# AMOC in MOM6

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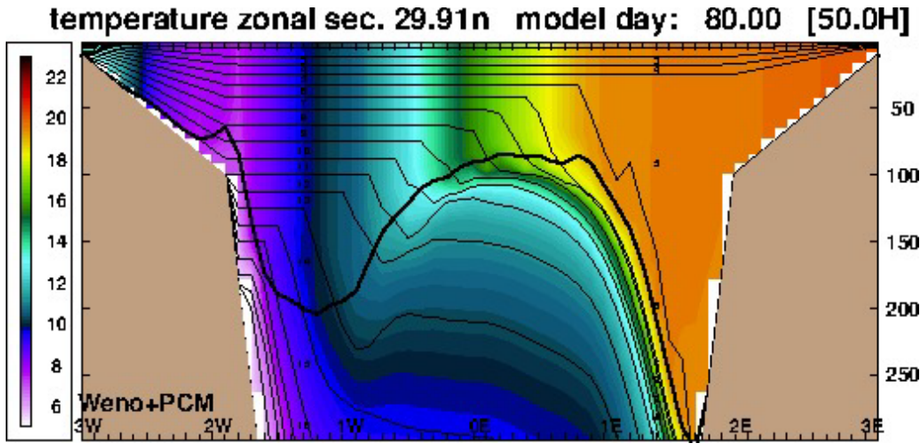
**CESM Earth System Prediction Working Group Meeting**

**27 January 2021**

# Motivation

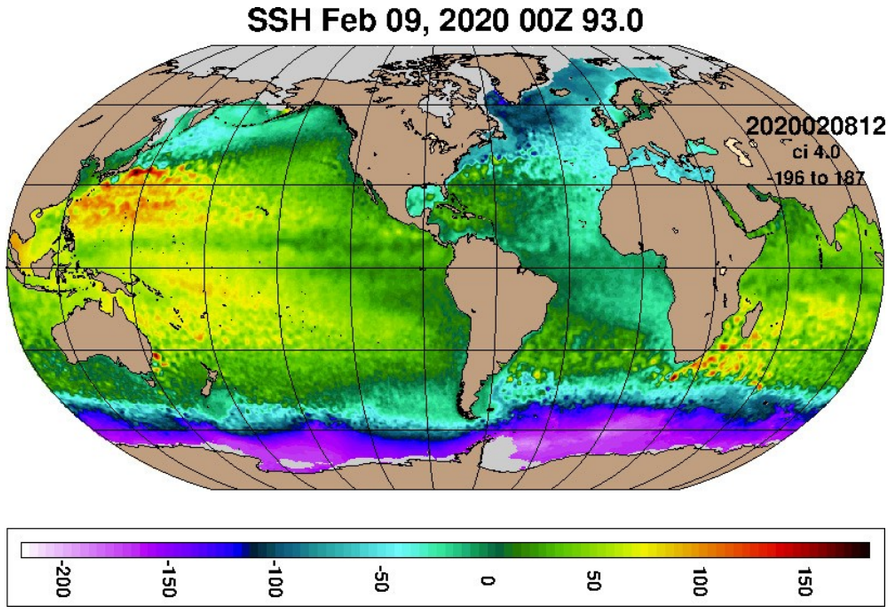



- **HYCOM was the first widely used ALE-based ocean model**
  **=> demonstrated the viability of this approach**

  **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

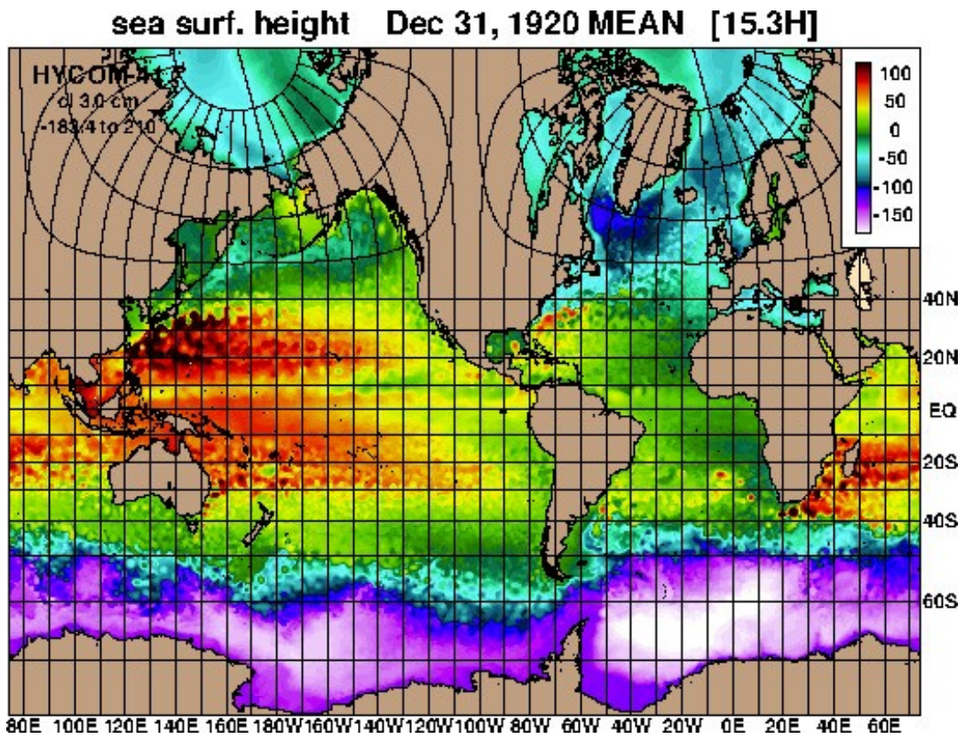



- Use the Navy GOFS 3.1 configuration
  - 41 hybrid layers in the vertical
    - Fixed vertical coordinate is Z-level only *(not sigma-Z)*
    - The same target isopycnals everywhere *(not spatially varying)*
  - Start from US Navy's GDEM 4.2 climatology
  - Use the KPP mixed layer
  - Repeat CFSR 2003 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

