

# New Features of HYCOM

Alan J. Wallcraft

Naval Research Laboratory

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With Additions From Previous Presentations

## **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 bogus 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)**

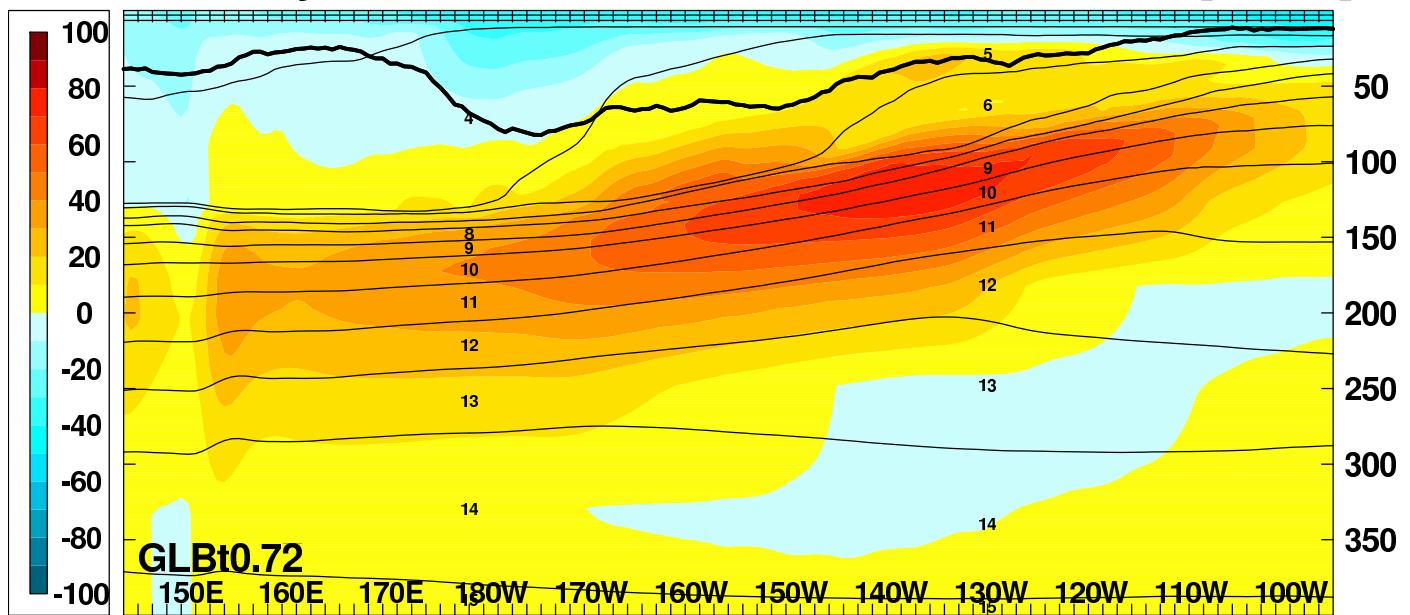
- Alternative LeapFrog barotropic time splitting
  - Provided by SHOM
  - Twice as expensive as standard scheme
    - ◊ Still a small fraction of total run time
  - Significantly more stable
  - May allow 2x longer baroclinic time step
- Alternative scalar advection techniques
  - Provided by Mohamed 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)**

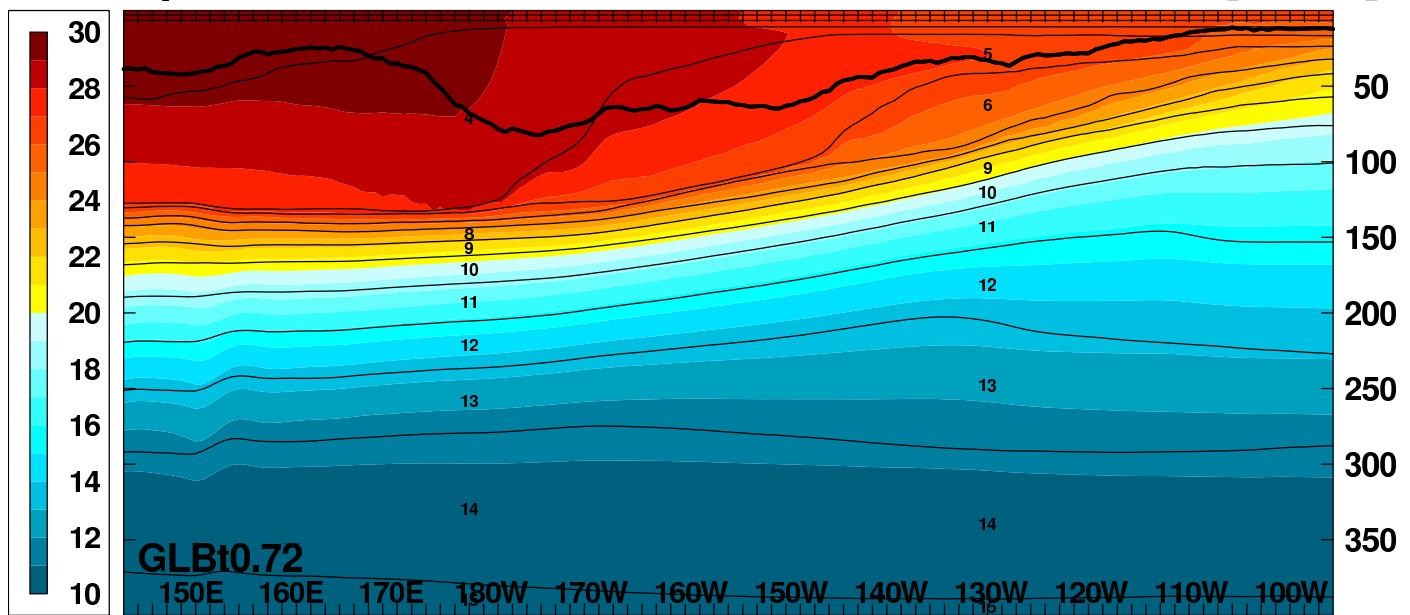
- Initial vertical coordinate changes
  - Must always use PCM for isopycnal layers
  - Vertical remapping used PLM for fixed coordinate layers
  - Thin deep iso-pycnal layers
  - Stability from locally referenced potential density
  - Spatially varying layer target densities
    - ◊ Different isopycnal layers in semi-enclosed seas
- Recent vertical coordinate changes
  - 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 (Laurent Debreu) 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

