New Features of HYCOM

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HYCOM 2.2 (I)

- Maintain all features of HYCOM 2.1
  - Orthogonal curvilinear grids
  - Can emulate Z or Sigma or Sigma-Z models
    - It is “Arbitrary Lagrangian-Eulerian”, see: Adcroft and Hallberg, O. Modelling 11 224-233.
  - Explicit support for 1-D and 2-D domains
  - KPP or Kraus-Turner or Mellor-Yamada 2.5 or Price-Weller-Pinkel
  - Rivers as bogused surface precipitation
  - Multiple tracers
  - Off-line one-way nesting
  - Scalability via OpenMP or MPI or both
    - Bit-for-bit multi-cpu reproducibility
- Special halo exchange for tripole global grid
  - Arctic dipole patch on standard Mercator globe
  - Logically rectangular domain
    - Two halves of top edge “fold” together
    - V-velocity changes sign across the fold

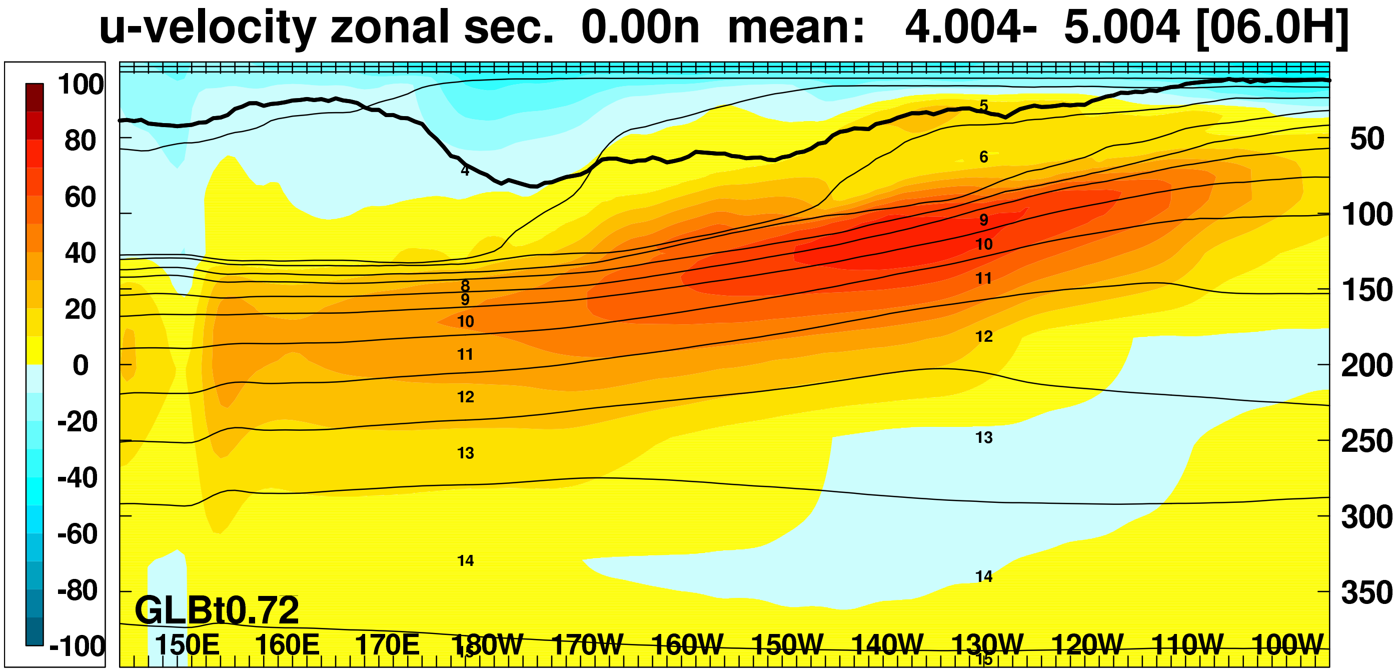
HYCOM 2.2 (IIa)

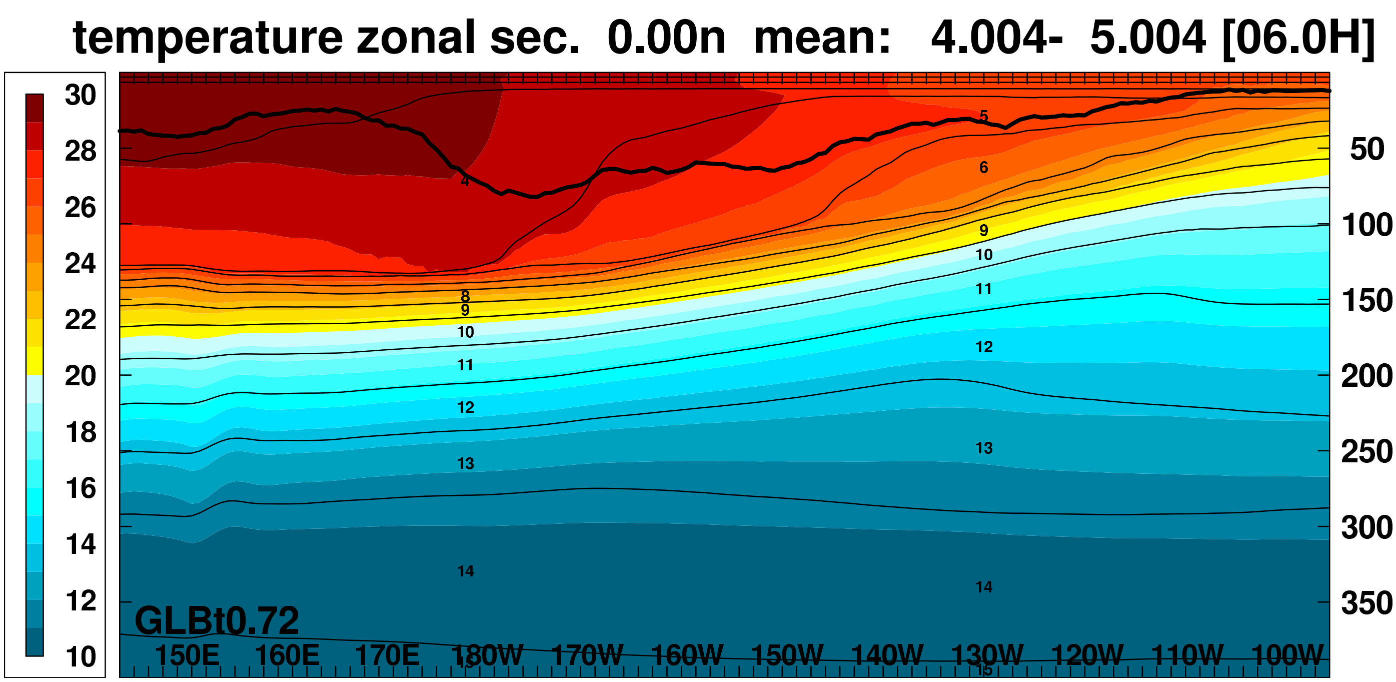
- Alternative LeapFrog barotropic time splitting
  - Provided by SHOM
  - Twice as expensive as standard scheme
    - Still a small fraction of total run time
  - Significantly more stable
  - May allow 2x longer baroclinic time step
- Alternative scalar advection techniques
  - Provided by Mohamed Iskandarani
  - Donor Cell, FCT (2nd and 4th order), MPDATA
  - FCT2 replaces MPDATA as standard scheme
- Mixed layer changes
  - GISS mixed layer model
    - Provided by Armando Howard
  - KPP bottom boundary layer
    - Provided by George Halliwell
  - KPP tuning

