A Comparison of Twin MOM6 and HYCOM Eddy-Resolving Global Ocean Simulations

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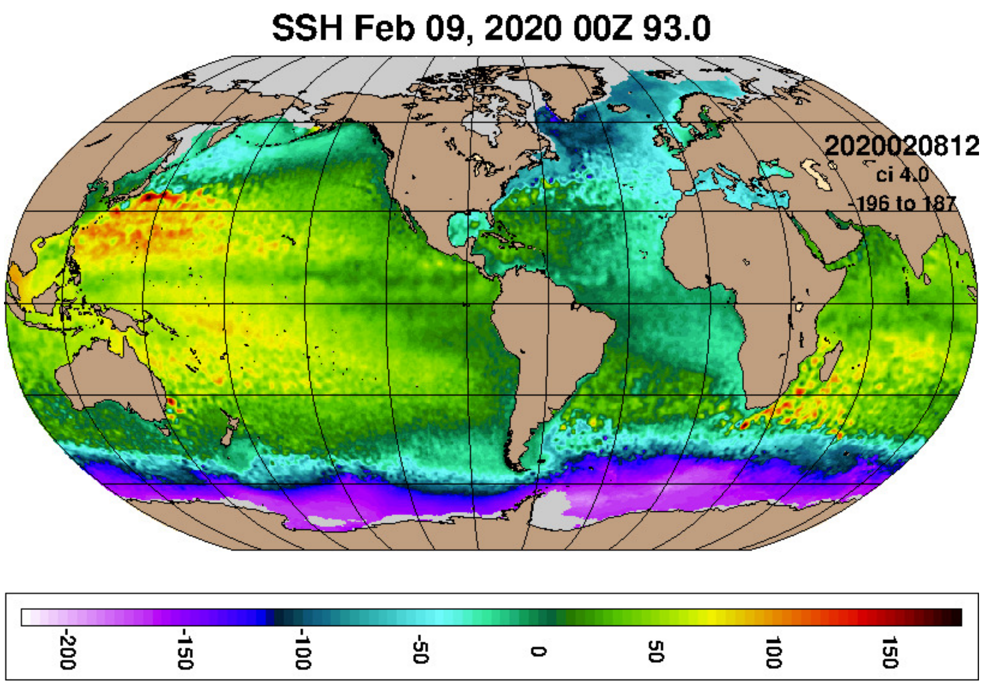
MOM6 Webinar

11 May 2020

NAVY GLOBAL OCEAN PREDICTION SYSTEM 3.1

- GOFS 3.1 runs every day on a 1/12° global tripole grid
  - Operational since 7 November 2018
    - https://www.hycom.org/ocean-prediction for images and movies
    - https://www.hycom.org/dataserver/gofs-3pt1/analysis for model fields
- Same model configuration is used by NOAA's global operational Real-Time Ocean Forecast System (Global RTOFS)
- 41-layer HYCOM coupled to LANL's CICEv4 for sea ice



ARBITRARY LAGRANGIAN-EULERIAN (ALE) OCEAN MODELS

- **HYCOM was the first widely used ALE-based ocean model**
  - **Demonstrated the viability of this approach**
- **HYCOM is 20 years old, lots of code inherited from the even older MICOM**
  - **Needs a complete refactoring**
  - **Many design choices showing their age**
    - **Multiple significant (high risk) algorithm changes required**
- **HYCOM is no longer the only ALE-based ocean model**
  - **GFDL's new MOM6, in particular, has many advantages over HYCOM**
    - **Modern numerics and coding style**
    - **Much larger developer base than HYCOM**
    - **Overall, very similar to HYCOM**
- **Rather than developing a next-generation HYCOM from the existing HYCOM2 code base, COAPS intends to switch focus to HYCOM3:**
  - **MOM6 configured to be HYCOM-like and using HYCOM-tools for pre- and post-processing**
    - **All the plots shown here are from HYCOM-tools**
  - **Features unique to HYCOM will be added to MOM6**

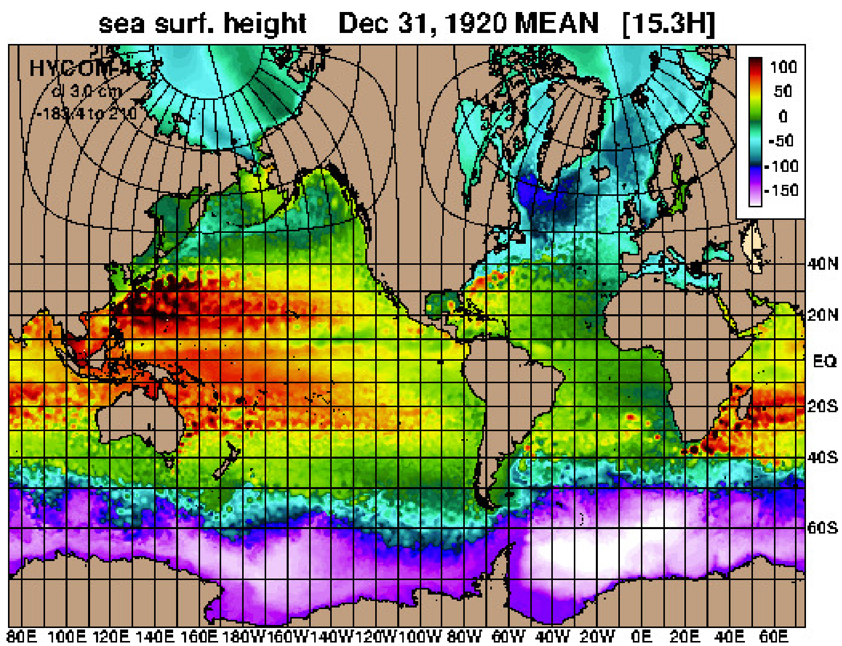
THE 1/12° GLOBAL TEST CASE FOR HYCOM AND MOM6

- **Use the GOFS 3.1 configuration, but without HYCOM-specific features**
  - **41 hybrid layers in the vertical, 1m top layer**
    - **Fixed vertical coordinate is Z-star only** *(not Z-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)**
    - **Incompressible with thermobaricity correction vs compressible**
  - **ALE isopycnal regridding 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**