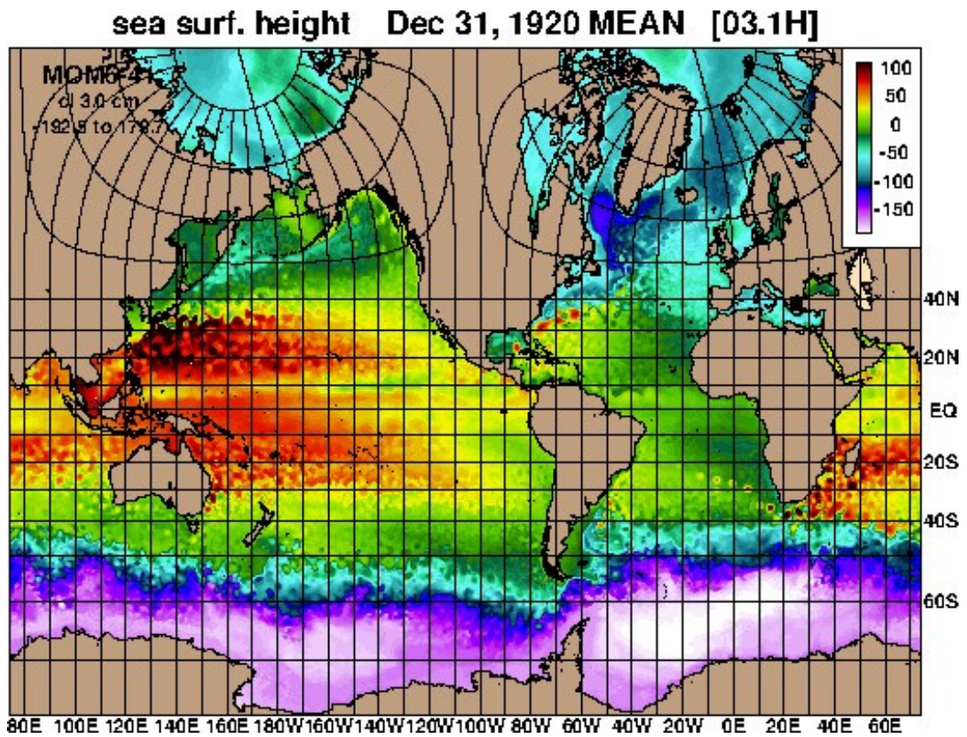
# SSH SNAPSHOT, END OF MODEL YEAR 10

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

## HYCOM




## MOM6

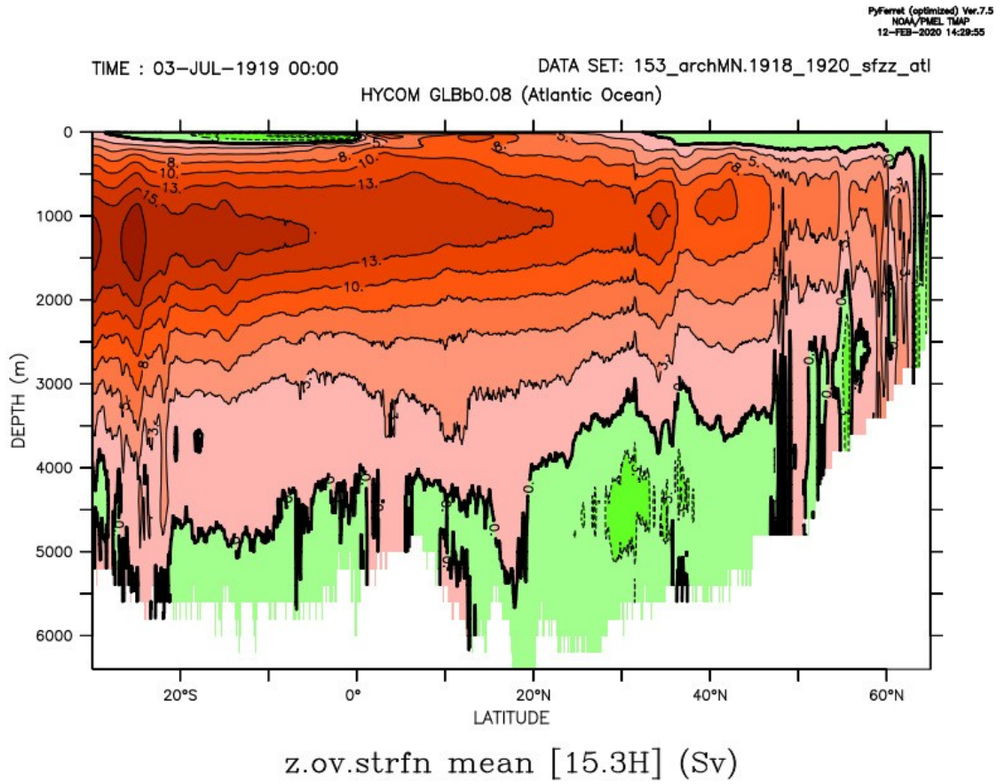



- On 1,800 Cray XC40 cores, MOM6 runs 1.5x faster than HYCOM
  - HYCOM is slightly faster than MOM6 per time step
  - MOM6 is stable with a significantly longer baroclinic time step, 300s vs 180s
  - Speedup similar to the time step ratio: 300/180 = 1.67

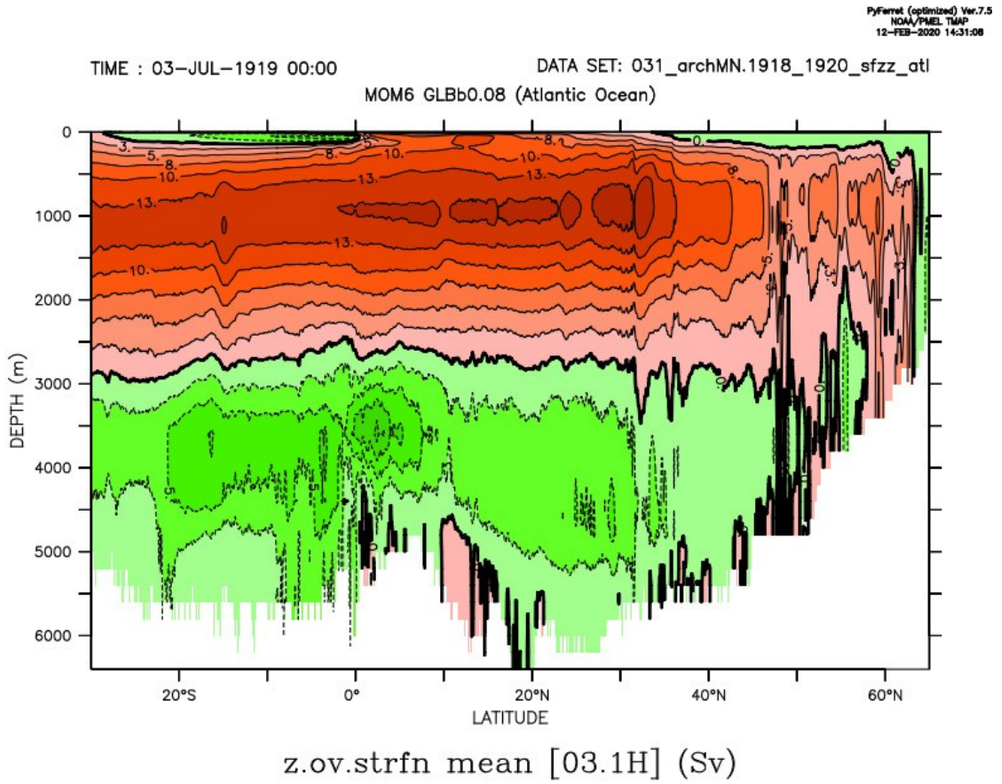
# ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10

