HYCOM1 VS HYBGEN FOR ALE REGRIDDING

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BASIC ALE APPROACH

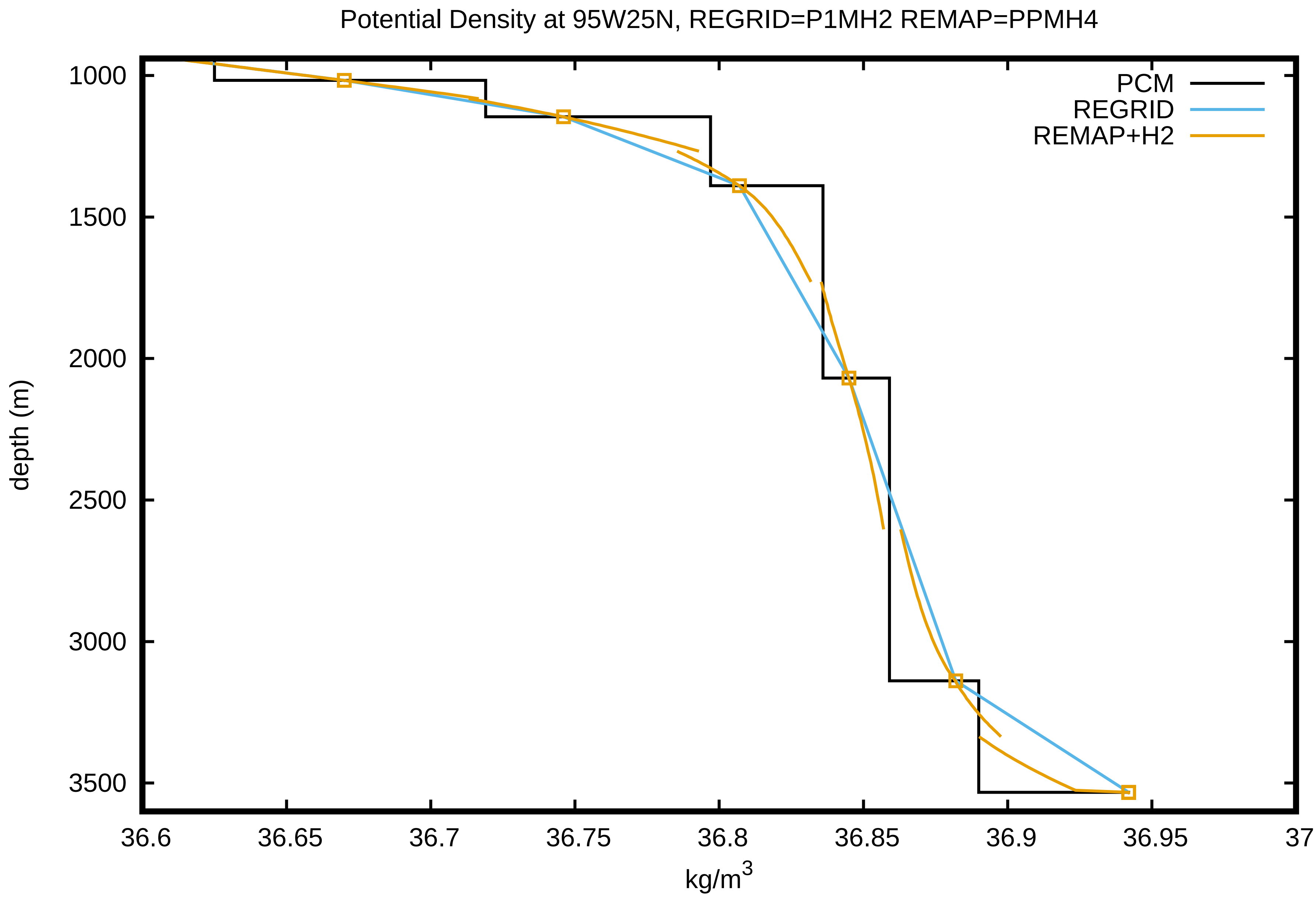
- **For each time step:**
- **Solve the layered continuity equation**
  - **Move all the layers**
- **Apply Arbitrary Lagrangian Eulerian (ALE) Method in the vertical**
  - **Regrid: select the "desired" layer structure**
    - **HYCOM1 and HYBGEN:**
      - **Favor isopycnals that outcrop into fixed depth layers**
  - **Remap: from the source to the regrid layers**
    - **Interfaces can move, but the fluid does not move**
    - **Choose interpolation that is conservative, with no new extrema**
    - **Nominally, this does not change the solution but it does add diffusion**