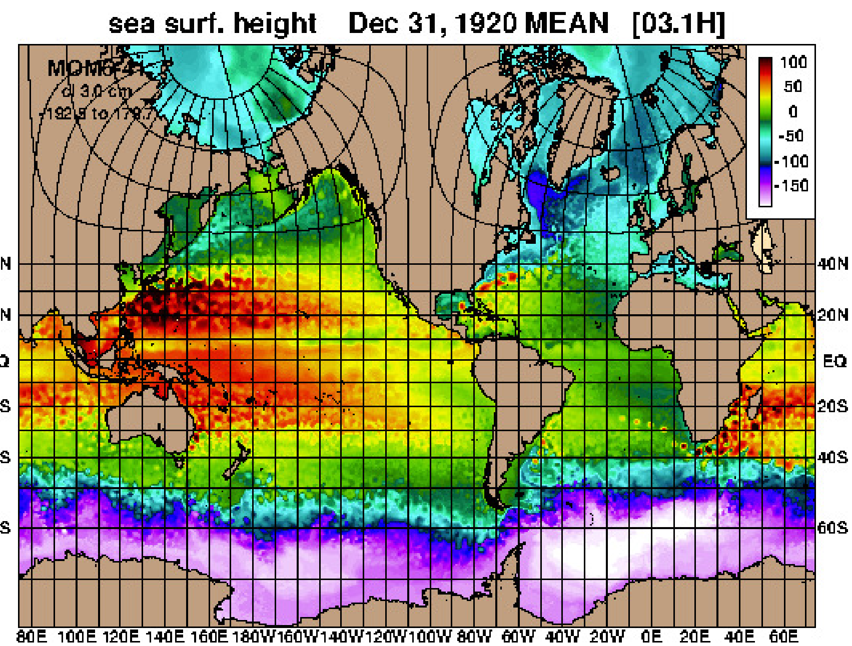
SSH (CM) SNAPSHOT, END OF MODEL YEAR 10

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

HYCOM



MOM6



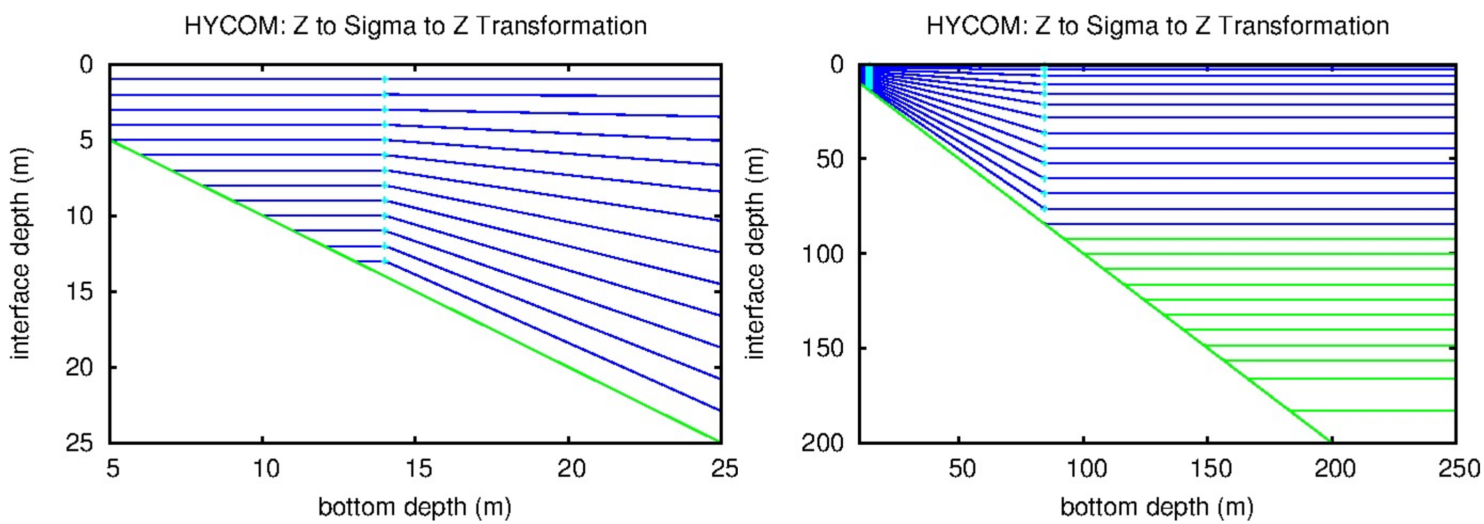
- **On 1,800 Cray XC40 cores, MOM6 runs 1.5x faster than HYCOM**
  - **HYCOM is slightly faster than MOM6 per time step**
  - **MOM6 is stable with a significantly longer baroclinic time step, 300s vs 180s**
  - **Speedup similar to the time step ratio: 300/180 = 1.67**

ALE VERTICAL REGRIDDING and REMAPPING

- **Each time step:**
  - **Solve the layered continuity equation (move the layers)**
  - **Then remap in the vertical to the "desired" layer structure**
    - **Fluid does not move, but layer interfaces are regridded across the fluid**
- **Power of ALE method is in the choice of new layer locations (regridding)**
  - **Geopotential and terrain-following coordinates can be emulated by holding the interfaces fixed in time**
- **HYCOM introduced a "favor isopycnals" approach, where isopycnals "outcrop" into fixed depth layers near the surface and at high latitudes**
  - **This is implemented in MOM6 by its HYCOM regridding option**
- **Finding isopycnal layers:**
  - **HYCOM: maintains** *layer averages* **at target sigma2 potential densities**
    - **Use local entrainent and detrainment logic to move the interfaces**
  - **MOM6: maintains** *layer interfaces* **at target sigma2 potential densities, with a small compressibility factor to ensure a monotonic density profile**
    - **Unique mapping from a monotonic profile to the target isopycnals**

GOFS FIXED COORDINATE Z-SIGMA-Z LAYERS

- **The 32-layer GOFS 3.0 had a 3 m top layer with 5 always fixed-depth layers**
  - **Not optimal for mixed layer and isopycnals could upwell onto the shelf**
- **GOFS 3.1 added 9 layers near the surface, 14 terrain-following**
  - **Terrain-following between 14 m and 96 m depth**
  - **The top layer is 1 m in both deep and shallow, with all 14 shallow minimums at 1 m and deep minimums increasing to 8 m at 96 m**
  - **Never isopycnal above 96 m depth, i.e. always Z-sigma on the shelf**

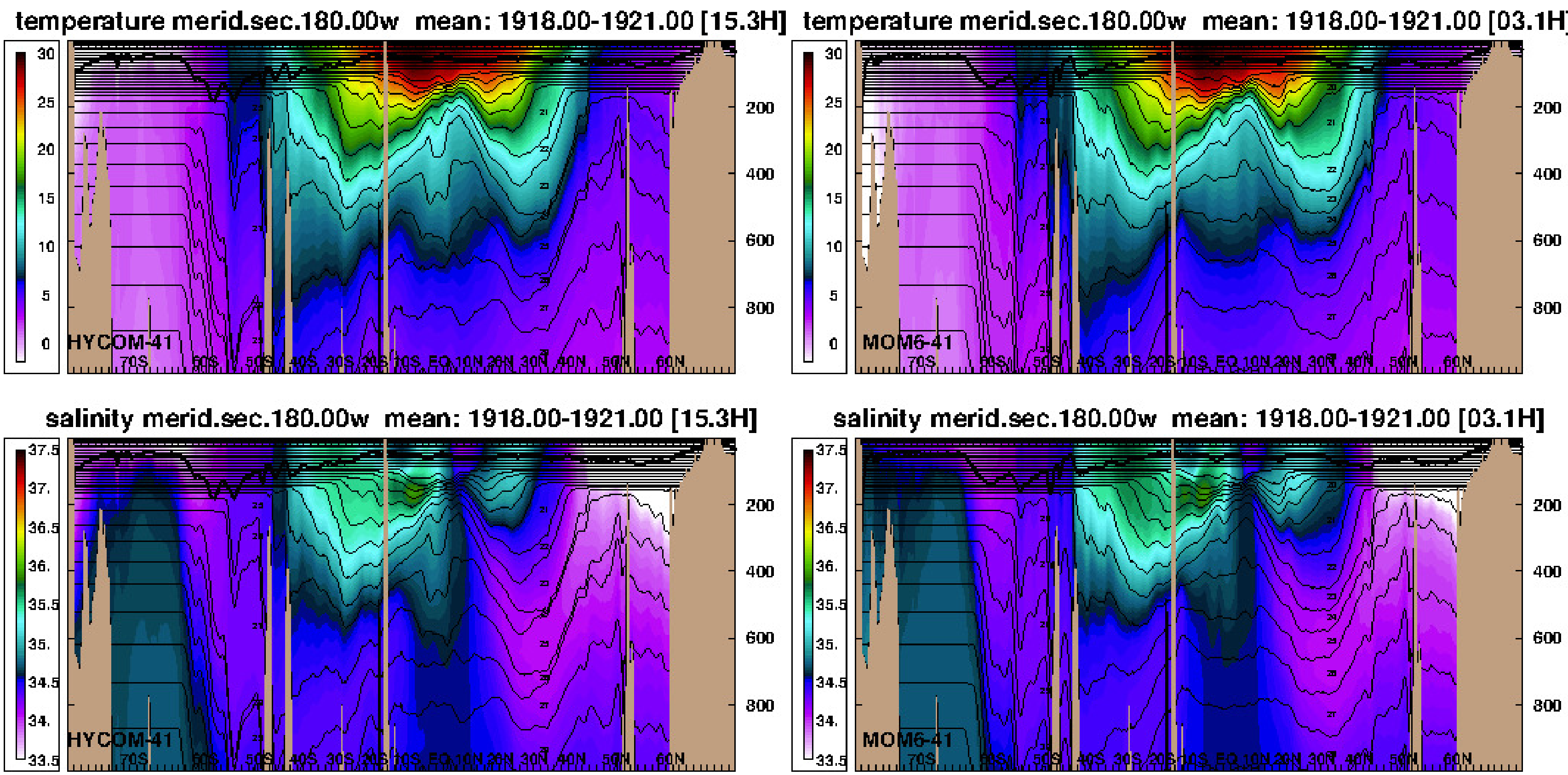


- **For the MOM6/HYCOM twins: same fixed grid without terrain following**
- **MOM6 sets target density very light (1000 to 1002) on top 14 interfaces, to force never isopycnal above 96m**