## 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

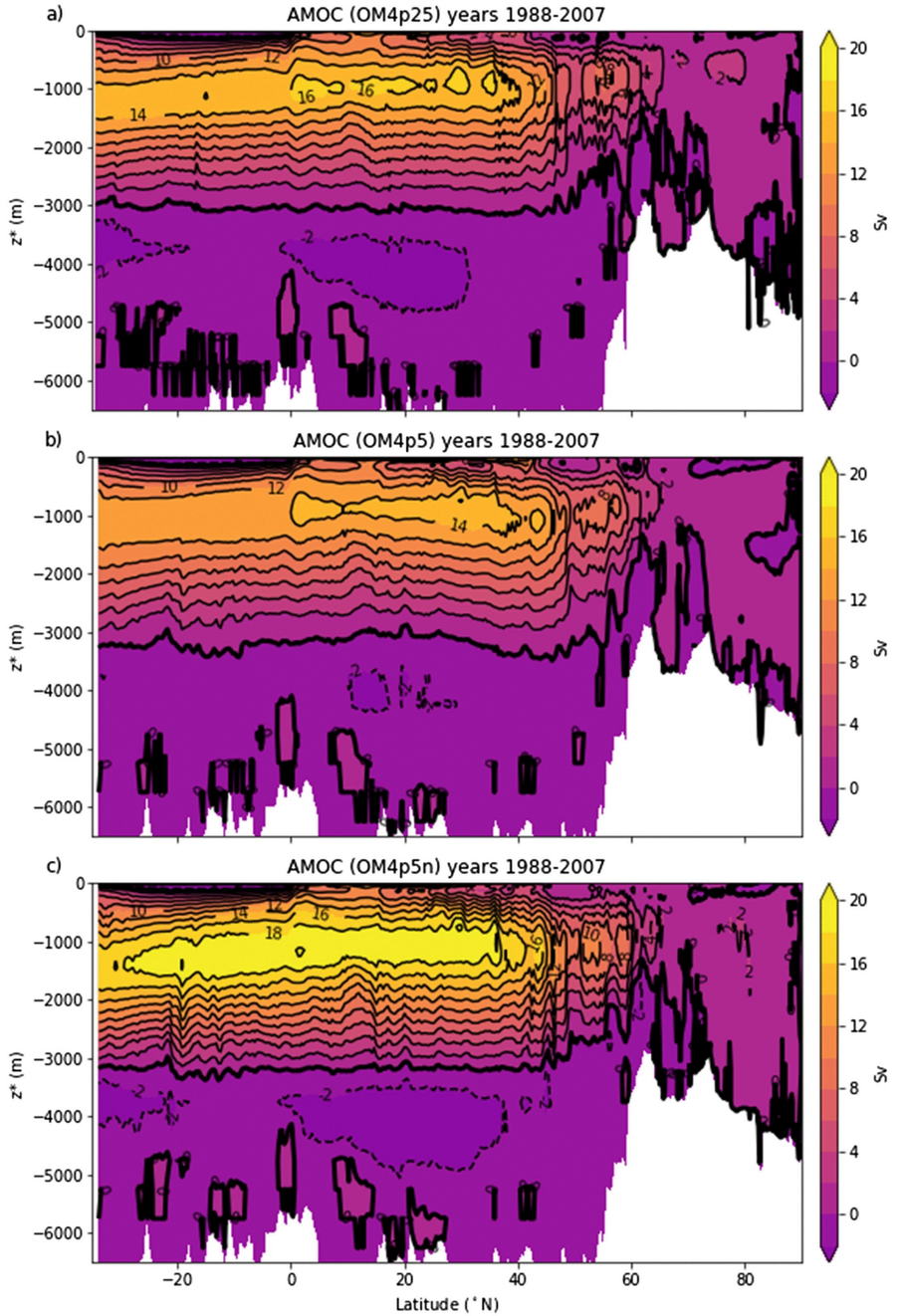
**MOM6 OM4 for years 1988-2007** (ocean – sea ice only)

**From Figure 12 of Adcroft et al. (2019)**

**(a) OM4p25 ¼°**

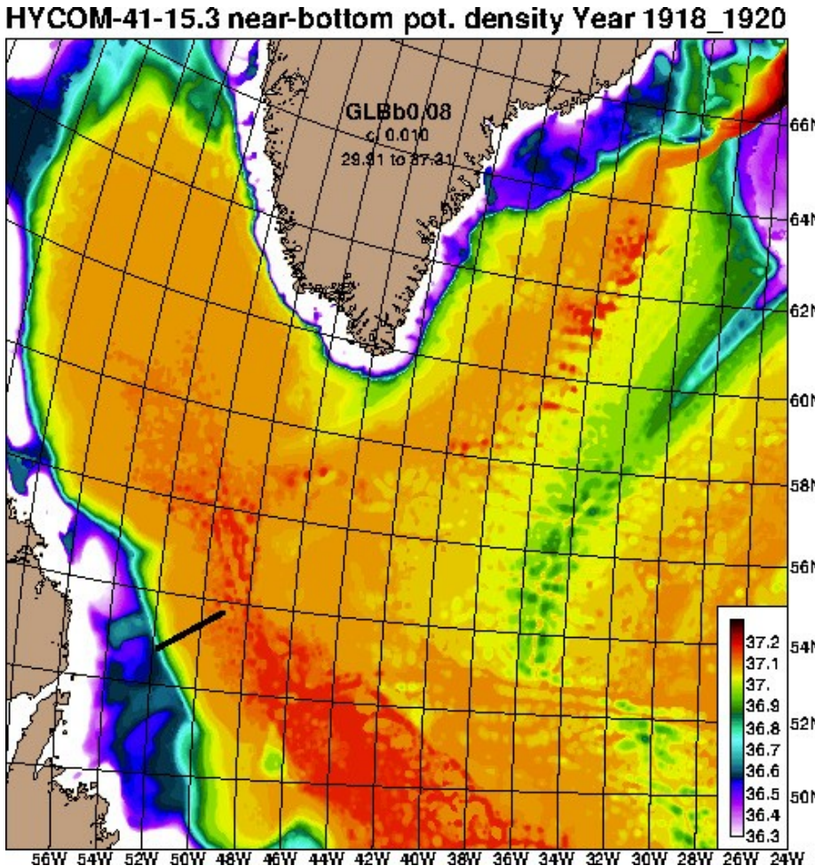
**(b) OM4p5 ½°**

**(c) OM4p5n CORE-II simulations**

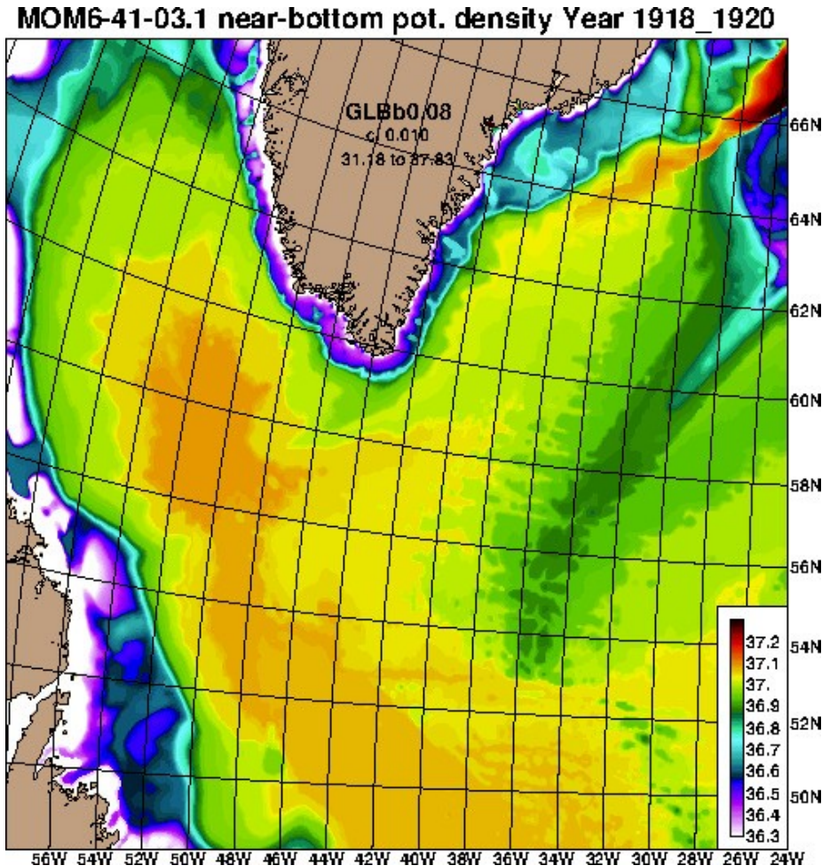


- **A shallow Atlantic overturning streamfuction is often due to too light overflow from the Nordic Seas**
- **MOM6 significantly less dense at the bottom than HYCOM**