u-velocity zonal sec. 0.00n mean: 4.004- 5.004 [06.0H]

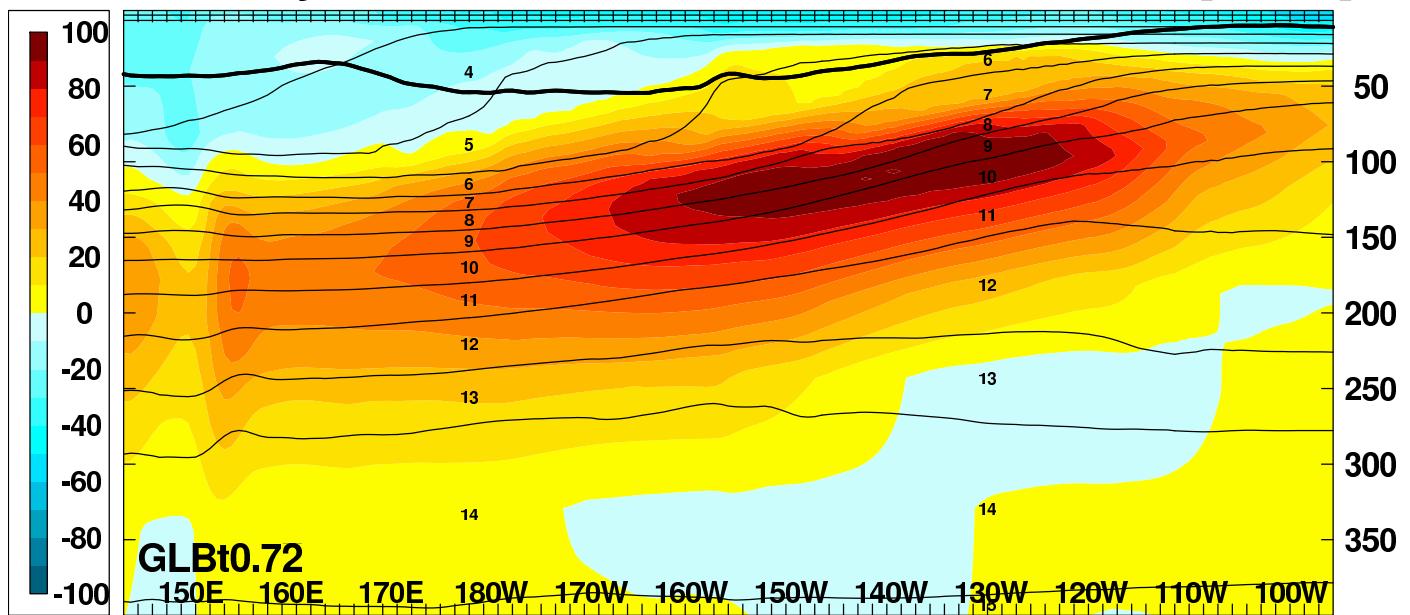


temperature zonal sec. 0.00n mean: 4.004- 5.004 [06.0H]

