AMOC in MOM6

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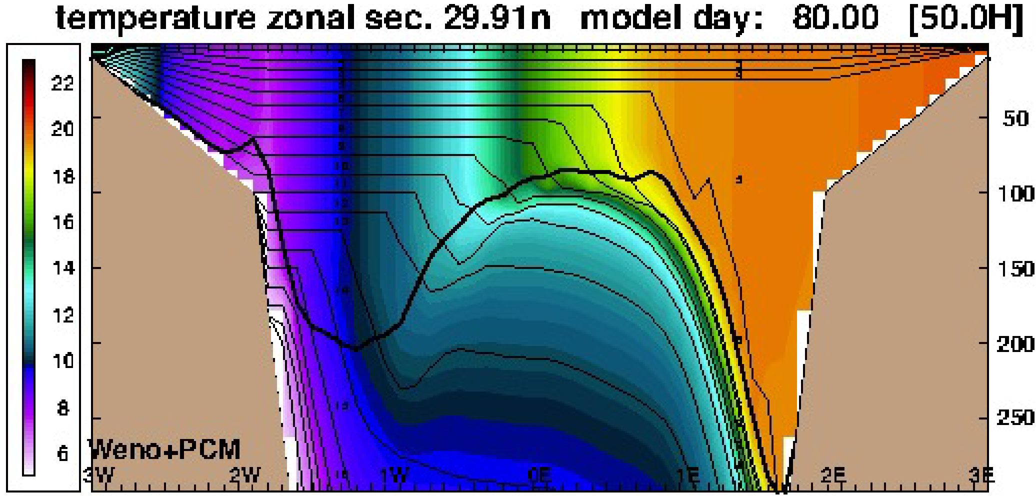
COAPS
Center for Ocean-Atmospheric Prediction Studies



Motivation

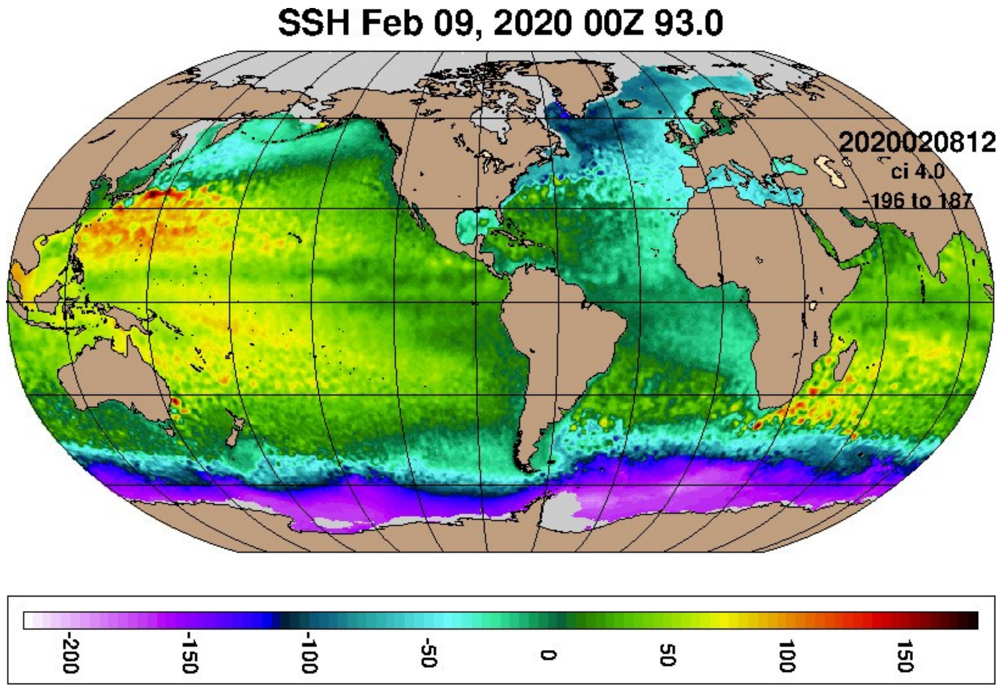
- HYCOM was the first widely used ALE-based ocean model
  => demonstrated the viability of this approach

  The arbitrary Lagrangian–Eulerian (ALE) method allows a hybrid vertical coordinate that can "emulate" a combination of vertical coordinates that varies in space and time

- HYCOM is no longer the only ALE-based ocean model
- GFDL's MOM6 is very similar to HYCOM, but has modern numerics and coding style and a much larger developer base than HYCOM. MOM6 to replace POP2 in CESM.
- MOM6 is primarily used for climate applications while HYCOM is primarily used in eddy resolving configurations for ocean prediction

=> Comparison of twin MOM6 and HYCOM eddy-resolving global ocean simulations

THE 1/12° GLOBAL TEST CASE FOR HYCOM AND MOM6

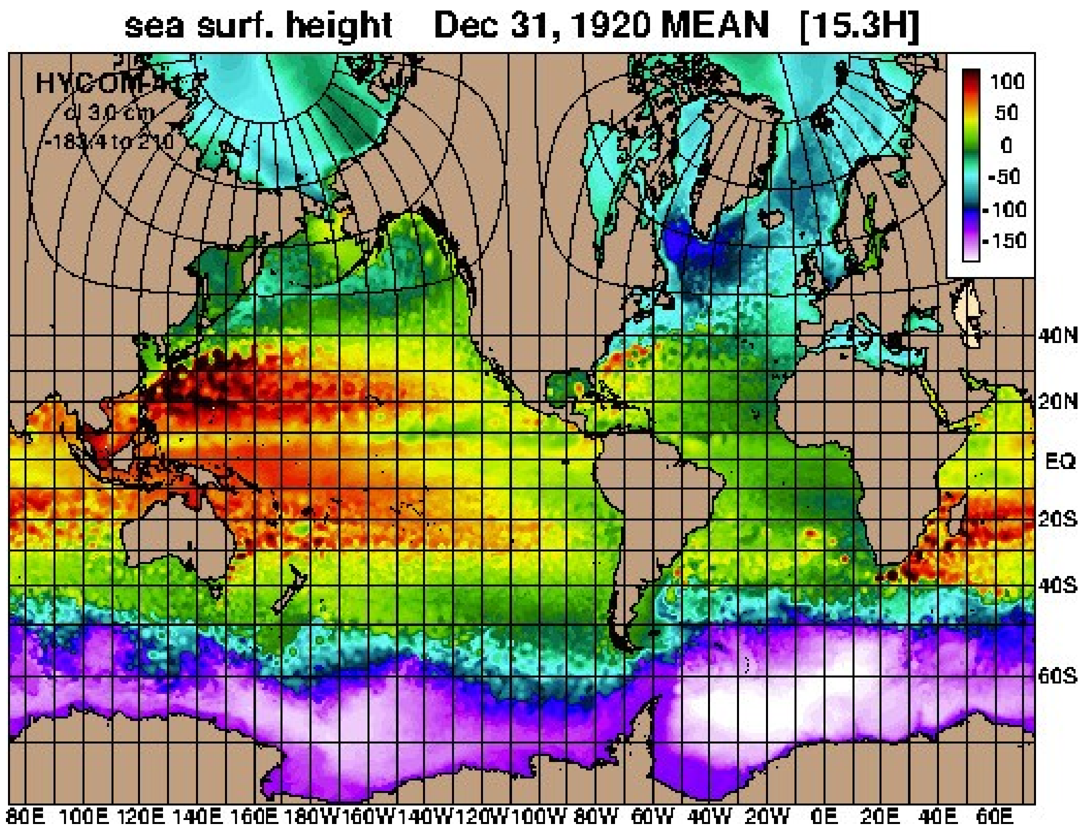


- **Use the Navy GOFS 3.1 configuration**
  - **41 hybrid layers in the vertical**
    - **Fixed vertical coordinate is Z-level only** *(not sigma-Z)*
    - **The same target isopycnals everywhere** *(not spatially varying)*
  - **Start from US Navy's GDEM 4.2 climatology**
  - **Use the KPP mixed layer**
  - **Repeat CFSR 2003 atmospheric forcing for 10 model years**
  - **Use the Large and Yeager (NCAR) bulk flux/stress parameterization** *(not COARE 3.0)*, **with absolute winds**
- **The differences between HYCOM and MOM6 cases (respectively) are:**
  - **Non-Boussinesq vs Boussinesq**
  - **Equation of state:**
    - **17-term rational function (Jackett et al, 2006) vs. pressure-separable (Wright, 1990)**
    - **Potential density with thermobaricity correction vs in-situ density**
  - **ALE isopycnal targets: layer averages vs layer interfaces**
  - **No-slip vs free-slip land boundary conditions**
  - **CICE v4 vs. SIS2 sea ice model**
- **The model parameters are tuned for HYCOM, may not be optimal for MOM6**