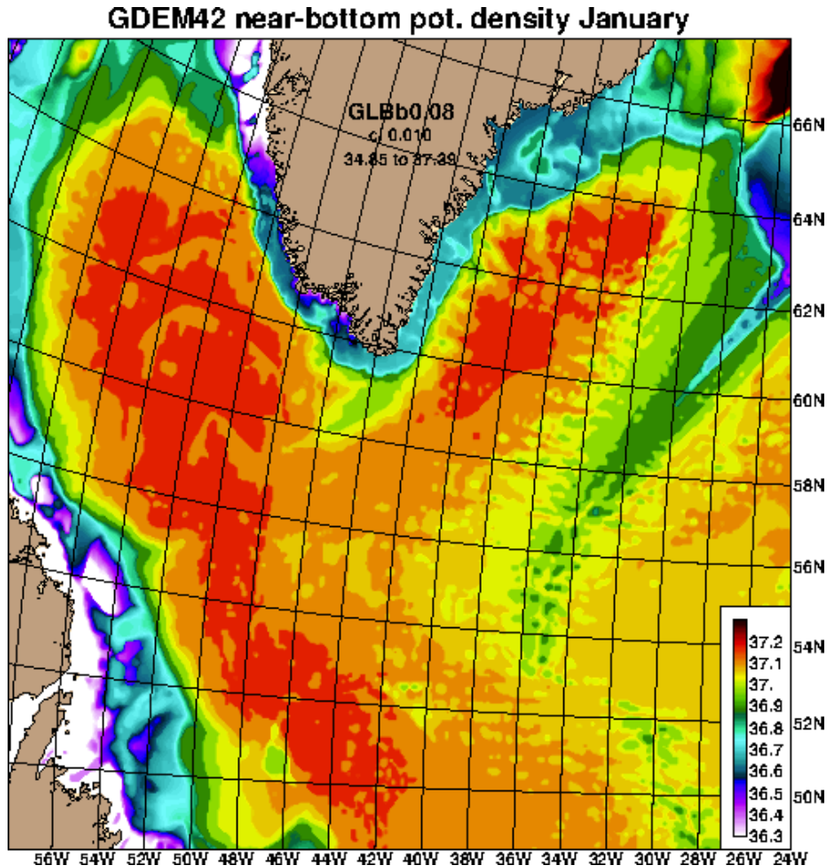
## HYCOM




## MOM6




## CLIMATOLOGY

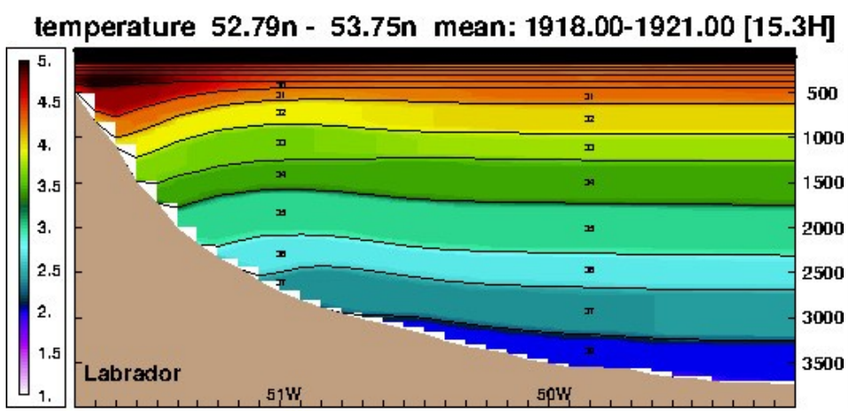


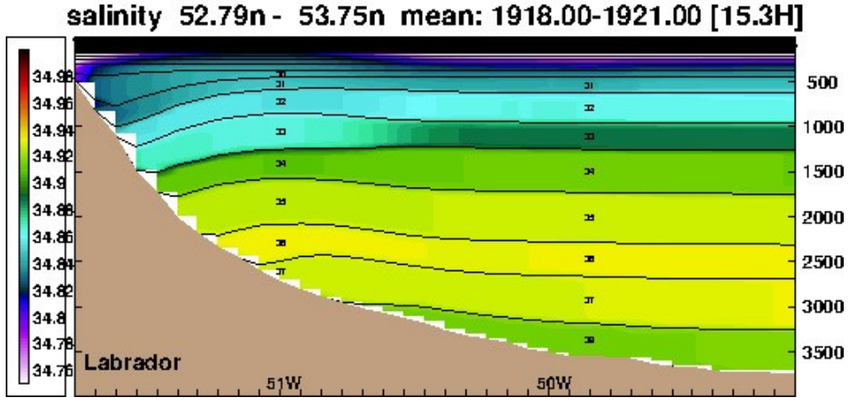

**Black bar on HYCOM plot at 52°W,53 ° N is the section plotted on the next slide**

# VERTICAL CROSS SECTION IN SOUTH LABRADOR SEA

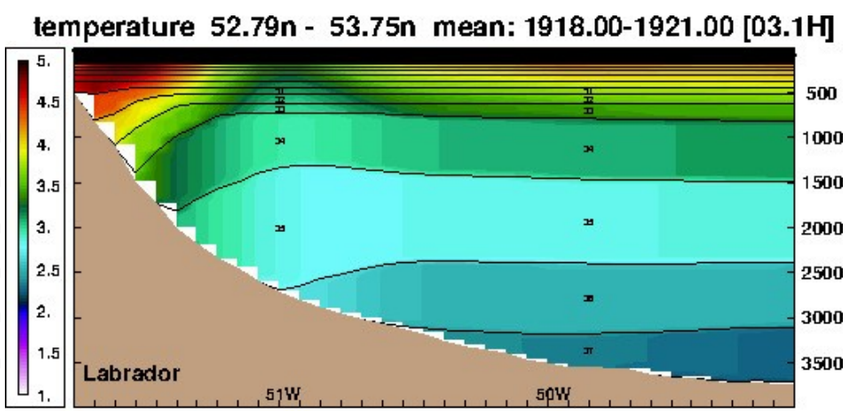
- The largest difference among the 68 section plots we routinely make
- MOM6 has lost layer 38 and is further from climatology than HYCOM