HYCOM 2.2 (IIb)

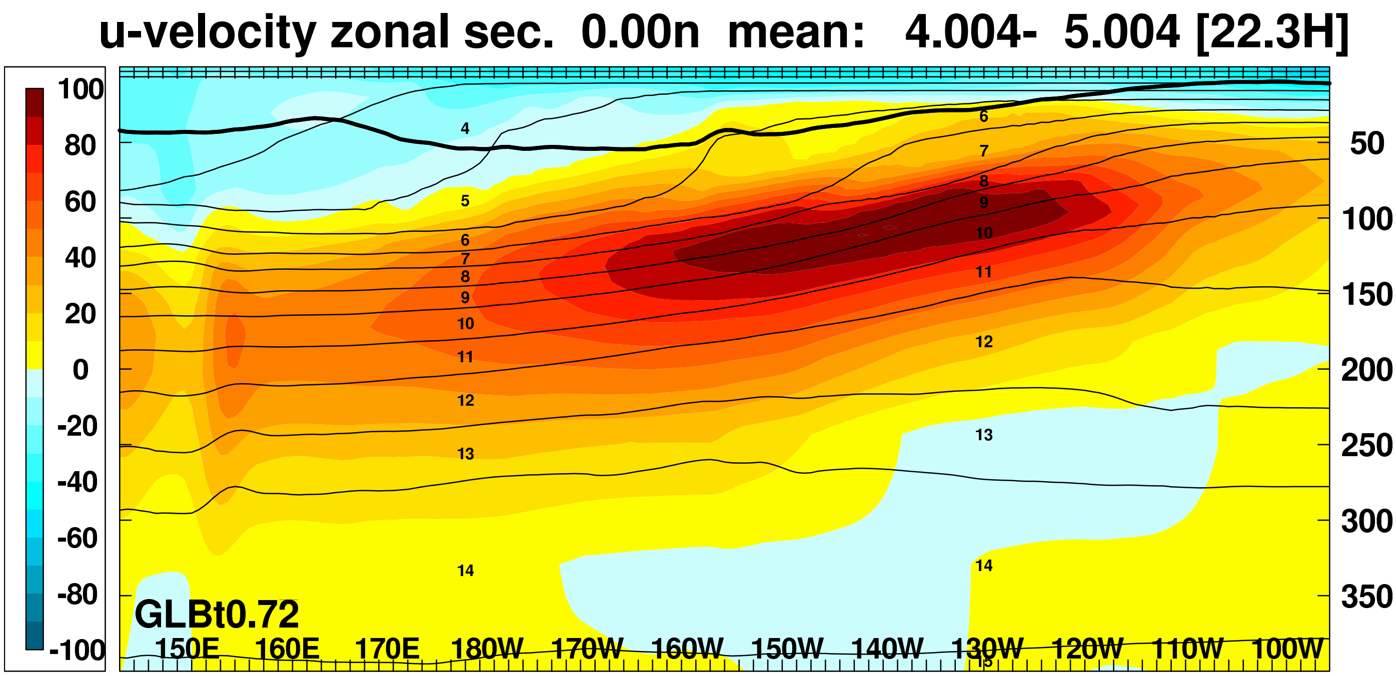
- Initial vertical coordinate changes
  - Must always use PCM for isopycnal layers
  - Vertical remapping used PLM for fixed coordinate layers
  - Thin deep iso-pycnal layers
  - Stability from locally referenced potential density
  - Spatially varying layer target densities
    - Different isopycnal layers in semi-enclosed seas
- Recent vertical coordinate changes (2.2.18)
  - hybrlx only active below “fixed coordinate” surface layers
  - Major re-write of HYBGEN by George Halliwell and Alan Wallcraft
    - Must always use PCM for isopycnal layers
    - Vertical remapping uses PLM or PPM or WENO-like PPM (Alexander Shchepetkin) for fixed and non-isopycnal coordinate layers
    - More layers are identified as non-isopycnal
    - Updated logic for two layers (one too dense, other too light)

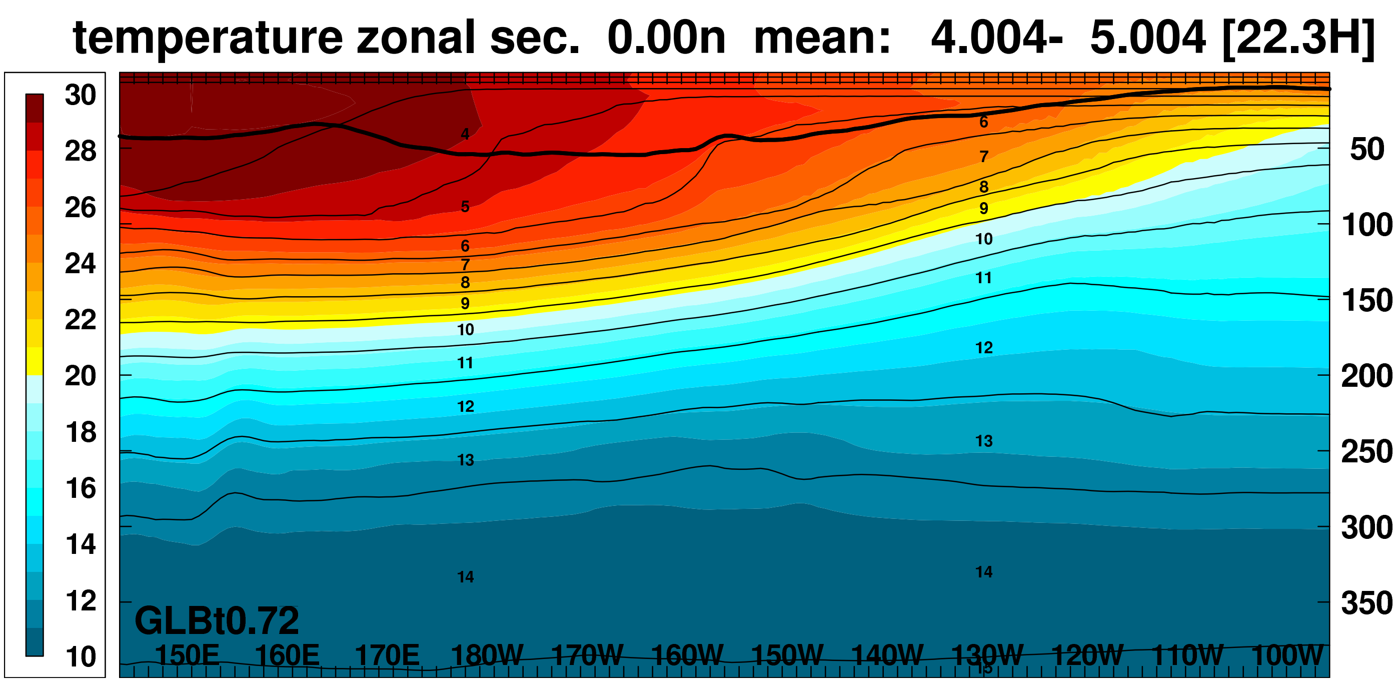
ANNUAL MEAN EQUATORIAL PACIFIC
GLBt0.72 HYCOM VERSION 2.2.03
3M TOP LAYER, GDEM3, 7-T EOS