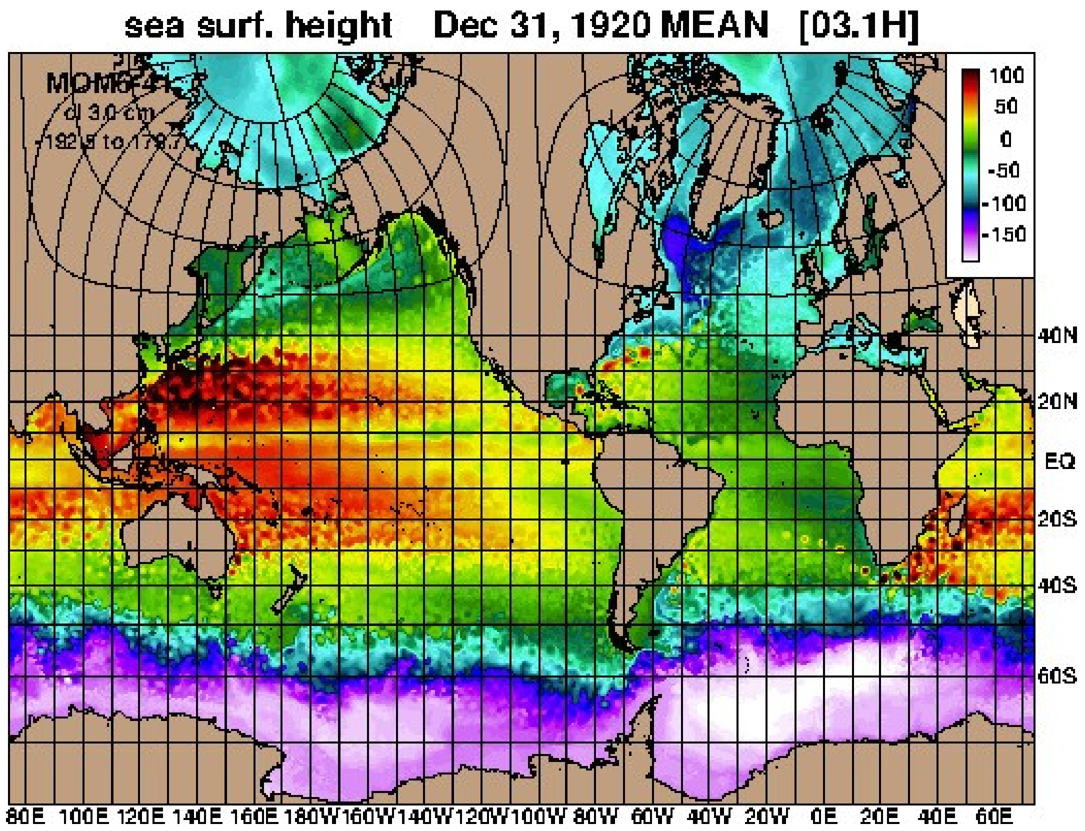
SSH SNAPSHOT, END OF MODEL YEAR 10

- MOM6 and HYCOM twin simulations on 1/12° global tripole grid
- 10 years with CFSR 2003 repeated atmospheric forcing

HYCOM



MOM6

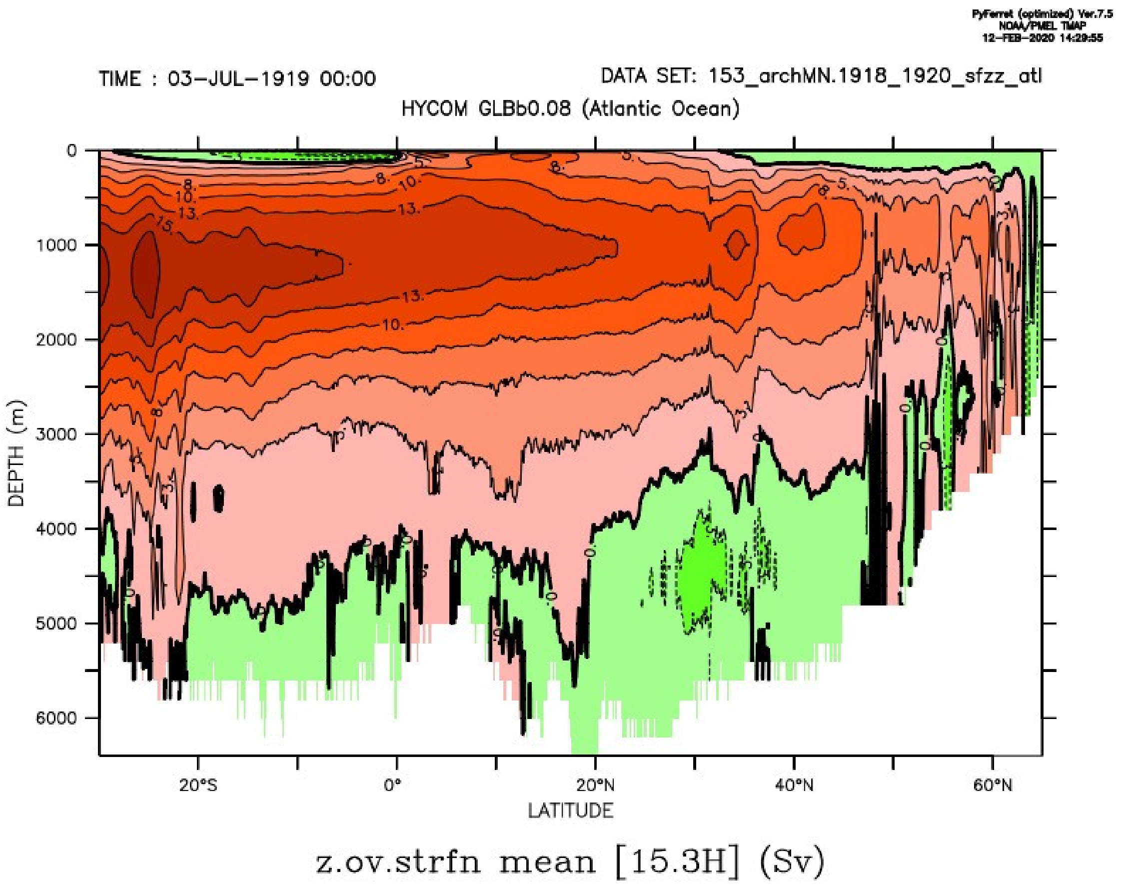


- On 1,800 Cray XC40 cores, MOM6 runs 1.5x faster than HYCOM
  - HYCOM is slightly faster than MOM6 per time step
  - MOM6 is stable with a significantly longer baroclinic time step, 300s vs 180s
  - Speedup similar to the time step ratio: 300/180 = 1.67

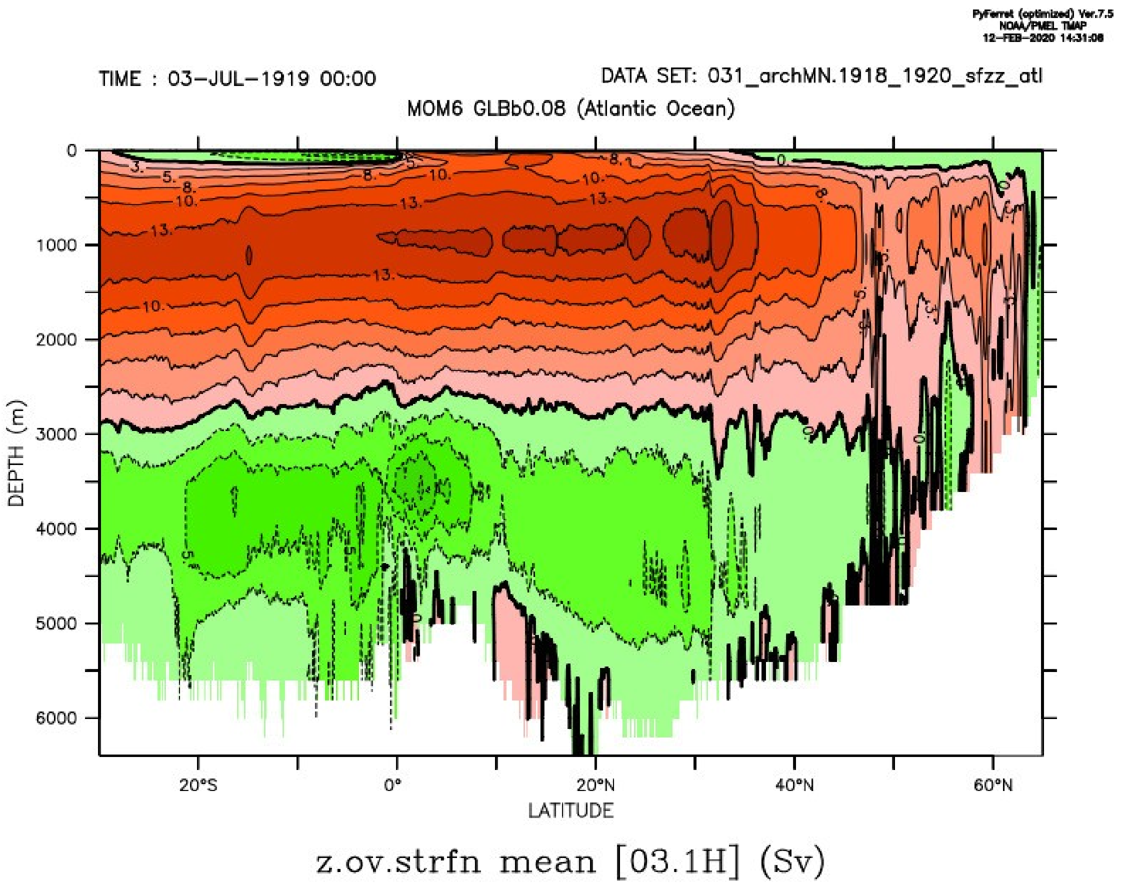
ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10

