Status of the ocean component in CESM3

Gustavo Marques
gmarques@ucar.edu

In collaboration with: Alper Altuntas, Frank Bryan, Frederic Castruccio, Gokhan Danabasoglu, Ian Grooms, Kristen Krumhardt, William Large, Micheal Levy, Keith Lindsay, Manish Venumuddula

CESM OMWG, February 28, 2025

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 hycom1* (z/isopyc), 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 + Langmuir + Flux Profile Mixing* + Stokes Similarity package*
GM+Redi	Marshall N^2 scaling	MEKE+GEOMETRIC scaling + EBT vertical structure
Mixed Layer Eddies	Fox-Kemper et al. (2008, 2011), L_f = 5 km	Fox-Kemper et al. (2008, 2011), L_f = 1 km + Bodner et al. (2023)**
H. Viscosity	Anisotropic Laplacian	Isotropic Laplacian + Biharmonic, via MEKE + LEITHY + backscatter**
Solar penetration	Ohlmann (2003)	Manizza (2005), Ohlmann (2003)*
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***

* new defaults

** inclusion is TBD

*** won’t be ready for CESM3

🟩 discussed today

Mixed layer eddy (MLE) parameterizations

Streamfunction implemented in GCMs (FFH, Fox-Kemper et al., 2008, 2011):

- C_e nondim 0.06-0.08
- L_f frontal length scale
- H mixed layer depth
- b buoyancy
- f Coriolis parameter
- Δs grid scale
- τ mixing time scale
- $\mu(z)$ vertical structure function

$$\Psi = C_e \frac{\Delta s\, H^2 \nabla_H \bar{b}^z \times \mathbf{z}}{L_f \sqrt{f^2 + \tau^{-2}}} \mu(z) \qquad (1)$$

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

Bodner et al. (2023) modified (1) to include frontogenesis arrest by boundary layer turbulence:

Scaling for frontal length

- $C_L \sim$ O(Ri)
- u_* frictional velocity
- h boundary layer depth
- w_* turbulent convective velocity
- m_* nondim 0.5
- n_* nondim 0.066

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

(1) becomes:

- $C_r = C_e / C_L$ tunable parameter

$$\Psi = C_r \frac{\Delta s\, |f|\, h\, H^2 \nabla_H \bar{b}^z \times \mathbf{z}}{\left(m_* u_*^3 + n_* w_*^3\right)^{2/3}} \mu(z) \qquad (3)$$

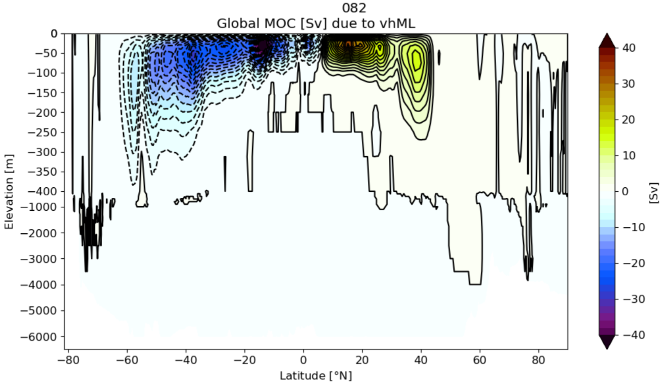
Global meridional overturning: FFH vs Bodner

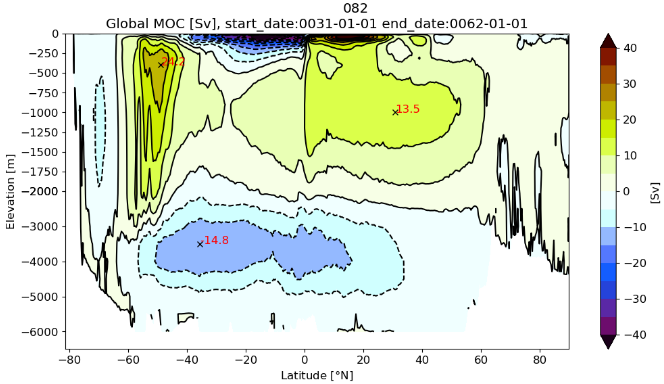
Induced by MLE | **Residual**

FFH

$L_f = 1$ km

👍

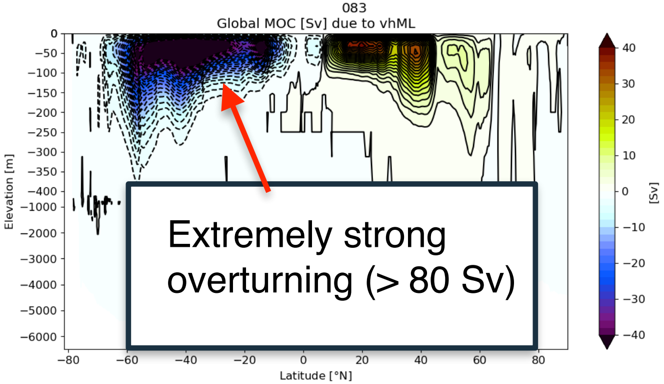




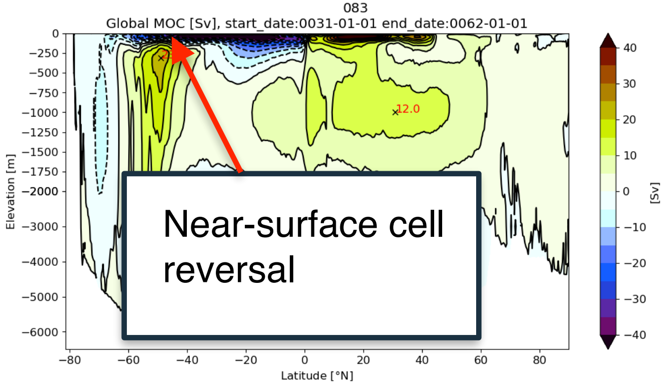
Bodner

$C_r = 0.03$

👎



Extremely strong overturning (> 80 Sv)

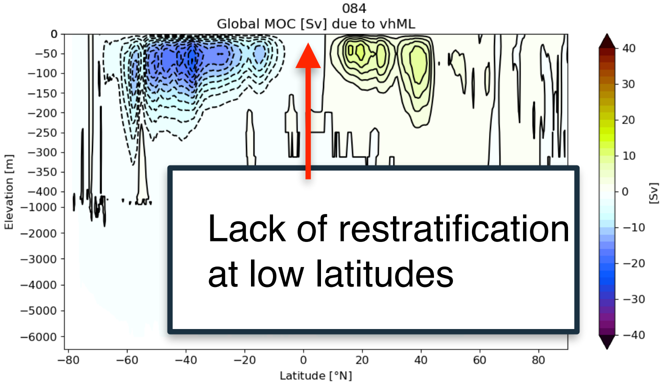


Near-surface cell reversal

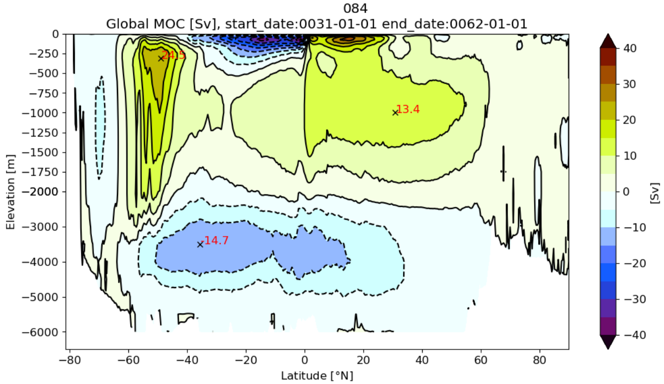
Bodner

$C_r = 0.003$

👎 👍



Lack of restratification at low latitudes

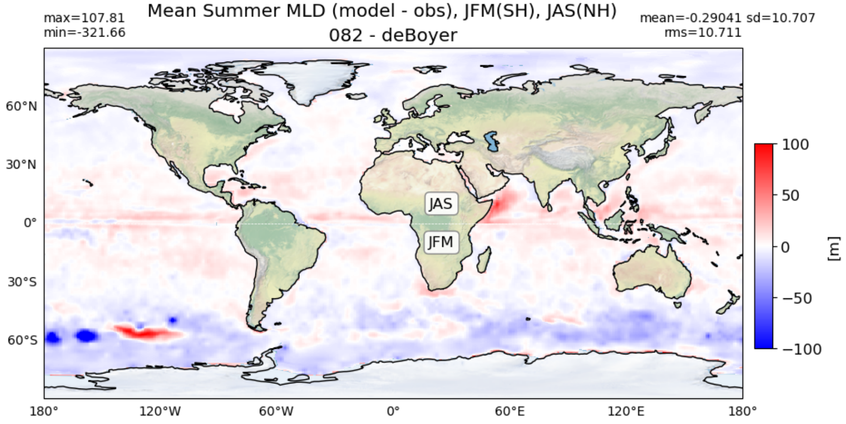


Summer mixed layer depth (m): Bodner vs control

Model - obs

FFH

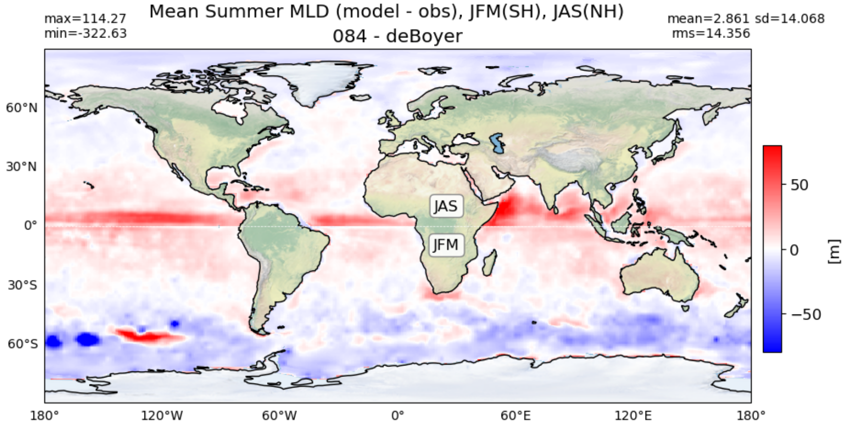
$L_f = 1$ km



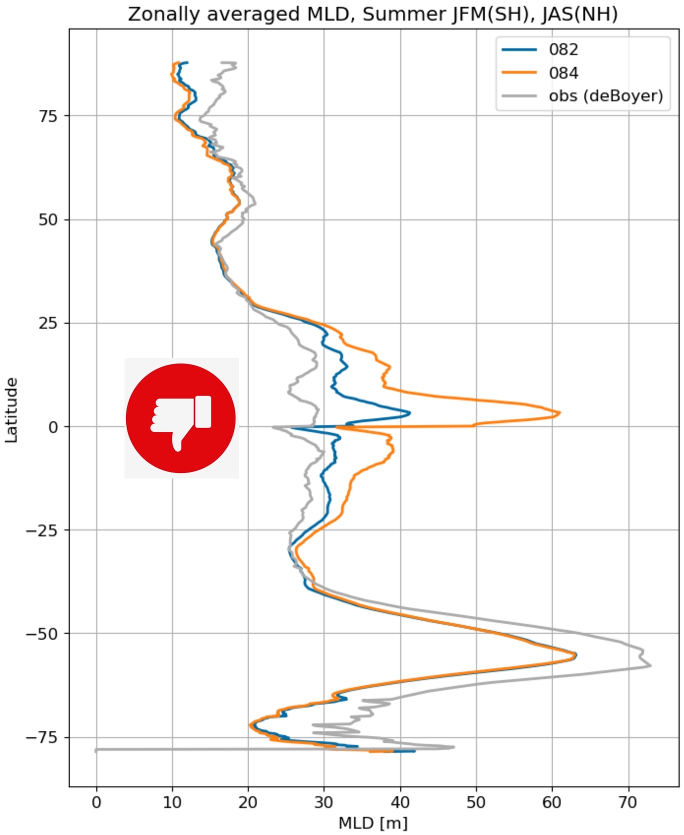
Mean Summer MLD (model - obs), JFM(SH), JAS(NH)
082 - deBoyer

Bodner

$C_r = 0.003$



Mean Summer MLD (model - obs), JFM(SH), JAS(NH)
084 - deBoyer

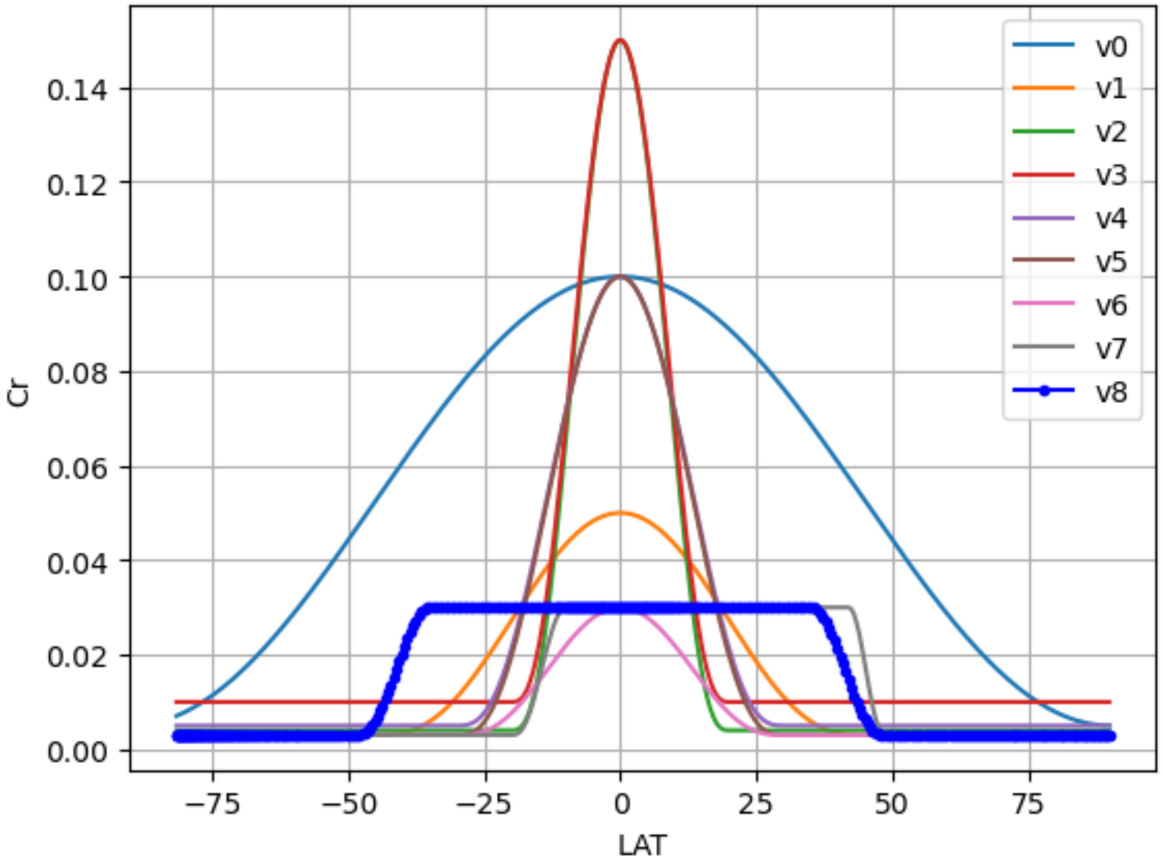


Zonally averaged MLD, Summer JFM(SH), JAS(NH)

Weak restratification leads to excessive summer MLD deepening at low latitudes.