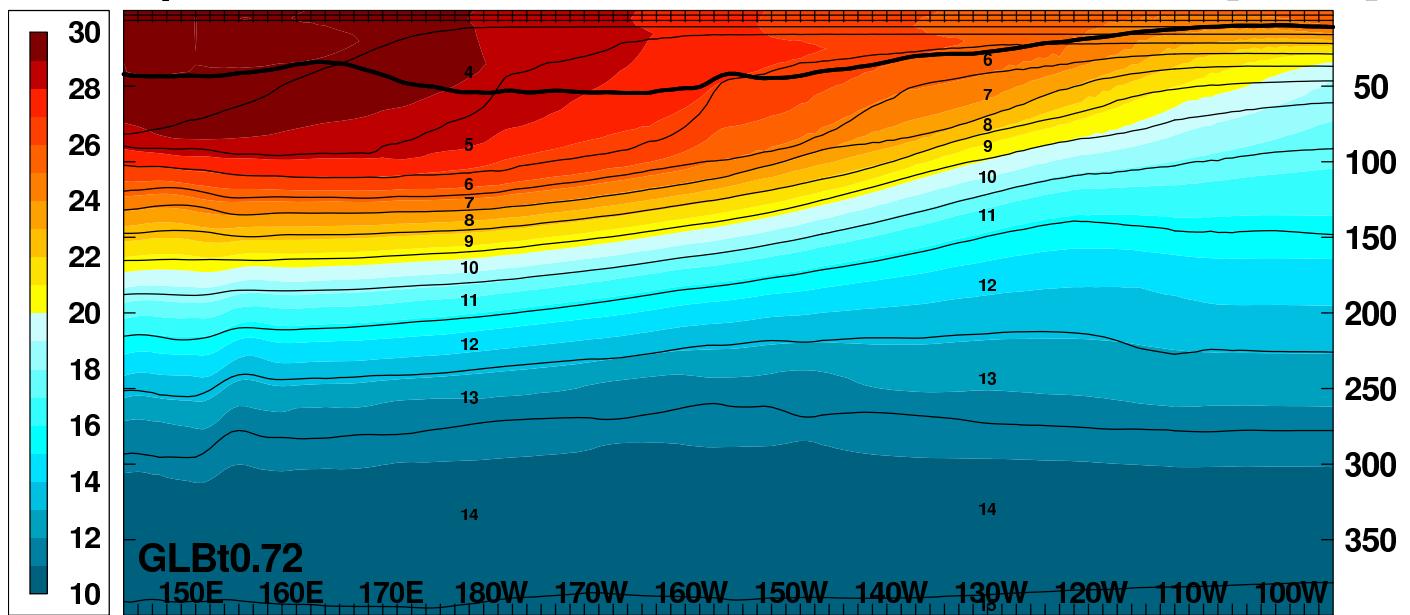


# ANNUAL MEAN EQUATORIAL PACIFIC GLBt0.72 HYCOM VERSION 2.2.18

u-velocity zonal sec. 0.00n mean: 4.004- 5.004 [22.3H]



temperature zonal sec. 0.00n mean: 4.004- 5.004 [22.3H]



## **HYCOM 2.2 (IIc)**

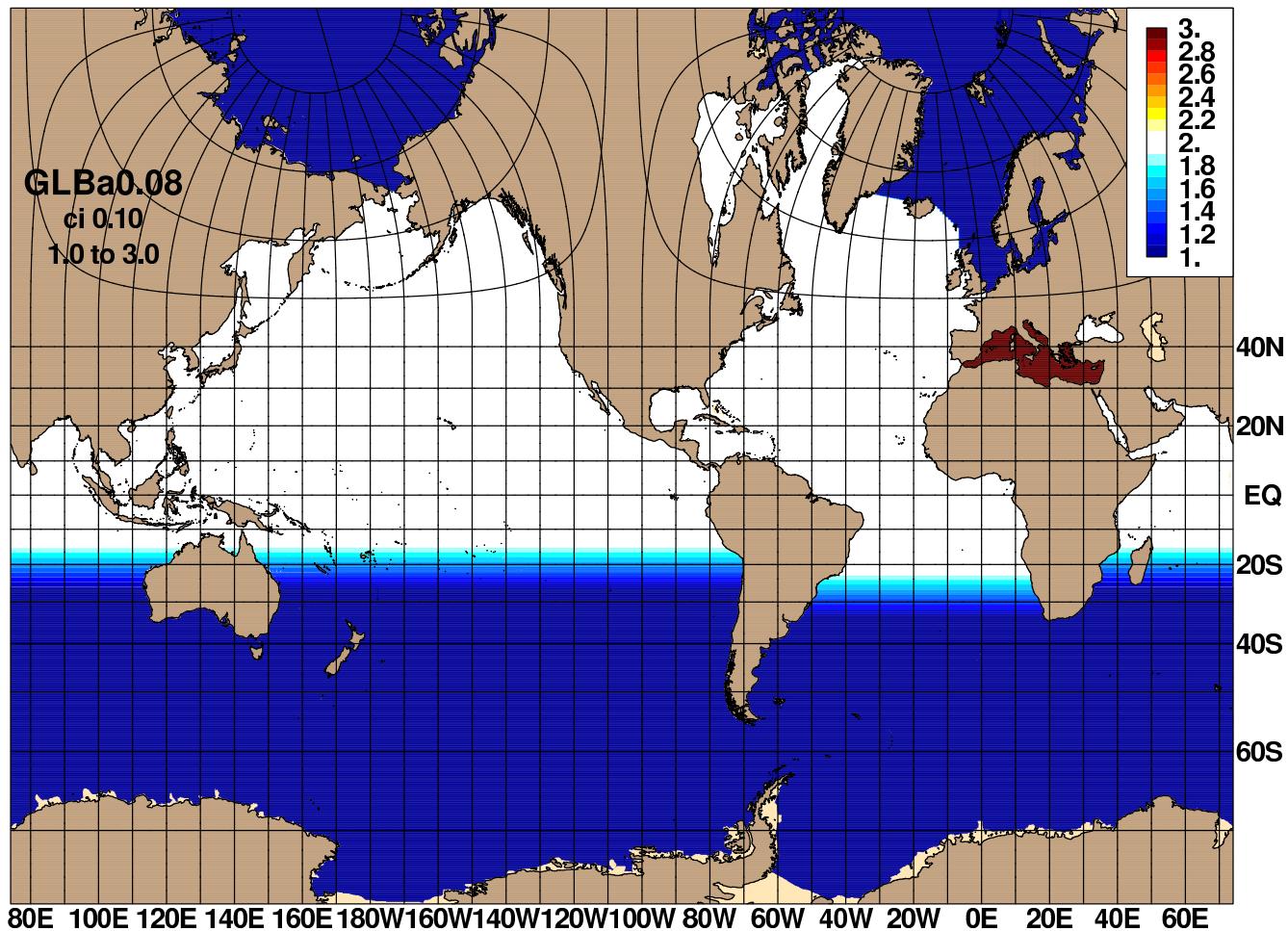
- Equation of state that is quadratic in salinity
  - HYCOM must “invert” the equation of state
    - ◊  $\text{tofsig}(r,s)$  and  $\text{sofsig}(r,t)$
  - Traditional version is cubic in T and linear in S
    - ◊ Finding the root of a cubic is expensive, but exact
    - ◊ Linear in S is not accurate at low salinity
  - Optional version is cubic in T and quadratic in S
    - ◊ Coefficients provided by Shan Sun
    - ◊ More accurate at low salinity
      - Rivers, Black Sea, Caspian Sea
    - ◊ Not much more expensive
- Pade equation of state
  - Optional Pade version:  $P_{22}/Q_{11}$ 
    - ◊  $P_{22}$  is quadratic in T and S
    - ◊  $Q_{11}$  is linear in T and S
  - Developed at NCEP
    - ◊ Only Sigma0 at present
  - More accurate at low salinity