30°S to 65°N and 0 to 6500m depth, 2.5 Sv contour interval

HYCOM



MOM6



HYCOM at 26°N: max 11.6Sv at 1000m; 0Sv at 3500m

MOM6 at 26°N: max 14.0Sv at 0900m; 0Sv at 2730m

RAPID array at 26°N: max 17.0Sv at 1000m; 0Sv at 4300m

ATLANTIC OVERTURNING STREAMFUNCTION

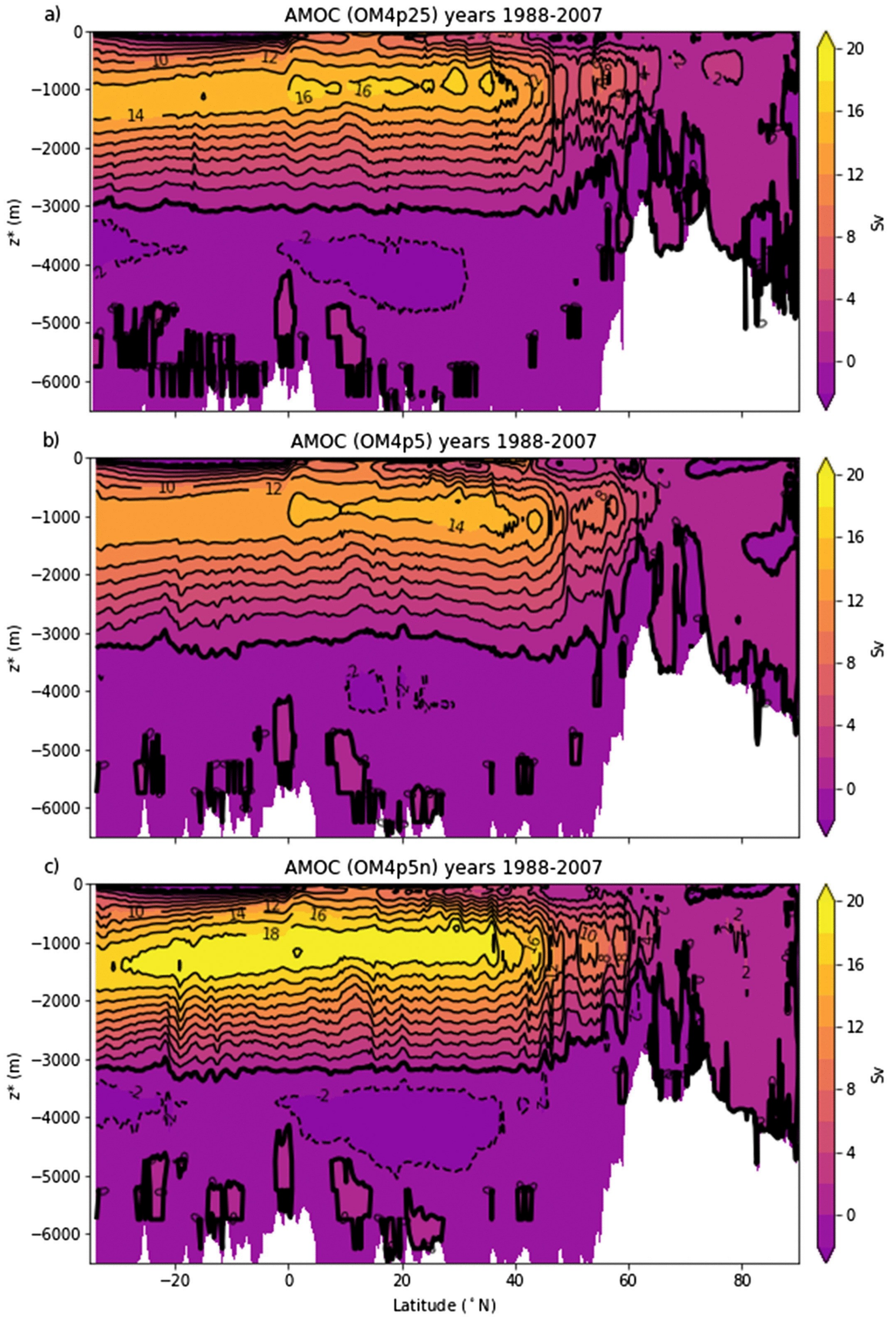
MOM6 OM4 for years 1988-2007 (ocean – sea ice only)

From Figure 12 of Adcroft et al. (2019)

(a) OM4p25 ¼°

(b) OM4p5 ½°

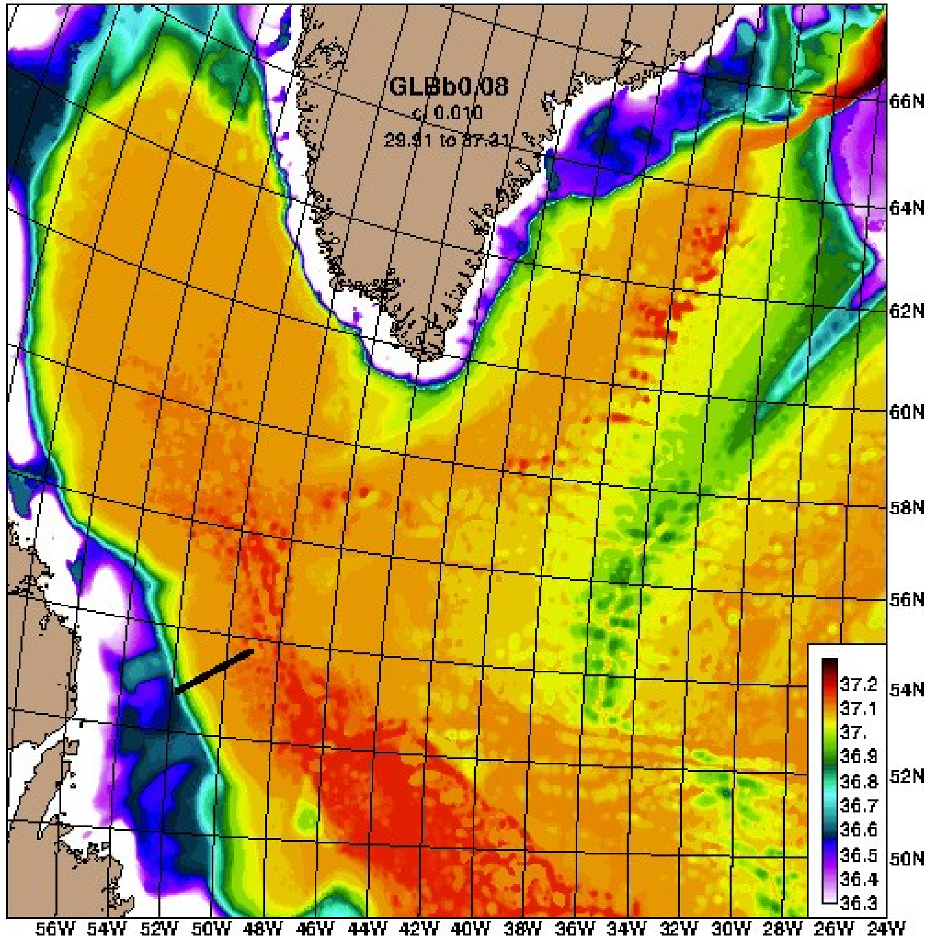
(c) OM4p5n CORE-II simulations



- A shallow Atlantic overturning streamfuction is often due to too light overflow from the Nordic Seas
- MOM6 significantly less dense at the bottom than HYCOM

