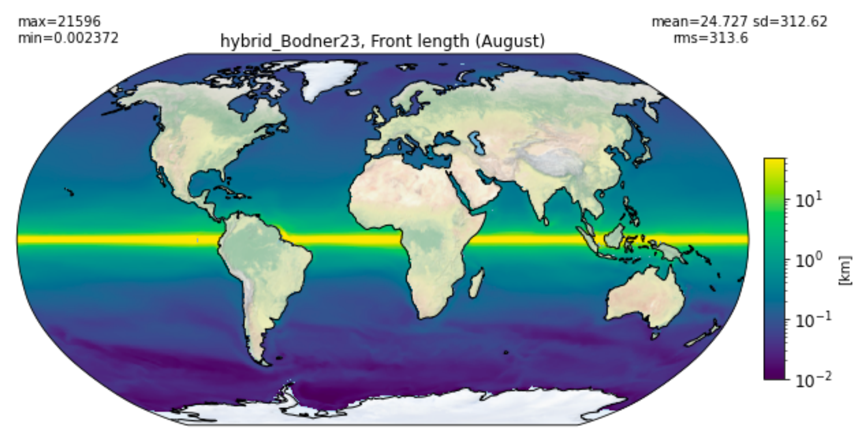
February





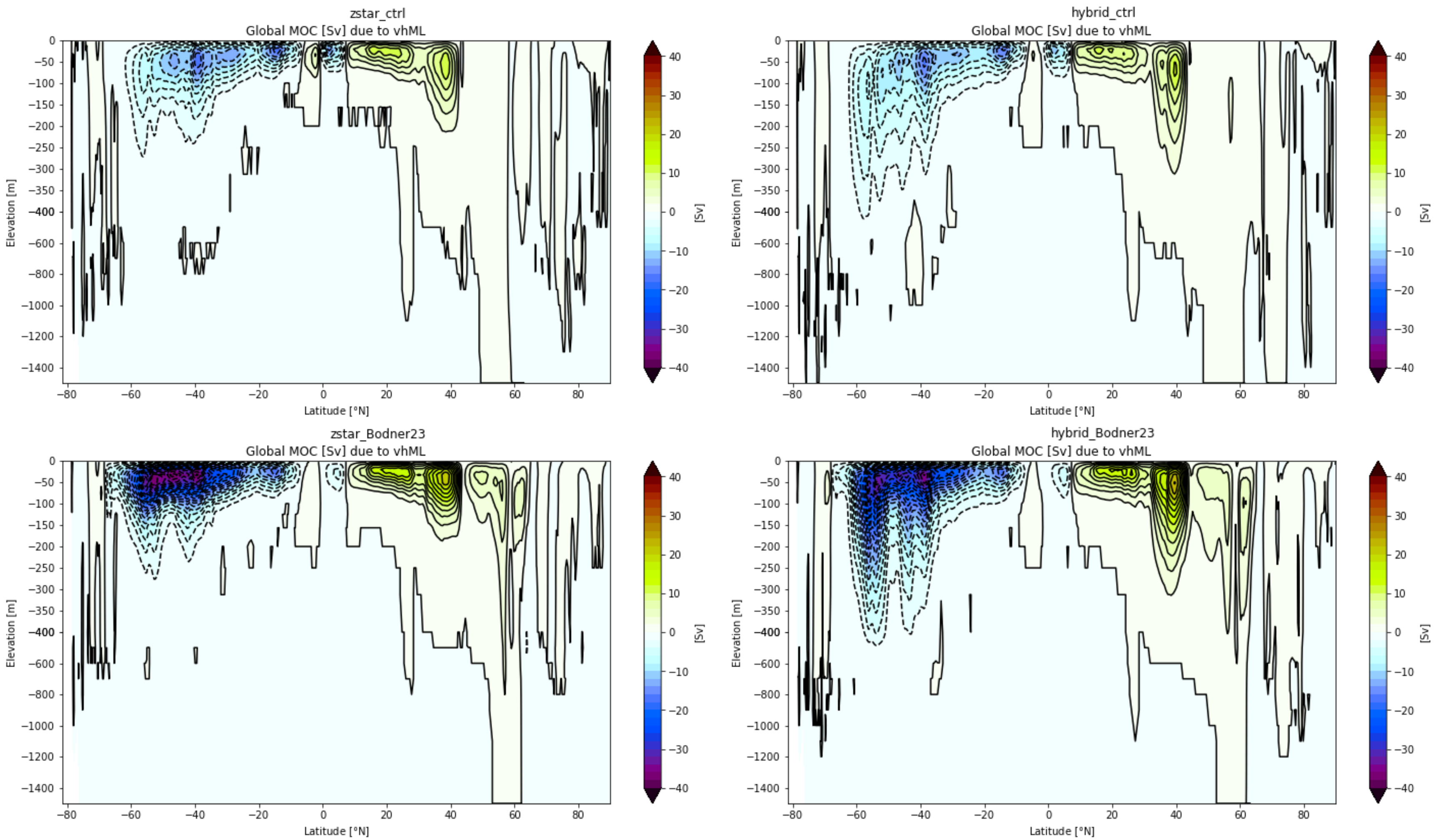