Latitudinal dependency in Cr

$$\Psi = \boxed{C_r(lat)} \frac{\Delta s\,|f|\,h\,H^2\,\nabla_H \overline{b}^z \times \mathbf{z}}{\left(m_* u_*^3 + n_* w_*^3\right)^{2/3}}\,\mu(z) \qquad (4)$$



Profiles we have tried so far.

We are pretty happy with V8.

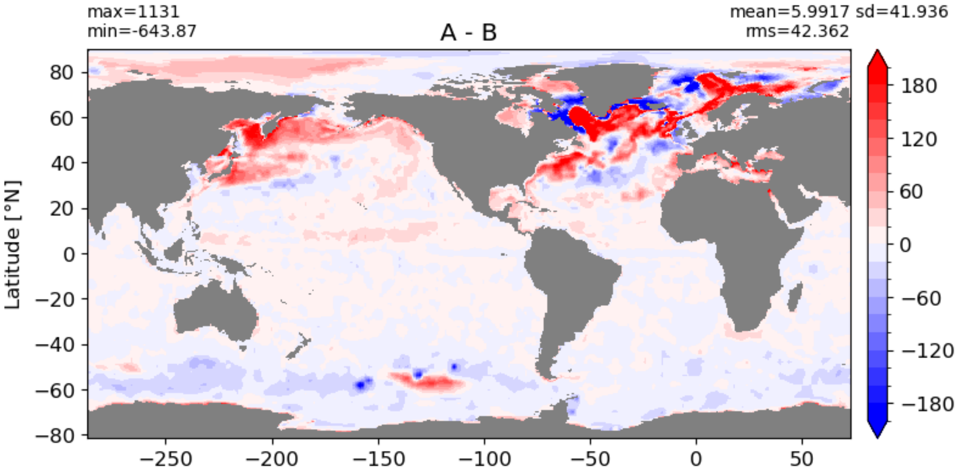
$$Cr(\text{lat}) = Cr_{\text{MIN}} + (Cr_{\text{MAX}} - Cr_{\text{MIN}})\left[1 - x^2\right]^p, \quad \text{where} \quad x = \min\left(\frac{|\text{Lat}|}{\text{Lat}_0}, 1\right)$$

March mixed layer depth (m): Bodner + Cr(lat) V8 vs control

Model - obs

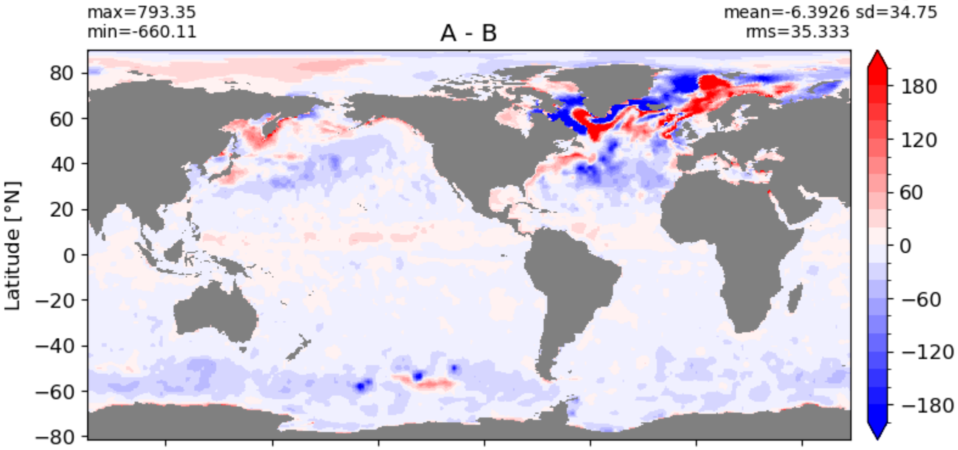
FFH

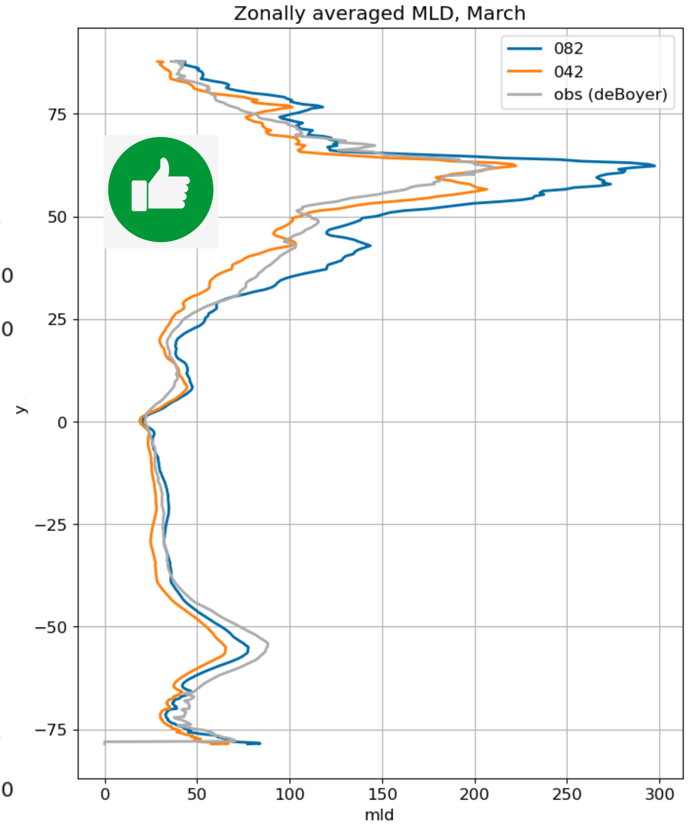
$L_f = 1$ km



Bodner +

$C_r(lat)$ V8



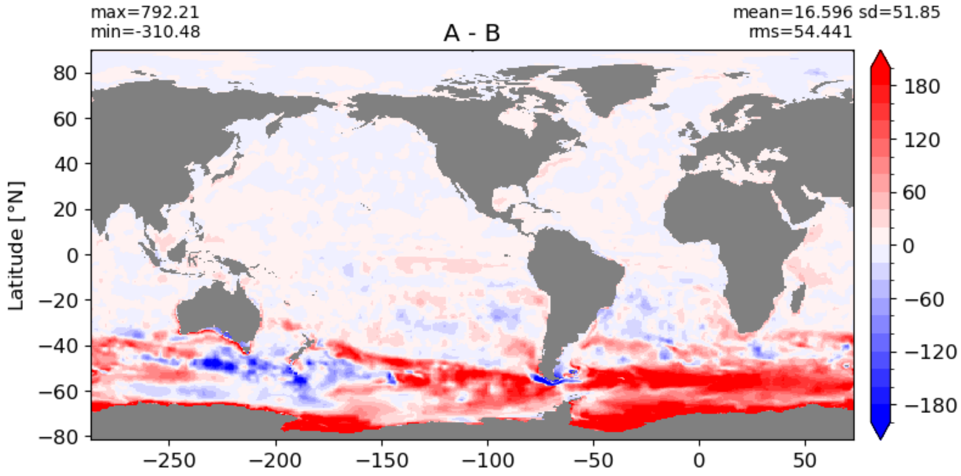


September mixed layer depth (m): Bodner + Cr(lat) V8 vs control

Model - obs

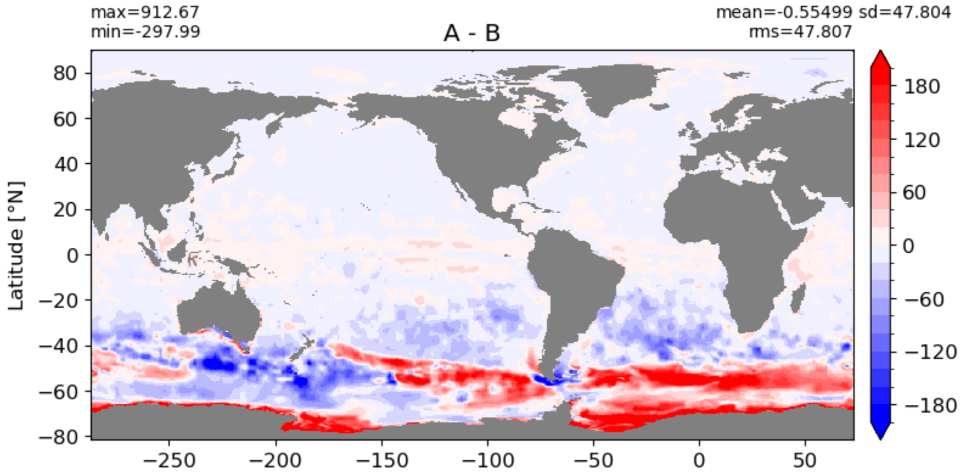
FFH

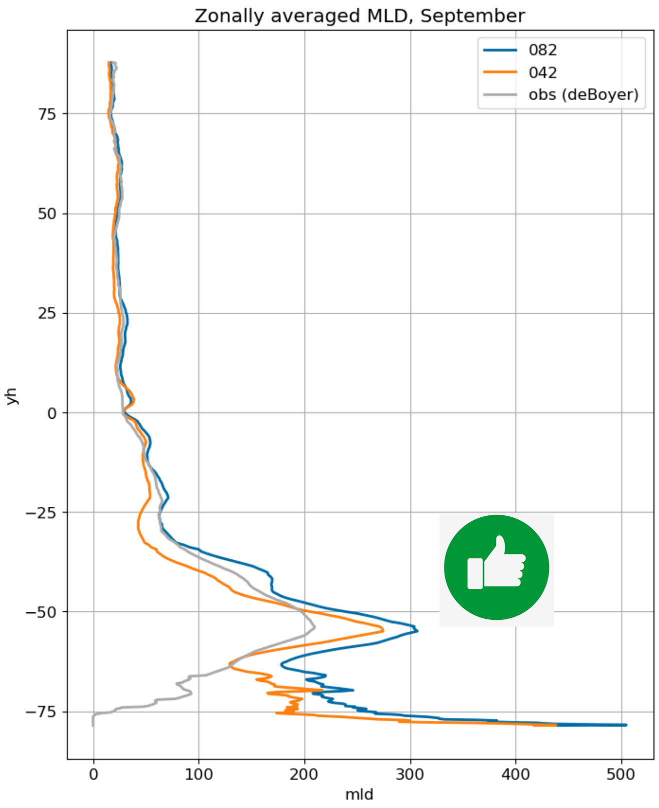
$L_f = 1$ km



Bodner +

$C_r(lat)$ V8





Buoyancy Contribution to PV: AAIW & Mode Water Formation

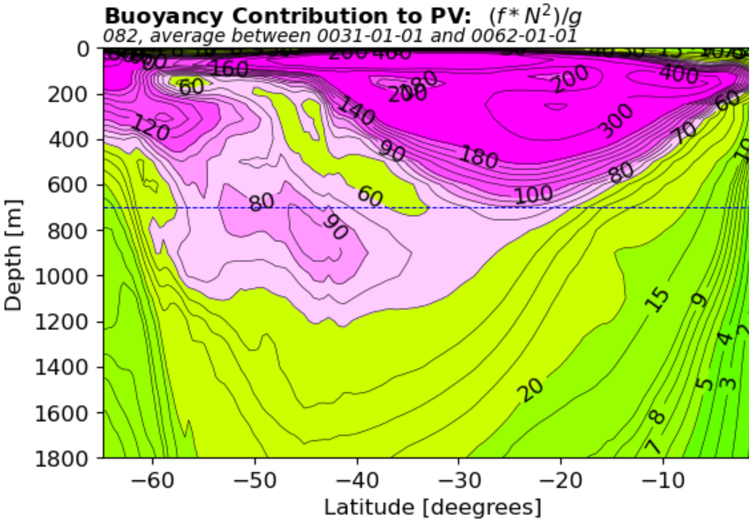
Eastern Pacific Ocean

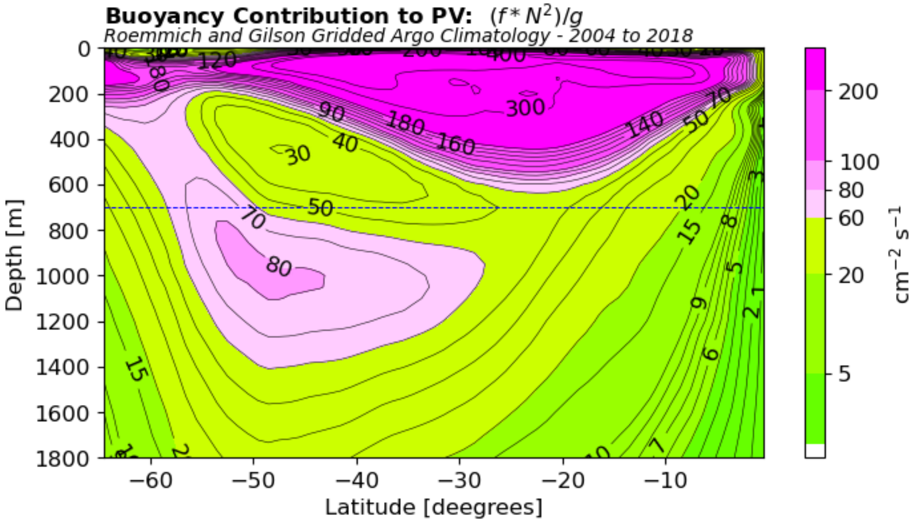
Model

Obs

FFH

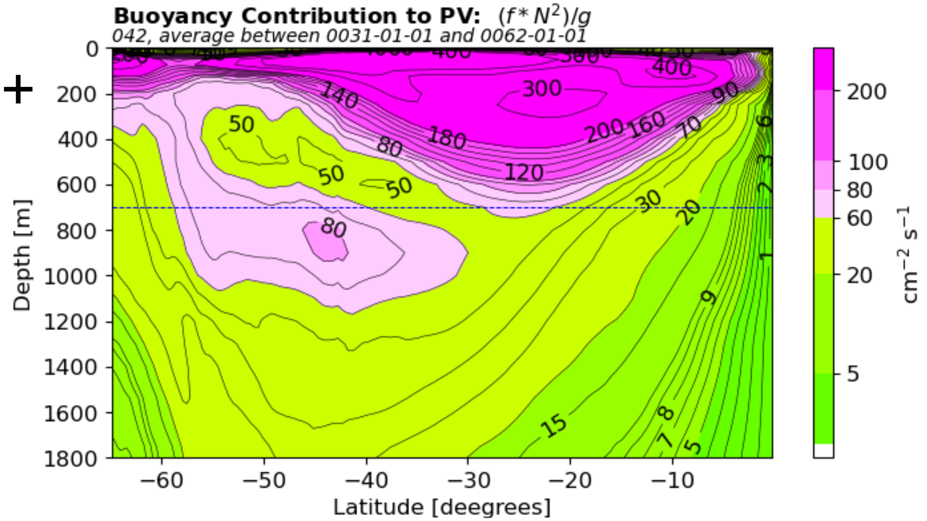
$L_f = 1$ km


Buoyancy Contribution to PV: $(f * N^2)/g$
082, average between 0031-01-01 and 0062-01-01