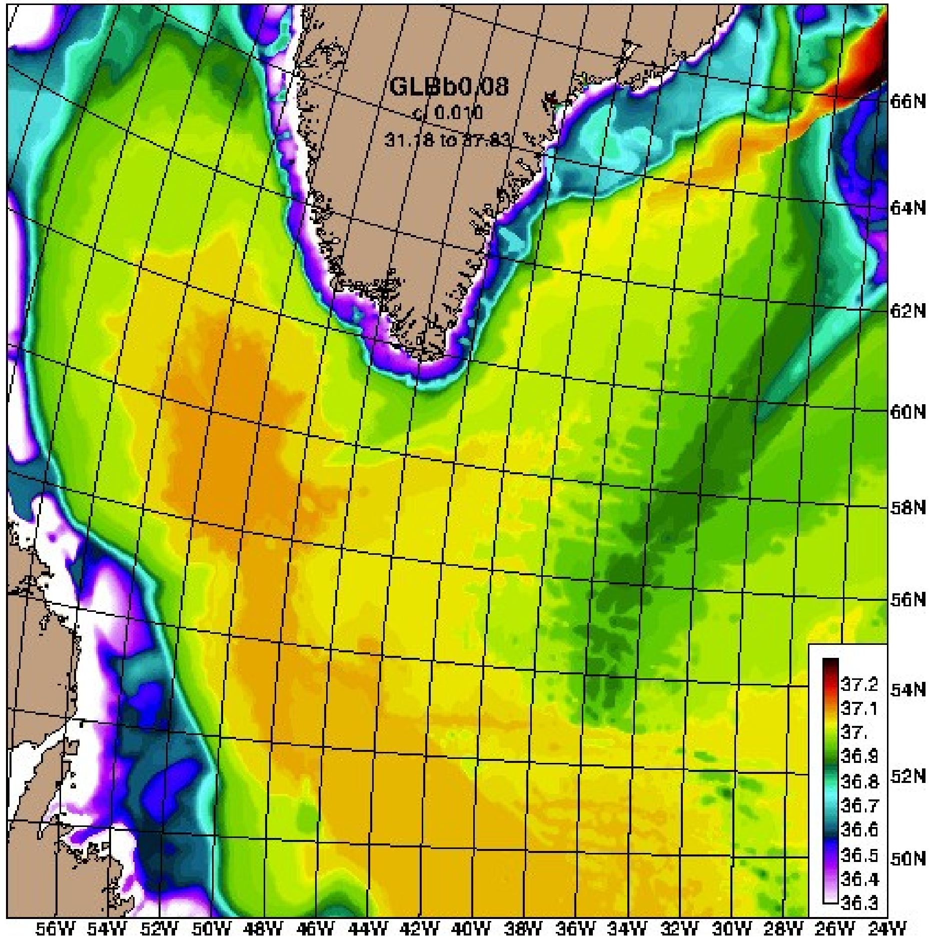
HYCOM

HYCOM-41-15.3 near-bottom pot. density Year 1918_1920



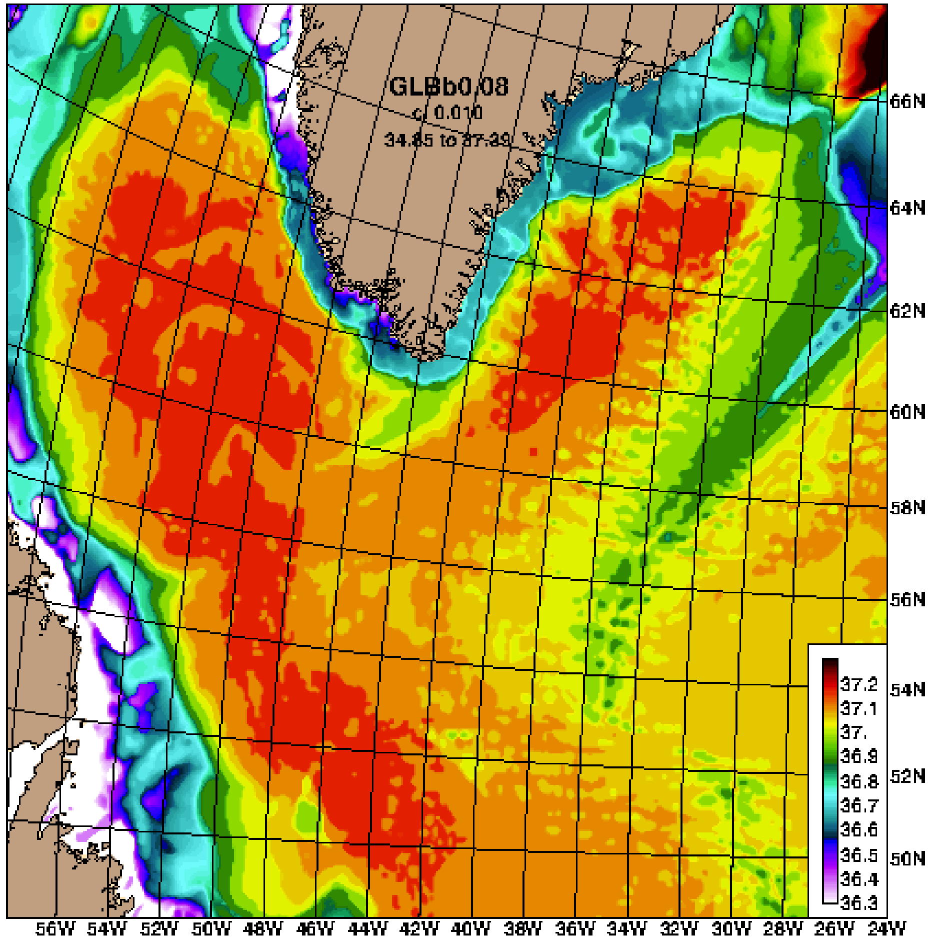
MOM6

MOM6-41-03.1 near-bottom pot. density Year 1918_1920



CLIMATOLOGY

GDEM42 near-bottom pot. density January

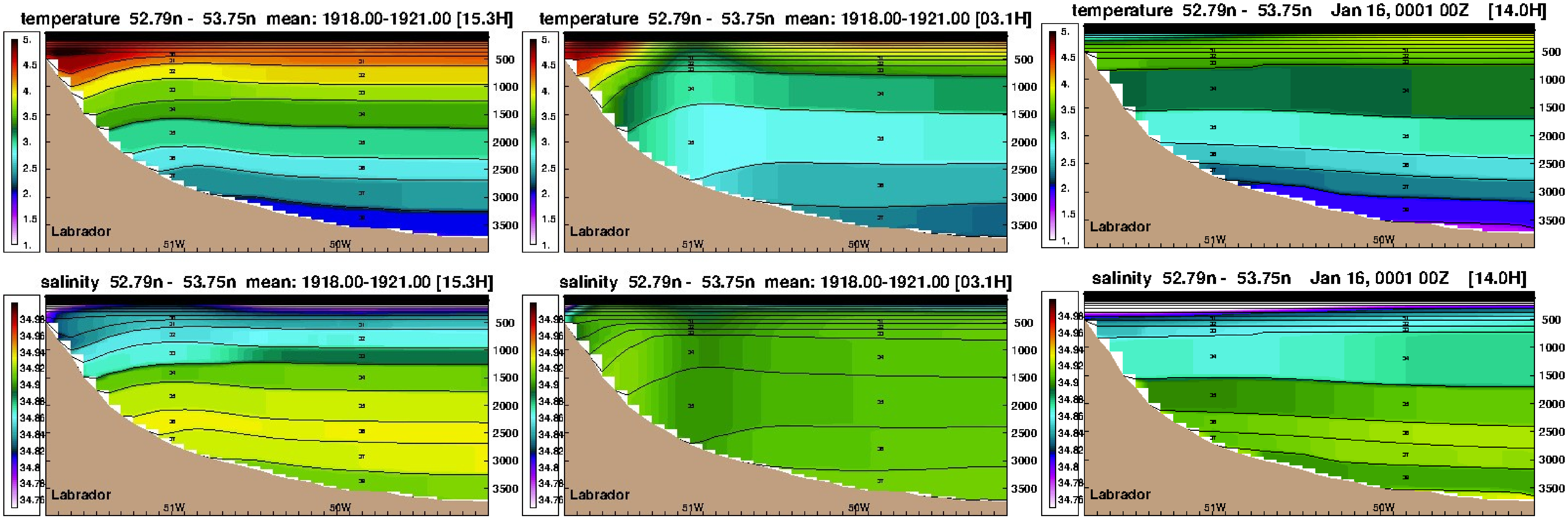


Black bar on HYCOM plot at 52°W,53 ° N is the section plotted on the next slide

VERTICAL CROSS SECTION IN SOUTH LABRADOR SEA

- The largest difference among the 68 section plots we routinely make
- MOM6 has lost layer 38 and is further from climatology than HYCOM