MOM6 ALE: HYCOM1

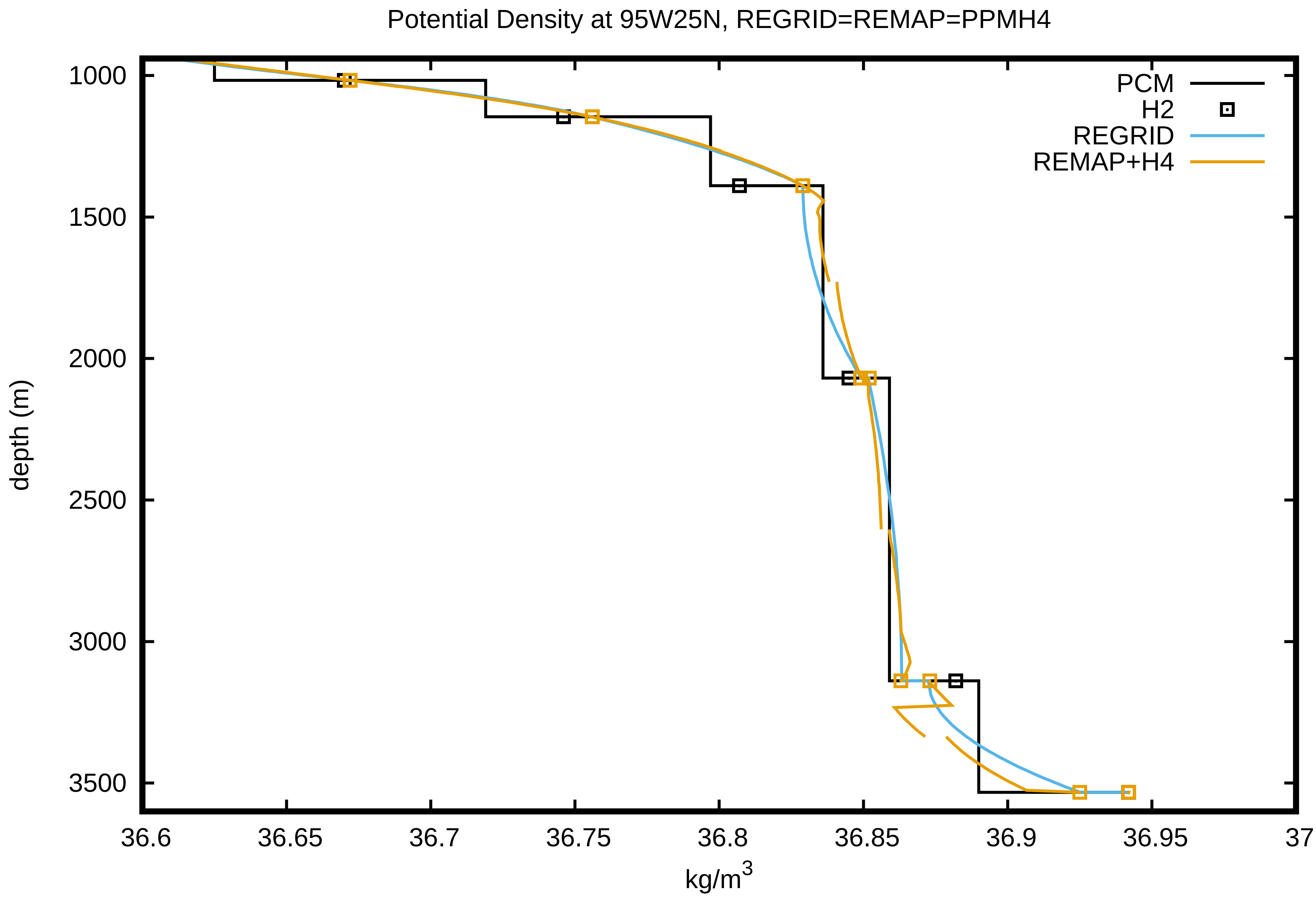
- Regridding walks a monotonic vertical profile
  - Source is layer sigma2 potential density, with a compressibility factor
    - Factor reduces the chance that layer N+1 is lighter than layer N
  - From these layer densities and the layer thicknesses, construct a vertical profile using piecewise polynomials
    - Profiles can be from a remapping scheme (e.g. PPM_H4)
      - P1M_H2, linear between H2 interfaces, is the only practical scheme
  - Target is interface sigma2 potential density plus compressibility factor
    - Constant in time and space
  - The new interface depths are at the location of targets on the profile
    - Unique mapping from a monotonic profile to the target isopycnals
- Vertical remapping typically uses PPM_H4 for all layers, where H4 indicates a cubic polynomial calculation of interface (edge) values
  - PPM limits edge values to lie between layer averages
- Produces smooth interfaces, no need for an additional interface smoother

MOM6 ALE: HYCOM1 REGRIDDING

- **Why not use the REMAP piecewise polynomials for REGRID?**
  - **PPM_H4 eventually produces unstable layers**
  - **PPM_CW, Colella and Woodward (1984), might be OK.**
    - **Adds a monotonic profile constraint to _H4 edges**
    - **Not yet in dev/gfdl**
- **The new interface depths are at the location of targets on the profile**
- **However, the actual new interface densities are:**
  - **Remap (e.g. PPM_H4) T & S to new interfaces, and then reapply _H2 (linear) or _H4 (cubic) to the new layer densities and thicknesses**
    - **The latter step is not performed in the running model**
- **The new interface densities can be approximated by holding the density profile fixed except for a single interface and applying the remapping and edge recalculation steps to get the new density at that interface**
  - **Allows us to visualize the effect of moving the interfaces**
    - **Orange curves on upcoming plots**



Potential Density at 95W25N, REGRID=P1MH2 REMAP=PPMH4
PCM
REGRID
REMAP+H2
1000
1500
2000
2500
3000
3500
depth (m)
36.6
36.65
36.7
36.75
36.8
36.85
36.9
36.95
37
kg/m3