Buoyancy Contribution to PV: $(f * N^2)/g$
Roemmich and Gilson Gridded Argo Climatology - 2004 to 2018

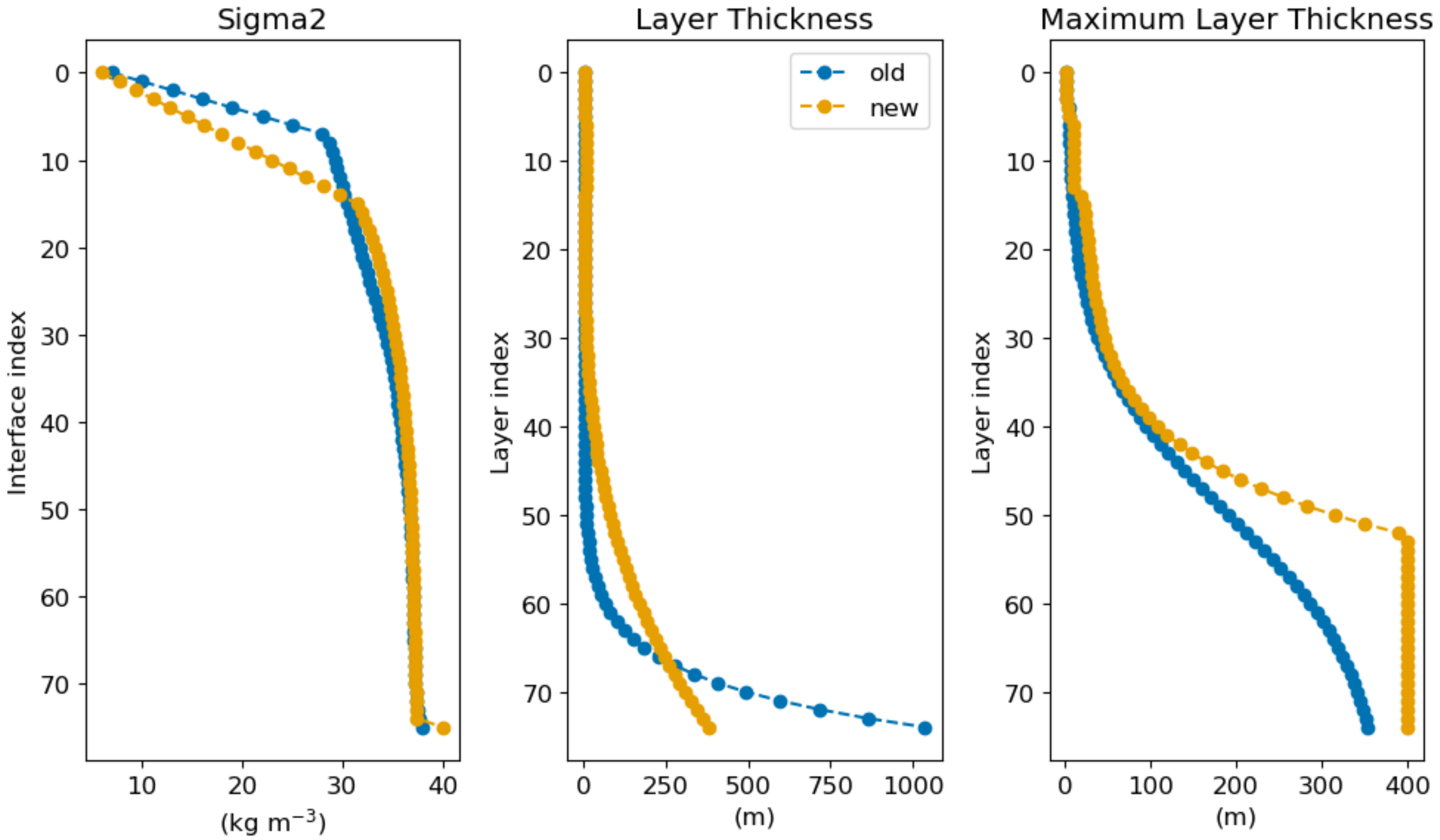
Bodner +

$C_r(lat)$ V8


Buoyancy Contribution to PV: $(f * N^2)/g$
042, average between 0031-01-01 and 0062-01-01

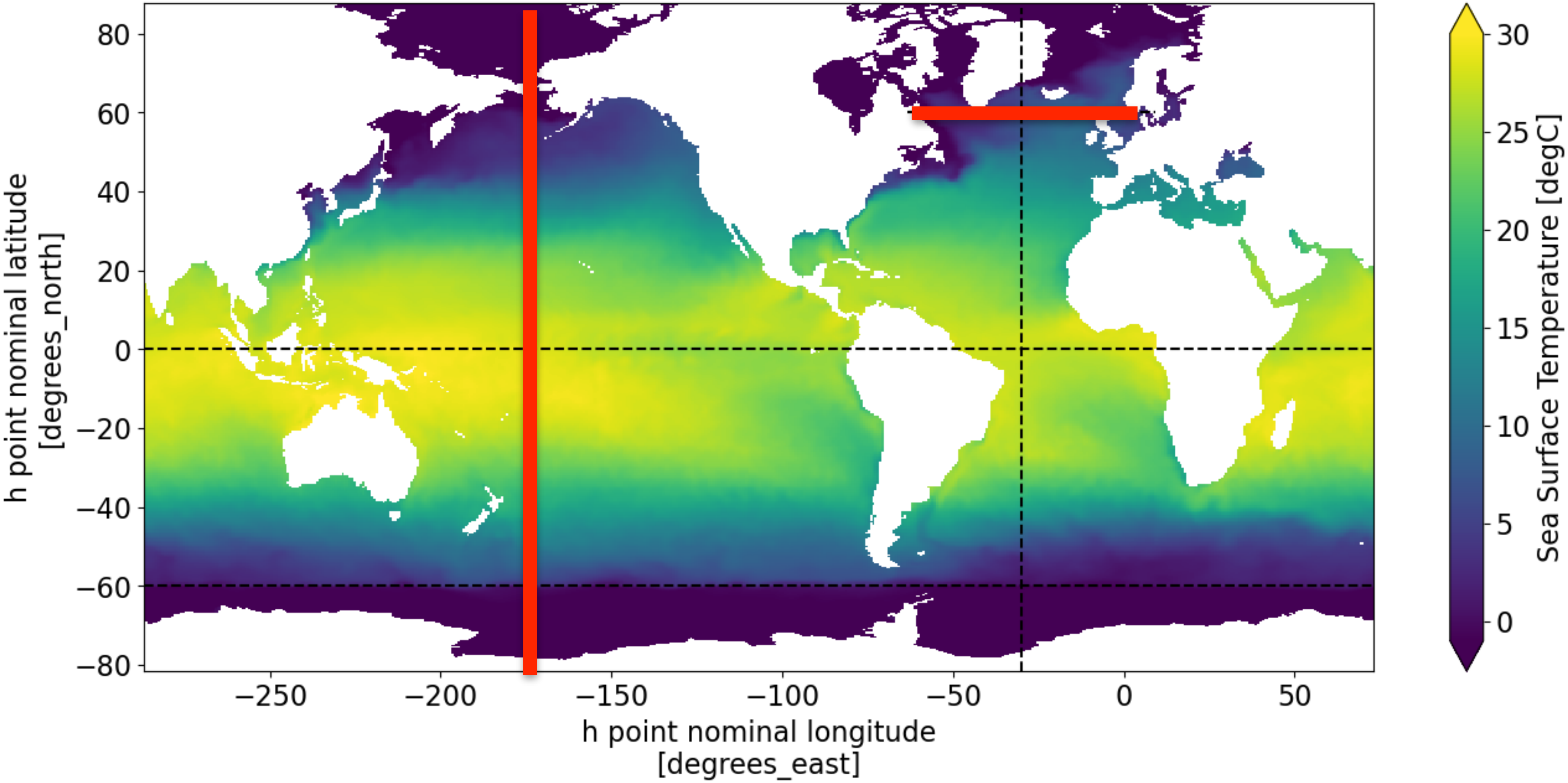
Significant improvements in the representation of AAIW and Subantarctic Mode Water.

Comparing HYCOM1 Configurations



In the following slides, case 42 has the old grid and case 43 has the new grid.

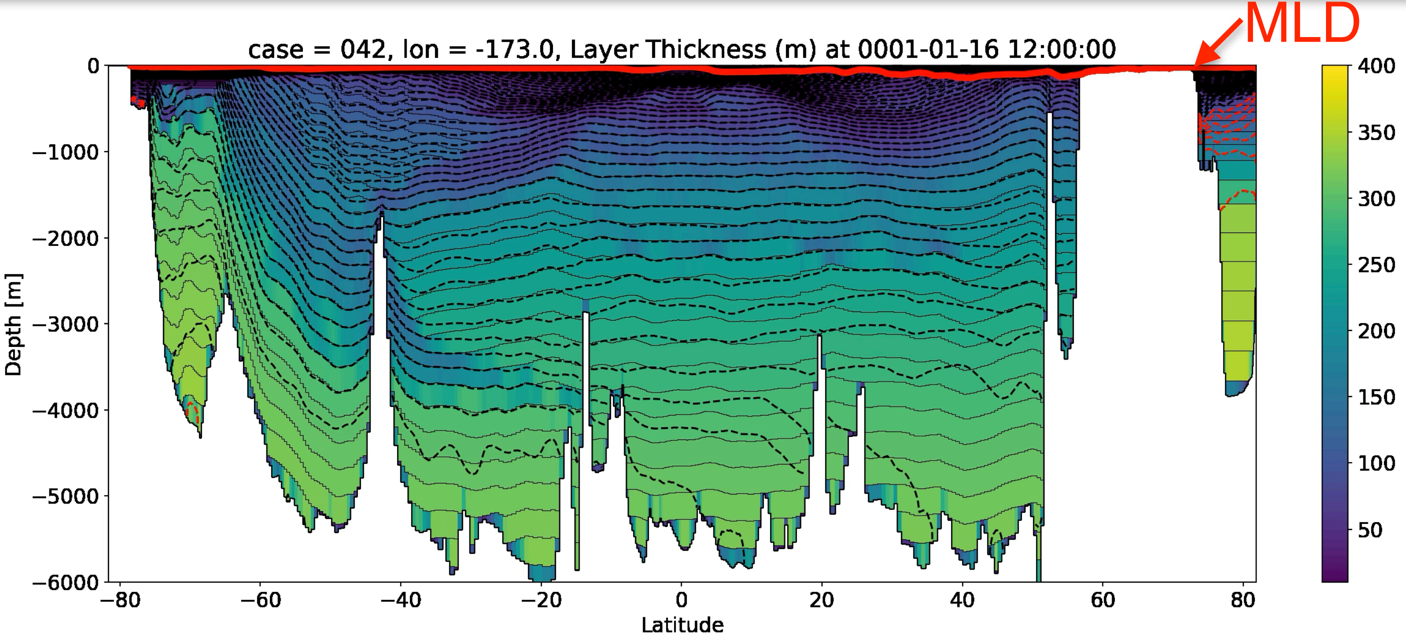
Vertical resolution at selected transects



Let's inspect the vertical layer thickness along the lines highlighted in red.

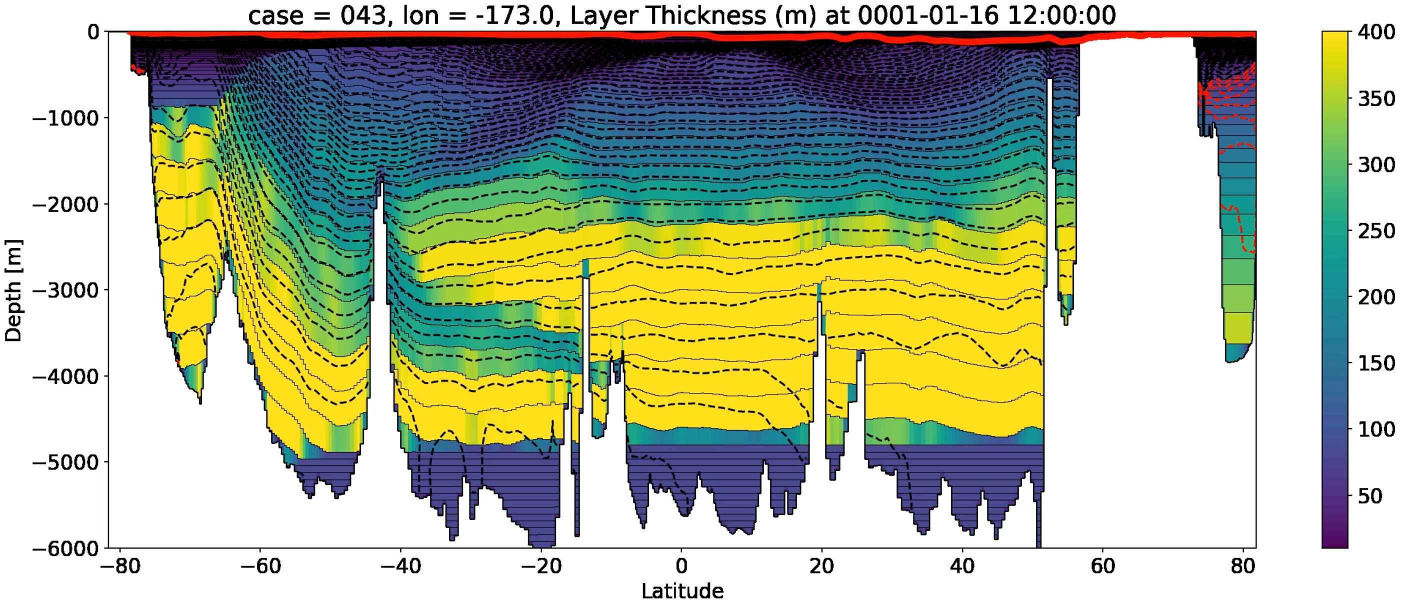
Layer thicknesses and target densities across Pacific