HYCOM MOM6 CLIMATOLOGY



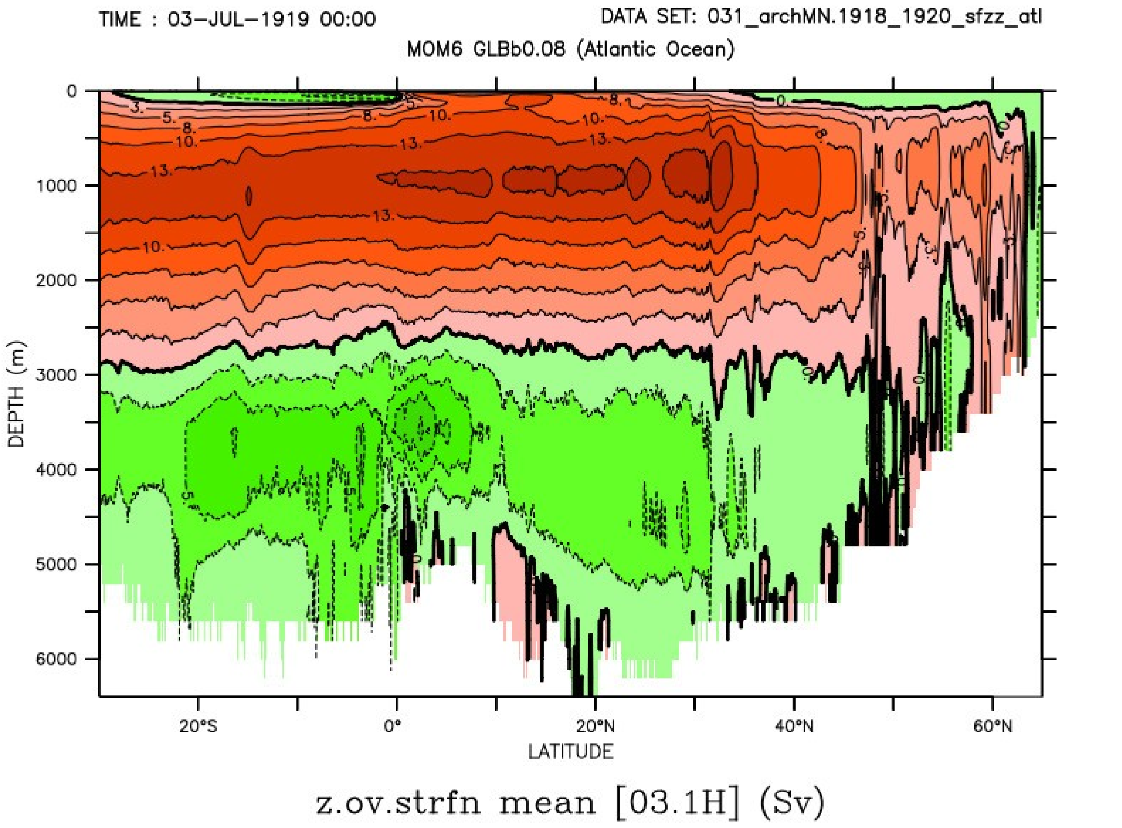
POSSIBLE CAUSES OF SHALLOW OVERTURNING CELL

- **Isopycnal and hybrid isopycnal-favoring models historically have produced relatively deep Atlantic overturning circulation, e.g. HYCOM**
- **Differences between HYCOM and MOM6 setup:**
  - **CICE v4 vs SIS2 sea ice and ice-ocean exchange**
  - **Vertical viscosity**
    - **Both based on KPP**
- **Hybrid vertical regridding, finding isopycnal layers:**
  - **HYCOM: maintains** *layer averages* **at target sigma2 potential densities**
  - **MOM6: maintains** *layer interfaces* **at target sigma2 potential densities, with a small compressibility factor to ensure a monotonic density profile**
- **Time scale for hybrid vertical grid regridding**
  - **HYCOM has hybrlx=16.0, use** $1/16$**th of the displacement when isopycnal**
  - **MOM6 does not have an identical option, REGRID TIME SCALE is closest, but it applies to all layers deeper than a specified range**
- **Perform tests with an Atlantic MOM6 domain**

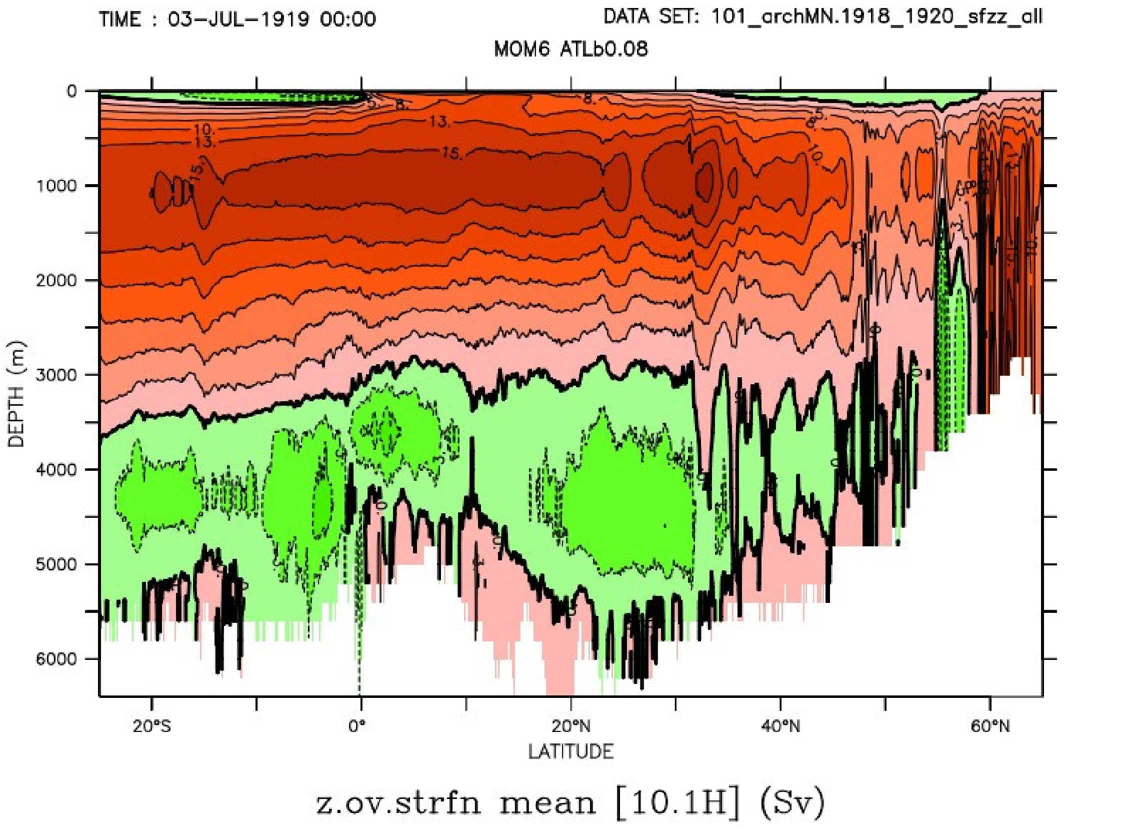
ATLANTIC OVERTURNING STREAMFUNCTION, MOM6 OVER YEARS 8-10

Atlantic domain is 28°S to 80°N from global grid with relaxation to GDEM4.2 monthly climatology in S/N zones: 43/103 grid points with 5-30/5-30 day e-folding time