August





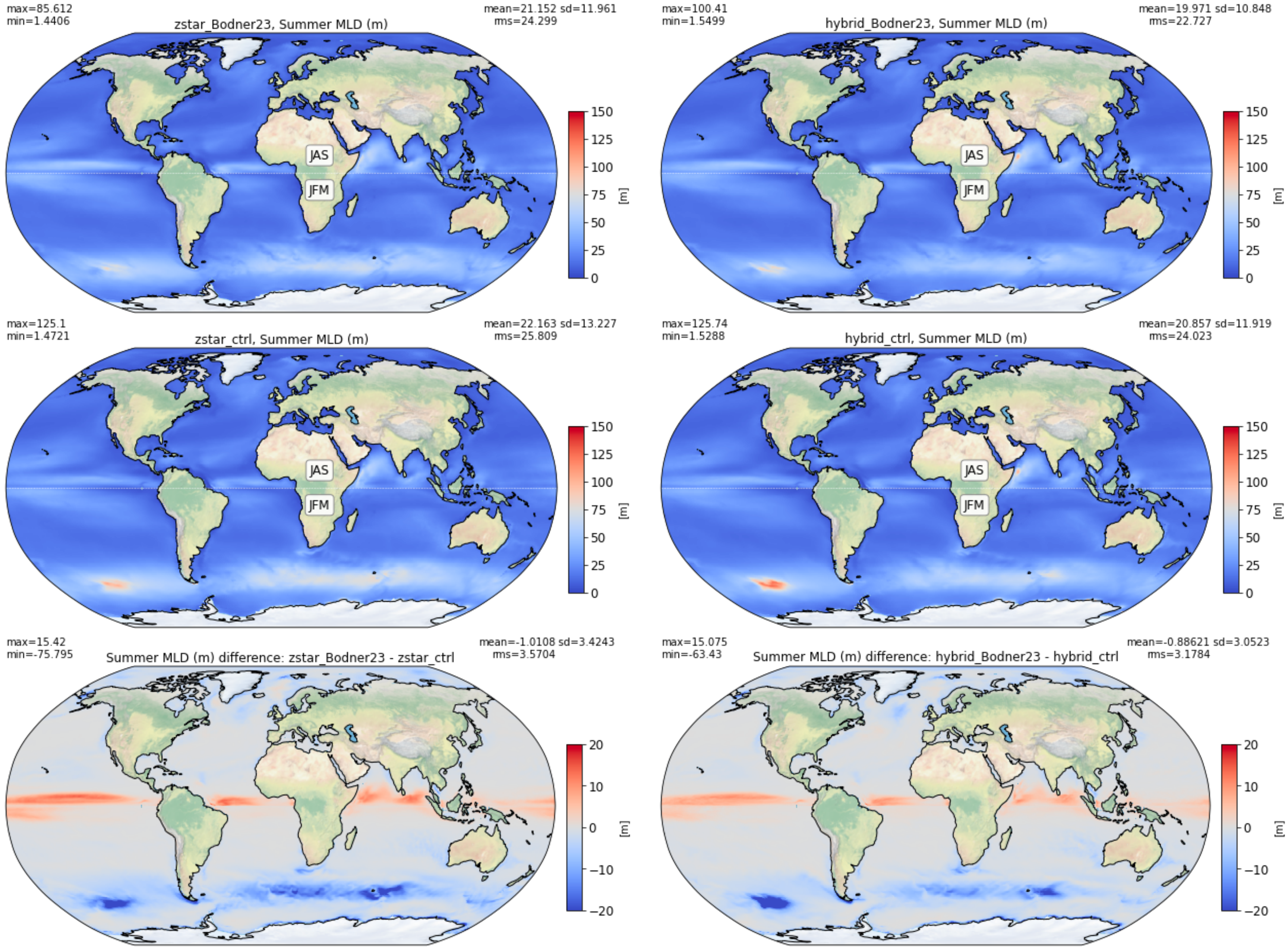
Similar length scales in zstar and hybrid