42


case = 042, lon = -173.0, Layer Thickness (m) at 0001-01-16 12:00:00

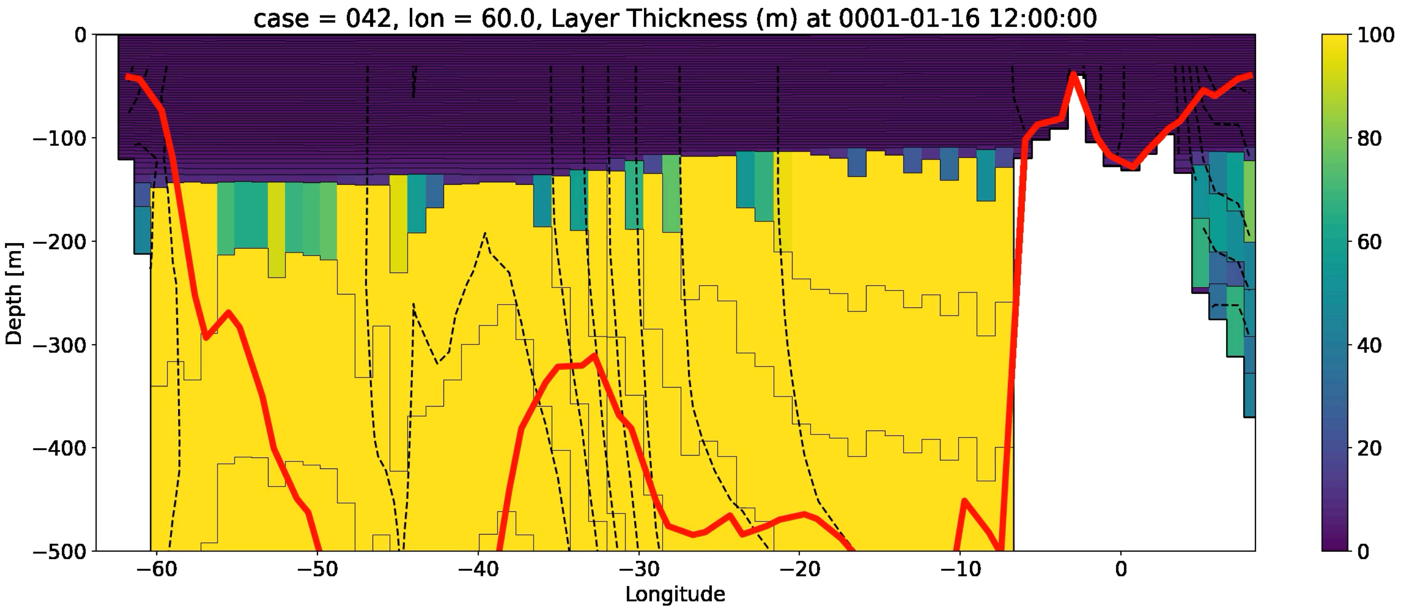
dz (m)

43


case = 043, lon = -173.0, Layer Thickness (m) at 0001-01-16 12:00:00

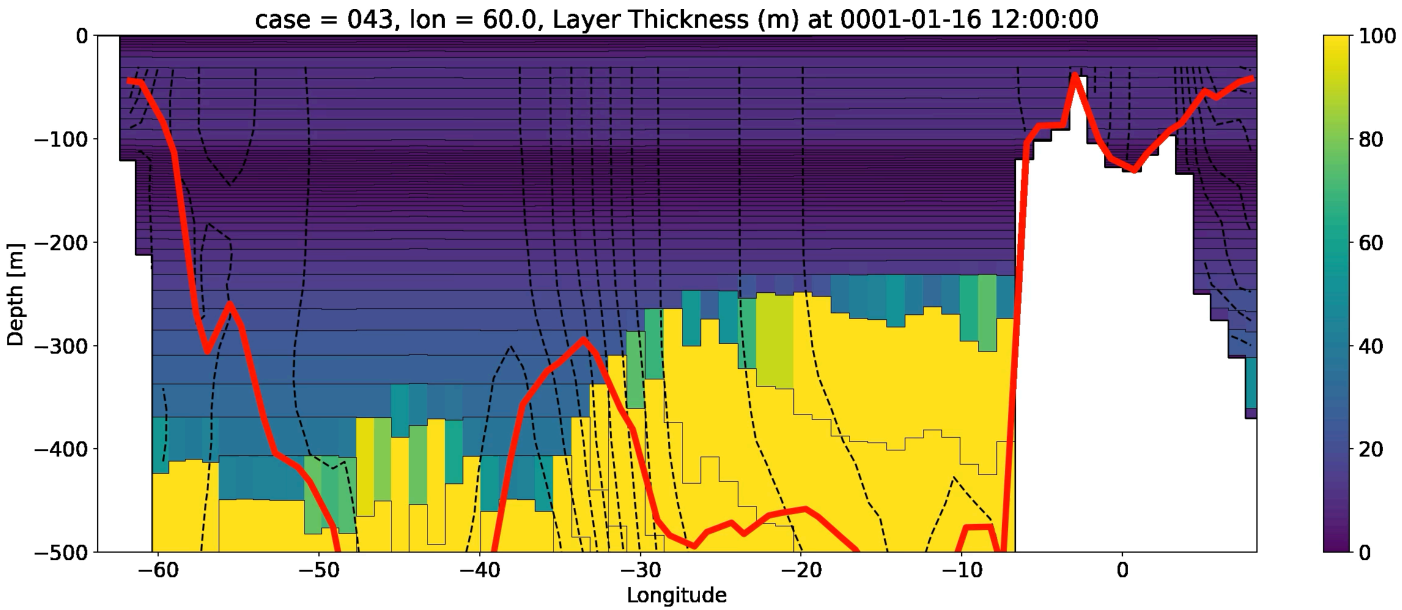
Thicknesses and target densities across subpolar N. Atlantic

42



dz (m)

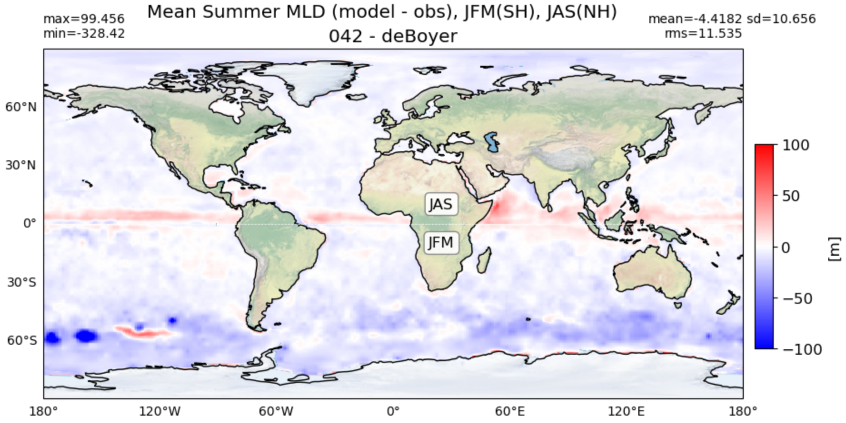
43



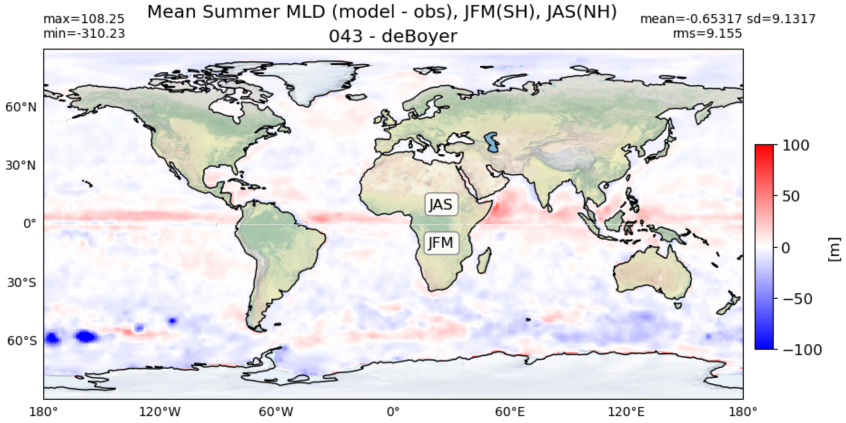
Summer Mixed Layer Depth bias, 0.03 kg m^{-3} criteria

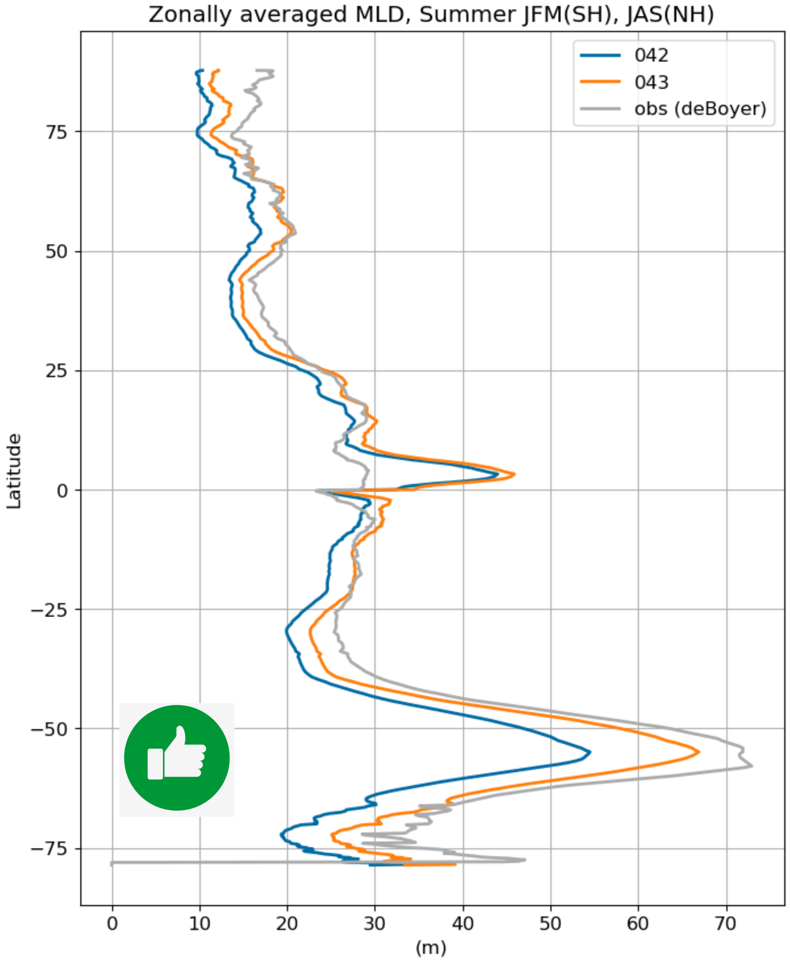
Model - obs

42



43



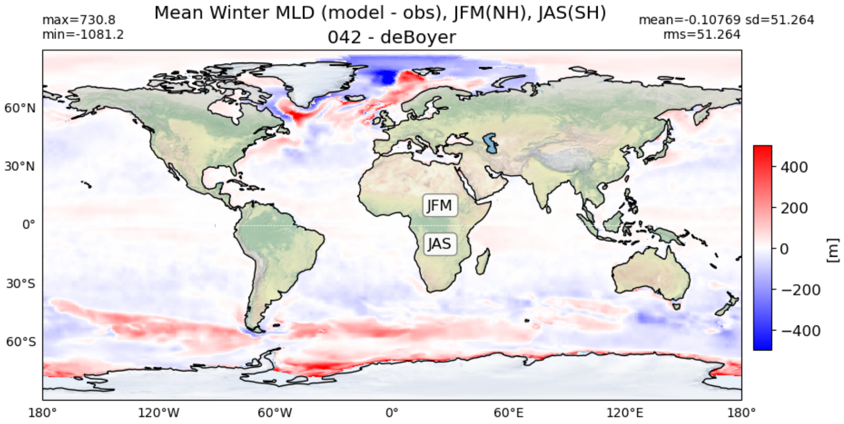


Overall improvement.

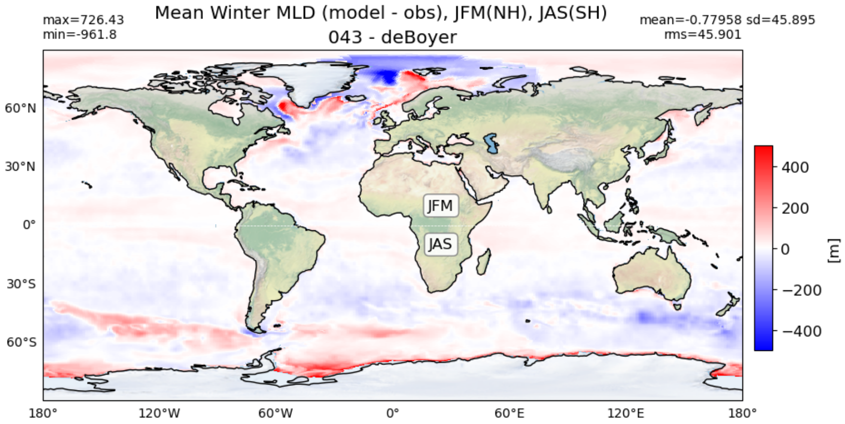
Winter Mixed Layer Depth, 0.03 kg m^{-3} criteria