GLOBAL MOM6



ATLANTIC MOM6



GLOBAL at 26°N, 0Sv: 2730m

ATLANTIC at 26°N, 0Sv: 2900m

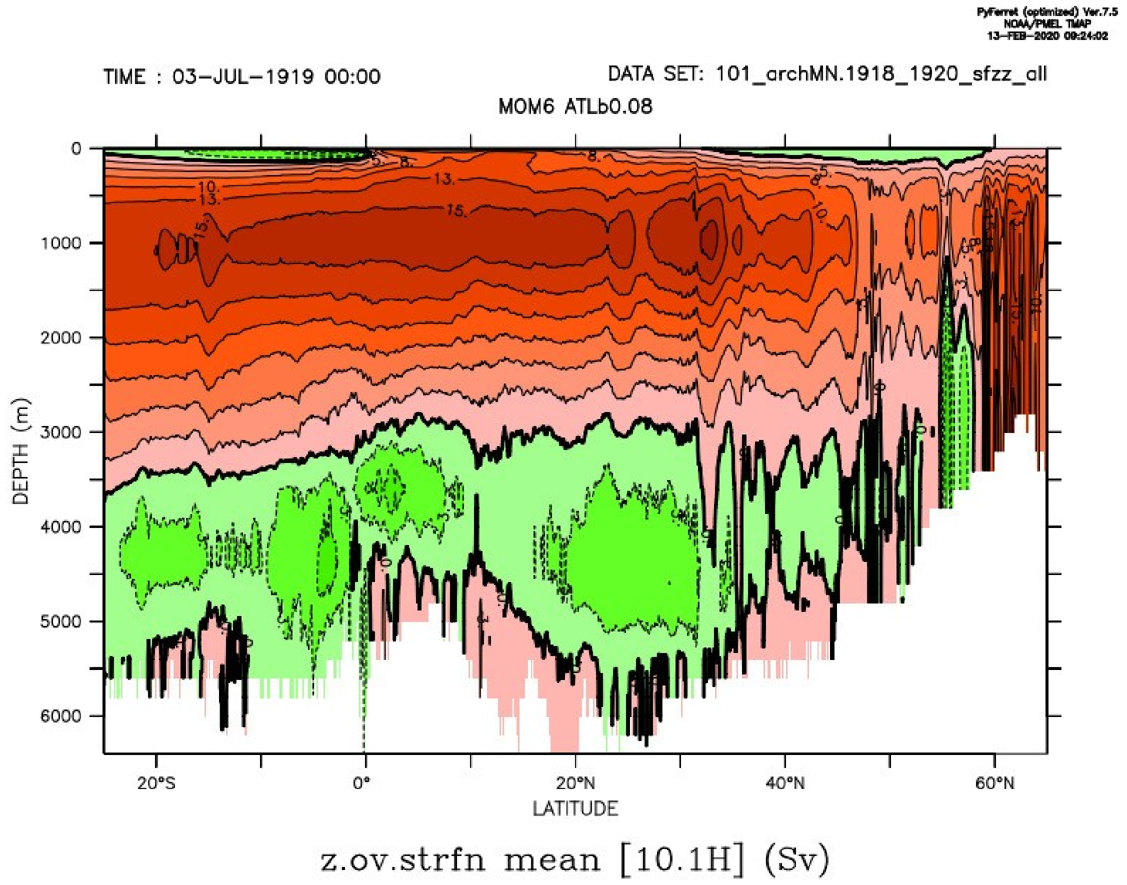
RAPID array at 26°N, 0Sv: 4300m

OVERTURNING STREAMFUNCTION, ATLANTIC MOM6 OVER YEARS 8-10

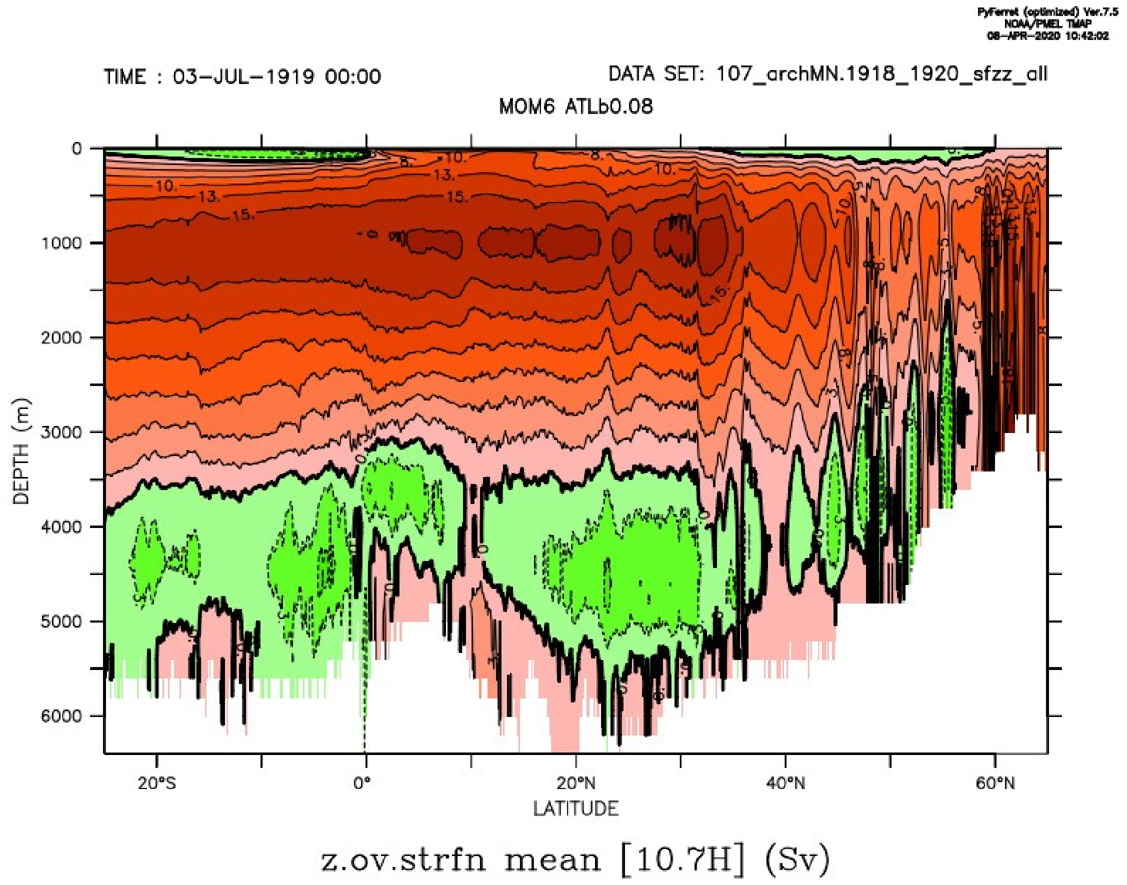
HYCOM has hybrlx=16.0, use $1/16$th of the displacement when isopycnal