PACIFIC VERTICAL CROSS SECTION AT 180°E 0-1000m

- **Isopycnals “outcrop” into fixed depth layers**
- **HYCOM shows some indication of thick-thin-thick-thin layers (3 year mean)**

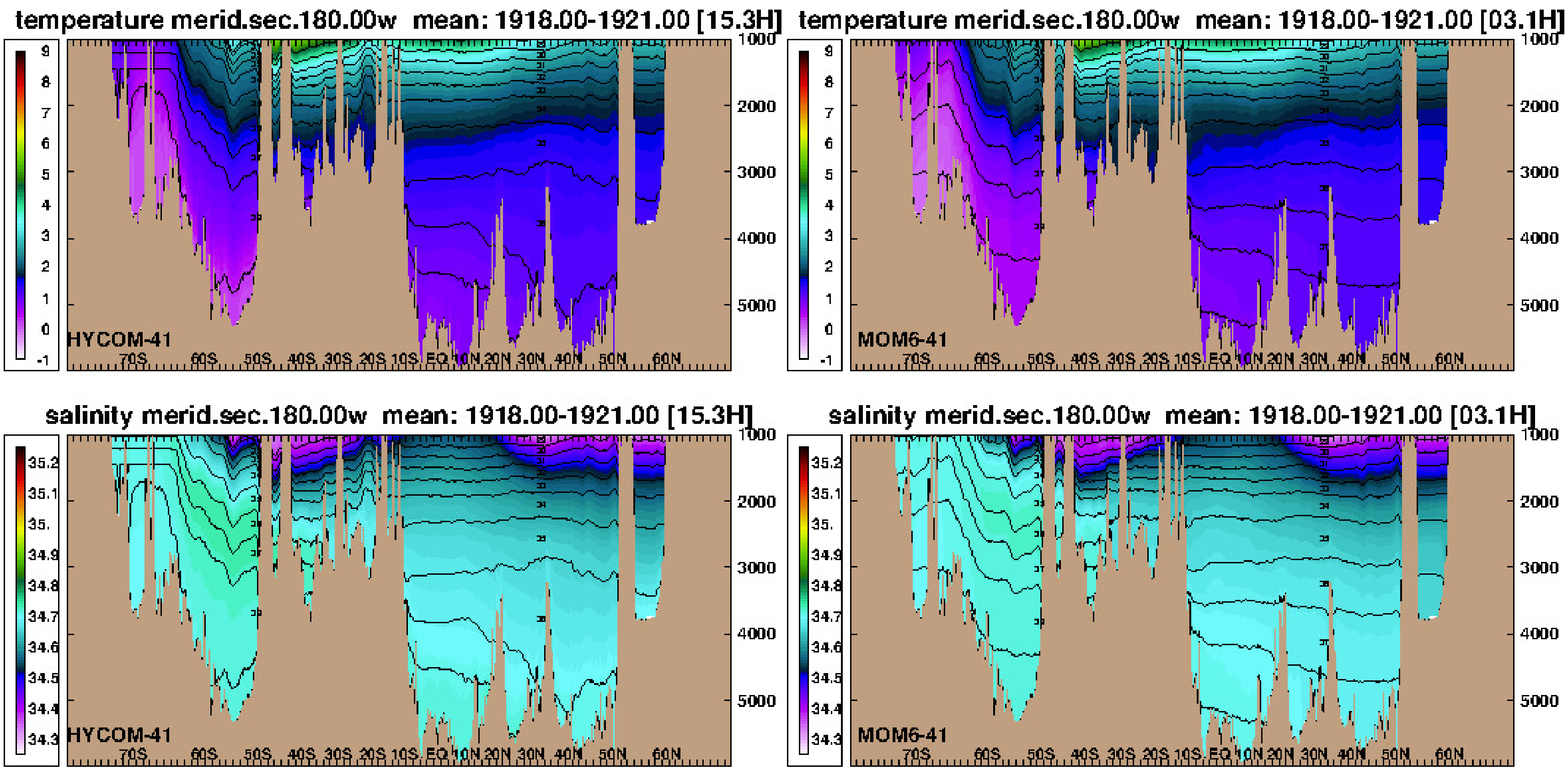
HYCOM **MOM6**



PACIFIC VERTICAL CROSS SECTION AT 180°E 1000-6000m

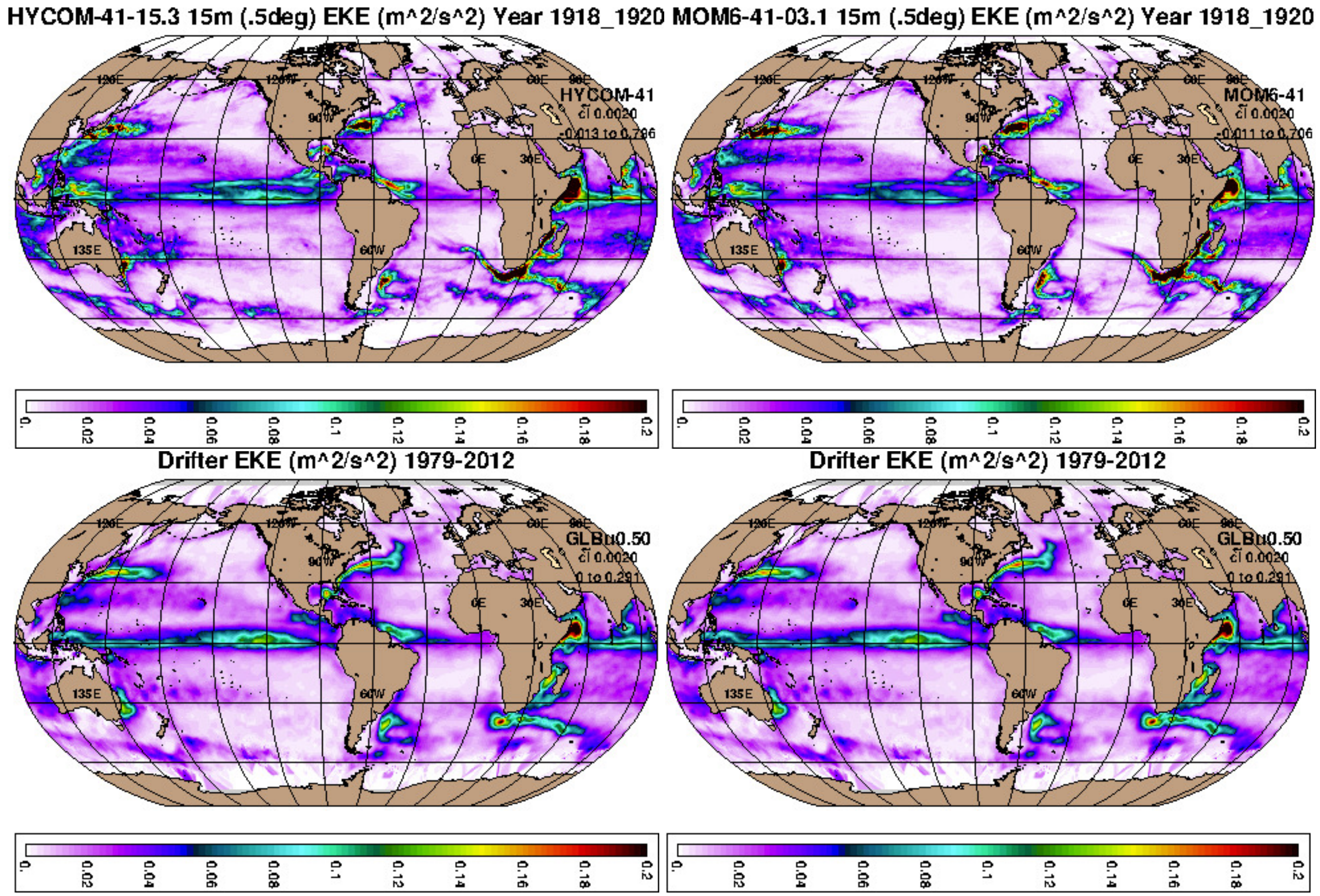
- **HYCOM: maintains** *layer averages* **at target sigma2 potential densities**
- **MOM6: maintains** *layer interfaces* **at target sigma2 potential densities, with a small compressibility factor to ensure a monotonic density profile**
- **MOM6 has a more uniform distribution of layers in the deep ocean**