Global MOC induced by MLE: Bodner vs control

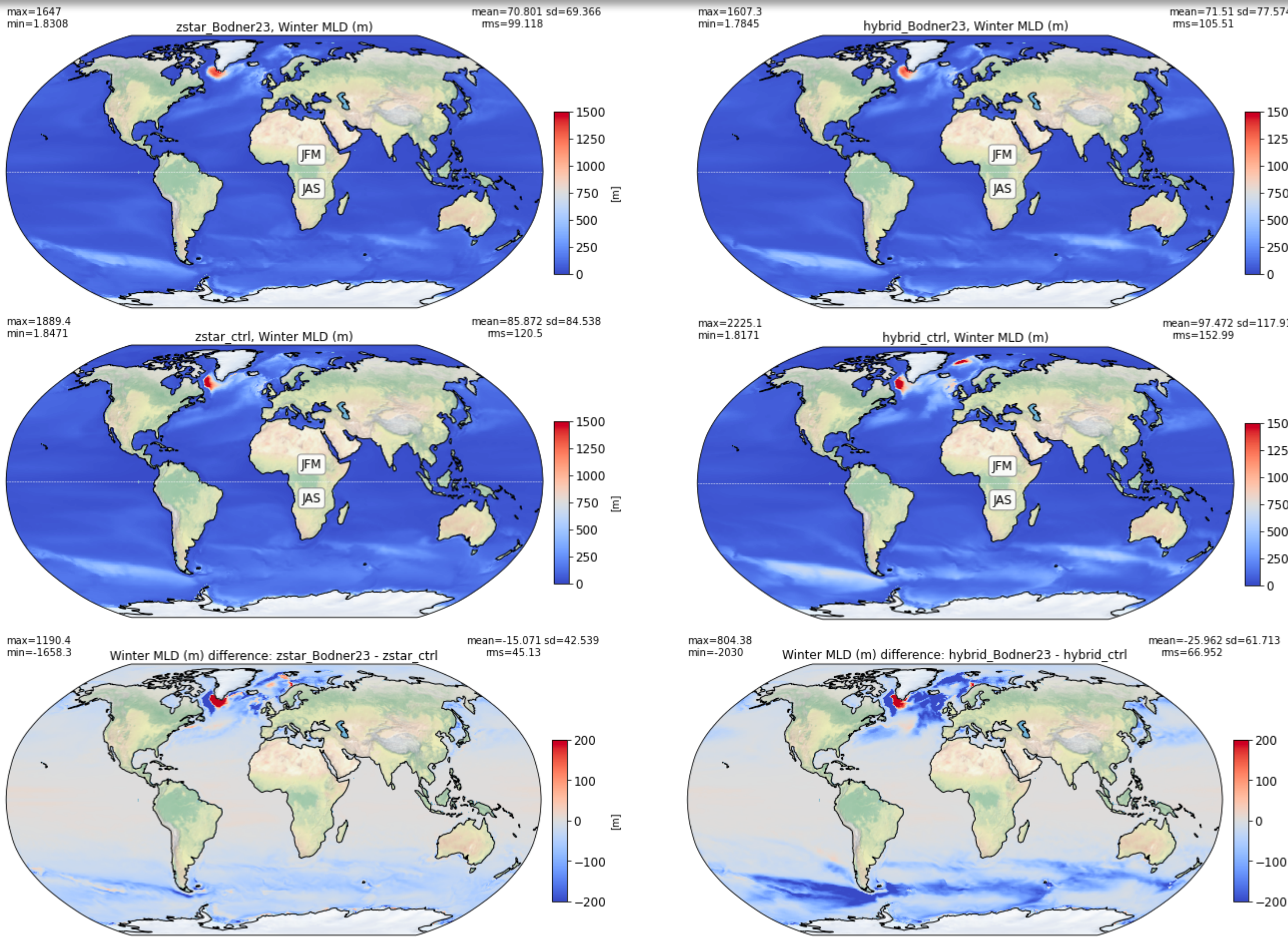


Significantly stronger circulation with the Bodner scheme, as expected.