Potential Density at 95W25N, REGRID=REMAP=PPMH4
PCM
H2
REGRID
REMAP+H4
depth (m)
1000
1500
2000
2500
3000
3500
36.6
36.65
36.7
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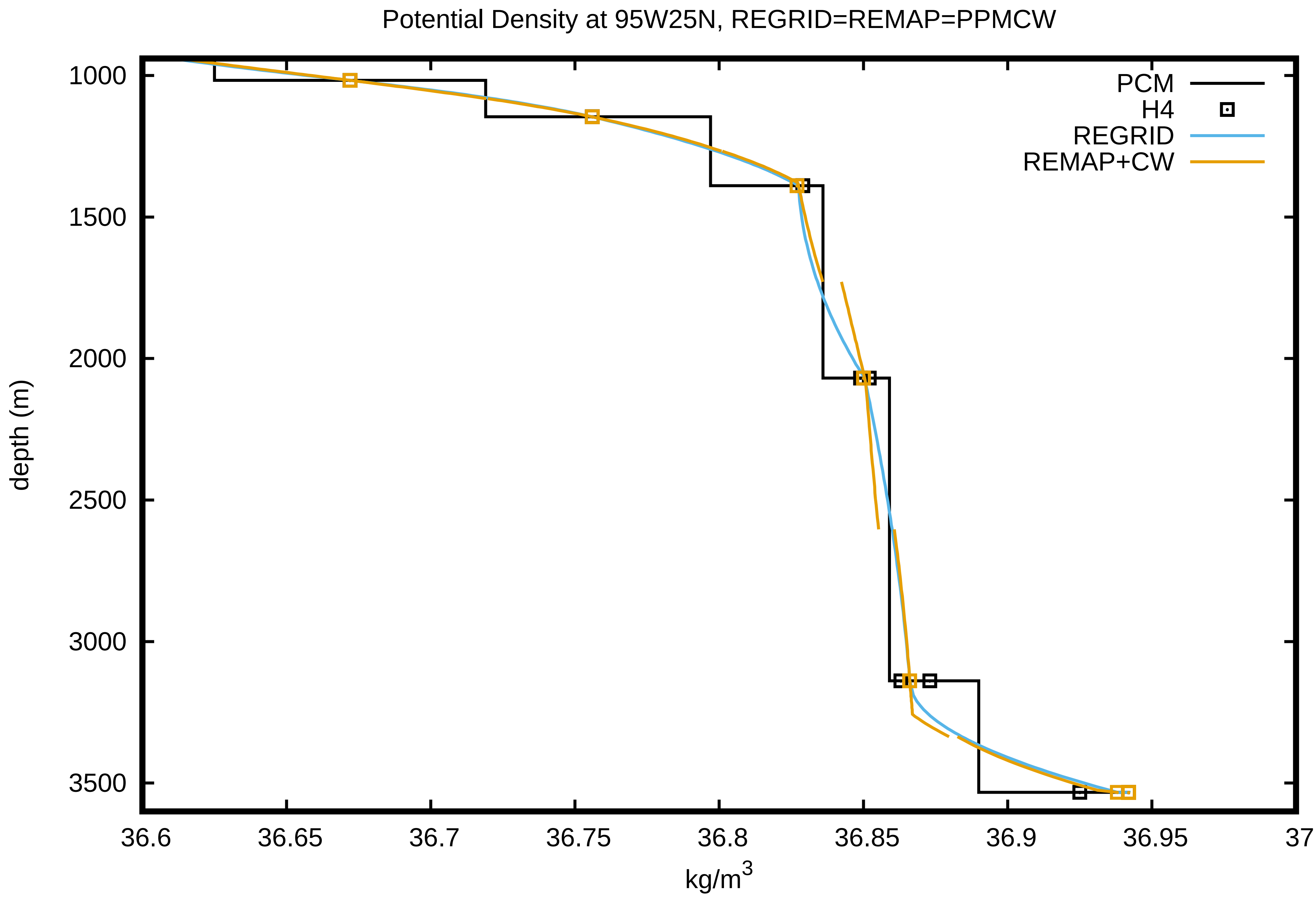
36.85
36.9
36.95
37
kg/m3


Potential Density at 95W25N, REGRID=REMAP=PPMCW
depth (m)
kg/m^3
PCM
H4
REGRID
REMAP+CW
1000
1500
2000
2500
3000
3500
36.6
36.65
36.7
36.75
36.8
36.85
36.9
36.95
37

HYCOM (MOM6) ALE: HYBGEN

- Target is layer average sigma2 potential density
  - Constant in time, constant (MOM6) or varying (HYCOM) in space
- Regridding uses entrainment
  - Maintain isopycnal layers
    - If layer is too heavy, entrain from layer above
    - If layer is too light, entrain from layer below
  - Sometimes an interface needs to move both up and down
    - Greedy algorithm, start from top and work down
    - Often get thick-thin-thick-thin layer structure
- Use PCM for near-isopycnal layers: regridding and remapping
  - Greatly simplifies entrainment/detrainment regridding
    - Detrainment (thinning) does not change layer density
  - PCM is 1st order accurate and very diffusive
    - Regridding does not effect most (iso-pycnal) layers
      - No regridding, no loss of accuracy and no diffusion
- Vertical remapping typically uses PPM with WENO-based cubic edge calculations for fixed and non-isopycnal coordinate layers
- Produces noisy interfaces, that require an interface smoother

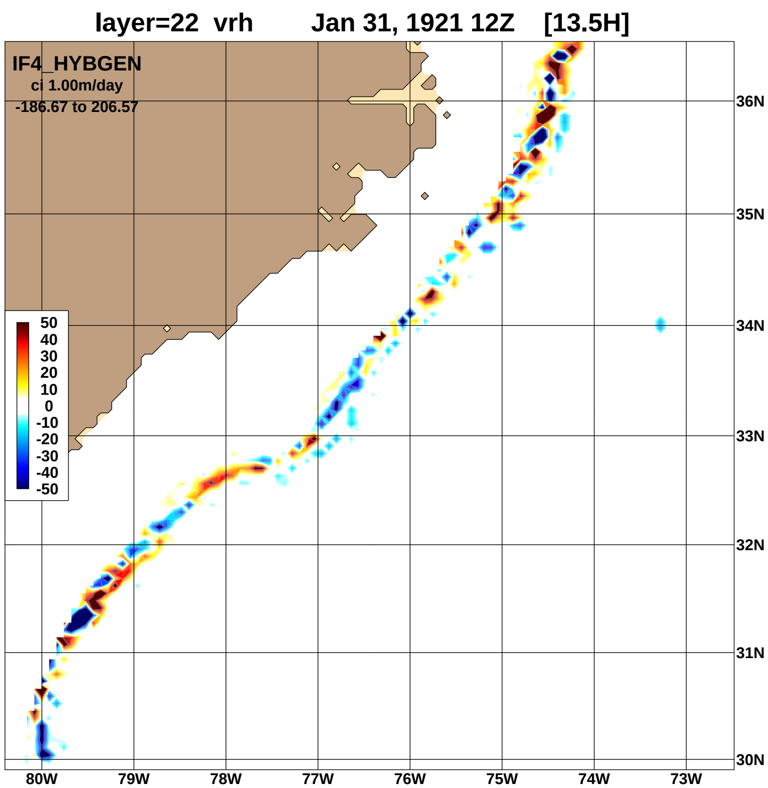
HYBGEN vs HYCOM1

- HYBGEN assumes the source layer structure is close to the desired result, HYCOM1 makes no such assumption (number of layers in/out can differ)
  - HYCOM1 can regrid from z coordinates to isopycnals,
    HYBGEN can't
  - MOM6 uses HYCOM1 as a vertical interpolator, e.g. for initialization, INTERPOLATE_SPONGE_TIME_SPACE and ODA_INCUPD
- HYBGEN often produces a thick-thin-thick-thin layer structure, and HYCOM1 does not
- HYBGEN maintains isopycnal layers exactly but HYCOM1 does not
  - If a layer changes thickness adiabatically:
    - Its layer average potential density (HYBGEN) is unchanged
    - Its interface potential density (HYCOM1) is not, because this depends on nearby layer thicknesses and densities
    - So the associated interfaces are moved by the HYCOM1 regridder and preserved by the HYBGEN regridder
- In general, HYBGEN moves interfaces significantly less than HYCOM1, so HYBGEN likely causes less diapycnal diffusion than HYCOM1