HYCOM **MOM6**



GLOBAL DRIFTER (15M) EKE

HYCOM (3 years) | MOM6 (3 years)



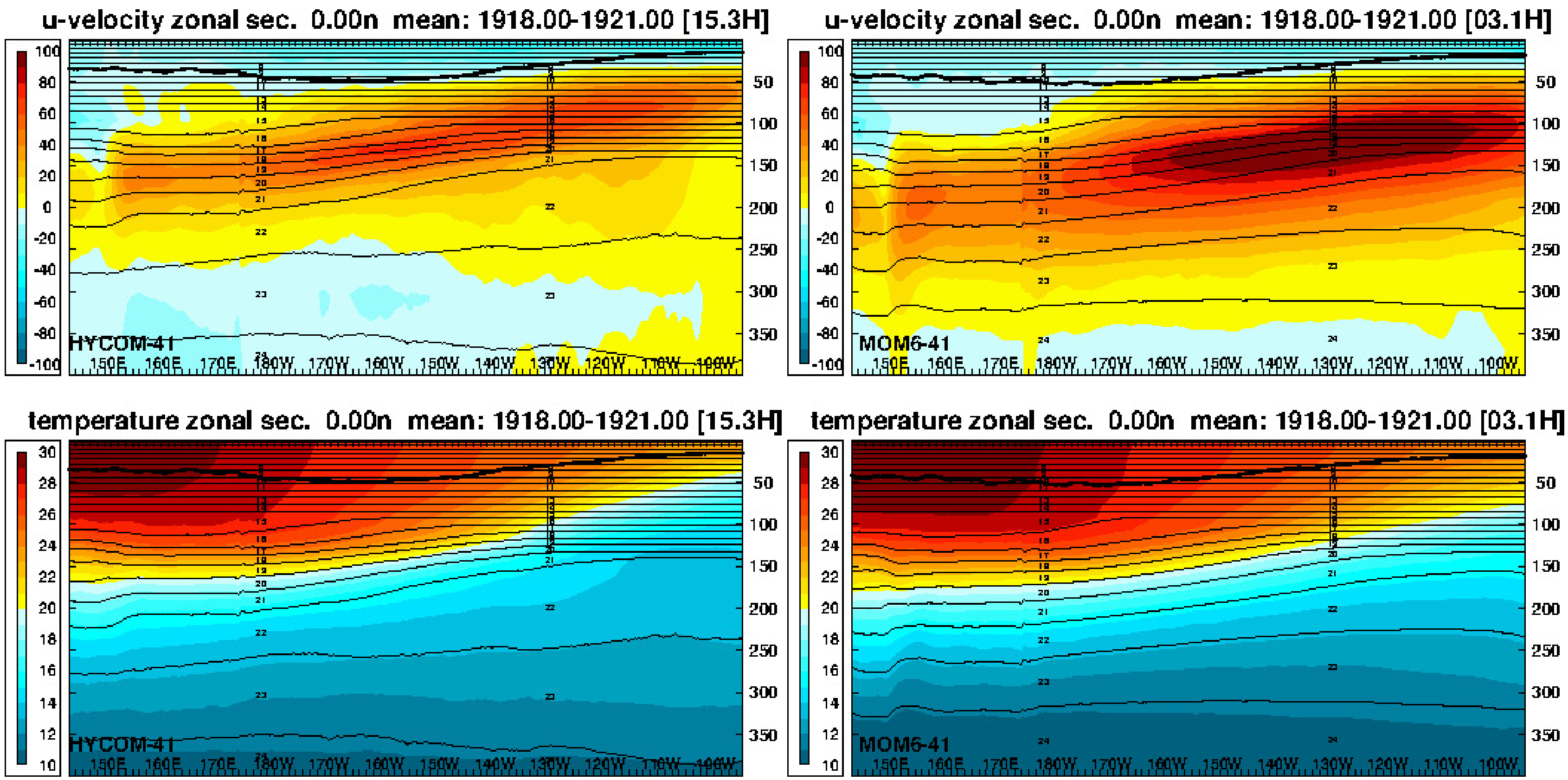
DRIFTERS (1979-2012)

- **Percentage area between 60°S and 60°N that is below 0.005 m^2/s^2**
  - **Drifters: 14.3%; HYCOM: 19.2%; MOM6: 25.9%**

EQUATORIAL PACIFIC VERTICAL CROSS SECTION 0-400m

- **Only region where layer 15 is isopycnal**
- **HYCOM equatorial undercurrent too weak**
- **MOM6 equatorial undercurrent slightly too deep**