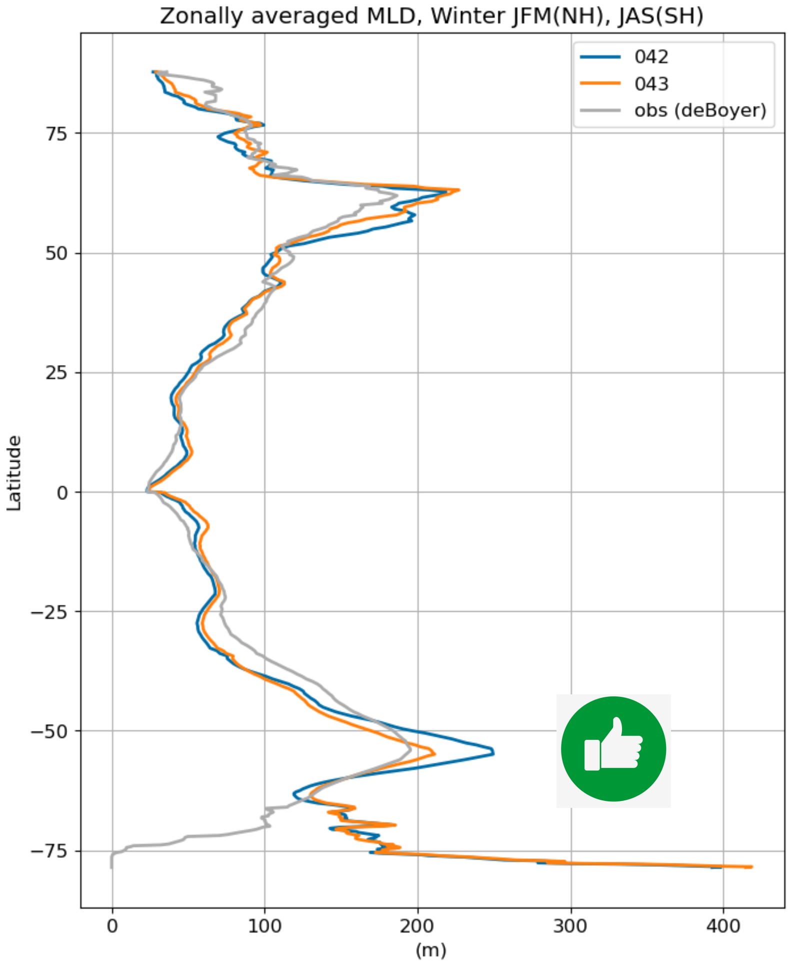
Model - obs

42



43

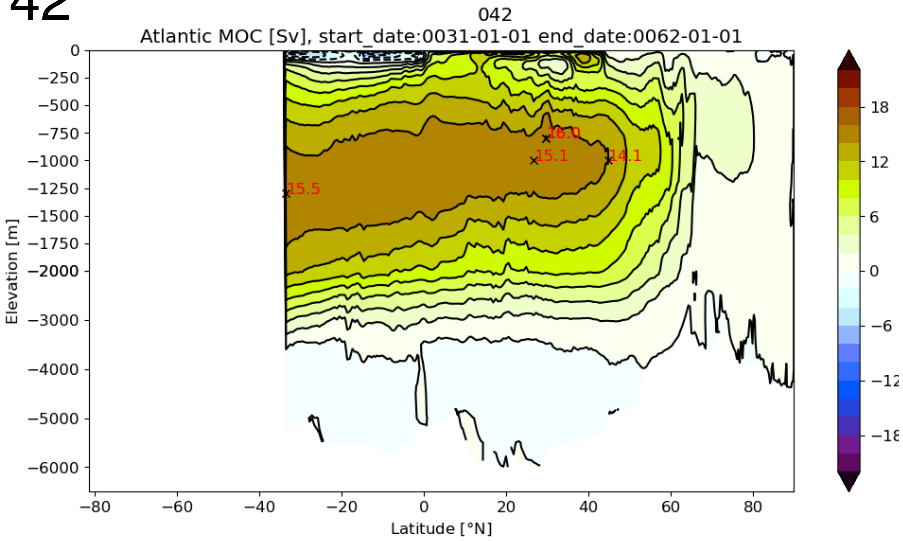




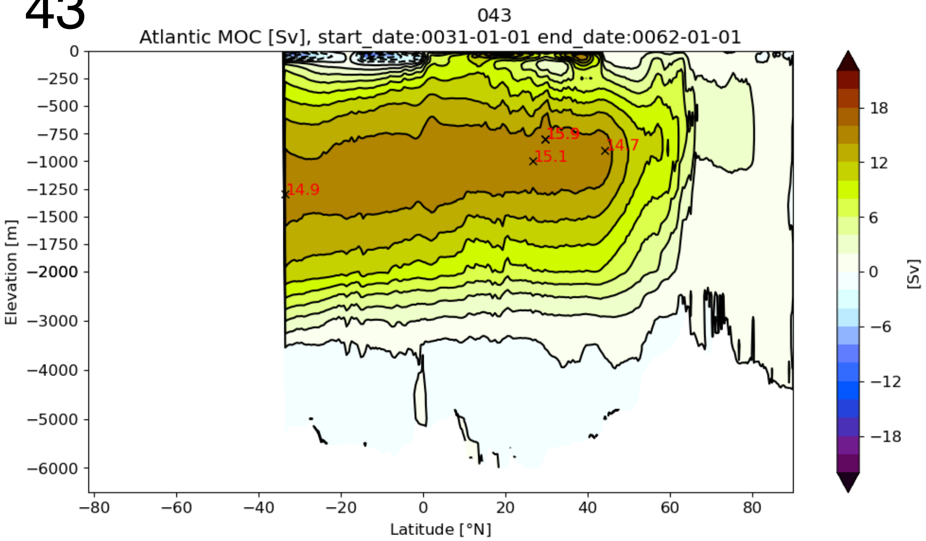
Overall improvement.

Atlantic Meridional Overturning Circulation (AMOC)

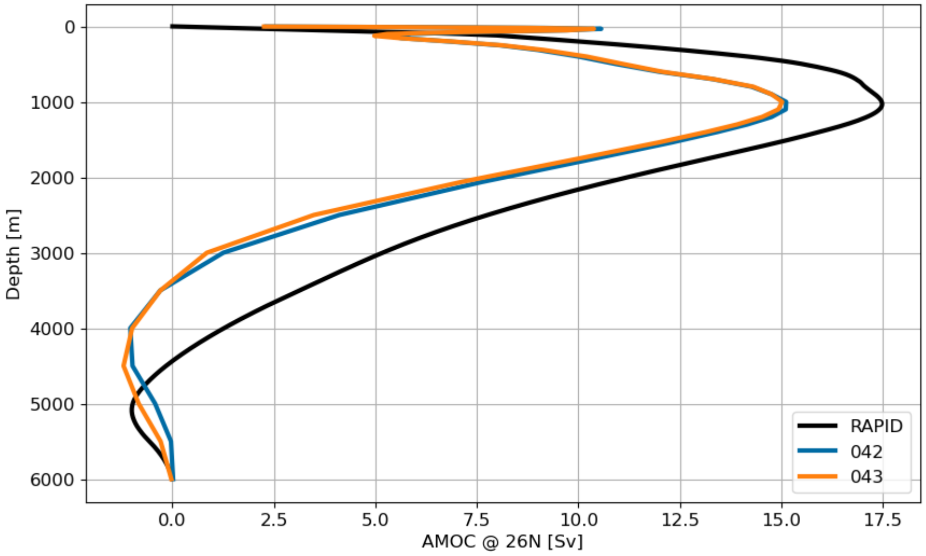
42



43

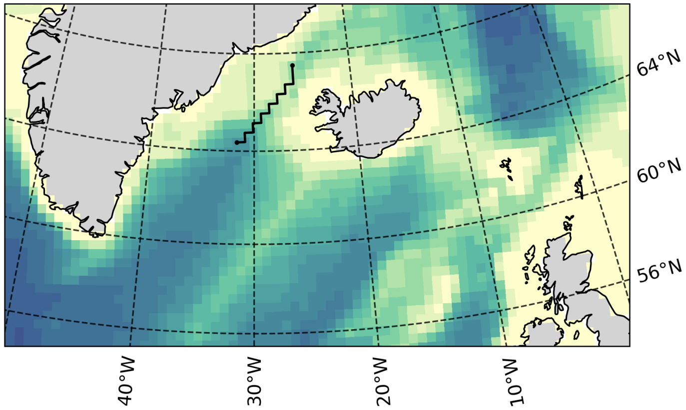


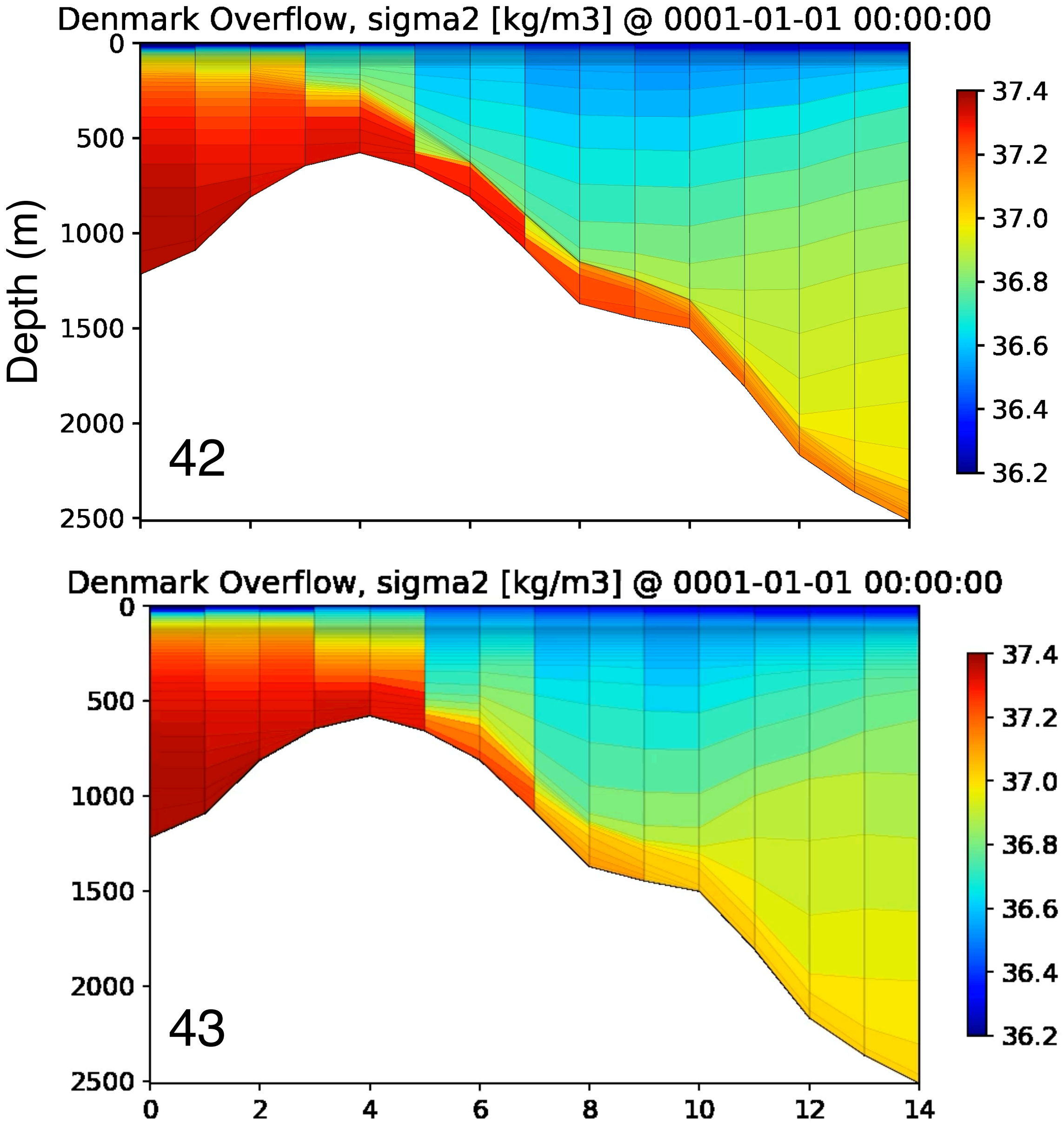
Profile @ 26 N



Overall similar AMOC. 43 slightly stronger in the abyss (resolution near the bottom?).

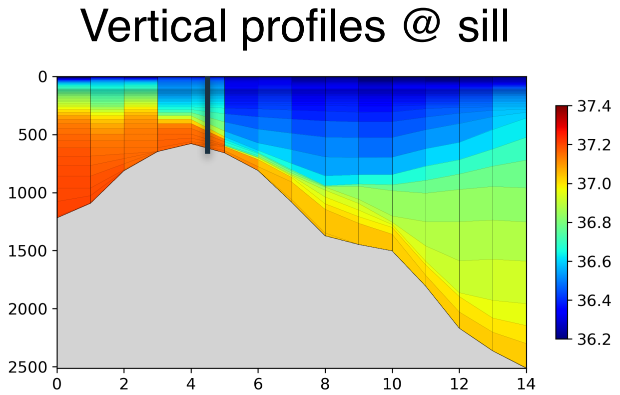
Denmark Strait Overflow

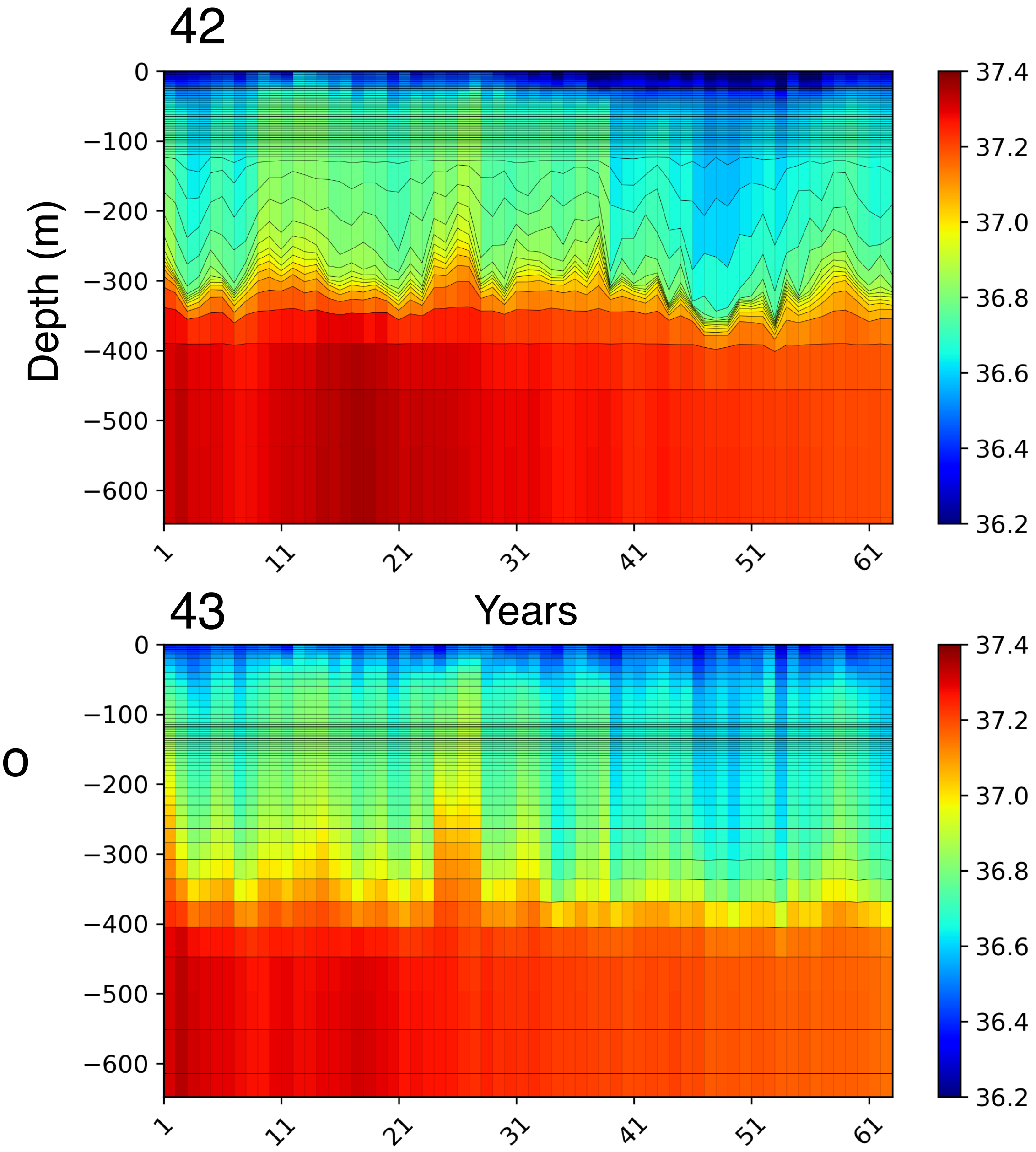



Denmark Overflow, sigma2 [kg/m3] @ 0001-01-01 00:00:00

Denmark Overflow, sigma2 [kg/m3] @ 0001-01-01 00:00:00

Denmark Strait Overflow: sigma2 @ sill

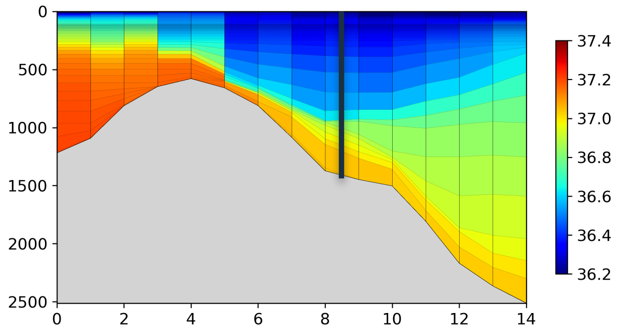




- Plume is thicker in 42;
- Higher resolution at the plume interface in 42 (also isopycnal).