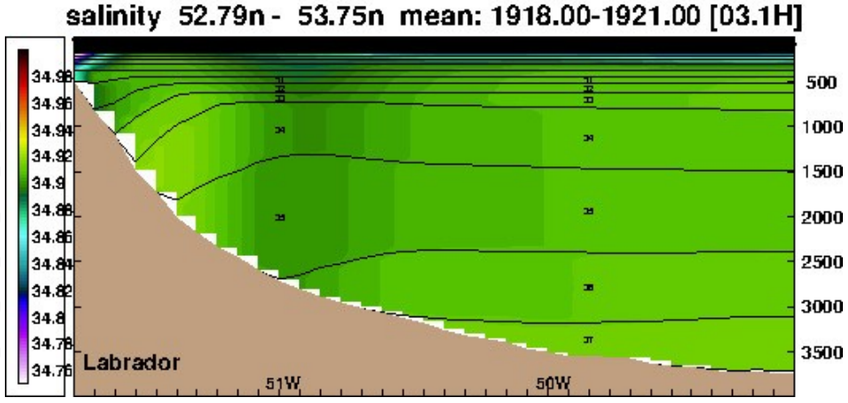
## HYCOM



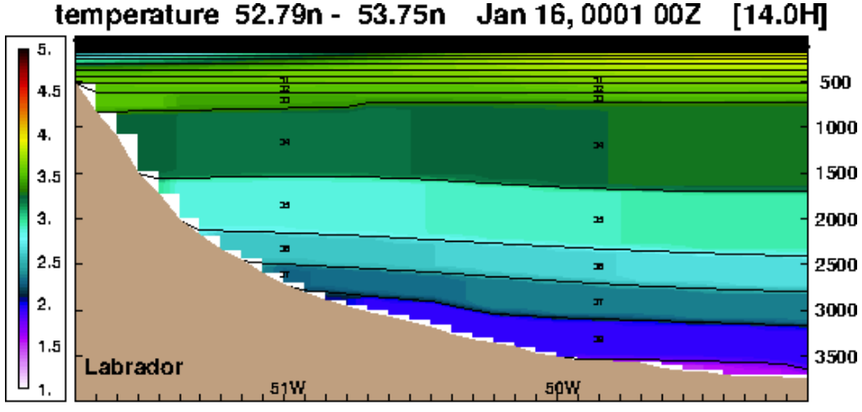



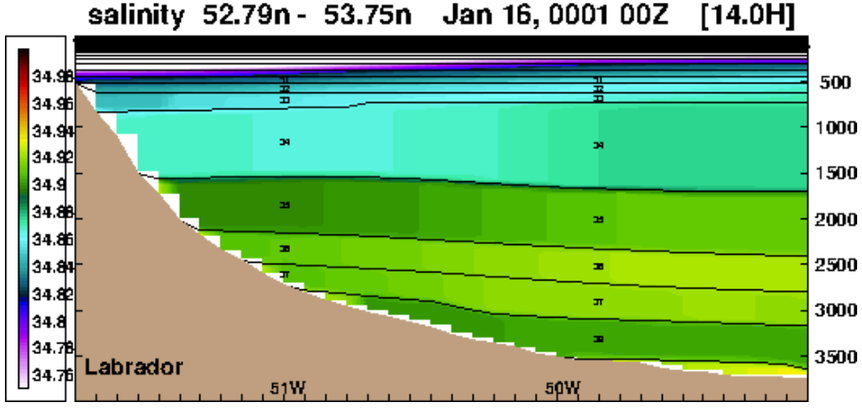

## MOM6




## CLIMATOLOGY



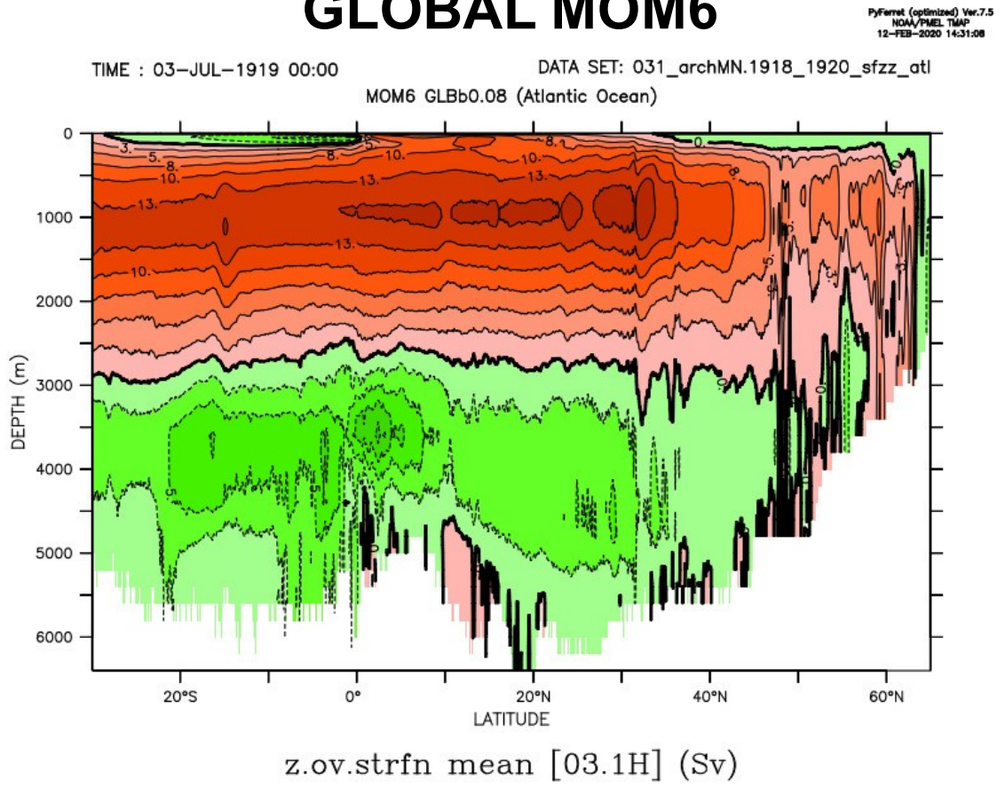
# POSSIBLE CAUSES OF SHALLOW OVERTURNING CELL

- **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**

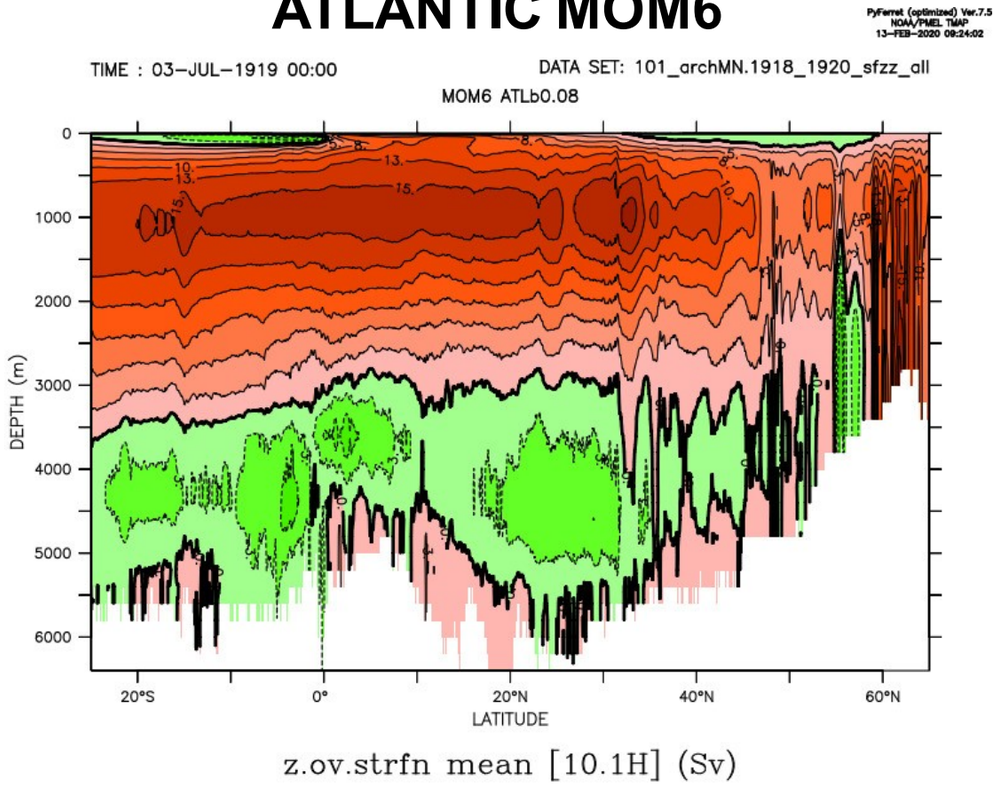
# ATLANTIC OVERTURNING STREAMFUNCTION, MOM6 OVER YEARS 8-10