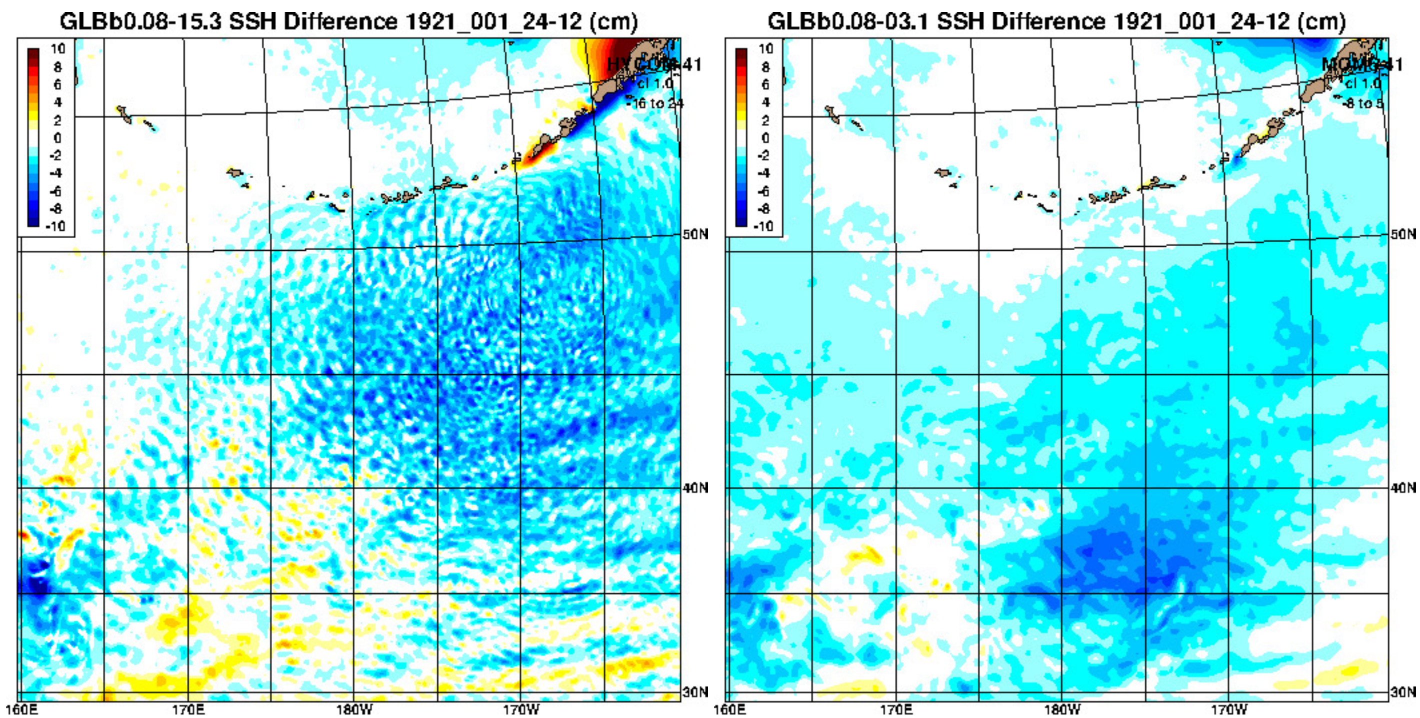
HYCOM **MOM6**



THERMOBARIC INSTABILITY IN HYCOM

- **HYCOM is incompressible with a thermobaricity correction**
  - **Can be unstable (Hallberg, 2005) and noisy**
- **MOM6 is compressible, integrating the finite volume pressure gradient force using numerical quadrature (Adcroft et al, 2008)**
- **Plot is difference in SSH over 12 hours in North Pacific**

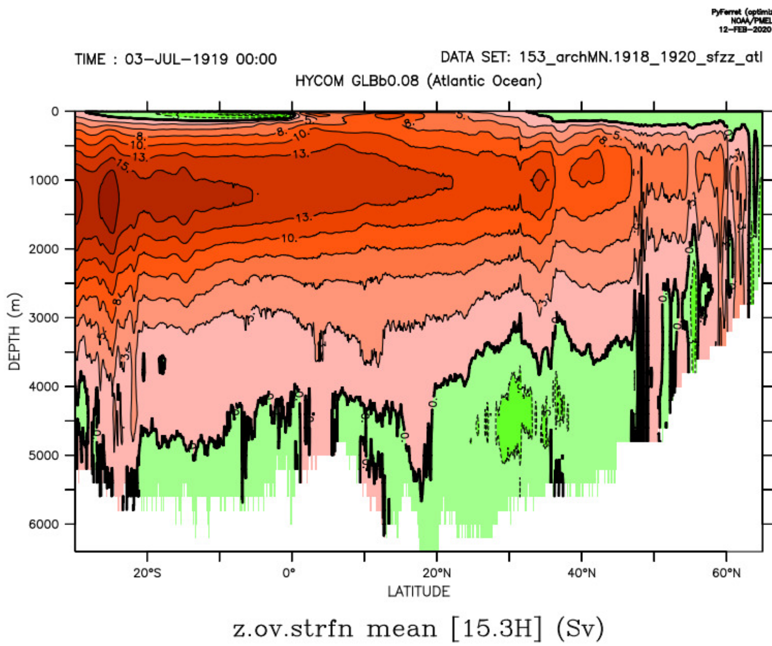
HYCOM **MOM6**



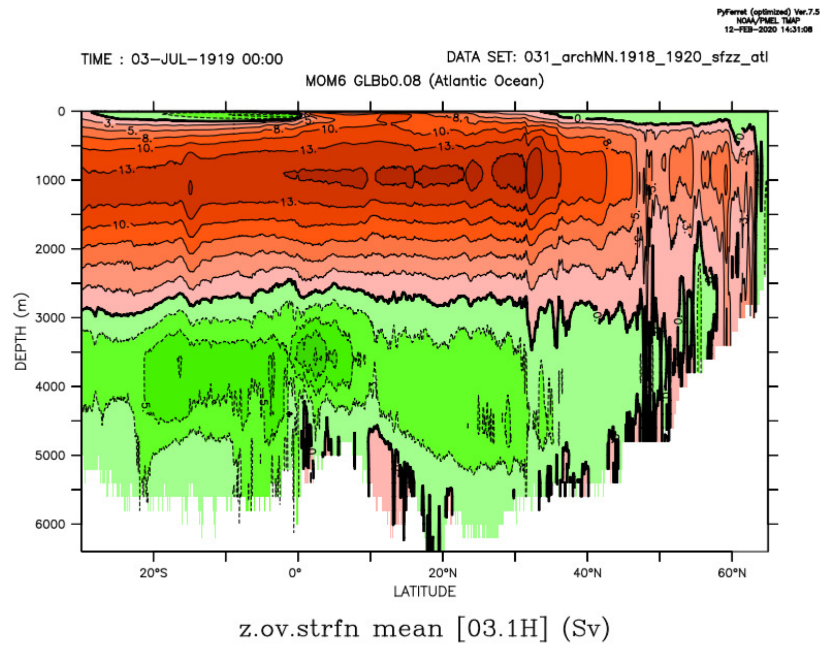
ATLANTIC OVERTURNING STREAMFUNCTION, OVER YEARS 8-10

- 30S to 65N and 0 to 6500m depth, 2.5 Sv contour interval
- Sigma 2 regridding (HYCOM) does not represent AABW well