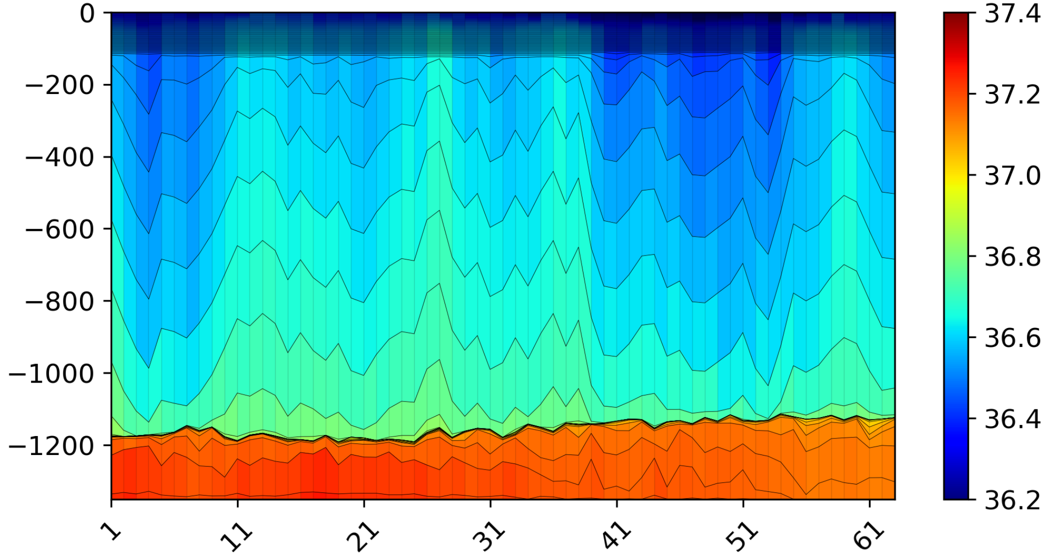
Denmark Strait Overflow: sigma2 @ ~ 1400m

Vertical profiles @ depth ~ 1400 m

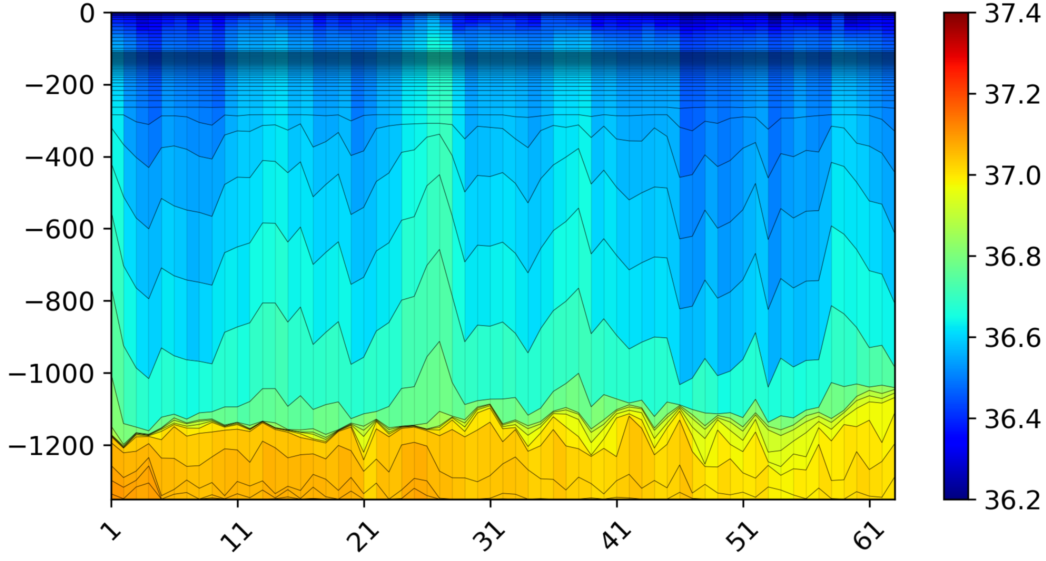


- 43 slightly thicker;
- Denser plume in 42;
- Higher resolution at the plume interface in 42;
- More entrainment in 43.

42



43

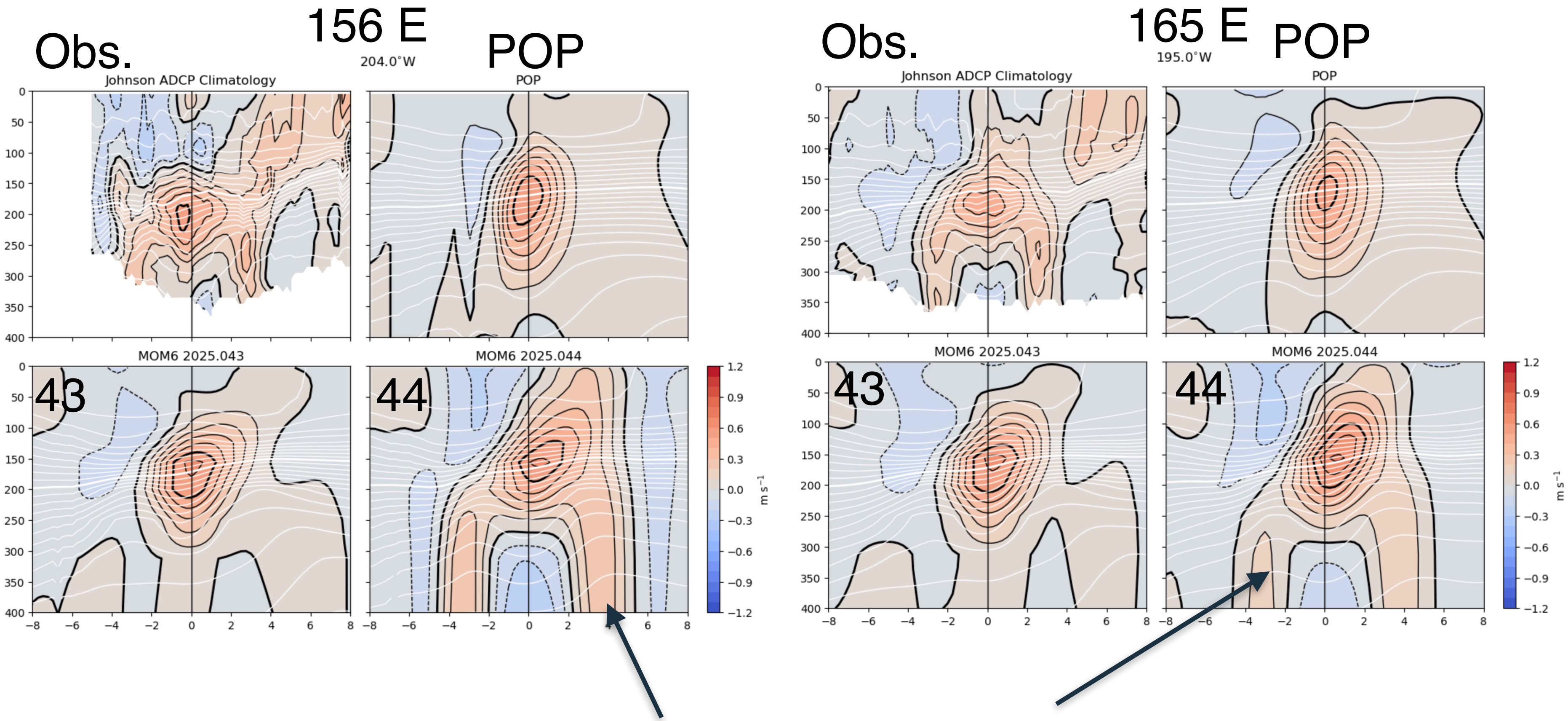


Energy backscatter

- **Backscatter balances dissipation**: The standard biharmonic viscosity dissipates energy, while a negative-viscosity Laplacian term backscatters energy to intermediate scales, avoiding grid-scale instabilities.
- Details provided in Grooms (2023), though within the context of a QG model;
- Backscatter is only applied where the computed Leith viscosity exceeds the background biharmonic viscosity, so it is mostly inactive in the 2/3° model.

```
USE_LEITHY = True     !   [Boolean] default = False
! If true, use a biharmonic Leith nonlinear eddy viscosity together with a harmonic
backscatter.
LEITH_BI_CONST = 78.0          !   [nondim] default = 0.0
! The nondimensional biharmonic Leith constant, typical values are thus far
undetermined.
LEITHY_CK = 1.0                 !   [nondim] default = 1.0
!Fraction of biharmonic dissipation that gets backscattered, in Leith+E.
```

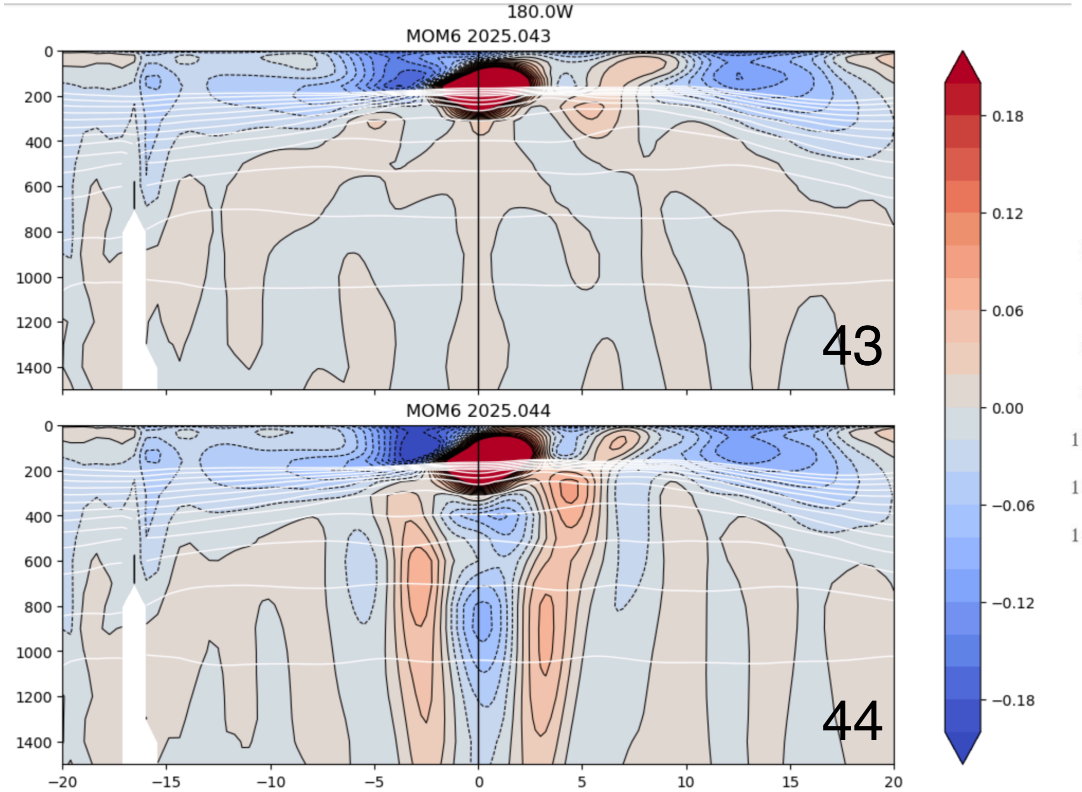
Equatorial Under Current

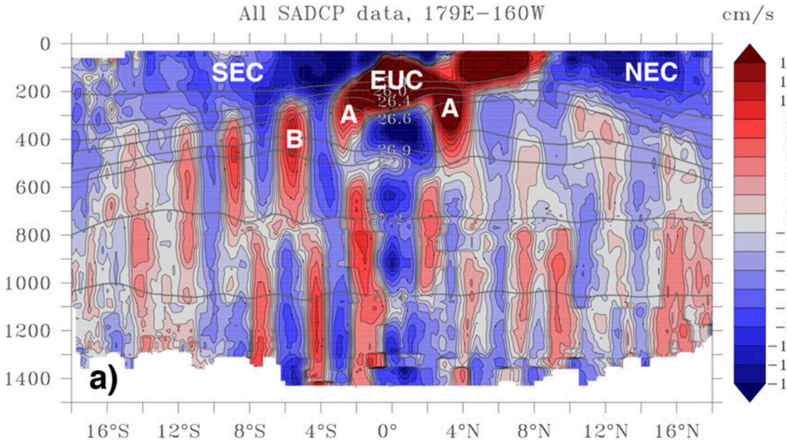


Tsuchiya Jets (Tsuchiya 1972, 1975, 1981).