**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**

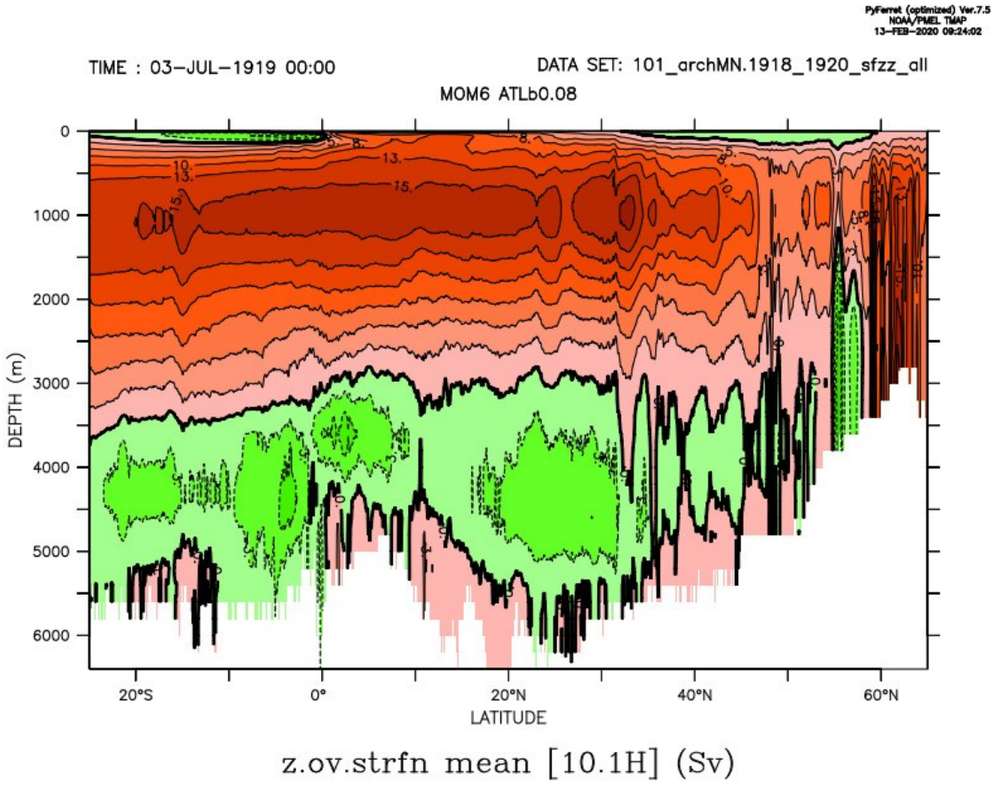
**RAPID array at 26°N, 0Sv: 4300m**

# OVERTURNING STREAMFUNCTION, ATLANTIC MOM6 OVER YEARS 8-10

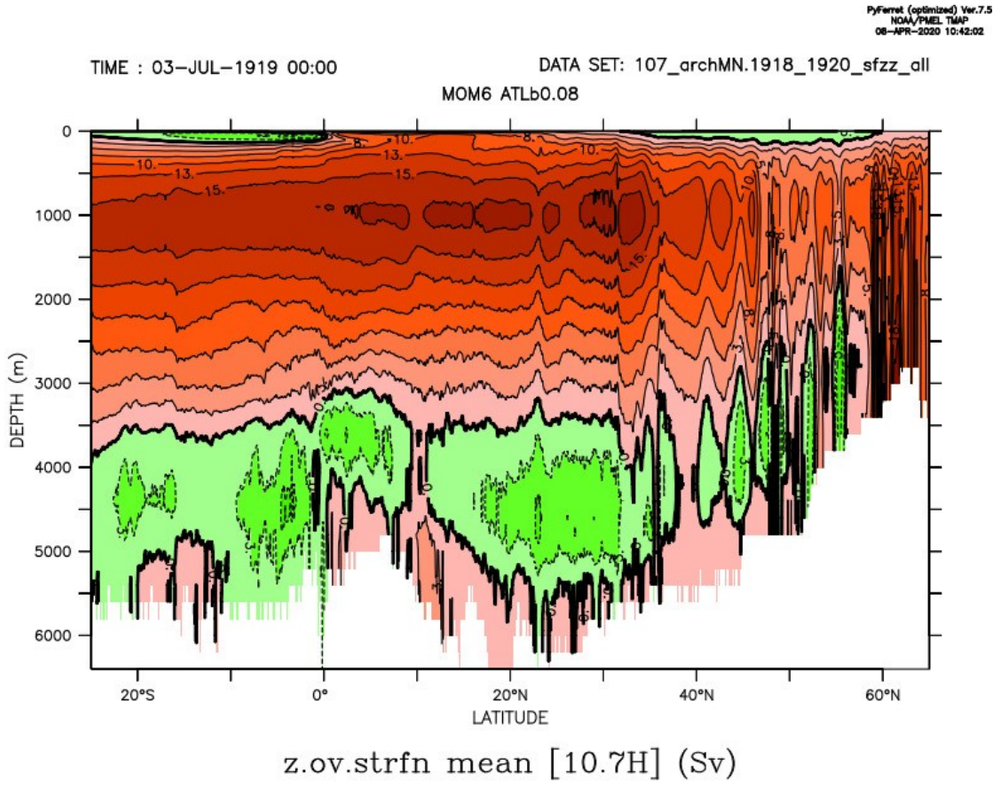
## HYCOM has hybrlx=16.0, use $1/16$th of the displacement when isopycnal