Summer mixed layer depth (m): Bodner vs control

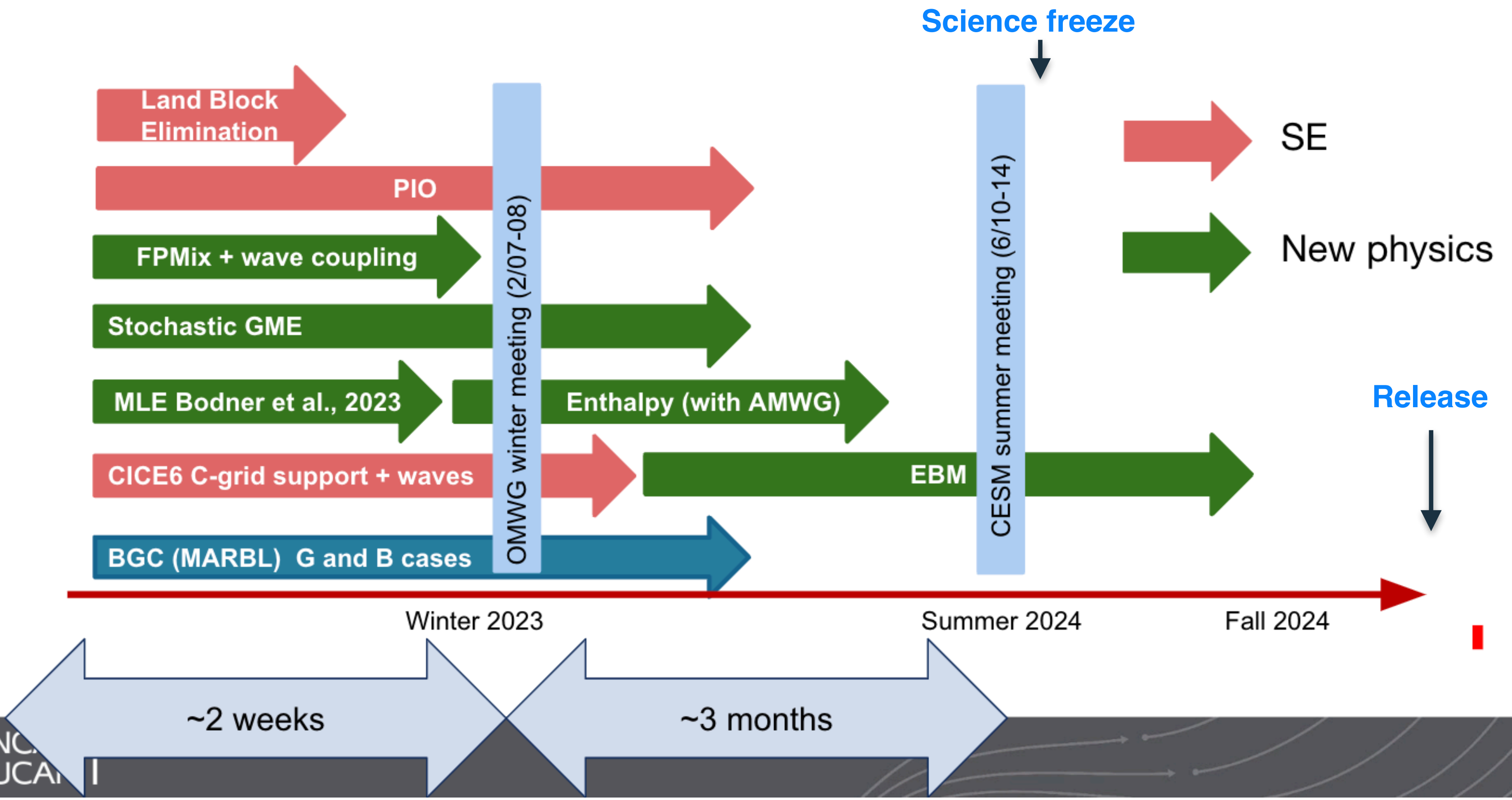


Winter mixed layer depth (m): Bodner vs control

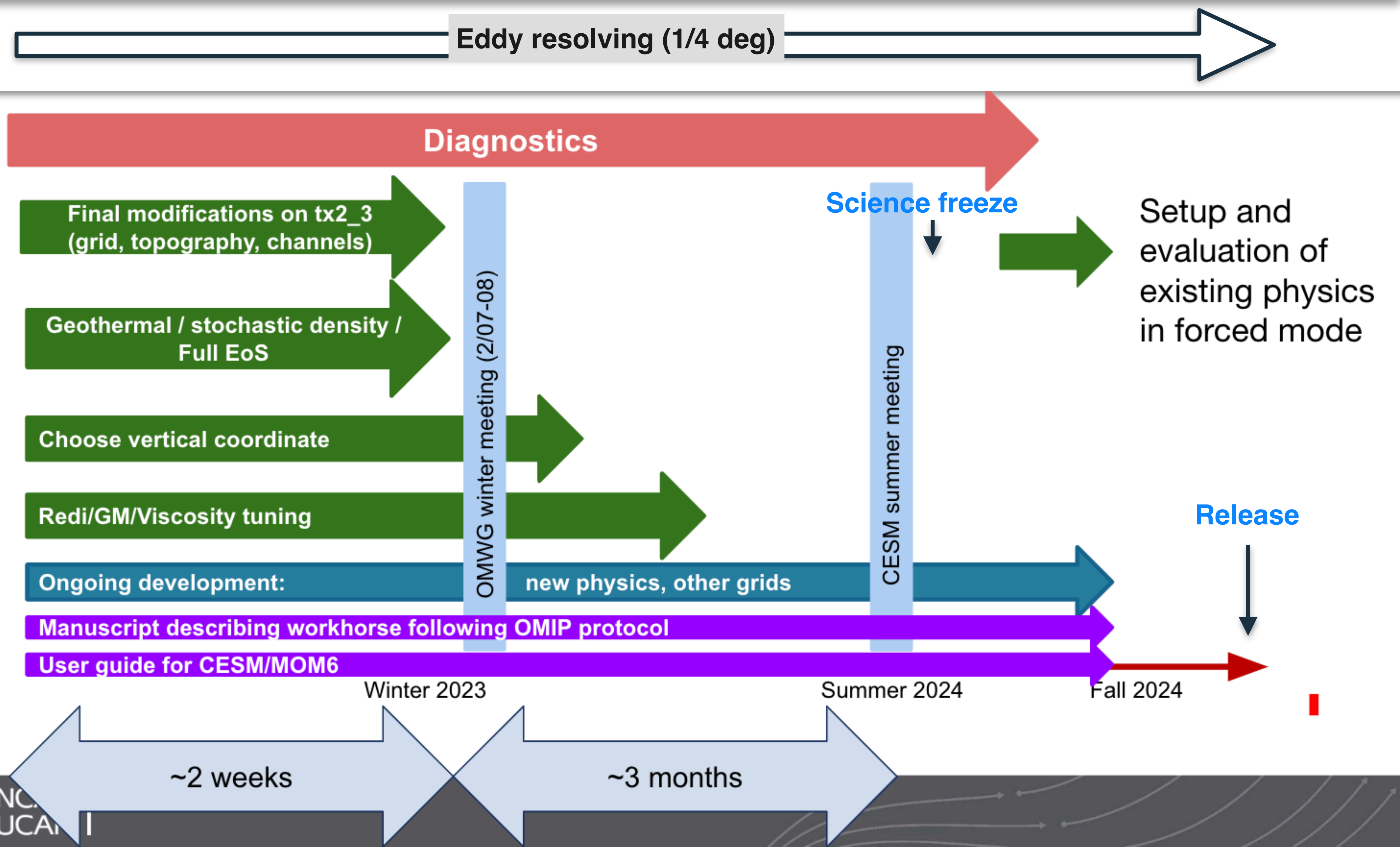


Towards CESM/MOM6 code base

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



Save the date

Ocean Model Development Panel &

COMMODORE

workshop

Community for the numerical modeling of the global, regional and coastal ocean

+ celebration of Frank's achievements!