- REGRID TIME SCALE=4800, REGRID_FILTER_SHALLOW_DEPTH=90, REGRID_FILTER_DEEP_DEPTH=114

ATLANTIC MOM6



REGRID MOM6



ATLANTIC at 26°N, 0Sv: 2900m

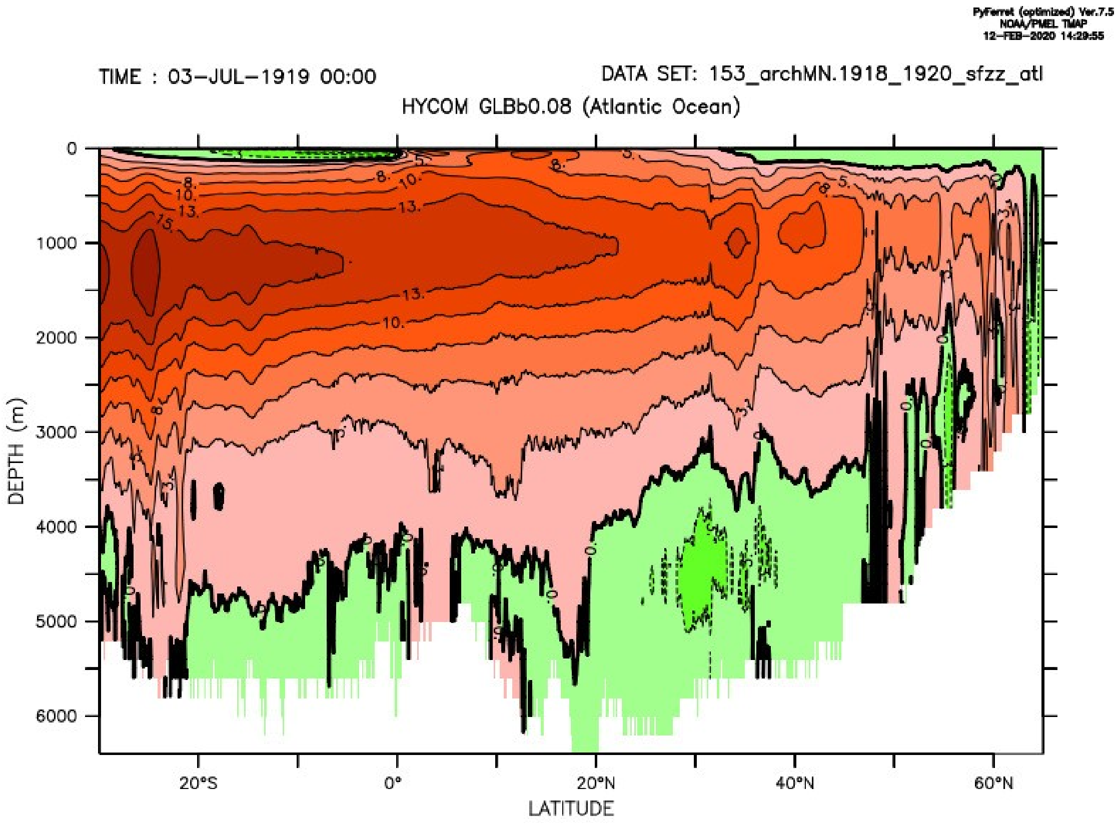
UPDATED2 at 26°N, 0Sv: 3400m

RAPID array at 26°N, 0Sv: 4300m

ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10

30°S to 65°N and 0 to 6500m depth, 2.5 Sv contour interval

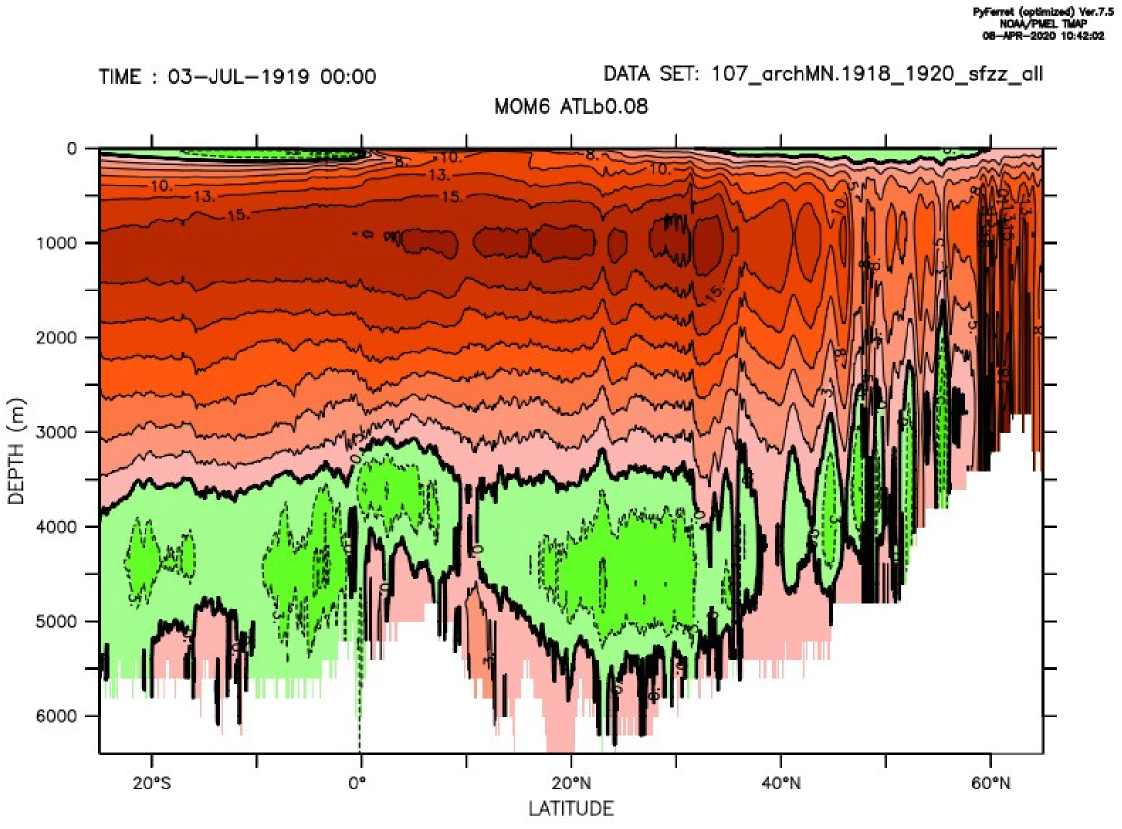
GLOBAL HYCOM



z.ov.strfn mean [15.3H] (Sv)

HYCOM at 26°N, 0Sv: 3500m

ATLANTIC MOM6 (REGRID)



z.ov.strfn mean [10.7H] (Sv)