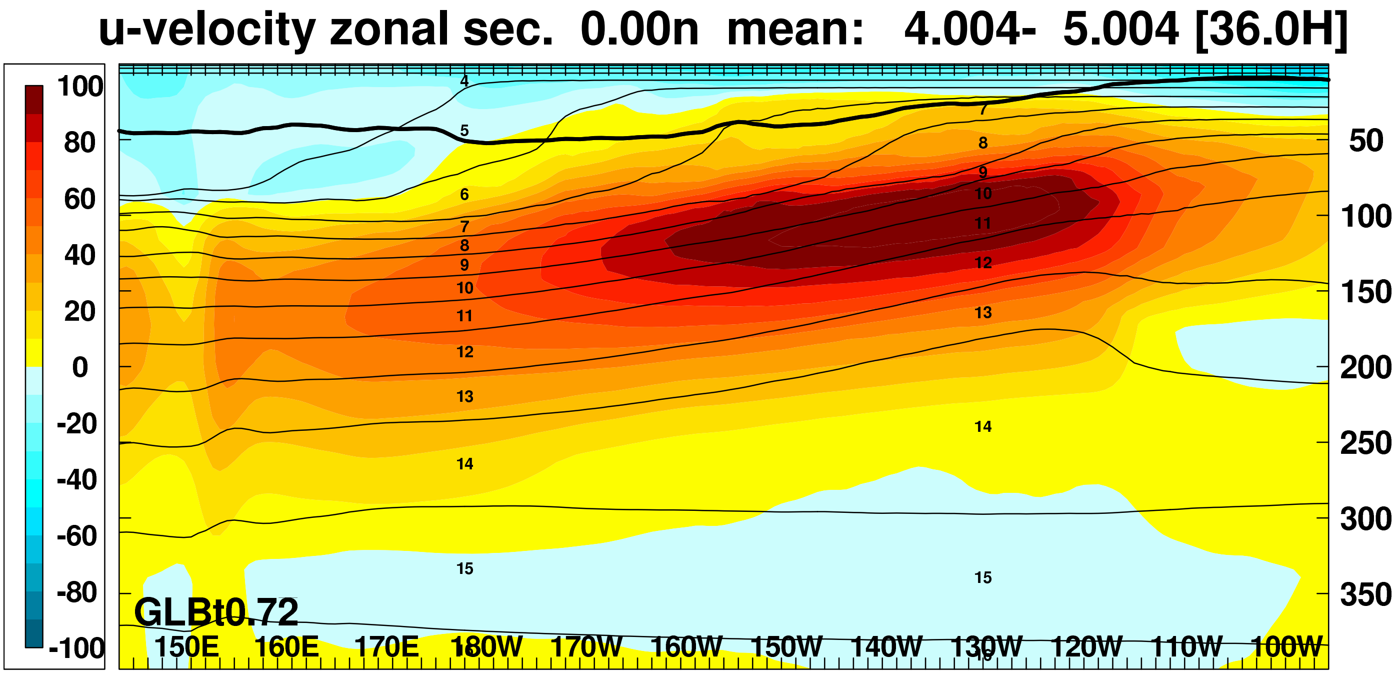


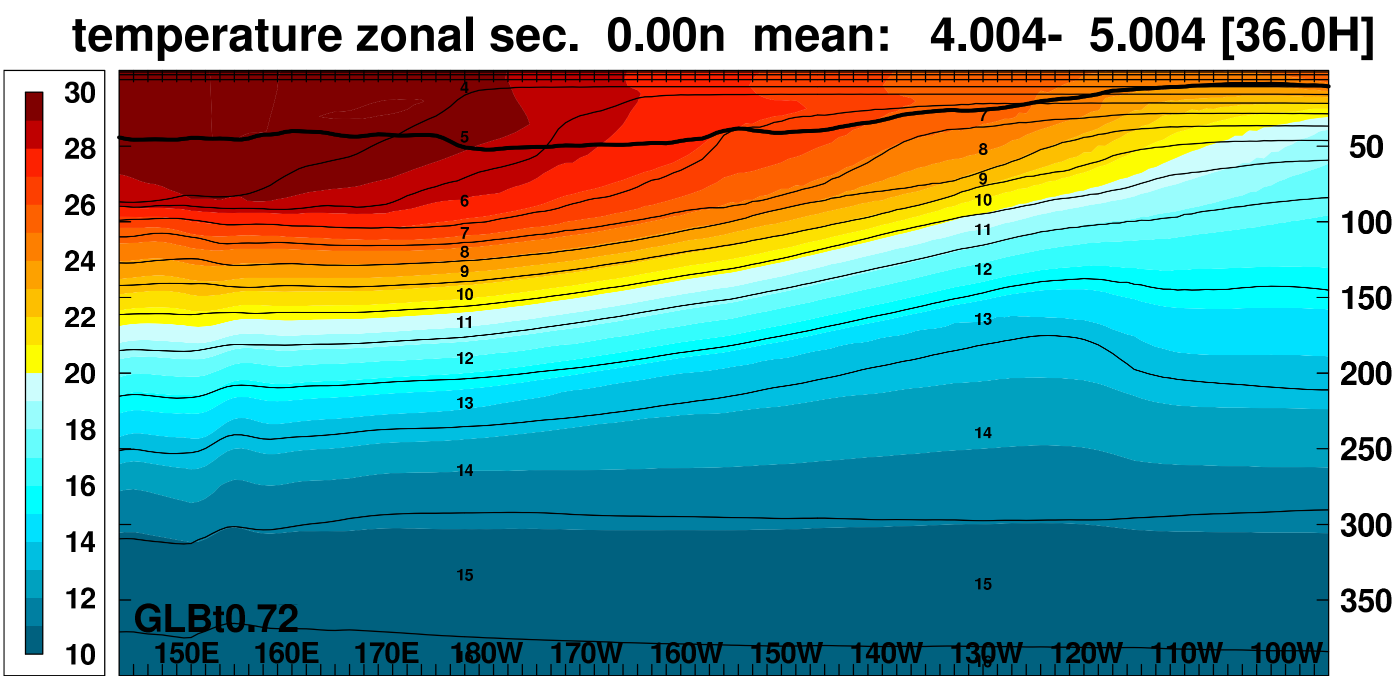
ANNUAL MEAN EQUATORIAL PACIFIC
GLBt0.72 HYCOM VERSION 2.2.18
3M TOP LAYER, GDEM3, 9-T EOS