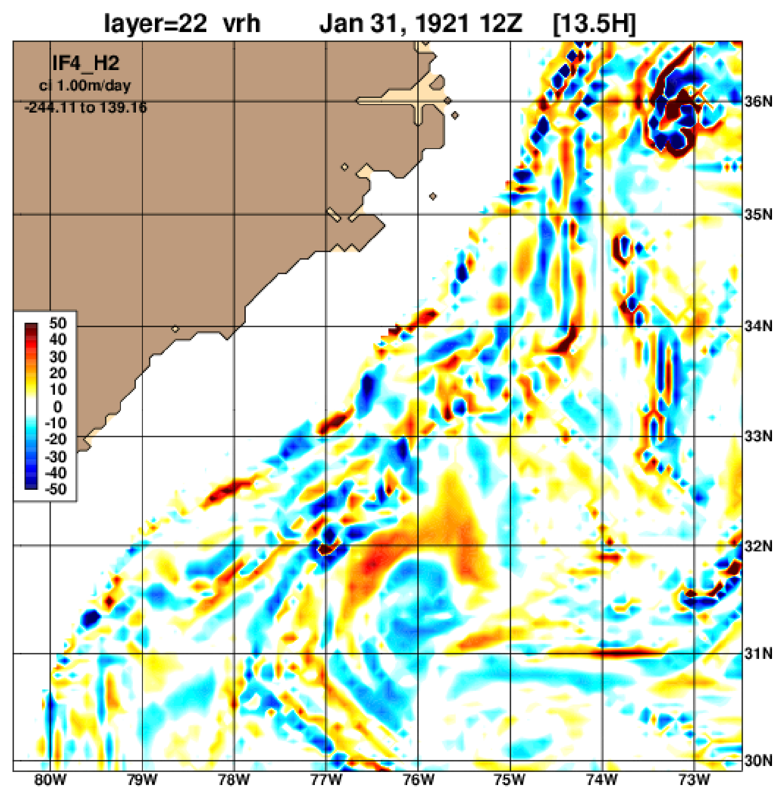
GULF STREAM LAYER 22 REGRID THICKNESS CHANGE (M/DAY) SNAPSHOT

- 0.08 degree Atlantic MOM6 with 41 layers, CFSR 2003 repeated forcing
- Run for 31 days with INTERFACE_FILTER after 10 years of HYCOM1
- Change from REGRID only, 50 m/day is 17 cm/timestep (DT_THERM=300s)

HYBGEN



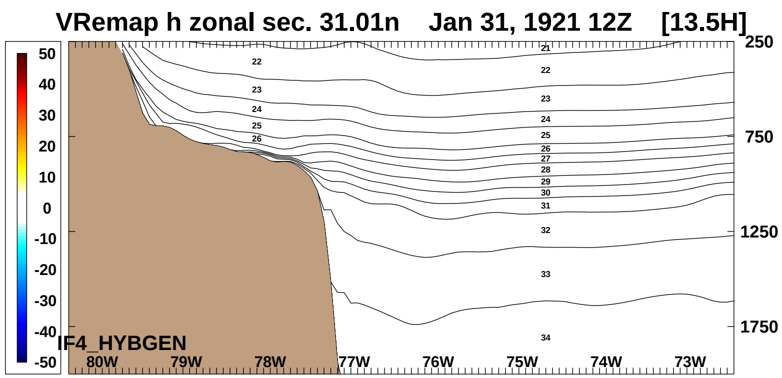
HYCOM1

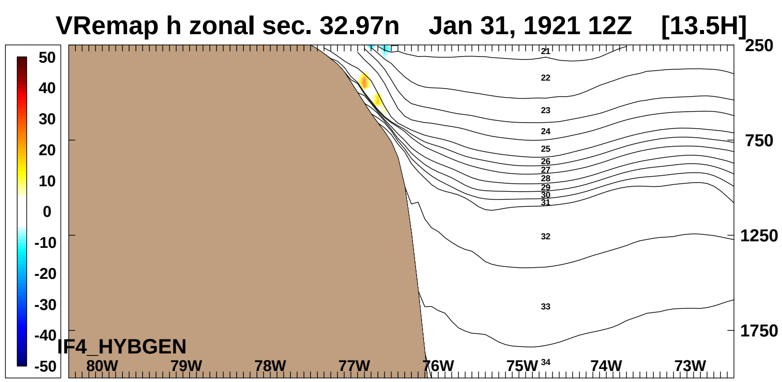


GULF STREAM 31N & 33N REGRID THICKNESS CHANGE (M/DAY) SNAPSHOT

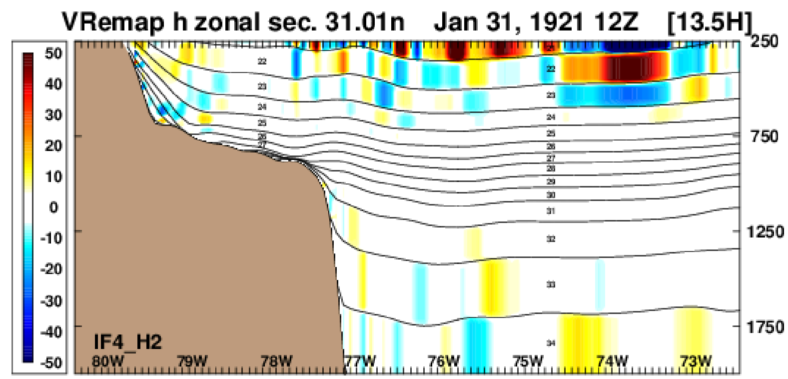
- 0.08 degree Atlantic MOM6 with 41 layers, CFSR 2003 repeated forcing
- Run for 31 days with INTERFACE_FILTER after 10 years of HYCOM1