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

### ATLANTIC MOM6




### REGRID MOM6




**ATLANTIC at 26°N, 0Sv: 2900m**

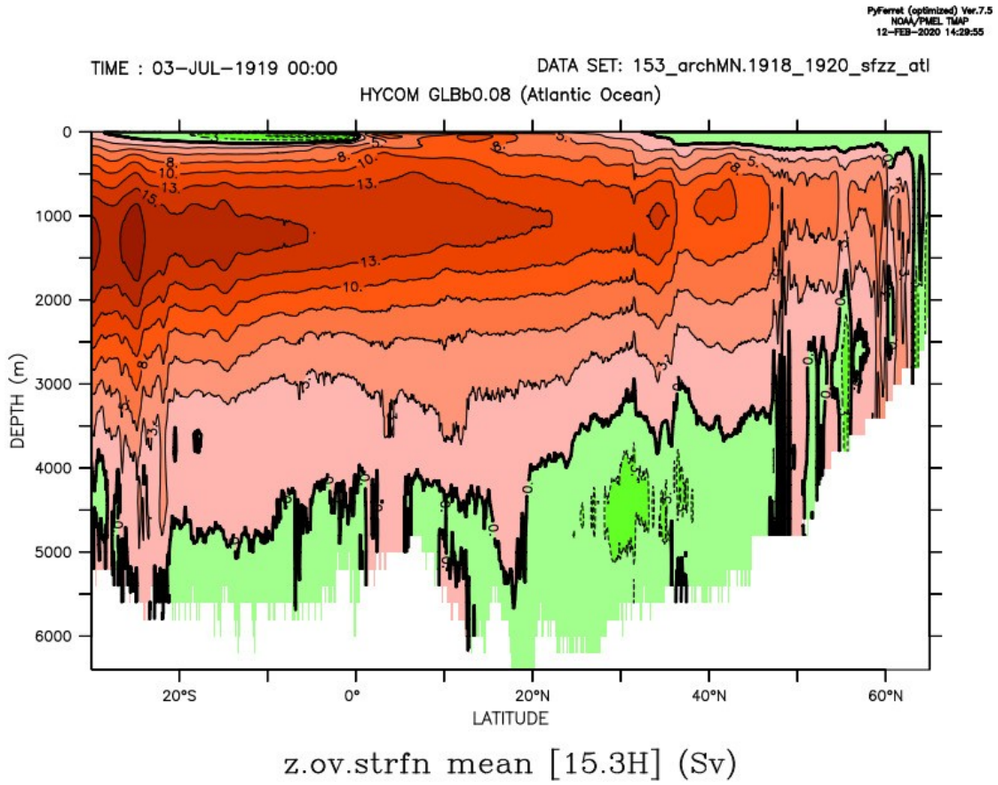
**UPDATED2 at 26°N, 0Sv: 3400m**

**RAPID array at 26°N, 0Sv: 4300m**

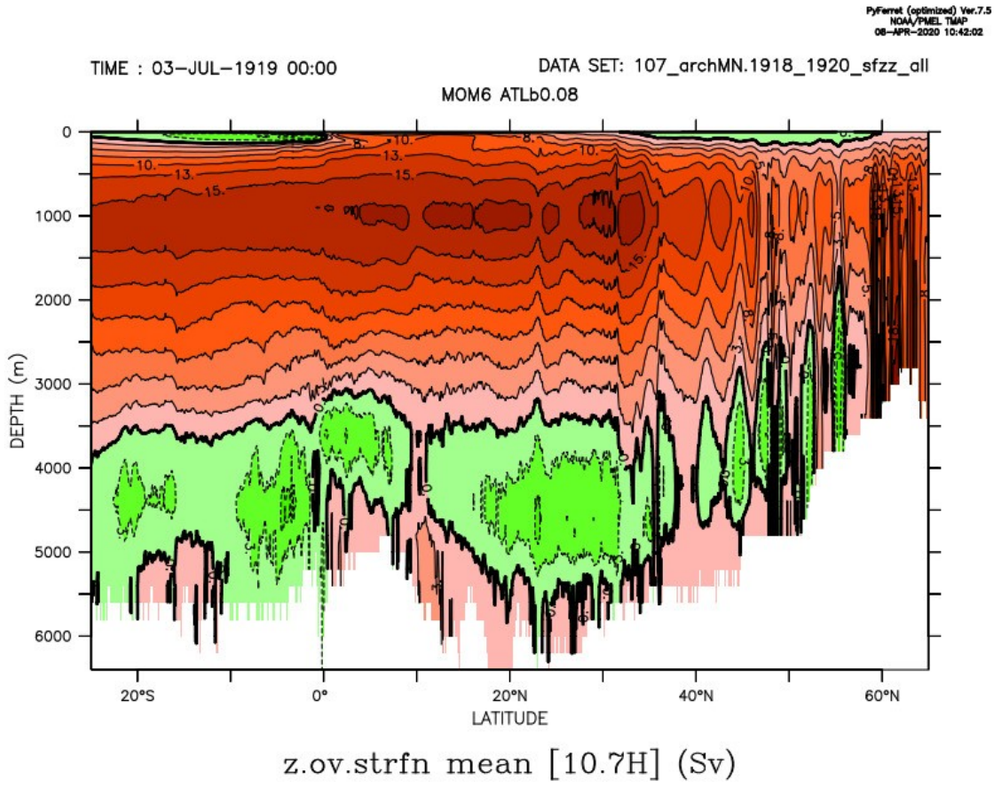
# ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10