ANNUAL MEAN EQUATORIAL PACIFIC
GLBt0.72 HYCOM VERSION 2.2.34
1M TOP LAYER, GDEM4, 17-T EOS

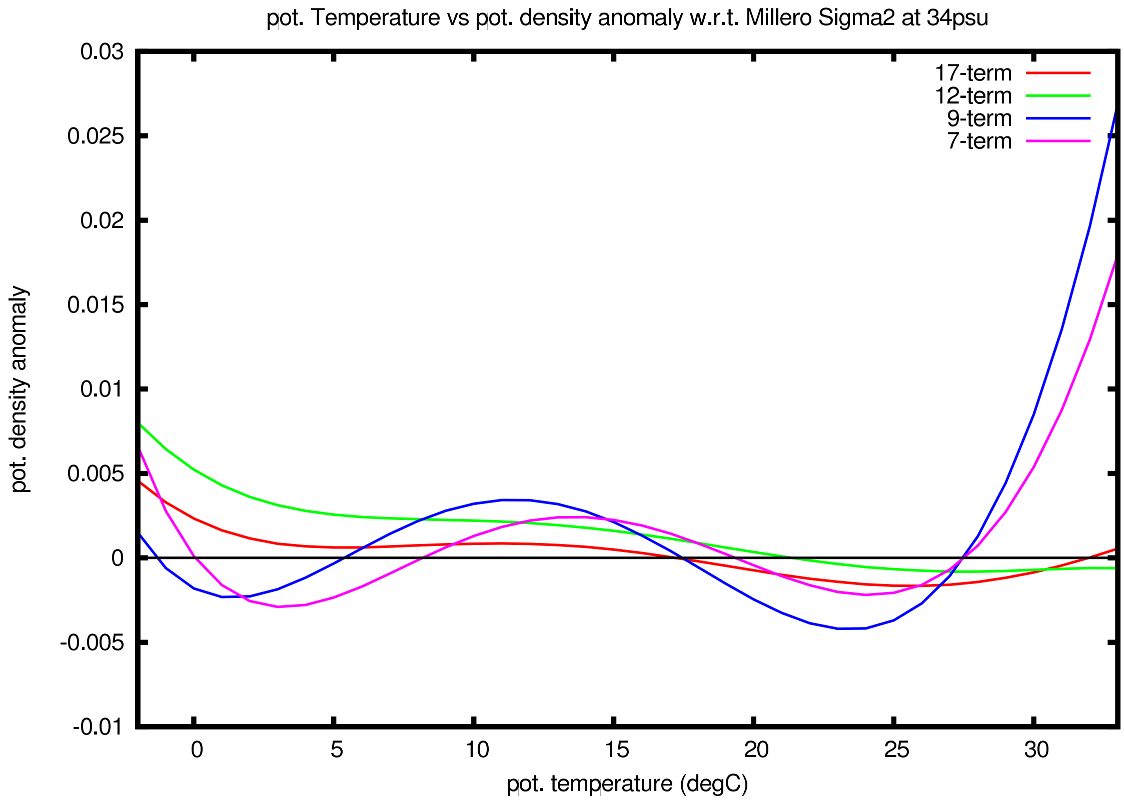


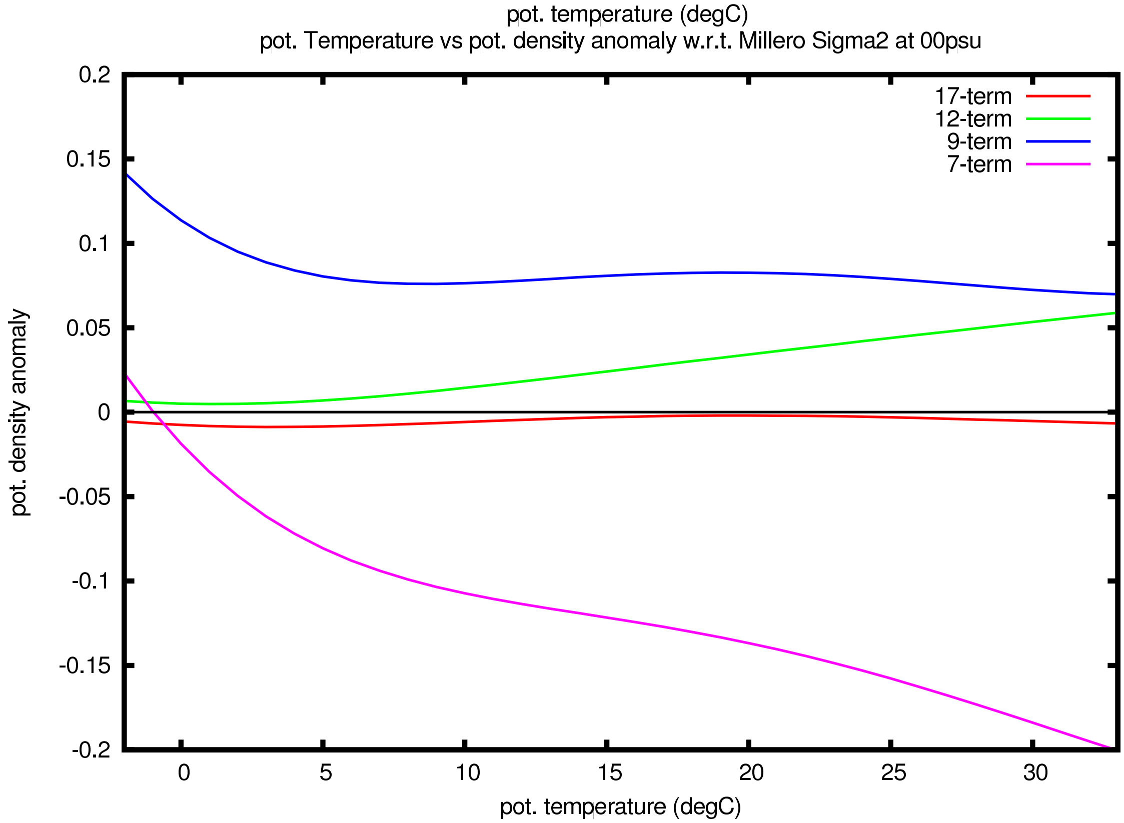


HYCOM 2.2 (IIc)