## **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

# 1/12° GLOBAL THERMOBARIC REFERENCE STATE

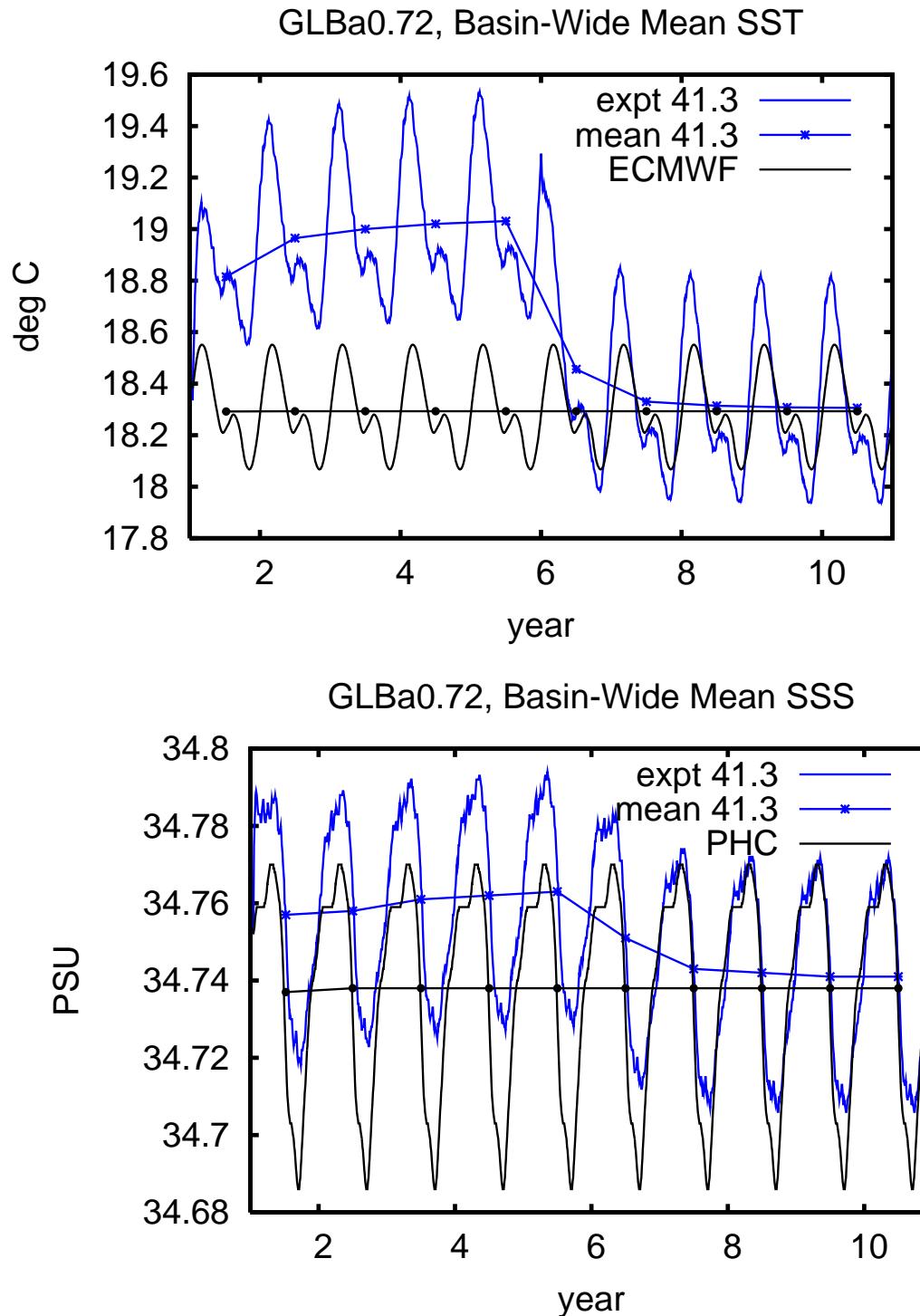
TBARIC MAP (1=Arctic,2=Atlantic,3=Med.)