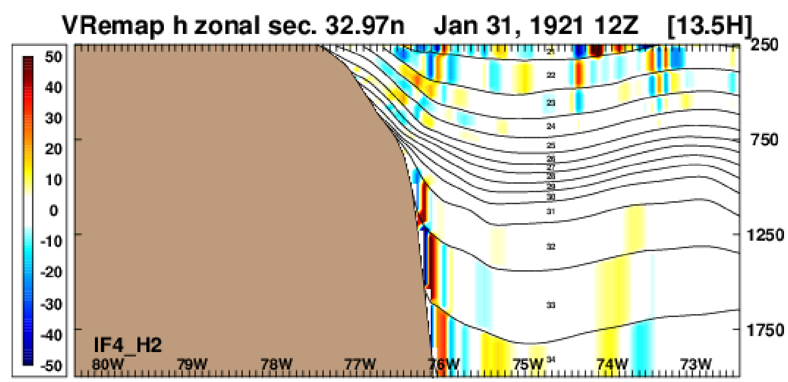
31N & 33N HYBGEN





31N & 33N HYCOM1

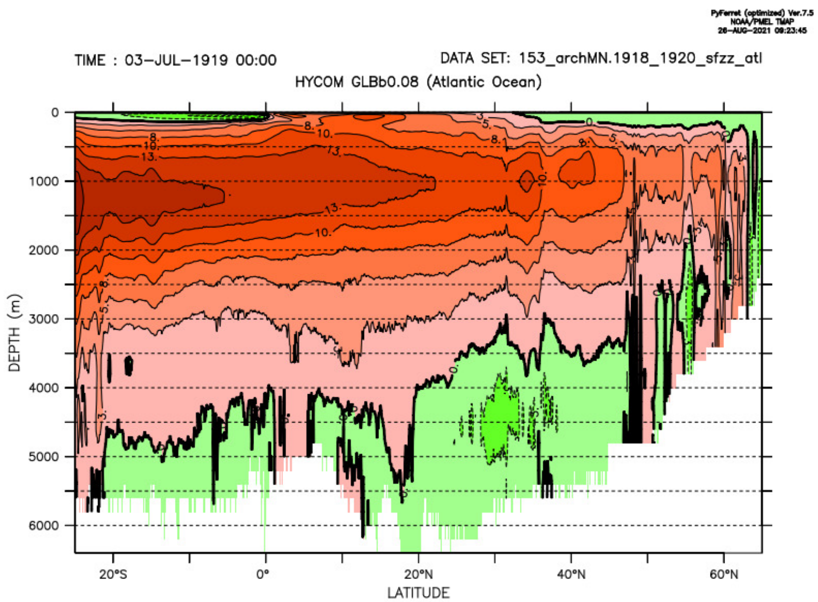




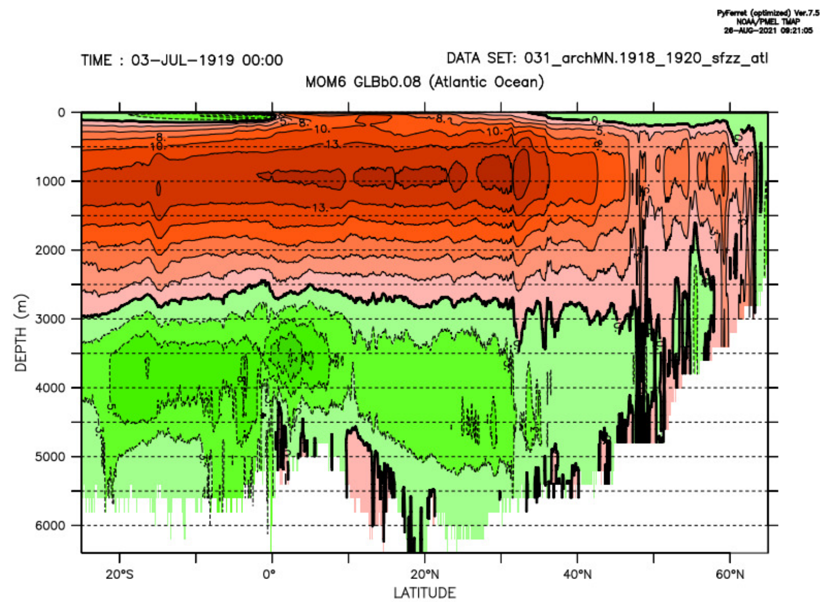
ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10 (I)

- **0.08 degree Global with 41 layers, CFSR 2003 repeated forcing**
- **25S to 65N and 0 to 6500m depth, 2.5 Sv contour interval**

GLOBAL HYCOM (HYBGEN) | **GLOBAL MOM6 (HYCOM1)**



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



z.ov.strfn mean [03.1H] (Sv)