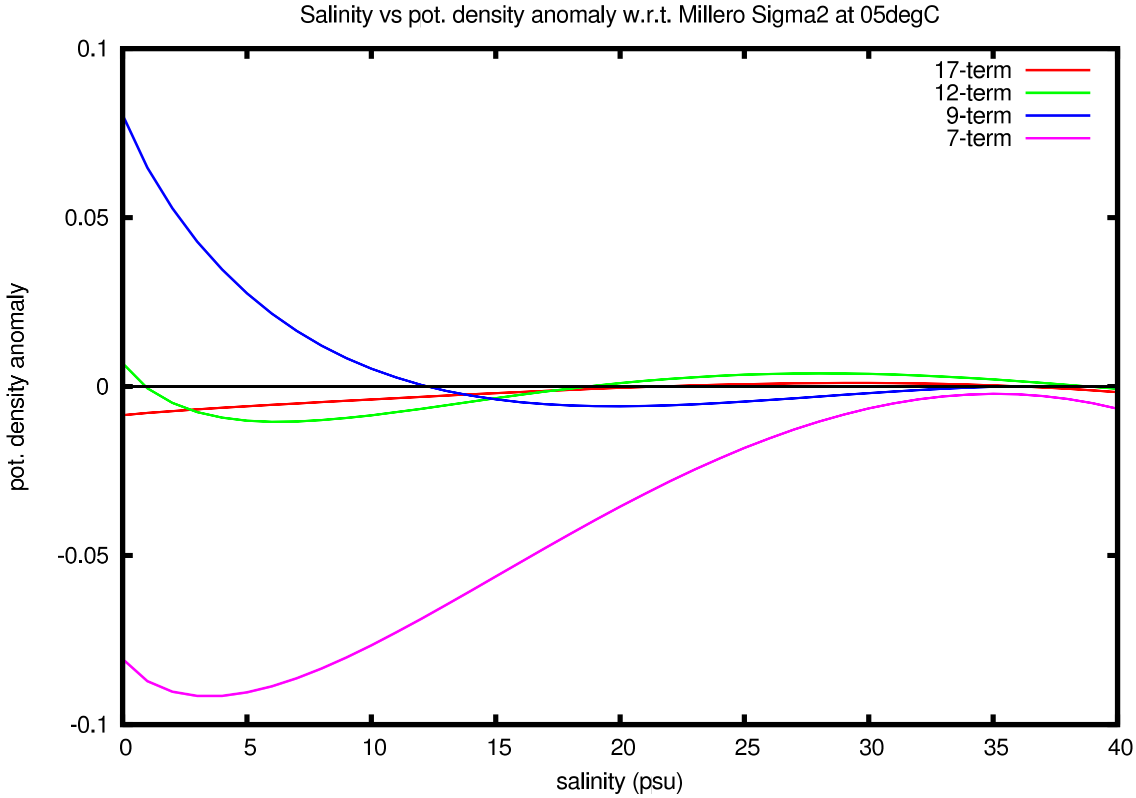
- MICOM must “invert” the equation of state
  - statement fns. tofsig(r,s) and sofsig(r,t)
- HYCOM must also invert, if density is prognostic
  - but not if T & S are prognostic
- Four equation of state options (HYCOM 2.2.34)
  - 7-term, cubic in T and linear in S
  - 9-term, cubic in T and quadratic in S
  - 12-term, rational function (invertable)
  - 17-term, rational function (not invertable)
- 12-term equation of state
  - P/Q, both P and Q quadratic in T & S
  - 18-term for locally referenced pressure
- 17-term equation of state
  - P/Q, P cubic T & linear S, Q quartic T & sqrt(S)
  - 25-term for locally referenced pressure
    - ◇ Same as MOM 4.1 (Jackett et al., 2006)
  - Must use T & S as prognostic variables
  - Diagnostic programs use Newton iteration from 12-term start

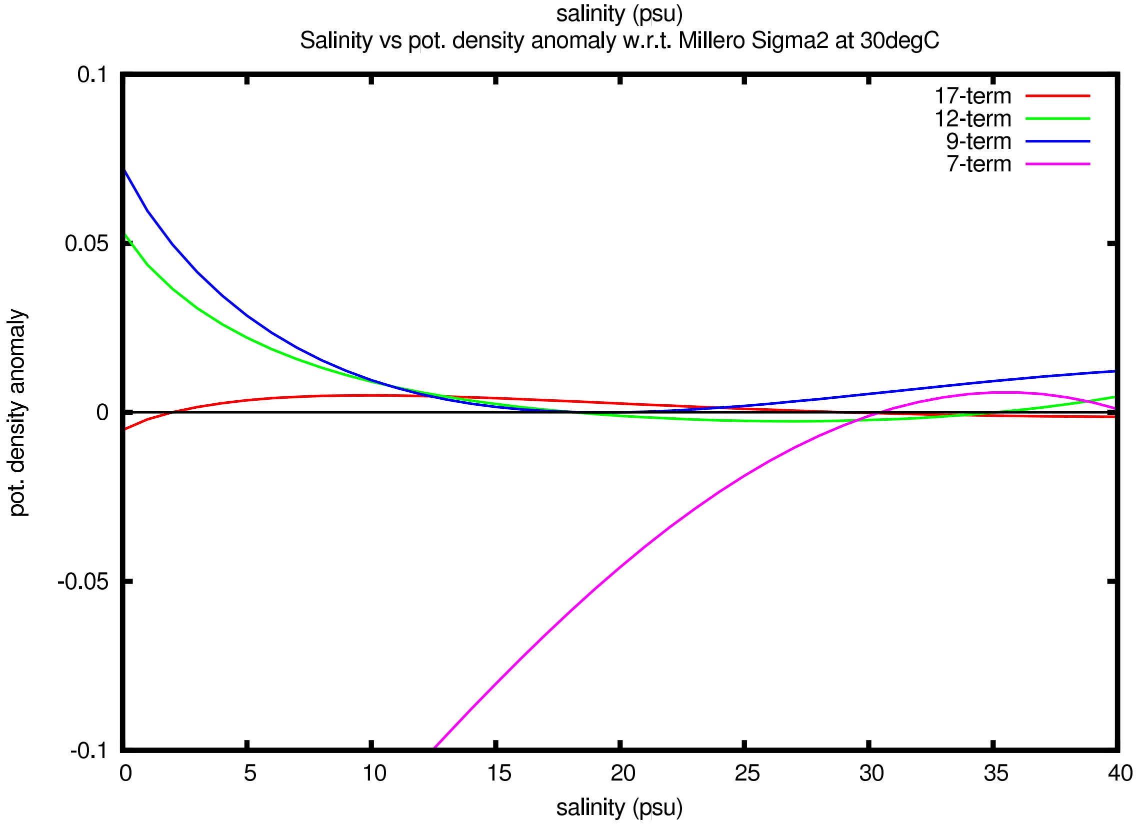
Pot. Density Anomaly at 34 psu and 0 psu





Pot. Density Anomaly at 5 degC and 30 degC





HYCOM RELAXATION TO SSS

- Standard HYCOM version:

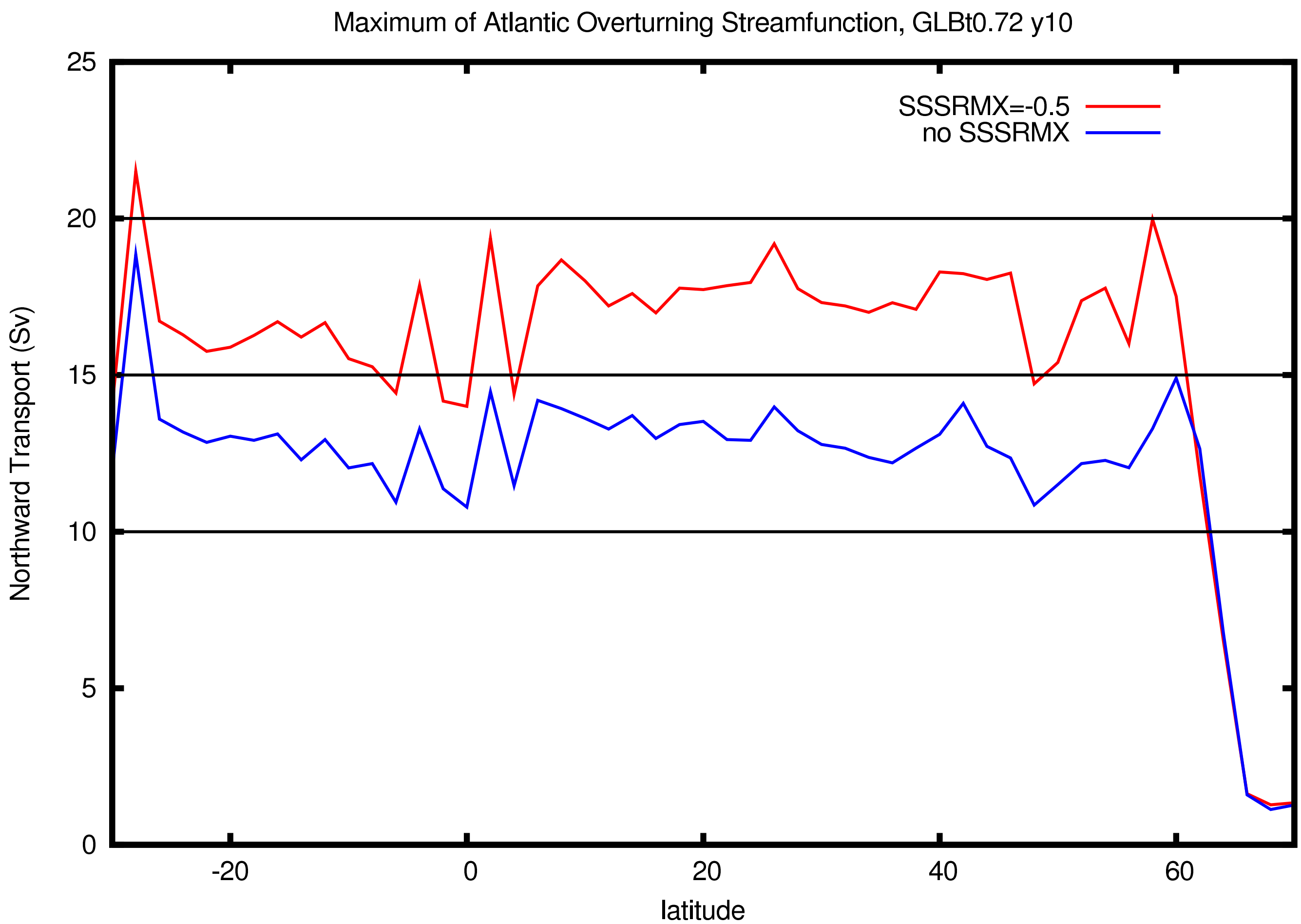
  $$\frac{\partial S_1}{\partial t} = \frac{H_s}{H_1(30\times 86400)}(S_c - S_1)$$

  - S_c is climatological SSS
  - H_s is a constant reference thickness
- E-folding time depends on actual MLD H_m:

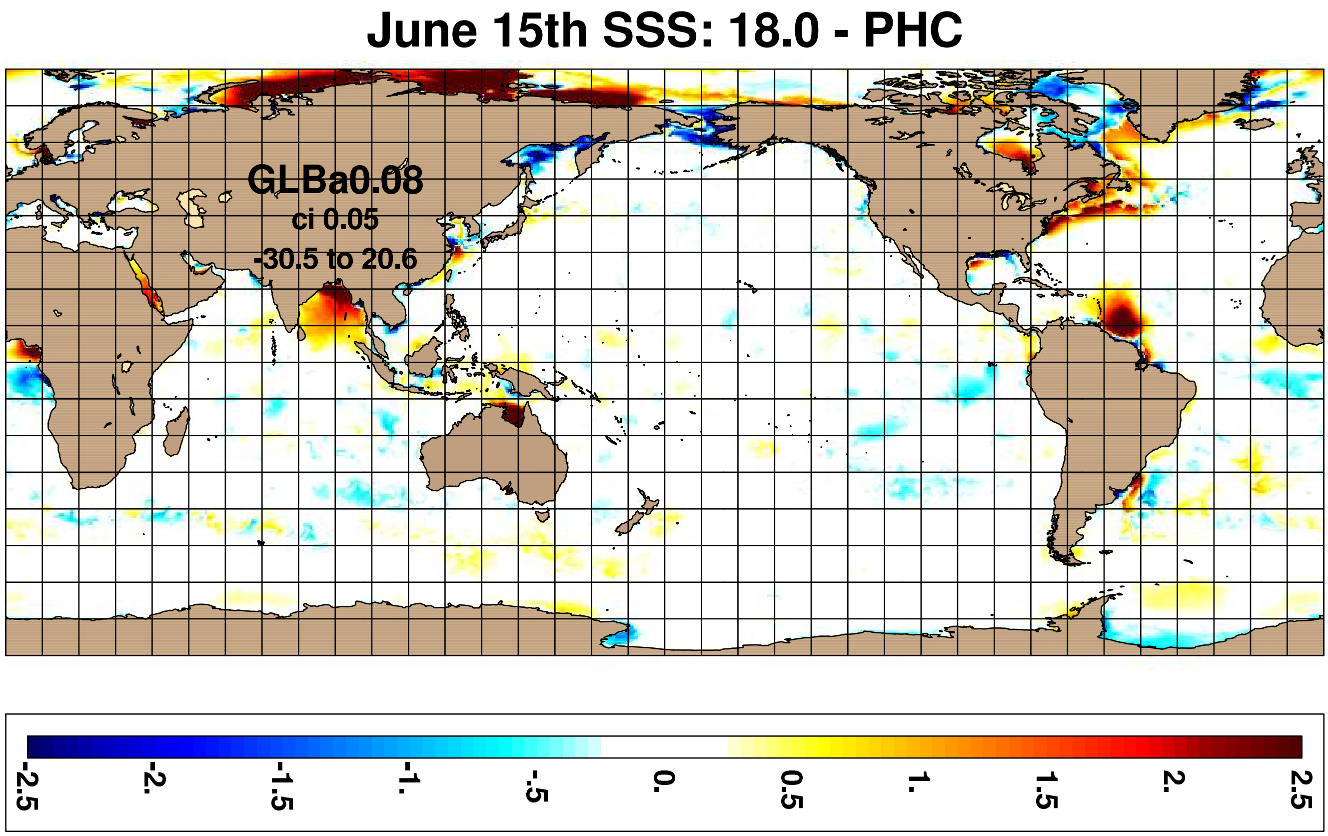
  30 days $\times H_m/H_s$

  - stronger relaxation when the MLD is shallower
- TOPAZ 4:
  - Small fix suggested by Mats Bentsen in order to avoid relaxation in the Gulf Stream.
  - Don’t relax where $S_1 - S_c >$ 0.5 psu
  - It avoids anomalous reduction of salinity for the water transported in the Nordic Sea.
- HYCOM 2.2.34:
  - Clip $|S_1 - S_c|$ at $\Delta S(x, y)$, or
  - Only relax where $|S_1 - S_c| < \Delta S(x, y)$
- In latest Global simultions:
  - Only relax where $|S_1 - S_c| <$ 0.5 psu
  - H_s is 15 m (was 30 m in earlier cases)

MAXIMUM OF ATLANTIC OVERTURNING STREAMFUNCTION
STD CASE VS RELAX WHERE $|S_1 - S_c| < 0.5$ PSU
YR10 GLBt0.72 ERA40-CLIMO



1/12° GLOBAL SSS ANOMALY
OUTSIDE 0.5 PSU IN GULF STREAM
BUT ALSO OTHER PLACES



HYCOM 2.2 (IId)

- Improved thermobaricity
  - Use exact formula for the thermobaricity
    - Eqn. 3 from Sun et al. 1999
  - No single reference state is appropriate for the global ocean
    - Hallberg, Ocean Modelling, 8, 279-300
  - Use a linear combination of pressure gradients from two out of three reference states
    - Atlantic (3°C, 35.0 psu)
    - Arctic/Antarctic (0°C, 34.5 psu)
    - Mediterranean (13°C, 38.5 psu)
  - Most locations use just one reference state
    - Linear combinations allow smooth transition between states
      - Do this in shallow water if possible
  - In deep water, constrain the T&S used for thermobaricity to be close to the reference state

HYCOM 2.2 (IIIa)

- Atmospheric forcing changes
  - Option to input ustar fields
    - Best option for monthly forcing
    - Otherwise calculated from wind stress or speed
  - Can relax to observed SST fields
  - Improved COARE 3.0 bulk exchange coefficients
  - Black-body correction to longwave flux
  - Climatological heat flux offset, $\overline{Q}_c$

    $$Q = (Q_{sw} - Q_{lw}) + (Q_l + Q_s) + \overline{Q}_c$$

    - $\overline{Q}_c$ is constant in time
      - Typically based on the model's climatological SST error, times (say) -45 $Wm^{-2}/°C$
  - Analytic diurnal heat flux cycle
    - Need hourly Q_{sw} for good cycle
    - For 3 or 6 hourly (snapshots or averages)
      - Input daily-running average Q_{sw}
        weighted sum for snapshots
      - Apply multiplicative correction:
        clear-sky_now / clear-sky_daily-average
      - Most cases from NRL use daily-running average only (no diurnal Q_{sw})

HYCOM 2.2 (IIIb)

- Improved support for rivers
  - Still bogused surface precipitation
  - High frequency inter-annual river flow allowed
    - Add it to atmospheric precip, off-line
    - Instead of monthly climatology,
      or in-addition to it (flow anomalies)
  - Better control of low salinity profiles
  - Option for mass (vs salinity) flux
  - Equation of state more accurate at low salinity
- Tidal forcing
  - Provided by NCEP
  - Body forcing and open boundary forcing
  - Boundary forcing currently for “Flather” ports
  - Body forcing for 8 largest components
  - SAL treated as a fraction of non-steric SSH
  - Tidal drag based on bottom roughness
    - Applied to near-bottom tidal velocity
      - Use a lagged 25-hour average as the non-tidal velocity
    - Limit e-folding time for stability

HYCOM 2.2 (IIIc)

- New diagnostics within HYCOM (2.2.34)
  - Skip fields in surface archives (smaller files)
  - Time-averaged fields (in archive files)
    - Same format as off-line mean archives
    - No in-line capability to capture variability
    - Instantaneous archives still available
  - Sub-region archive files
    - Example: hourly 3-D from Global 1/12°
      - 3-4 small regions only
    - One file per involved MPI task (entire tile)
    - Reconstruct standard regional archive files off-line
    - Instantaneous archives still available
  - List of locations for profile output
    - Just like itest,jtest .txt profile
  - Synthetic instrumentation
    - Provided by George Halliwell
    - 3-D particle tracking
    - surface and constant depth drifters
    - isopycnic drifters
    - fixed instruments and moorings

HYCOM 2.2 (IIId)

- I/O optimizations
  - Typically, all I/O is from a single MPI task
  - I/O can be a bottleneck when running on many processors
    - MPI-2 I/O option
      - Do I/O from 1st MPI task in each row of tiles
    - HYCOM files are always big-endian, but Intel and AMD are little-endian
      - ENDIAN_IO macro faster than compiler switch and does the conversion in parallel
  - Removes density from restart and archive files
    - Less I/O, smaller files
    - Must track which equation of state is used
  - Skip fields in surface archives
    - Less I/O, smaller files
  - Sub-region archive files
    - One file per involved MPI task
    - Can be much faster than writing a full archive
  - List of locations for profile output
    - I/O is small and from local MPI task
    - Can replace 3-D archives in some cases

HYCOM 2.2 AND SEA ICE

- Finer control over energy loan ice model
  - Melting point can be linear in salinity
  - Set ice minimum and maximum thickness
  - Set ice vertical temperature gradient
    - Or get ice surface temperature from T_a
  - Made compatible with coupled sea-ice approach
- Two-way coupling to LANL's CICE sea ice model
  - HYCOM exports:
    - SST, SSS, SSH
    - Surface Currents
    - Available Freeze/Melt Heat Flux
  - CICE exports:
    - Ice Concentration
    - Ice-Ocean Stress
    - Actual Freeze/Melt Heat/Salt/Mass Flux
    - Solar Radiation at Ice Base
  - Coupling via the Earth System Modeling Framework
    - Currently for non-global domains only

HYCOM 2.2 AND CCSM

- Community Climate System Model
  http://www.ccsm.ucar.edu/
  - Fully-coupled, global climate model
  - Sea-Ice: CICE
  - Ocean: POP
- HYCOM can be used in place of POP in CCSM3
- Uses the standard HYCOM source code
- Subdirectory CCSM3 used to hold and build the CCSM3 version
  - Some source code files are specific to CCSM3
  - HYCOM ".f" files are renamed ".F" to simplify CCMS3 integration
  - Macro USE_CCSM3 for CCSM3-specific code