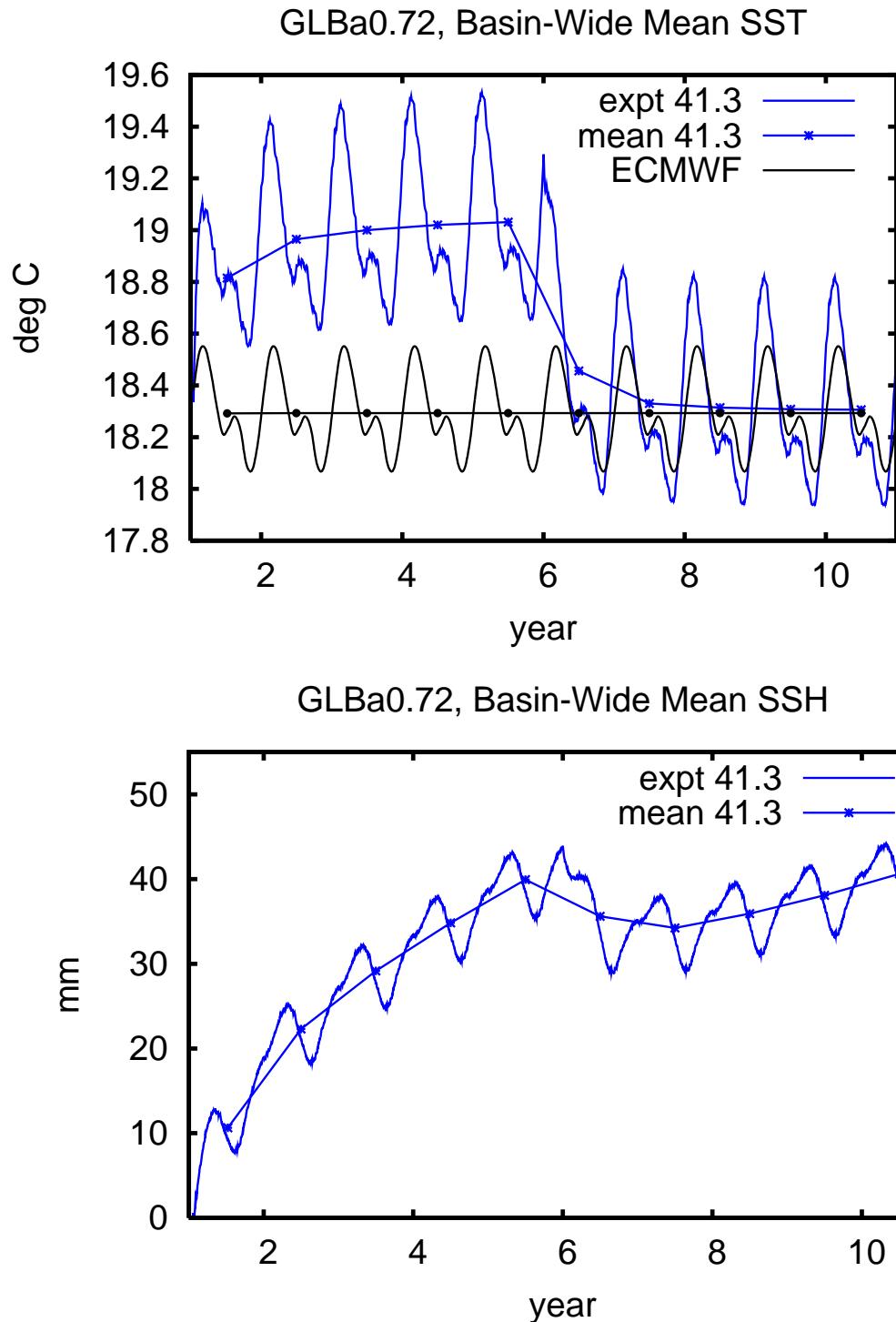
## HYCOM 2.2 (IIIa)

- 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)  $-45 \text{ W m}^{-2}/^\circ\text{C}$
  - Analytic diurnal heat flux cycle
    - ◊ Need hourly  $Q_{sw}$  for good cycle
      - Have 3 or 6 hourly (snapshots or averages)
    - ◊ Input daily-running average  $Q_{sw}$
    - ◊ Apply multiplicative correction:
      - clear-sky\_now / clear-sky\_daily-average