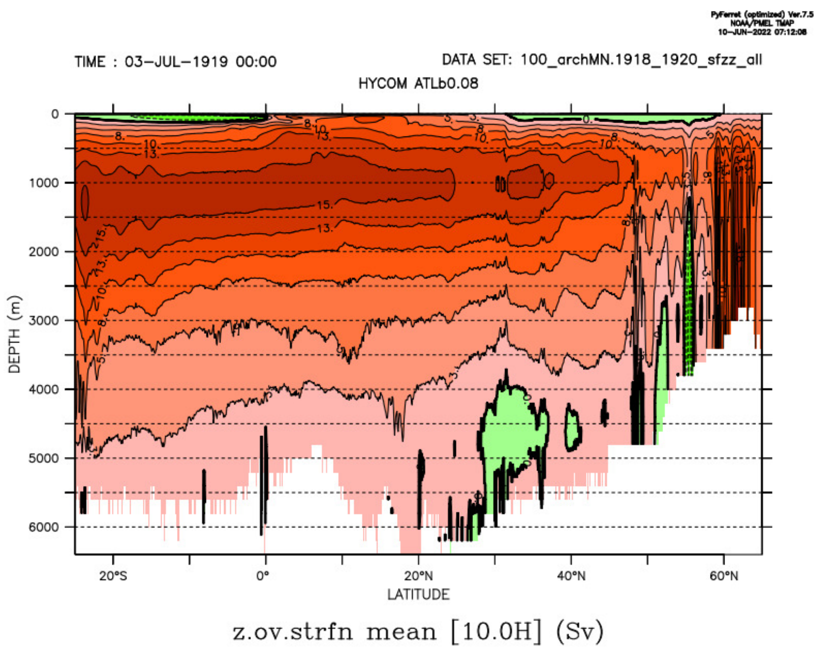
HYCOM at 26°N: max 11.6Sv at 1000m; 0Sv at 3500m
MOM6 at 26°N: max 14.0Sv at 0900m; 0Sv at 2730m
RAPID array at 26°N: max 17.0Sv at 1000m; 0Sv at 4300m

- **GFDL's MOM6 HYCOM1 cases (e.g. 75-layer OM4_025) are similar**

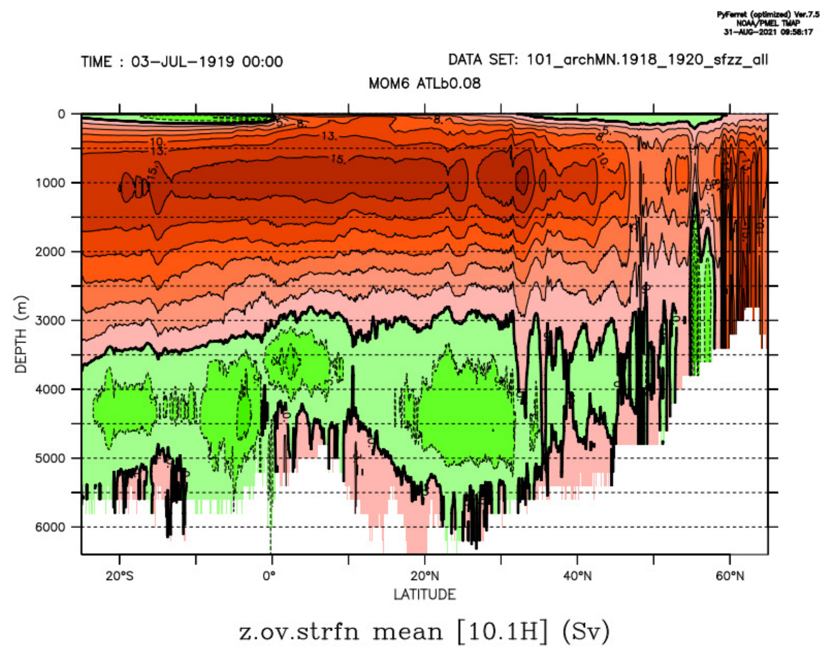
ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10 (II)

- **0.08 degree Atlantic-only with 41 layers, CFSR 2003 repeated forcing**
- **SPONGE to monthly climatology near 28S and 80N**
- **25S to 65N and 0 to 6500m depth, 2.5 Sv contour interval**

ATLANTIC HYCOM (HYBGEN)



ATLANTIC MOM6 (HYCOM1)

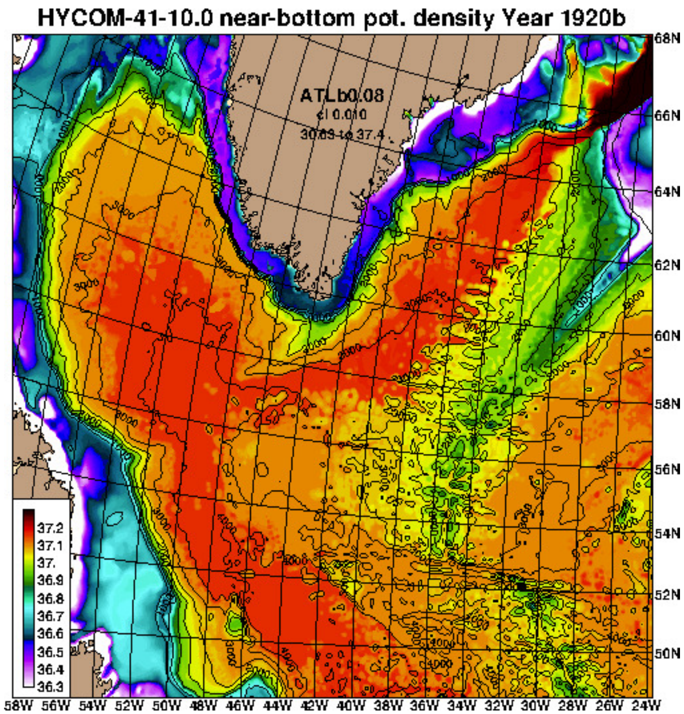


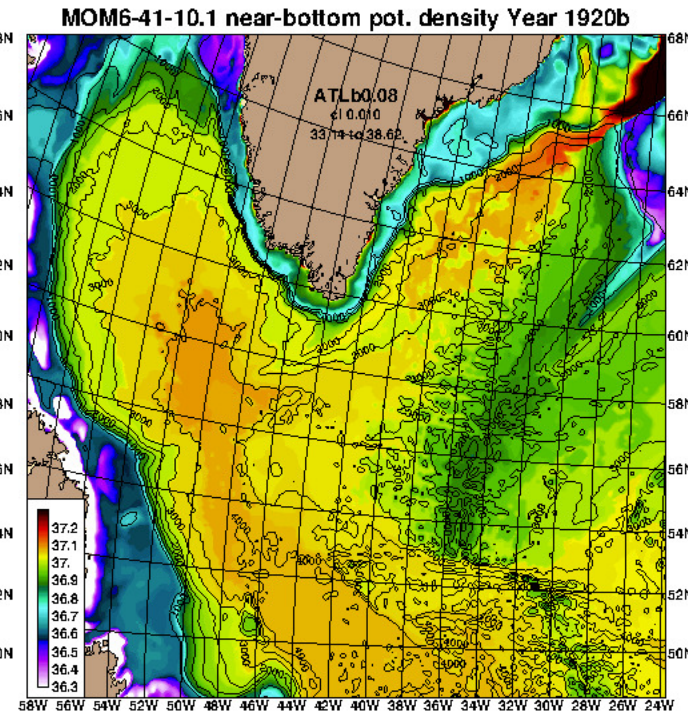
HYCOM at 26°N: max 14.9Sv at 1000m; 0Sv at 6200m
MOM6 at 26°N: max 14.8Sv at 0900m; 0Sv at 2910m
RAPID array at 26°N: max 17.0Sv at 1000m; 0Sv at 4300m