Plots courtesy of Frank Bryan

Zonal velocity @ 180 W



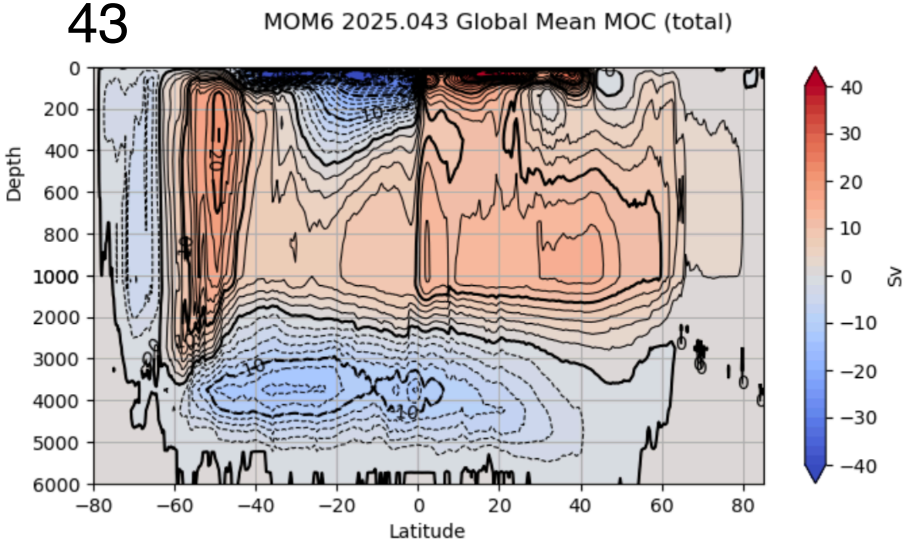


From Cravatte et al. (2017)

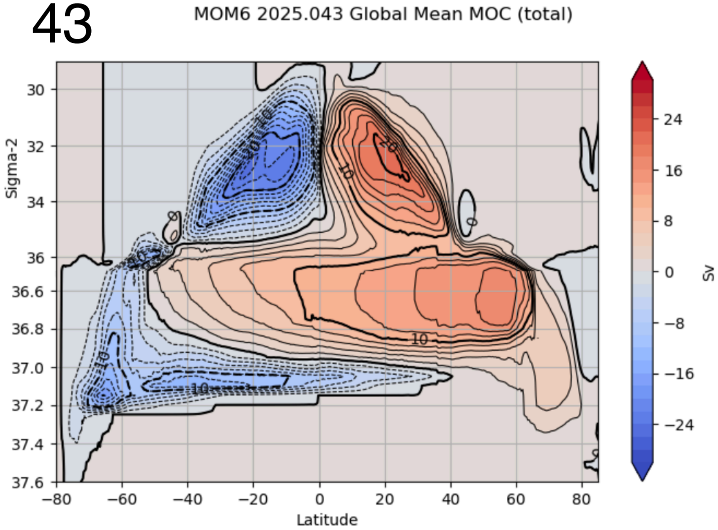
Plots courtesy of Frank Bryan

Global meridional overturning circulation [Sv]

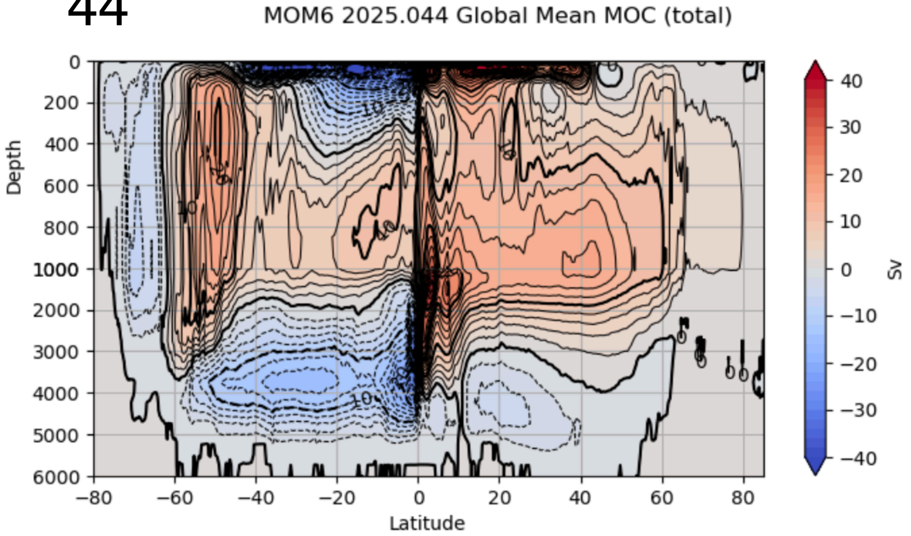
43



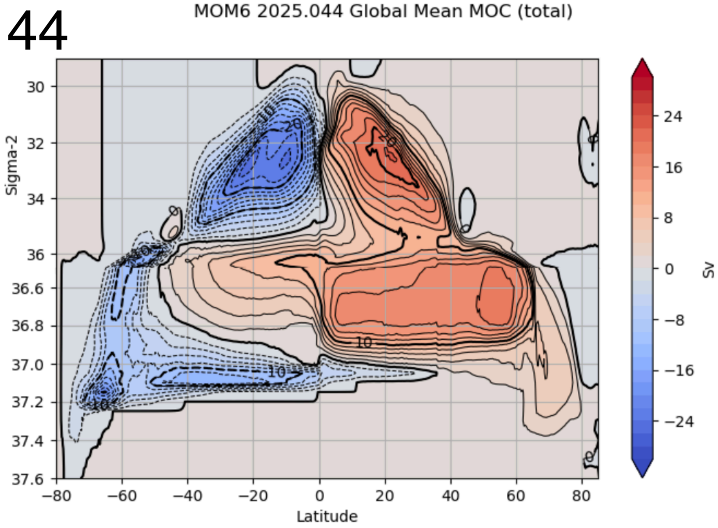
43



44



44

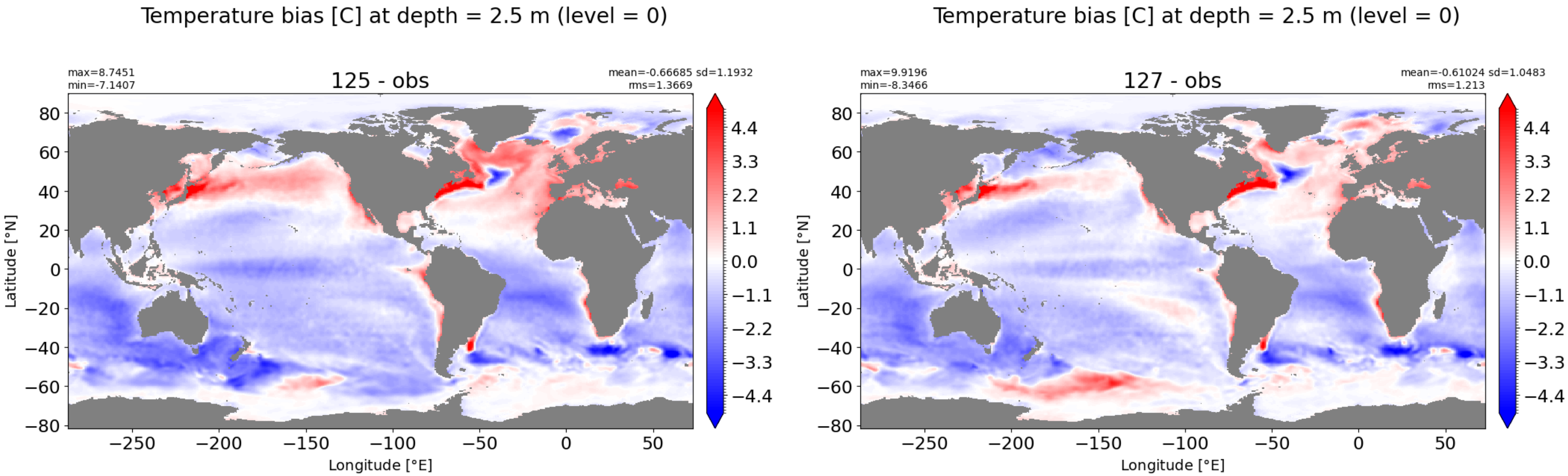


Plots courtesy of Frank Bryan

Status of coupled simulations

Run	Compset	Description	Nyrs	Issue	Purpose of the run + comments
125	BLT1850	Same as 122 but **revert ocn/lnd to a 121** to look at impact of **cam changes only** (all the upcoming changes except moving mountains)	53	#41	New baseline with only cam changes RESTOM went from 0.6->0.1 W/m2
127	BLT1850	Same as 125 + **new ocean settings** - vertical grid, MLE and topography - start from Atlas	25	#45	Adding new ocean setting to 125

Mean SST bias (model - woa18), yrs 11-21

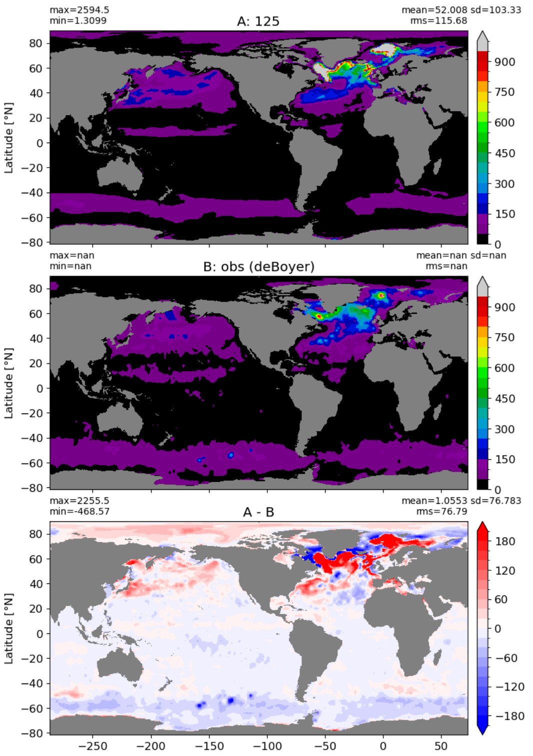


Overall pattern is similar. Warm bias in N. Pacific is reduced in 127. 127 is also warmer in the S. Pacific Gyre and Southern Ocean (Pacific sector).

March mixed layer depth (m), yrs 11-21

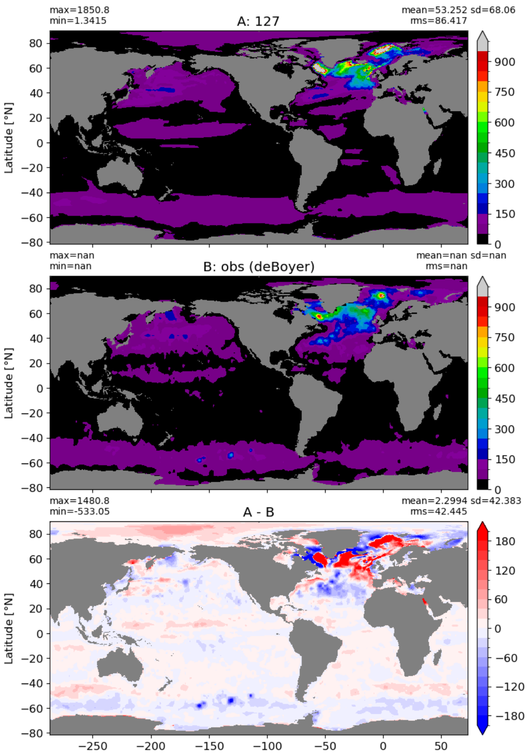
125

March climatology, 0011-01-01 to 0021-01-01

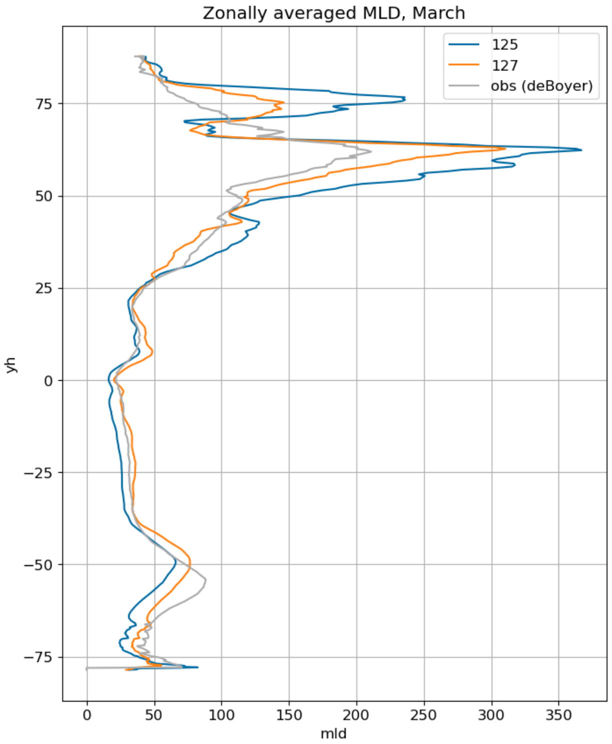


127

March climatology, 0011-01-01 to 0021-01-01



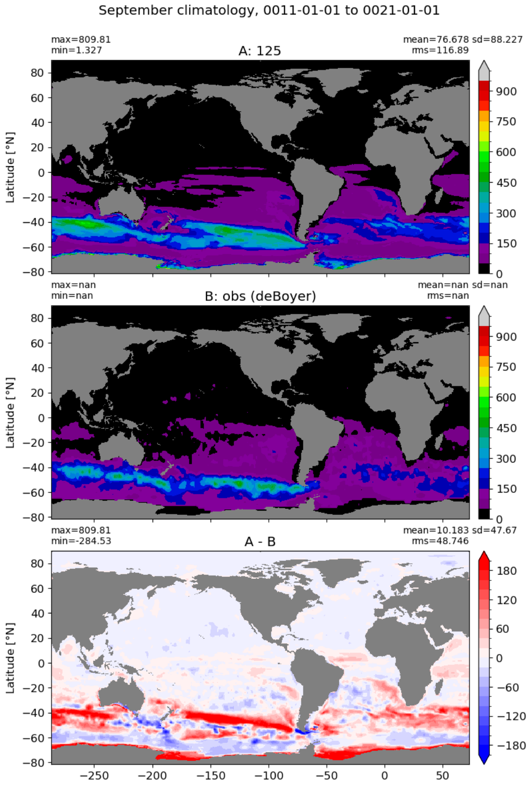
Zonal average



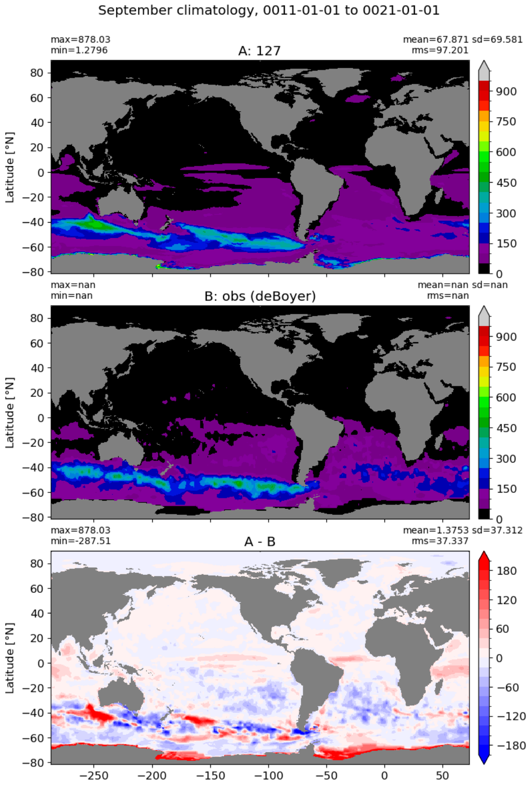
127 is closer to obs in both hemispheres.