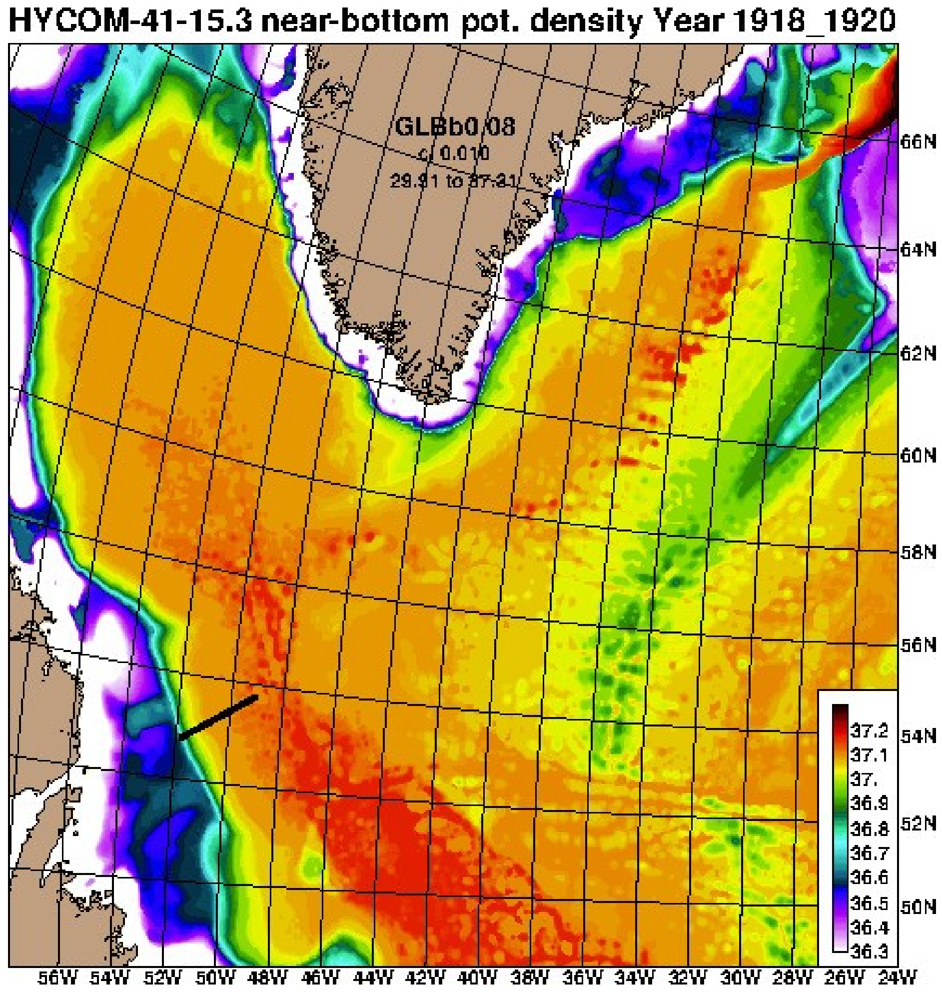
MOM6 at 26°N, 0Sv: 3400m

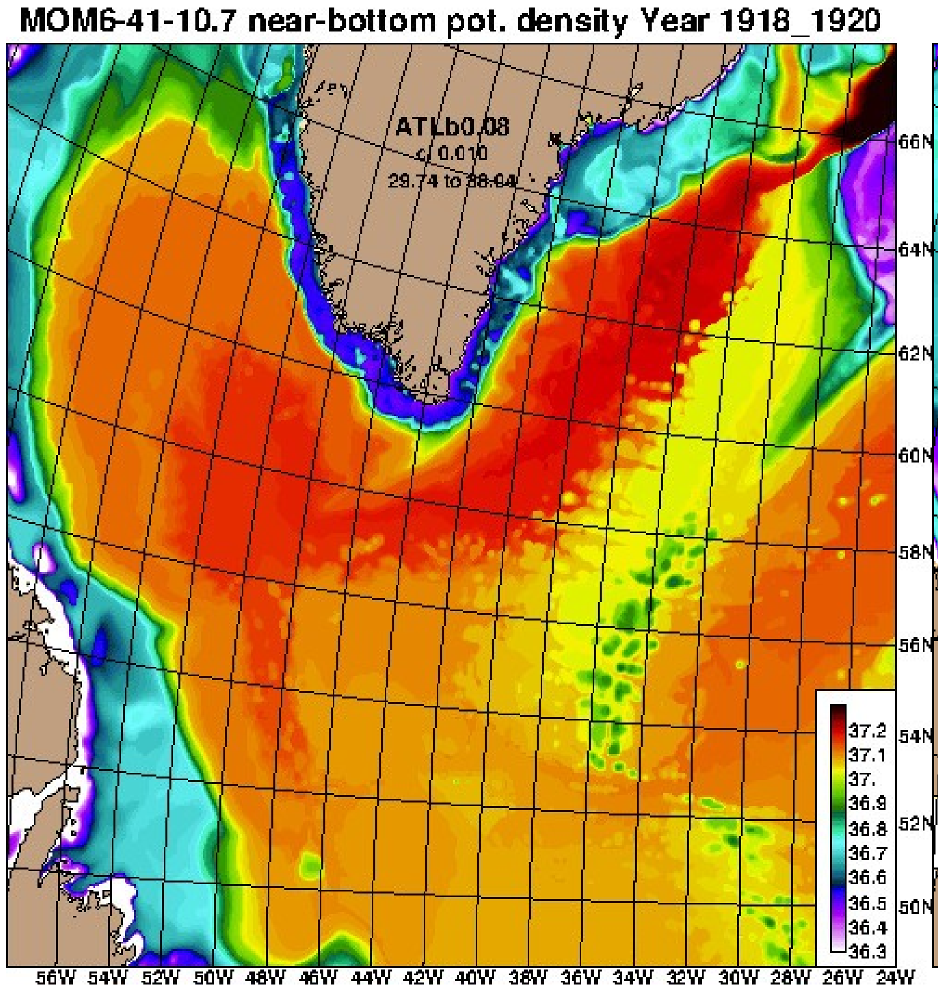
RAPID array at 26°N, 0Sv: 4300m

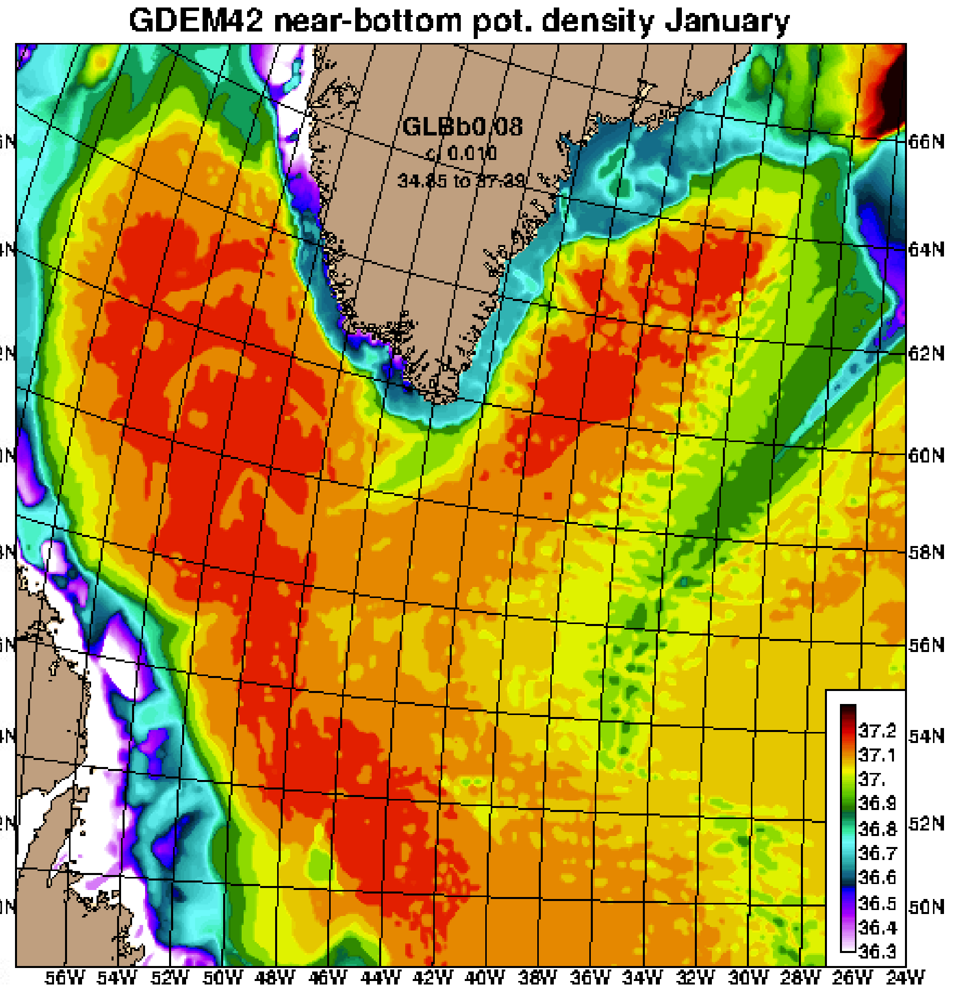
NEAR-BOTTOM POTENTIAL DENSITY (SIGMA2) IN LABRADOR SEA

REGRID TIME SCALE primarily responsible for the change in MOM6 density, now denser than GLOBAL HYCOM north of 52°N

GLOBAL HYCOM | **ATLANTIC MOM6 (REGRID)** | **CLIMATOLOGY**



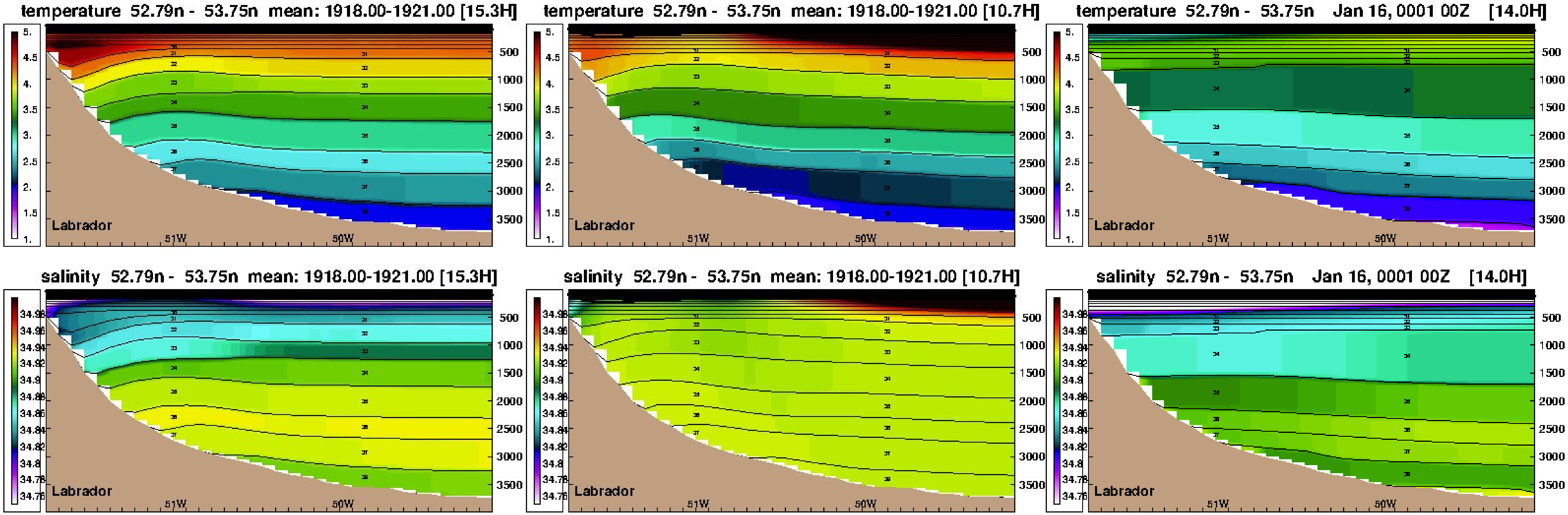




VERTICAL CROSS SECTION IN SOUTH LABRADOR SEA

Salinity still different between HYCOM and MOM6

GLOBAL HYCOM | **ATLANTIC MOM6 (REGRID)** | **CLIMATOLOGY**



SUMMARY

- **MOM6 was initially developed for climate applications at lower horizontal resolution than used for global ocean prediction**
- **Our MOM6 and HYCOM twin simulations on a 1/12° global tripole grid produced broadly similar solutions**
- **One difference was a shallow Atlantic overturning streamfuction in MOM6, that was shared by other MOM6 cases using the HYCOM-like hybrid vertical grid**
- **The cause of this has not been definitely identified, but it may be due to MOM6's vertical regridding approach being more viscous than HYCOM's**