0.08 ATLANTIC BOTTOM SIGMA-2 P.DENSITY: FEBRUARY YR10 (I)

- A shallow Atlantic overturning streamfuction is often due to too light overflow from the Nordic Seas
- HYCOM is denser below 1500m isobath
  - Slightly lighter than observed

ATLANTIC HYCOM (HYBGEN) **ATLANTIC MOM6 (HYCOM1)**





- Both are slightly denser than their GLOBAL twins

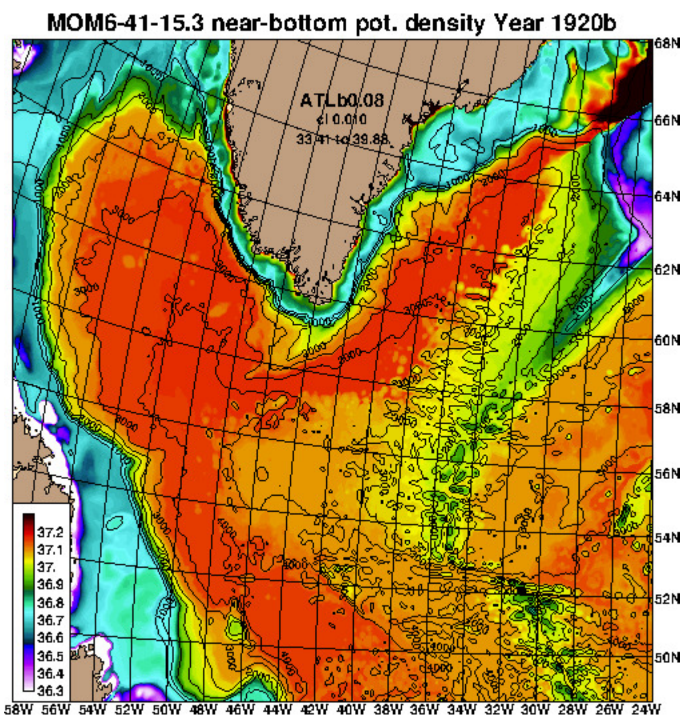
BEST MOM6 ATLANTIC CONFIGURATION

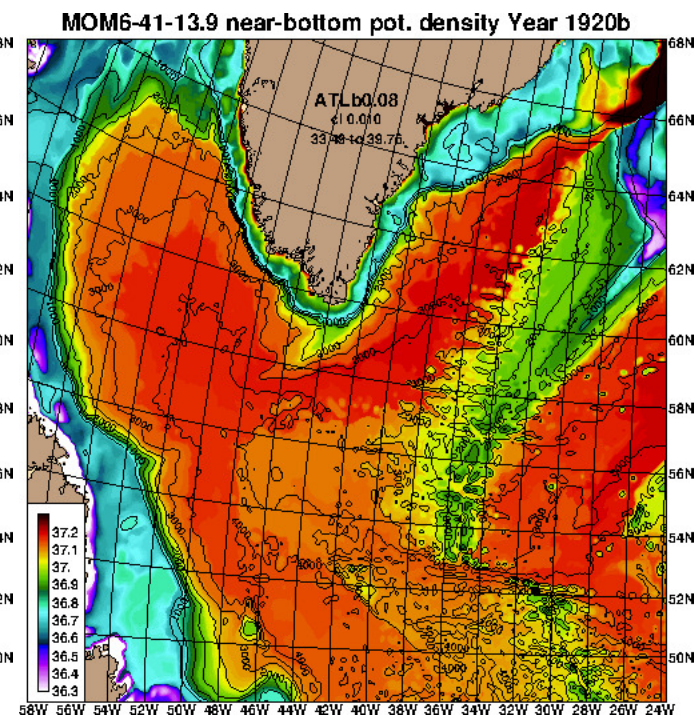
- 0.08 degree Atlantic-only with 41 layers, CFSR 2003 repeated forcing
- USE_MEKE=False, BBL_EFFIC=0, CORRECT_BBL_BOUNDS=True
- CORIOLIS_SCHEME="SADOURNY75_ENERGY"
- KD=.1E-4, KV=.3E-4, HENYEY_IGW_BACKGROUND=False
- KH_VEL_SCALE=.00286, AH_VEL_SCALE=.02, no SMAGORINSKY
- REGRIDDING_COORDINATE_MODE="HYCOM1":
  - KH_ETA_CONST=20 (for OM_025 this would be 62.5), DETANGLE_INTERFACES=True, KHTH_MAX_CFL=.8
  - REGRID_COMPRESSIBILITY_FRACTION=0.01
  - INTERPOLATION_SCHEME="P1M_H2", REMAPPING_SCHEME="PPM_H4"
  - REGRID_FILTER_SHALLOW_DEPTH=90, REGRID_FILTER_DEEP_DEPTH=114, REGRID_TIME_SCALE=6000 (5 * DT_THERM): better Gulf Stream separation
- or REGRIDDING_COORDINATE_MODE="HYBGEN":
  - THICKNESSDIFFUSE=False, APPLY_INTERFACE_FILTER=True
  - INTERFACE_FILTER_ORDER=4, INTERFACE_FILTER_TIME=10800
  - REMAPPING_SCHEME="WENO_HYBGEN"
  - HYBGEN_RELAX_PERIOD=16 (16 x DT_THERM = 4800s)
  - DT_THERM=300 (same as DT)