HYCOM



MOM6



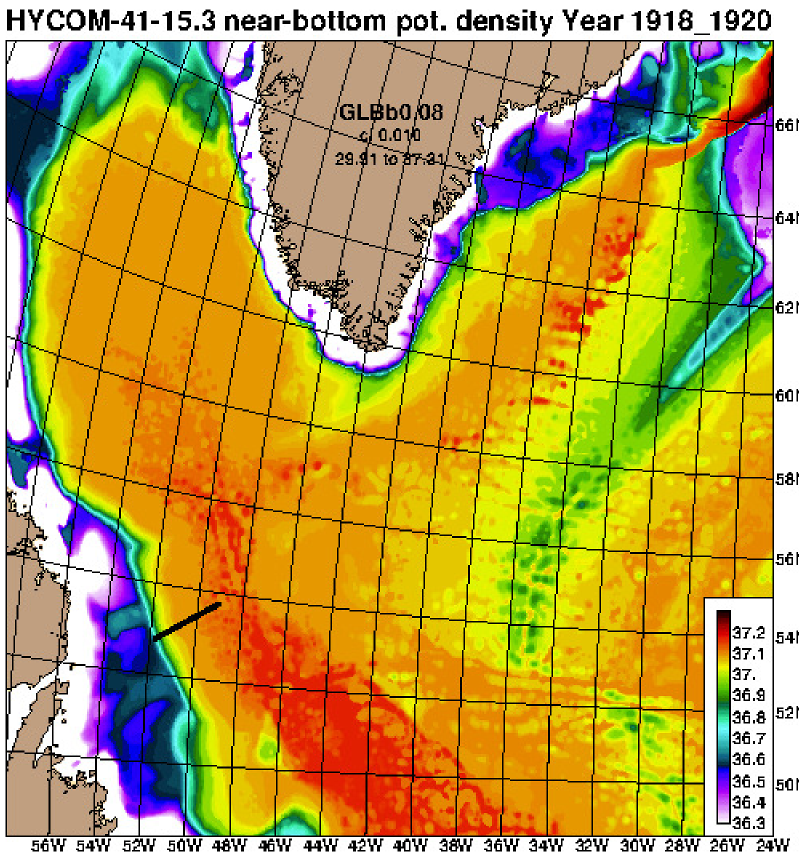
HYCOM at 26°N, 0Sv: 3500m

MOM6 at 26°N, 0Sv: 2730m

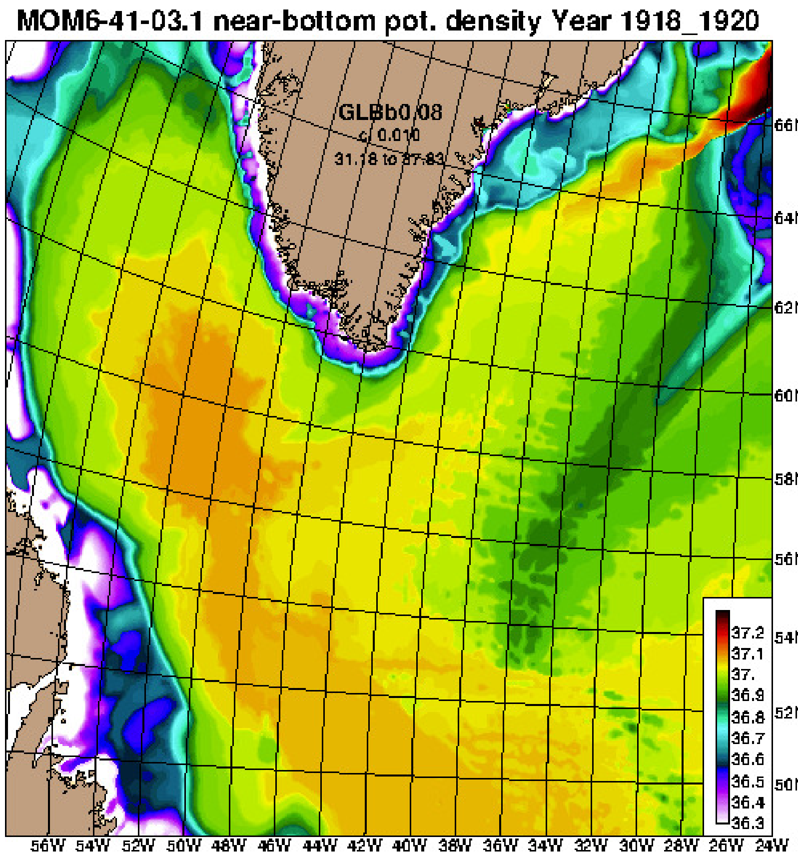
NEAR-BOTTOM POTENTIAL DENSITY (SIGMA2) IN LABRADOR SEA