September mixed layer depth bias (m), yrs 11-21

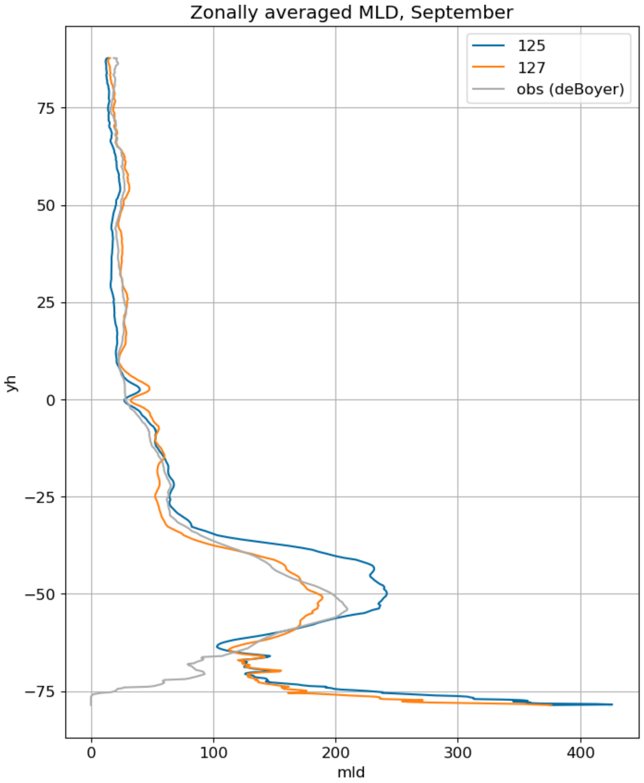
125



127



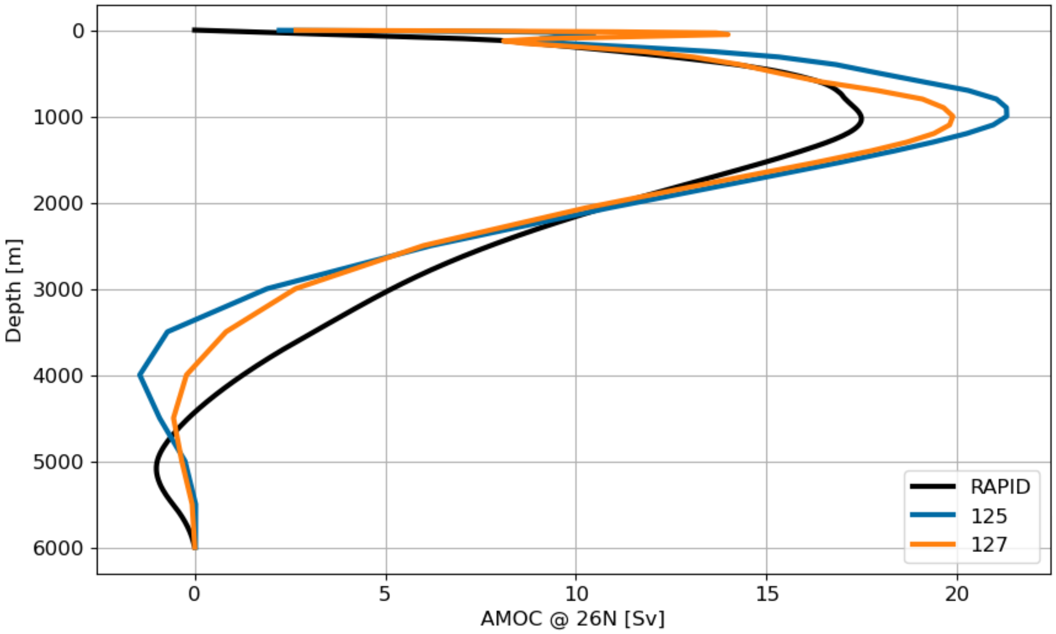
Zonal average



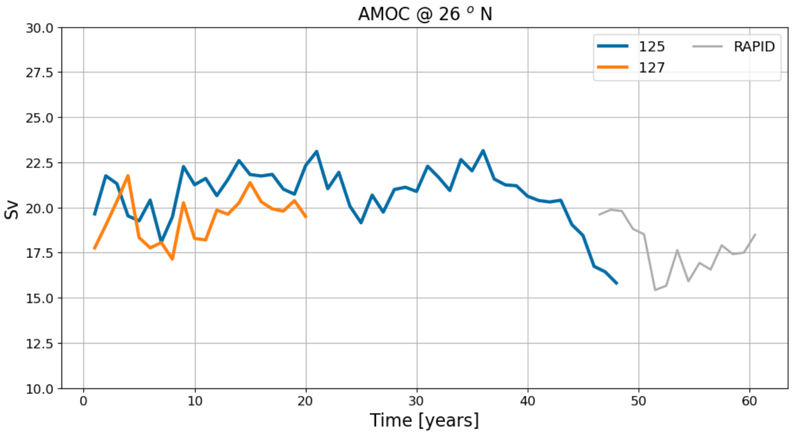
127 is closer to obs in both hemispheres (except @ ~ 5 N).

AMOC @ 25 N

Profile

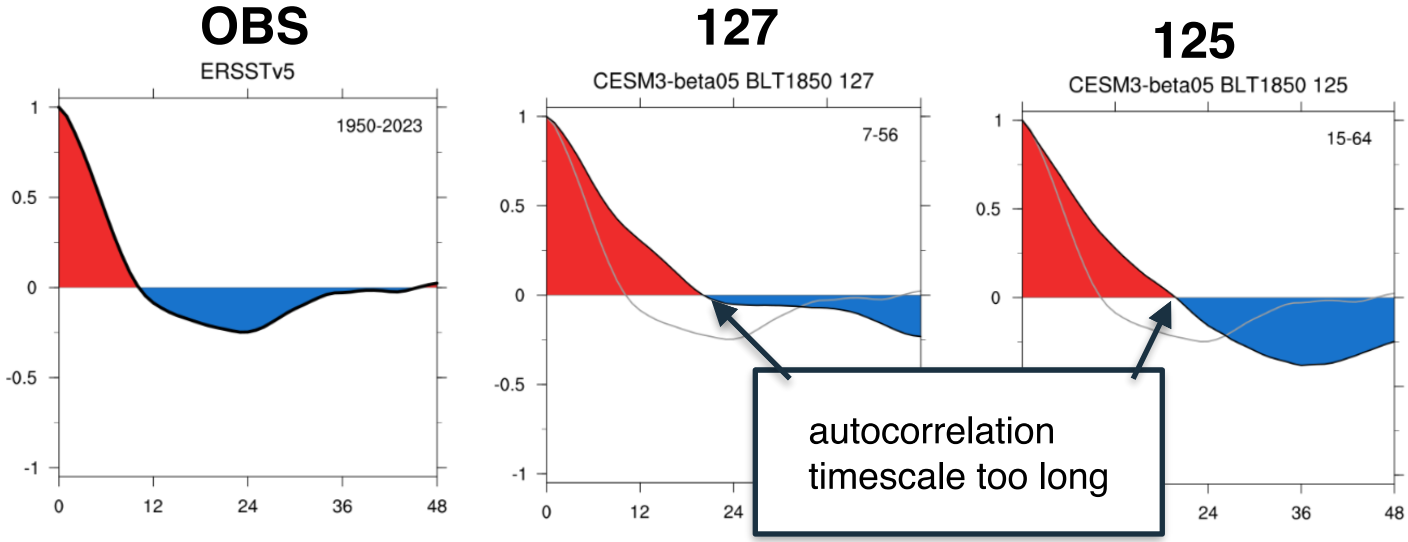


Time series

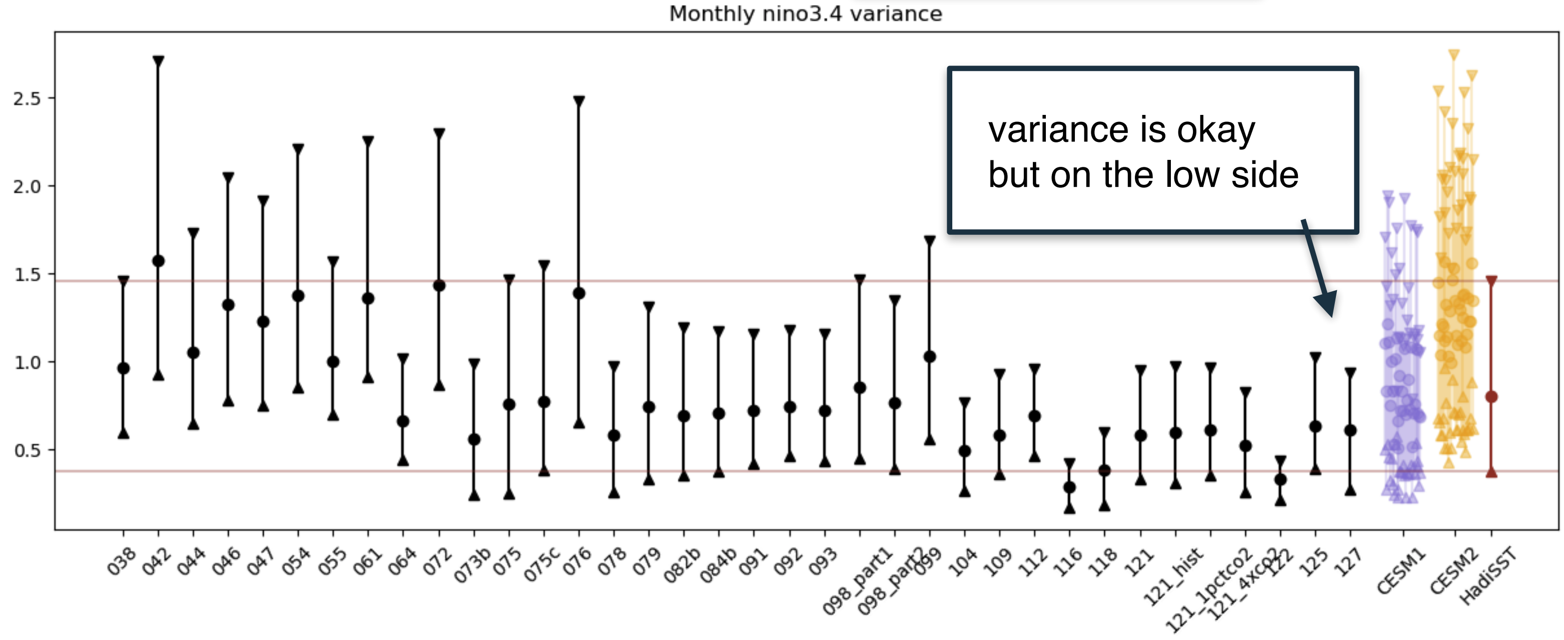


Overall good AMOC in both cases. Flow reversal is deeper (and closer to RAPID) in 127.

The ENSO Autocorrelation Problem



autocorrelation timescale too long



variance is okay but on the low side

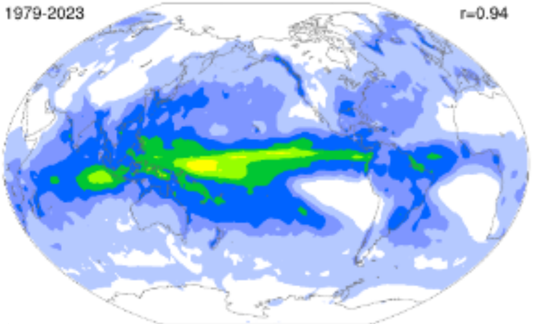
Plots courtesy of CESM3 dev team

Annual Mean Precipitation Standard Deviations

OBS

GPCP

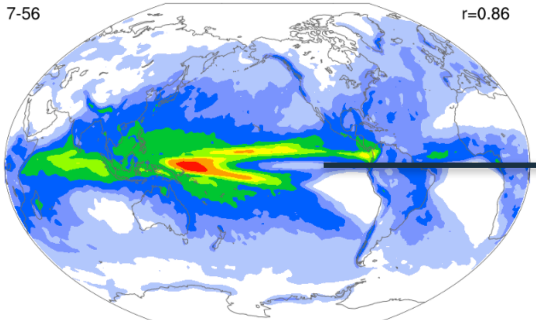
1979-2023 r=0.94



127

CESM3-beta05 BLT1850 127

7-56 r=0.86

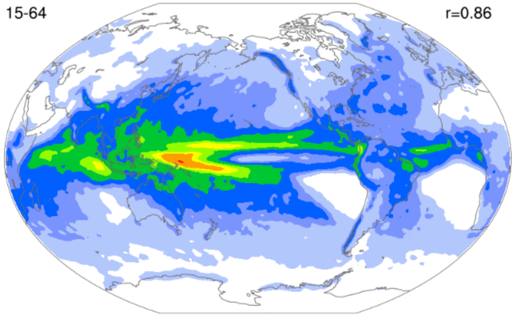


Still have a dry patch in the Eastern Eq. Pacific.

125

CESM3-beta05 BLT1850 125

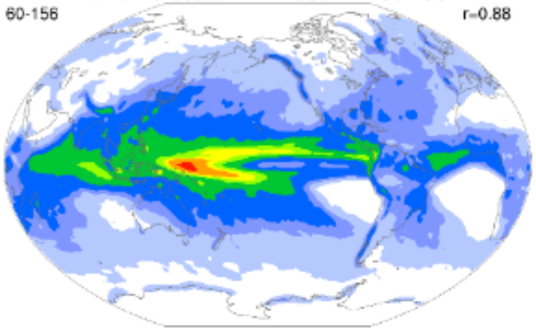
15-64 r=0.86



121

CESM3-beta04 BLT1850 121 60-156

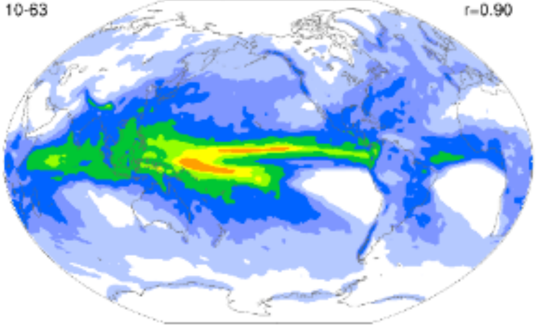
60-156 r=0.88



116

CESM3-beta04 BLT1850 116

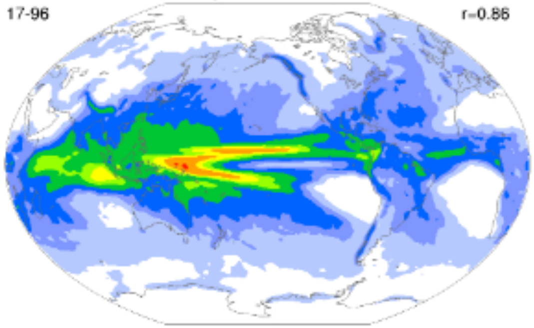
10-63 r=0.90



112

CESM3-alpha03d BLT1850 112

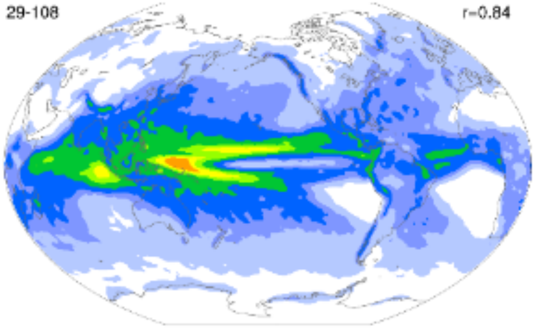
17-96 r=0.86



104

CESM3-beta02 BLT1850 104

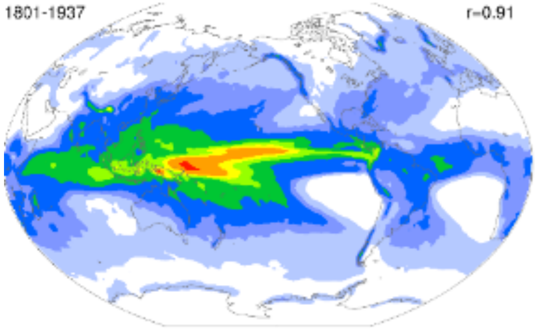
29-108 r=0.84



CESM2

CESM2 piControl F

1801-1937 r=0.91



Plots courtesy of CESM3 dev team