$\overline{Q}_c$  ADDED AFTER FIVE YEARS  
GLOBAL MEAN SST and SSS

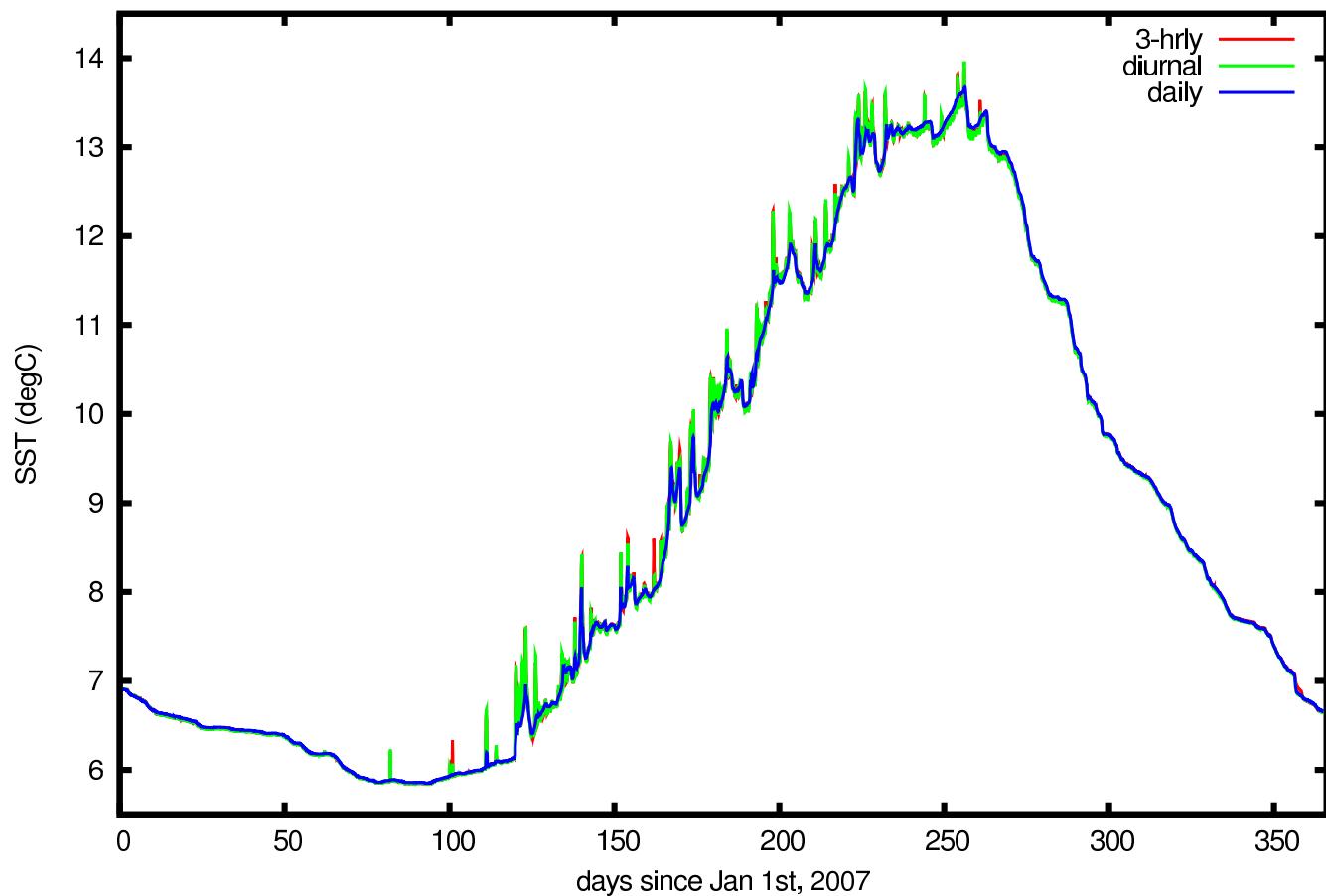


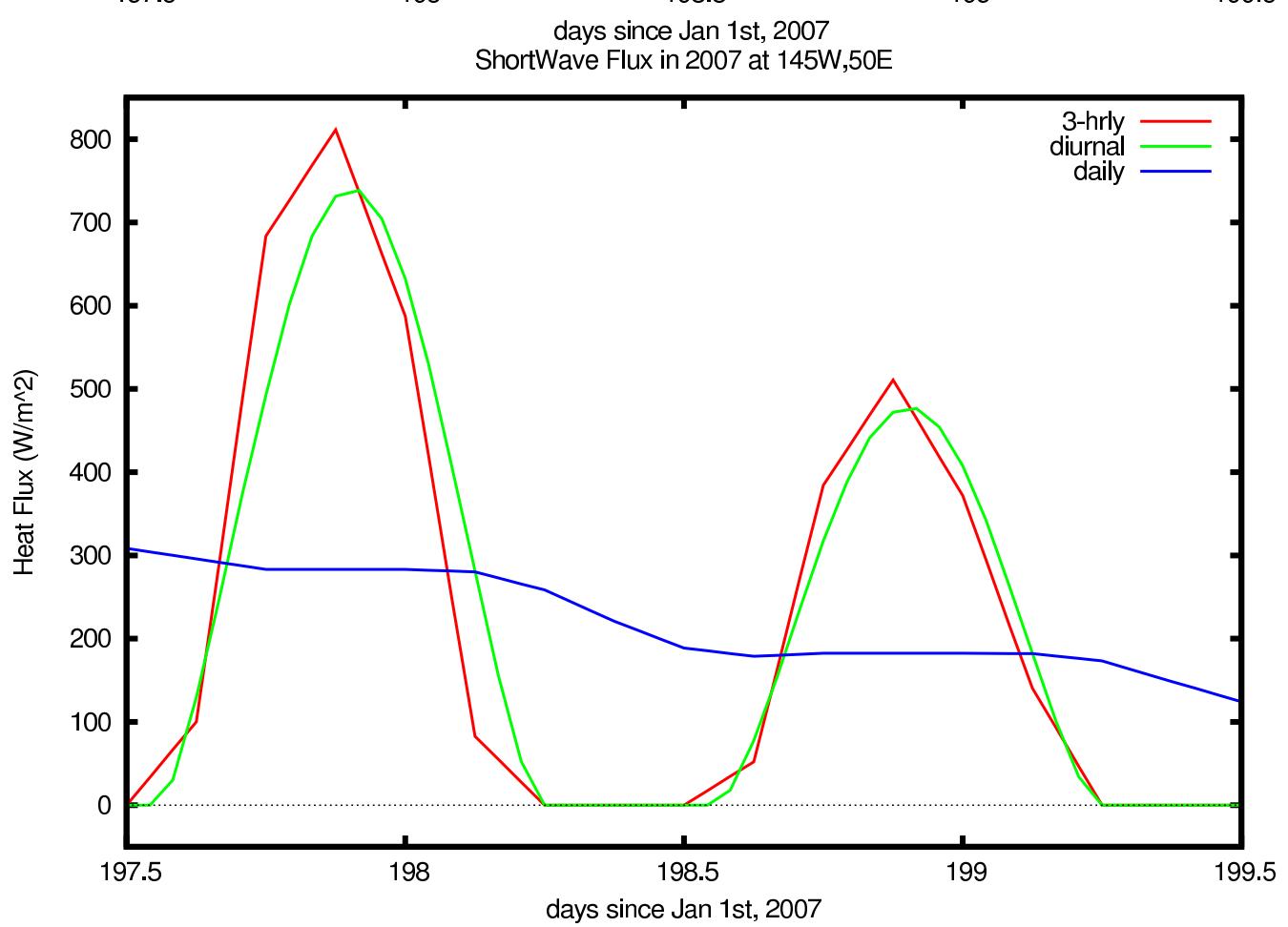