- 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

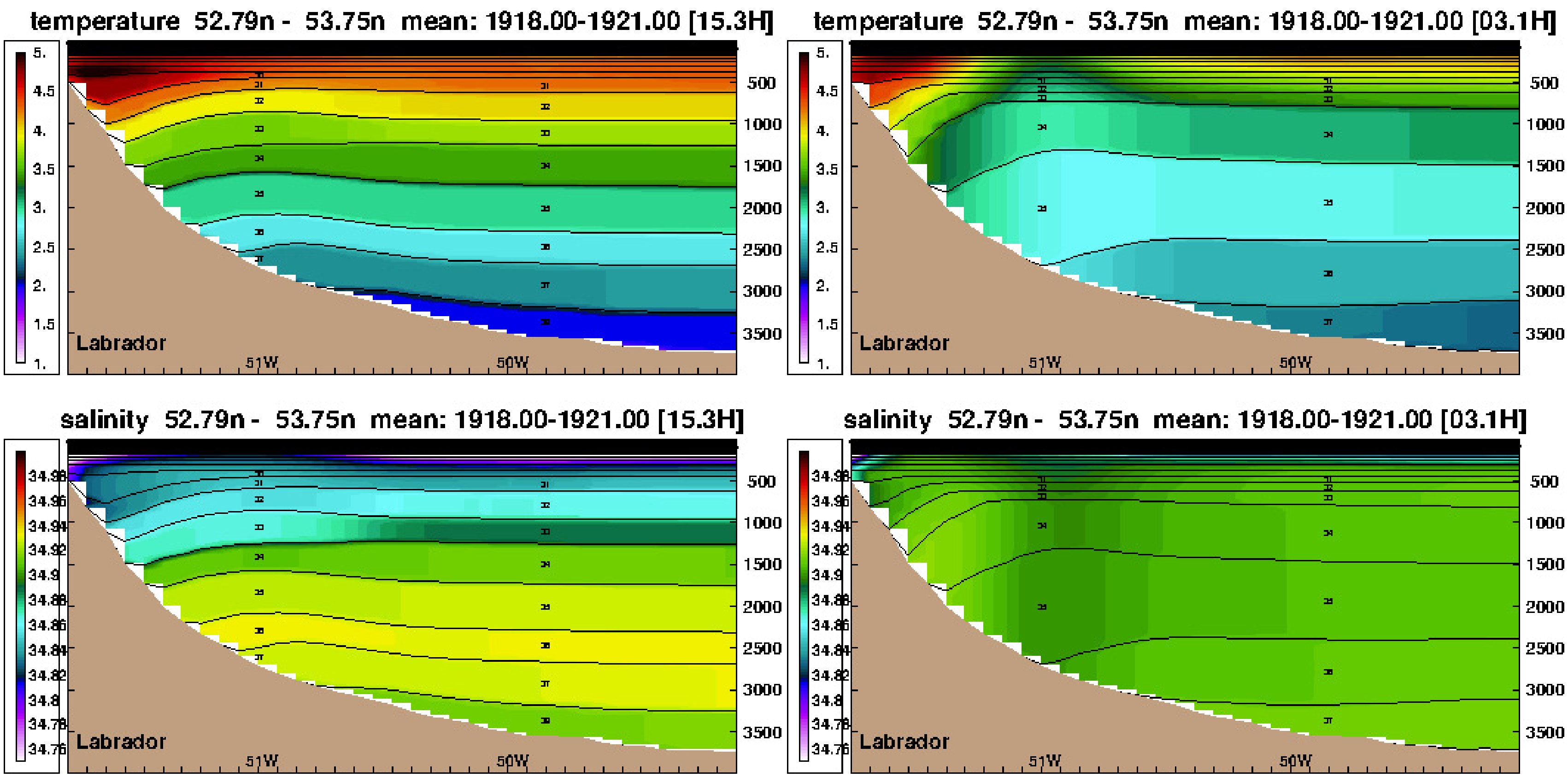


- Black bar on HYCOM plot at 52W,53N is the section plotted on the next slide

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

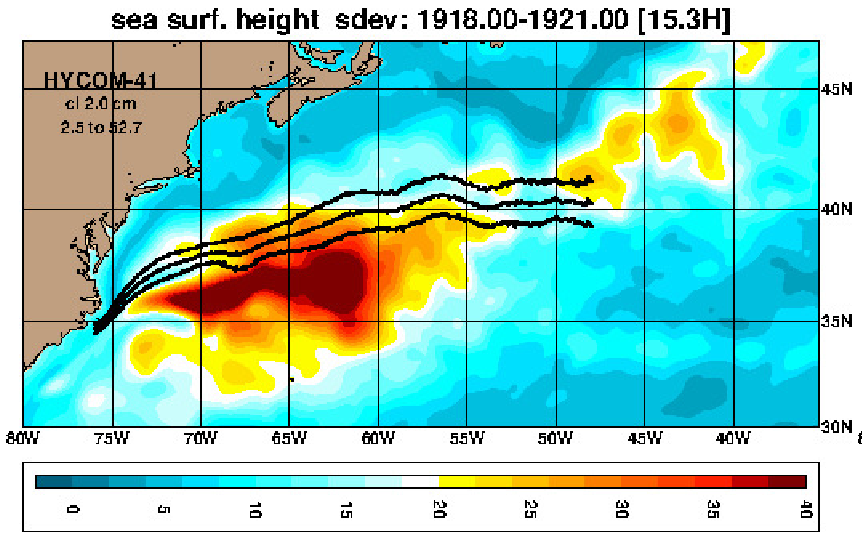
HYCOM **MOM6**



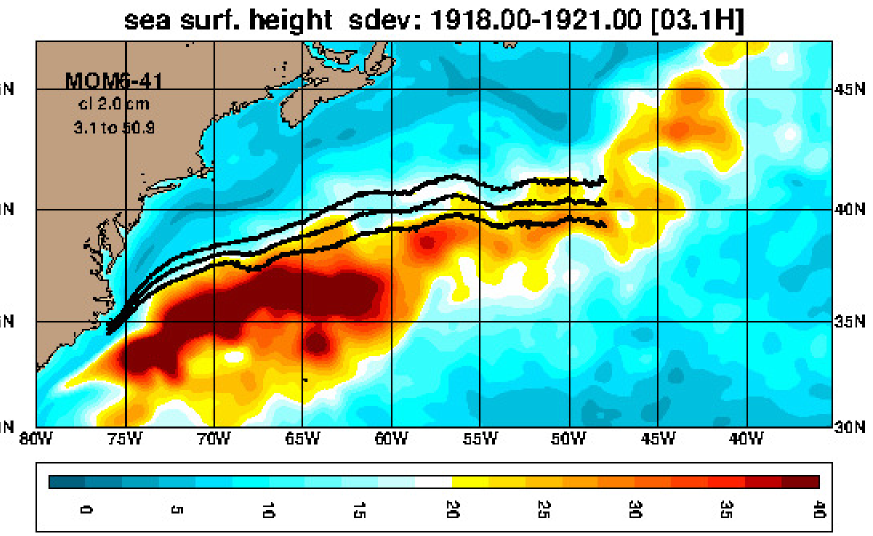
SSH VARIABILITY (CM), OVER YEARS 8-10, GULF STREAM

- **Black lines are mean location of the Gulf Stream +/- a std.dev.**
- **HYCOM separating at Cape Hatteras, slightly too far south overall**
- **MOM6 separating from the coast early at about 32°N,
but the Gulf Stream is penetrating further east**

HYCOM



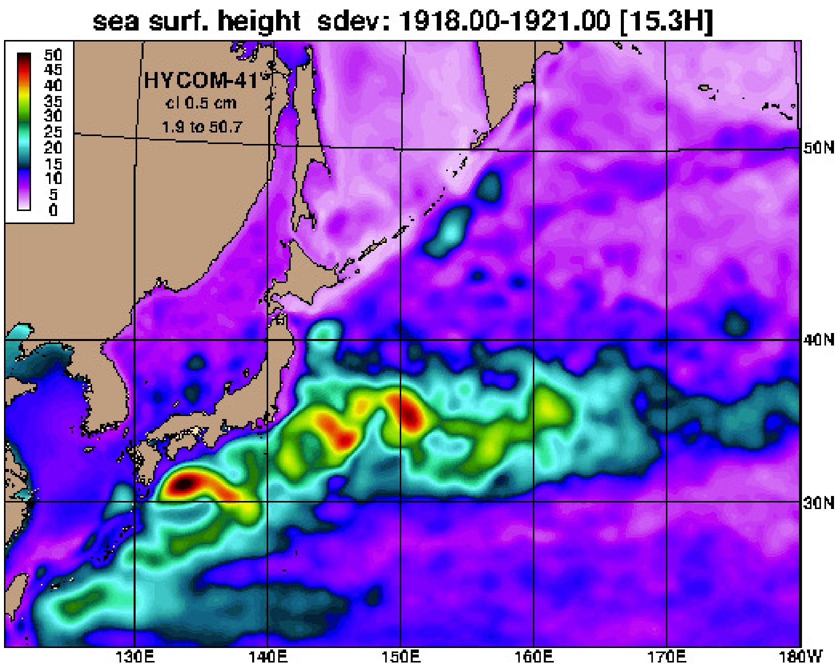
MOM6



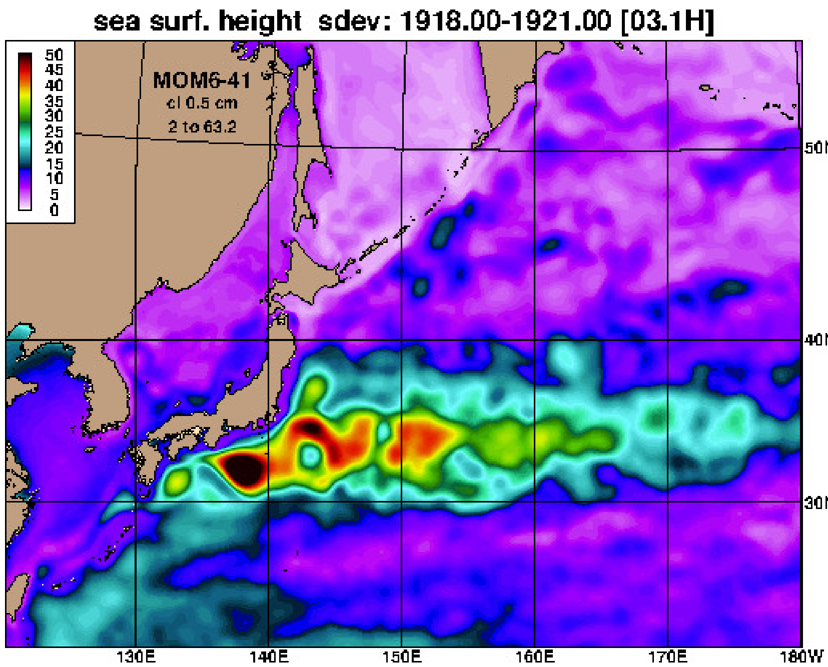
SSH VARIABILITY (CM), OVER YEARS 8-10, KUROSHIO

- **MOM6 and HYCOM both have good representations of the Kuroshio**
- **MOM6 penetrating a bit further into the basin**