0.08 ATLANTIC BOTTOM SIGMA-2 P.DENSITY: FEBRUARY YR10 (I)

- **HYBGEN: INTERFACE_FILTER_TIME=10800, DT_THERM=300**
  — slightly denser than ATLANTIC HYCOM —
- **HYCOM1: KH_ETA_CONST=20, DT_THERM=1200**
  — correct/to dense west/east of the Reykjanes Ridge —

ATLANTIC MOM6 HYBGEN | **ATLANTIC MOM6 HYCOM1**



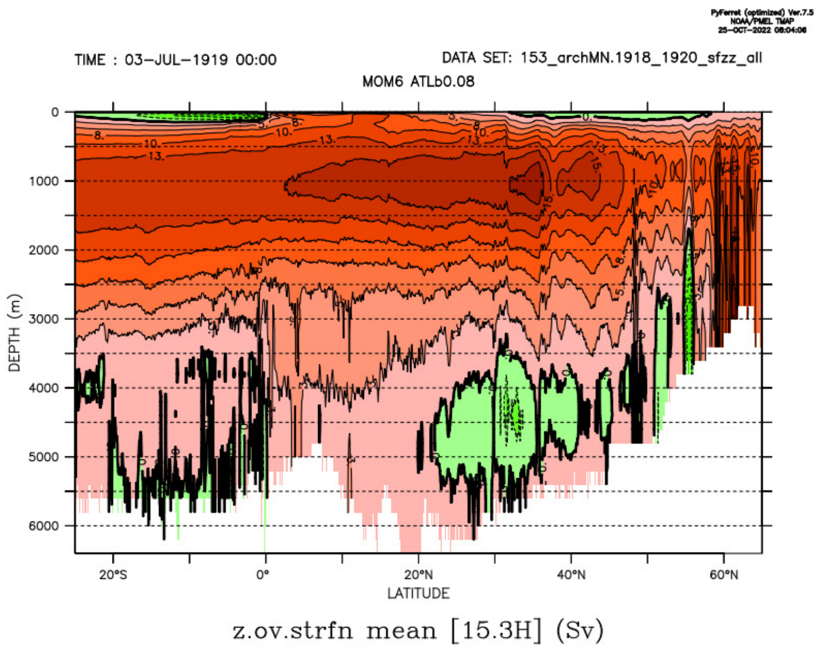


- **However, "BEST" GLOBAL MOM6 HYCOM1 still very light**

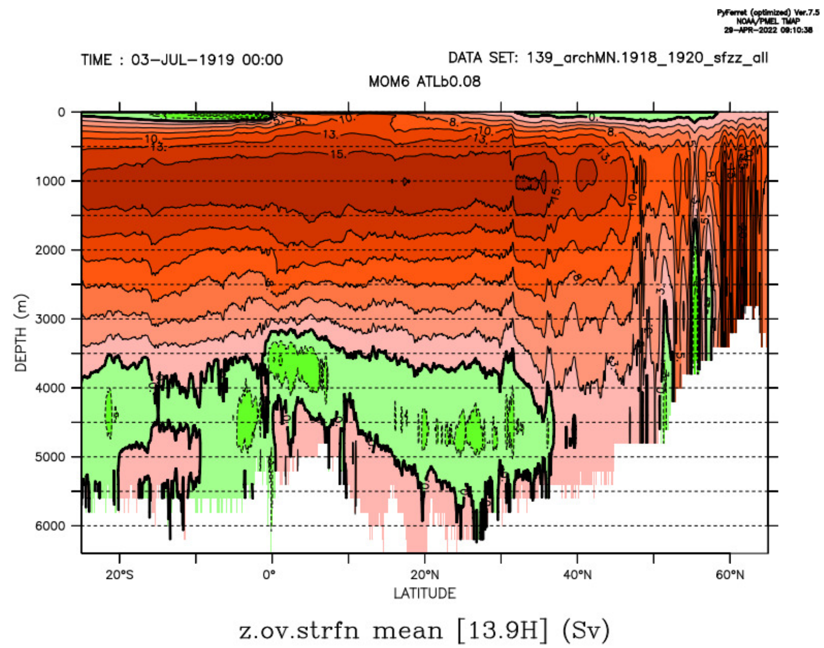
ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10 (III)

- **Best 0.08 degree Atlantic-only with 41 layers, CFSR 2003 repeated forcing**
- **25S to 65N and 0 to 6500m depth, 2.5 Sv contour interval**

ATLANTIC MOM6 HYBGEN



ATLANTIC MOM6 HYCOM1



HYBGEN at 26°N: max 16.2Sv at 1000m; 0Sv at 3900m
HYCOM1 at 26°N: max 16.3Sv at 1000m; 0Sv at 3600m
RAPID array at 26°N: max 17.0Sv at 1000m; 0Sv at 4300m

SUMMARY

- Based on results presented here, and other evidence, HYCOM1 has more diapycnal diffusion than an isopycnal-favoring method should
  - PPM_CW + PPM_CW less diffusive than P1M_H2 + PPM_H4
  - No exact measurements, but for a Gulf of Mexico domain HYBGEN with 10x KD has better Loop Current eddy behavior that HYCOM1
- HYBGEN has minimal diapycnal diffusion, but has other issues
  - Thick-thin-thick-thin layer structure reduces effective vertical resolution
  - MOM6: DT=DT_THERM, no compressibility factor, not an interpolator
  - Requires additional interface smoothing
- Can we engineer a layer density based approach that improves on HYBGEN?
  - HYBGENI walks a monotonic vertical density profile, like HYCOM1
    - Does not produce a thick-thin-thick-thin layer structure
    - More diapycnal diffusion than HYBGEN, much less than HYCOM1
    - Stabilizes the density profile, but not with a compressibility factor
    - Working in HYCOM, still being tested in MOM6
- Can we engineer a HYCOM1-like scheme with acceptable diapycnal diffusion?
  - Still some ideas to try, but not so far for interface density targets
  - HYBGENI, which targets layer density, is inspired by HYCOM1
    - Similar to HYCOM1 P1M_H2 when its isopycnal detection is turned off