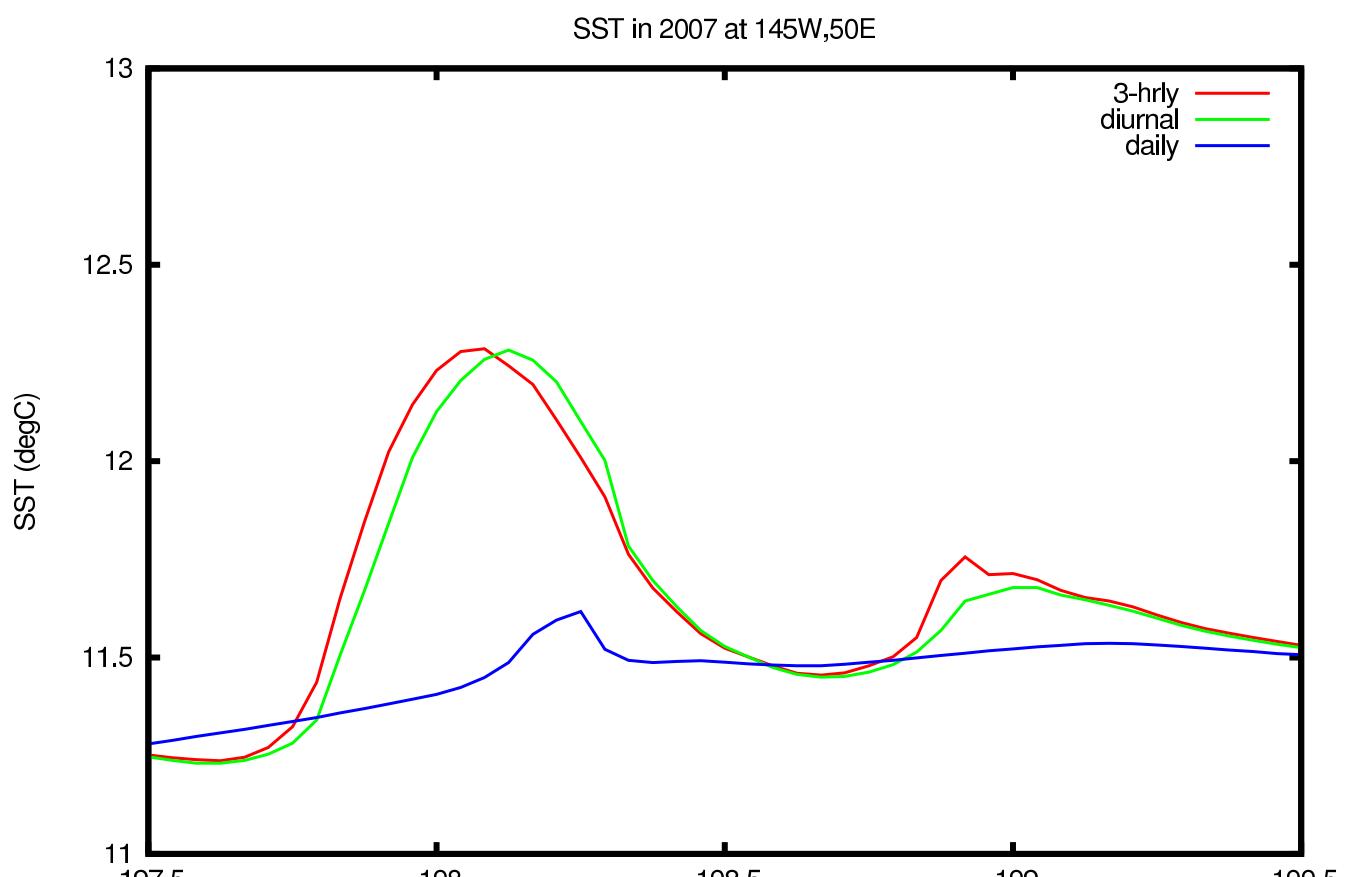
$\overline{Q}_c$  ADDED AFTER FIVE YEARS  
GLOBAL MEAN SST and SSH