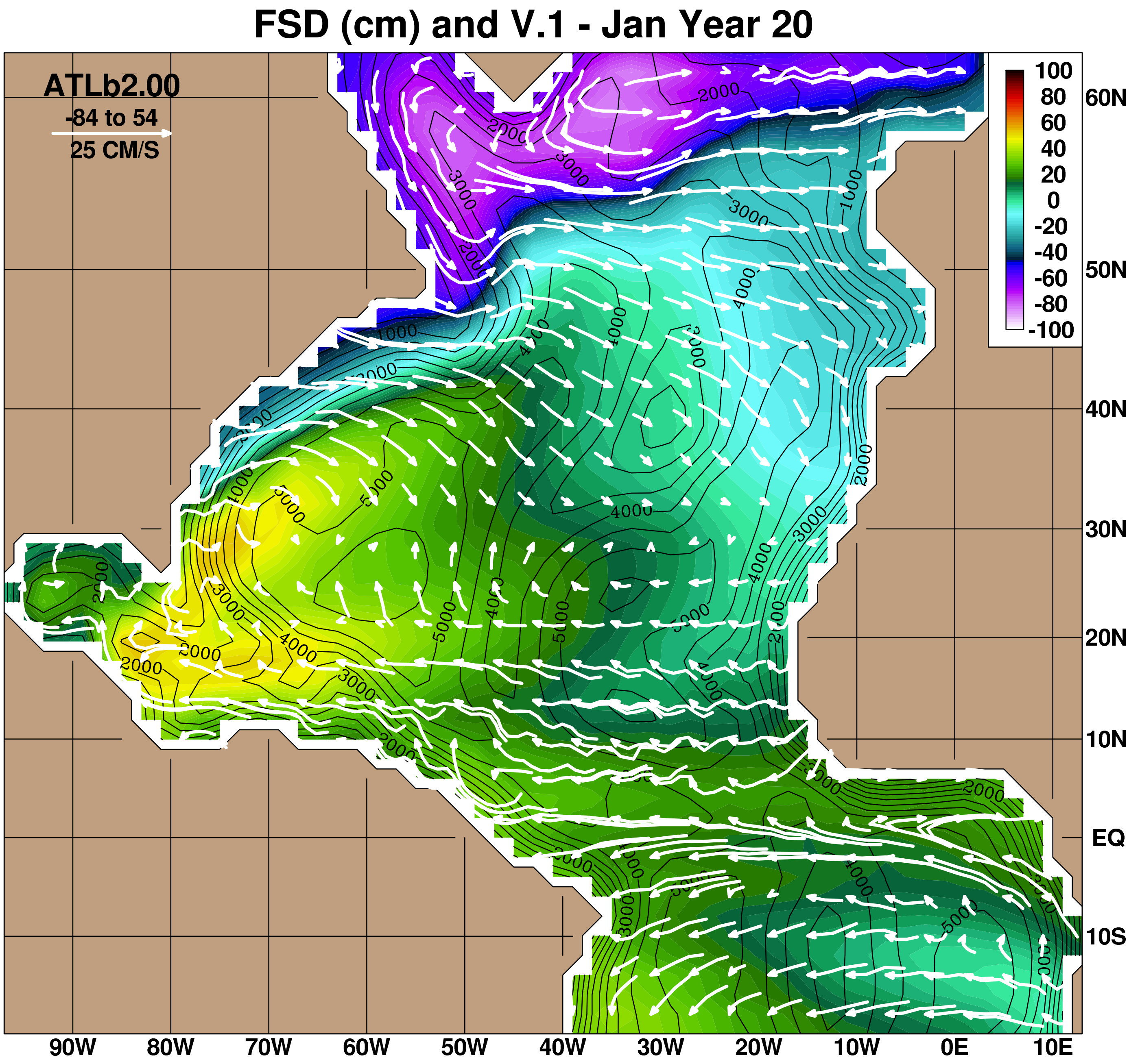
HYCOM 2.2 (IV)

- Climatological nesting now allowed
  - Start from monthly mean outer model archive files
  - Allows nested runs longer than the outer run
    - But with less accurate boundary state
  - Probably only suitable for regional nests
- Nesting no longer requires co-located grids
  - General horizontal interpolation (curvilinear grids)
    - Find the source array-index-space location of each point on the target grid
      - Produces a regional.gmap file (do once)
    - Bi-linear interpolation
    - archive to archive or field to field
- Hybrid to fixed vertical grid remapper
  - Allows fixed-coordinate nests inside hybrid coordinate outer domains
    - HYCOM to (fixed-grid) HYCOM
    - HYCOM to NCOM

HYCOM 2.2 (V)

- Enhanced hycomproc and fieldproc
  - NCAR-graphics based
  - Many more color palette options
    - Can read in an arbitrary palette
  - Mark locations, and draw tracks, on plot
  - Plot diffusion coefficients and tracers (hycomproc)
  - Overlay vector and line-contours (fieldproc)
    - Vectors can optionally follow streamlines
- Added fieldcell
  - Like fieldproc, but for cell-array (vs contouring)
    - Mark locations and draw tracks
    - Overlay line-contours
  - Uses NCAR's map projections
  - Typically much faster than fieldproc,
    but can leave unfilled cells
  - Option to increase resolution of input
    (bi-linear interpolation)

EXAMPLE OF FIELDPROC
SSH, SURFACE CURRENTS, AND BATHYMETRY



HYCOM 2.2 (VI)

- Diagnostic fields to netCDF and other file formats
  - Any p-grid fields in HYCOM ".a" file
    - On original grid, or
    - Binned into lon-lat cells
  - Archive fields in layer space
    - On p-grid (interpolated velocity)
  - 3-D archive fields interpolated to z-space
    - On p-grid, or
    - Sampled at stations or along arbitrary tracks
  - 3-D archive fields sampled on iso-therms
  - Meridional stream-function from (mean) 3-D archive
    - In logical array space (rectilinear grids)
    - Binned to latitude bands (curvilinear grids)
- Atmospheric forcing native grid files
  - NRL .D or (new) netCDF integer*2
  - Use bi-cubic interpolation for stresses
    - Faster than cubic spline, equally good curl

CANDIDATE FEATURES FOR HYCOM 2.3

- Wind drag coefficient based on model SST
- Wave forcing
  - Stokes Drift Current (SDC)
  - Surface Wave Radiation Stress Gradents (WRSG)
  - Bottom Orbital Wave Current (OWC)
- Regional tides and Browning-Kreiss nesting
- Wetting and Drying
- New framework for mixed layer sub-models
  - Support generic two-equation models
  - Decouple vertical grids for dynamics and mixing
- Fully region-independent
  - Compile once, run on any region and any number of processors
    - Run-time memory allocation
    - Might reduce performance (fewer compiler optimizations available)
  - Needed for full ESMF compliance
    - Single executable, multiple components each running on separate cpus
    - HYCOM arrays currently on all cpus