CLIVAR

September 9-13, 2024 **Boulder, CO USA**

Ocean model development, data-driven parameterization, and machine learning in numerical ocean circulation and climate models.

Thank you!

Pros and cons of zstar and hybrid

zstar

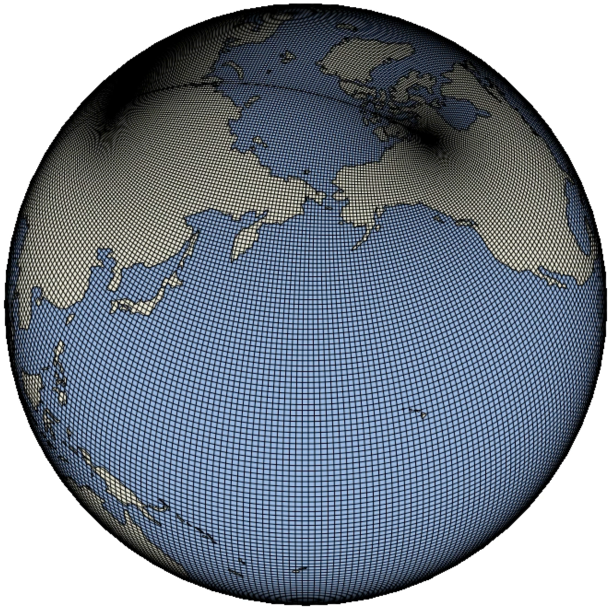
Pros	Cons
• Easier to work with native grid	• Stronger global heat uptake • Worse Med Sea overflow

hybrid (hycom1)

Pros	Cons
• Mitigate thermocline warm bias • Good ENSO • Better overflows? • Stronger AMOC	• Loss of upper-ocean resolution

CESM/MOM6 global 1/4° configuration

https://github.com/NCAR/tx1_4



- Ocean (MOM6) and sea ice (CICE6) components;
- Nominal 1/4° horizontal resolution in a tripolar grid. Grid built using modified ORCA grid generation;
- Bathymetry and land/sea mask are derived from the Shuttle Radar Topography Mission (SRTM) dataset;
- Vertical grid is z* with 65 layers;
- NCAR vertical physics package via CVmix;
- Mixed-layer eddies parameterization (Fox-Kemper et al., 2011);
- Control has no mesoscale parameterizations (like OM4_025, Adcroft et al., 2019). Biharmonic dissipation is the **maximum** of i) dynamic (Griffies & Hallberg, 2000) $C_s \Delta^4 \sqrt{D_t^2 + D_s^2}$ ($C_s = 0.06$) and ii) static $u_4 \Delta^3$ ($u_4 = 0.01$ m/s) contributions;

Implementing MEKE/GEOMETRIC in MOM6

Led by Scott Bachman (new CPT, Energetics and mesoscale parameterization)

Mesoscale eddy kinetic energy (MEKE) (Jensen et al., 2015):

MEKE — **SOURCE** — **SINK** — **SMOOTHING**

$$\partial_t E = \dot{E}_{bg} + \underbrace{\gamma_{GM}\dot{E}_{GM}}_{\text{Energy transferred from GM}} + \gamma_\nu \dot{E}_\nu \rightarrow 0 - \left(\underbrace{2\frac{C_d}{H}|U_b|E_b}_{\text{Energy lost to bottom drag}}\right) + \underbrace{\mathcal{D}_E}_{\text{Diffusion}} \quad (1)$$

GEOMETRIC (Marshall et al., 2012) →

$$\kappa_{GM} = \alpha E \frac{N}{|\nabla b|} \quad (2)$$

MEKE EQUILIBRIUM →

$$E_{eq} = \alpha \frac{H^2}{C_D}\frac{|\nabla b|^2}{N^2} \quad (3)$$

Energy transferred from GM ≈ Energy lost to bottom drag

MEKE FINAL

$$\partial_t E = \dot{E}_{bg} + \gamma_{GM}\dot{E}_{GM} + \gamma_\nu \dot{E}_\nu - \left(2\frac{C_d}{H}|U_b|E_b\right) + \mathcal{D}_E - \lambda(E - E_{eq}) \quad (4)$$

Time-scale ↑ (λ)