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

### GLOBAL HYCOM




### ATLANTIC MOM6 (REGRID)




**HYCOM at 26°N, 0Sv: 3500m**

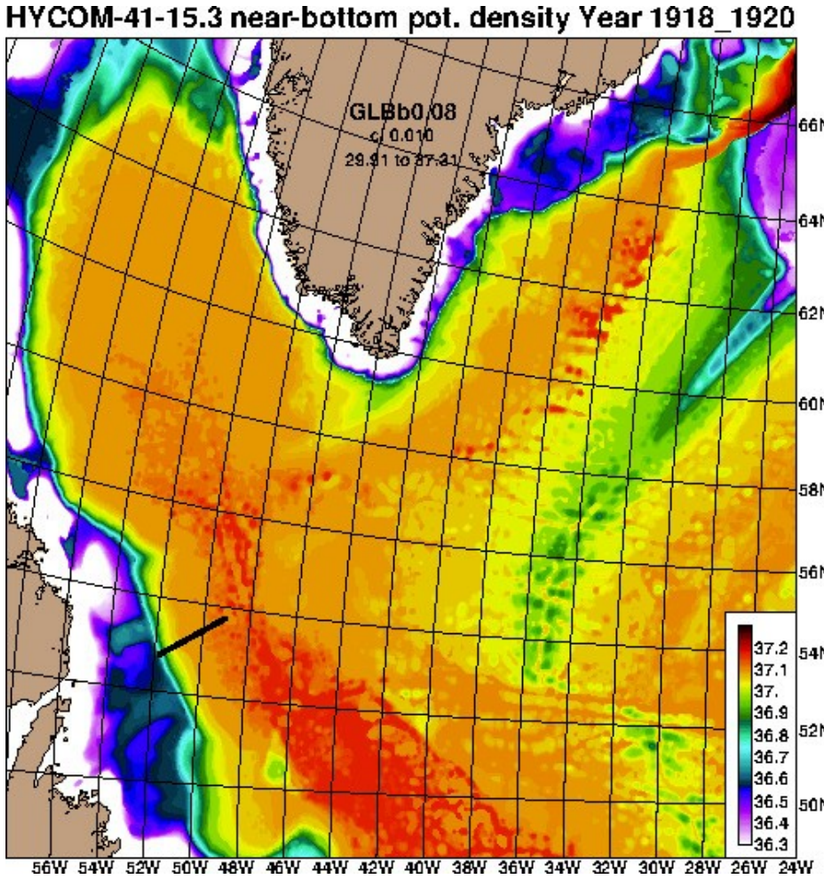
**MOM6 at 26°N, 0Sv: 3400m**

**RAPID array at 26°N, 0Sv: 4300m**

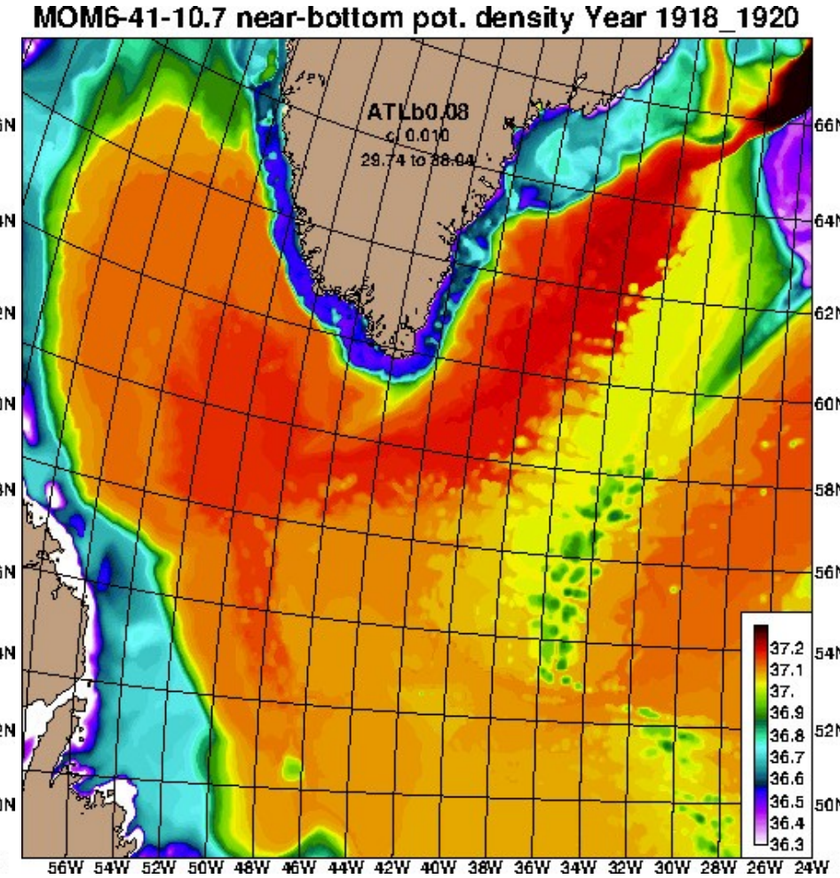
# NEAR-BOTTOM POTENTIAL DENSITY (SIGMA2) IN LABRADOR SEA

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

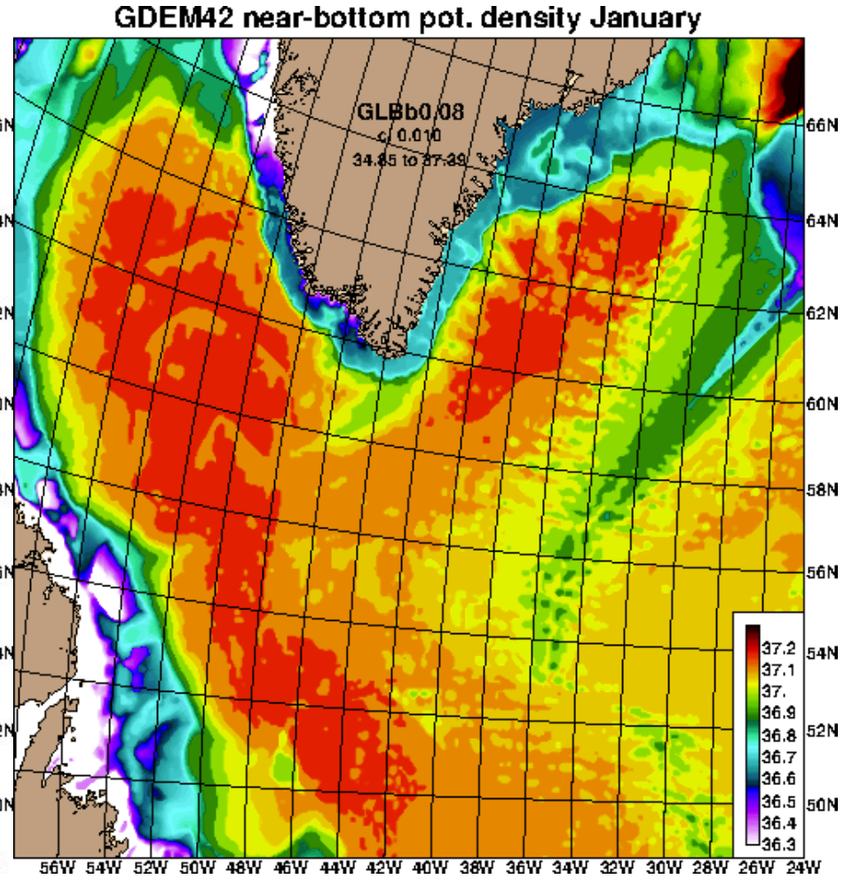
### GLOBAL HYCOM




### ATLANTIC MOM6 (REGRID)




### CLIMATOLOGY



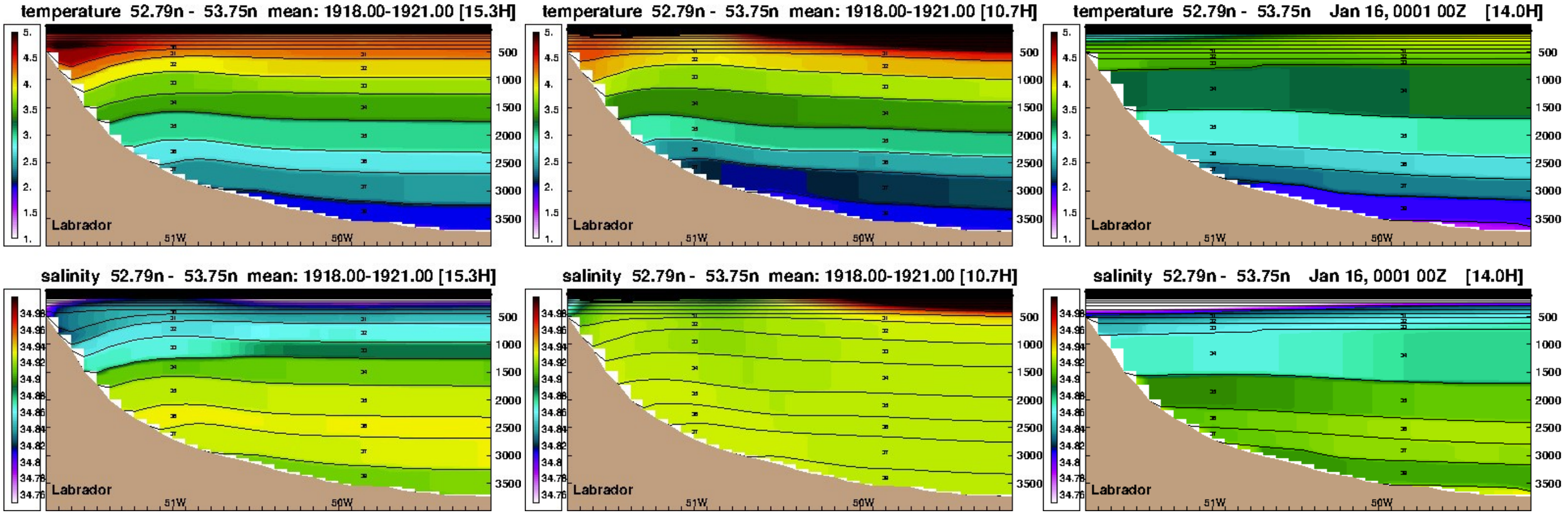
# VERTICAL CROSS SECTION IN SOUTH LABRADOR SEA

## 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