HYCOM



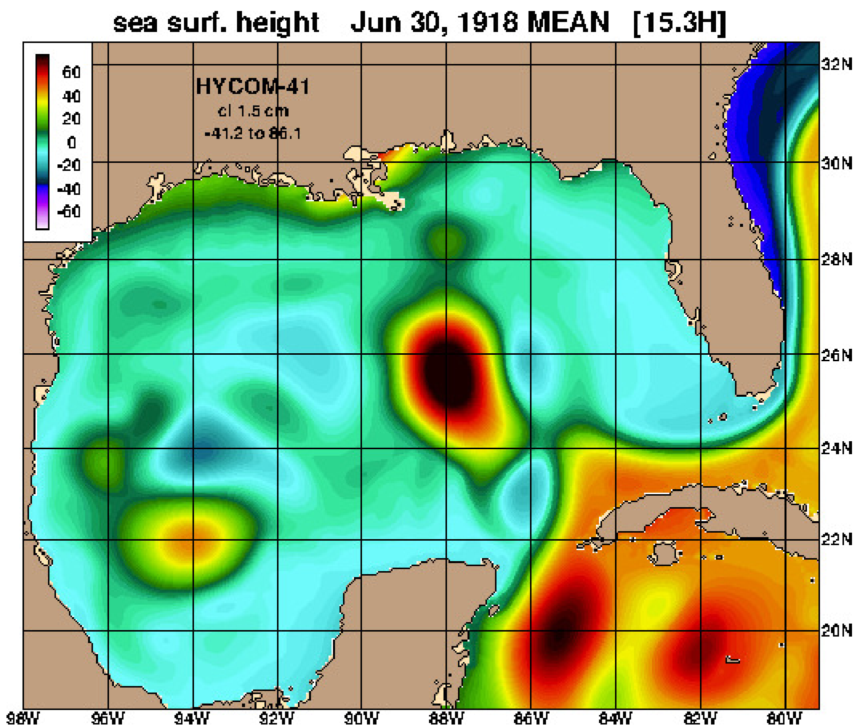
MOM6



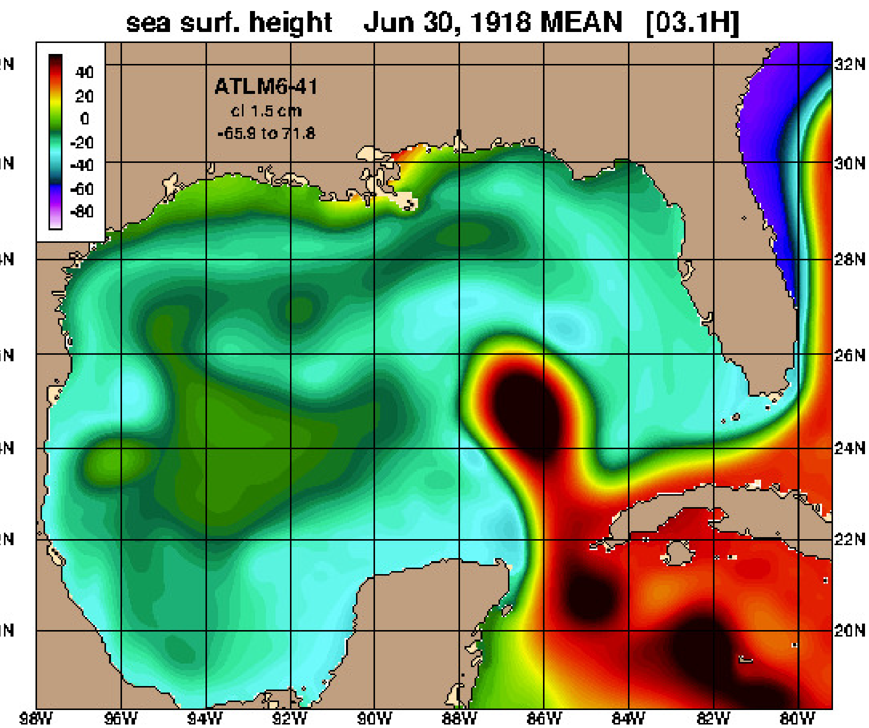
SSH (CM) SNAPSHOT, GULF OF MEXICO

- **MOM6 Loop Current Eddies never migrate into the Western Gulf**
  - **Eddies form and detach but then re-attach to the Loop Current**

HYCOM



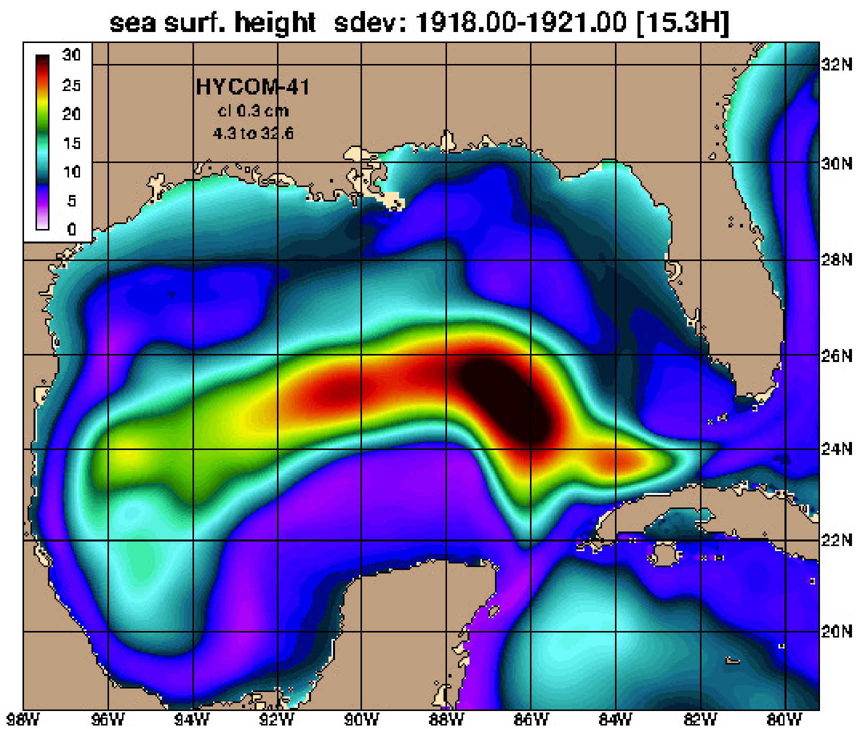
MOM6



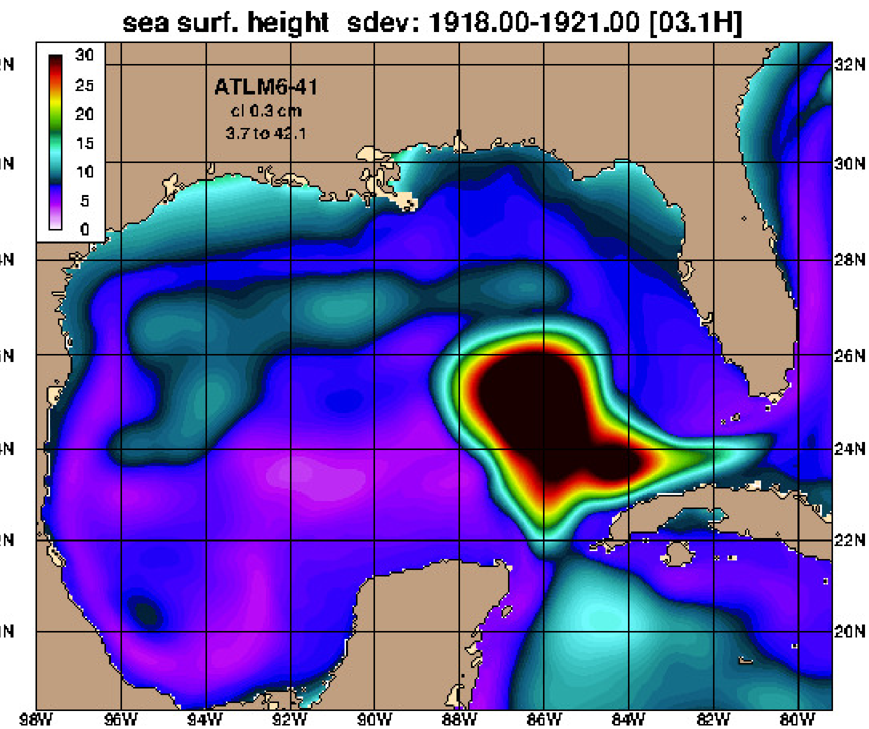
SSH VARIABILITY (CM), OVER YEARS 8-10, GULF OF MEXICO

- **MOM6 not shedding Loop Current Eddies**

HYCOM



MOM6



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
- The most serious issue with the MOM6 simulation was premature separation of the Gulf Stream from the US east coast
  - Also, Loop Curent eddies don't reliably shed in the Gulf of Mexico
  - We are exploring these issues using an Atlantic only configuration
- MOM6 is a good candidate for future high resolution ocean prediction systems
  - Allows the same model to be used from synoptic to climate time scales
- HYCOM3 is MOM6 configured to be HYCOM-like and using HYCOM-tools for pre- and post-processing
  - Simplifies the transition to MOM6 for existing users of HYCOM