# 1-D HYCOM at OCEAN STATION PAPA NOGAPS FORCING

SST in 2007 at 145W,50E





## **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 that is quadratic in salinity
- Tidal forcing
  - Provided by NCEP
  - Body forcing and open boundary forcing
  - Boundary forcing currently for “Flather” ports
    - ◊ v2.3: Extend it to Browning-Kreiss nesting
  - 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

## **HYCOM 2.2 (IIIc)**

- New diagnostics within HYCOM
  - Time-averaged fields (in archive files)
    - ◊ Identical to off-line mean archives
    - ◊ Daily 25-hour average for tides
    - ◊ 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
  - 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
    - ◊ Faster code for “endian” conversion
      - HYCOM files are always big-endian
      - Intel and AMD are little-endian
      - Do the conversion in parallel
  - Sub-region archive files
    - ◊ One file per involved MPI task
    - ◊ Can be much faster than writing a full archive
  - Remove density from restart and archive files
    - ◊ Less I/O, smaller files
    - ◊ Must track which equation of state is used

## 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
    - ◊ v2.3: ESMF version 4 and global domains

## **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)**

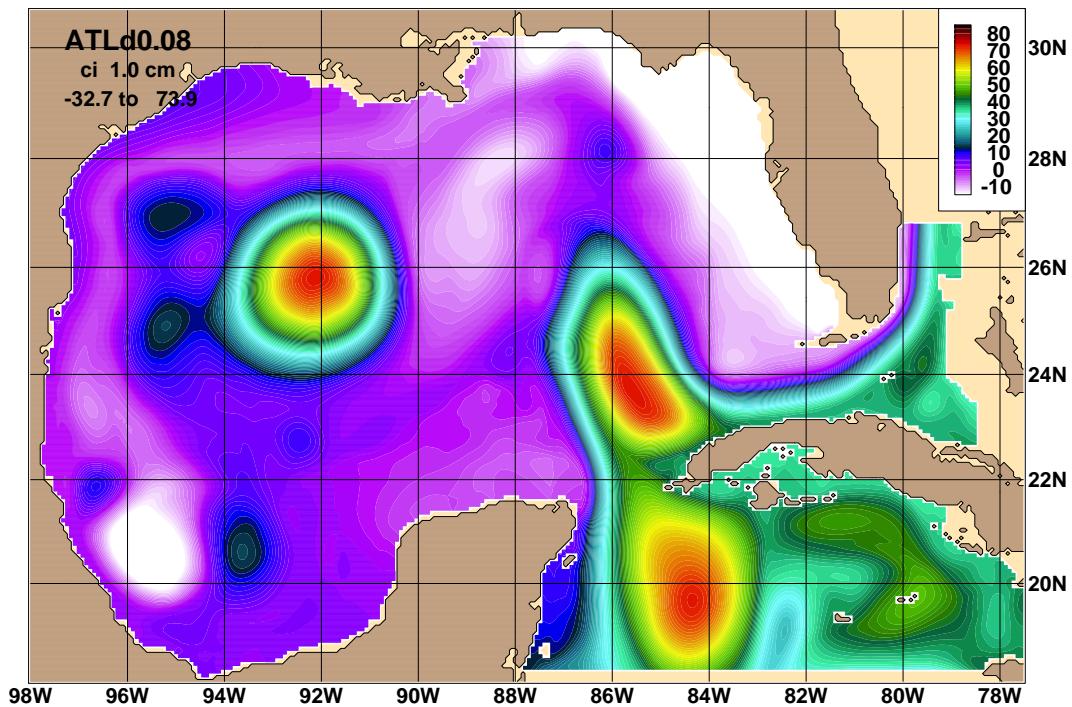
- Climatological nesting now allowed
  - Start from monthly mean outer model archive files
  - Allows nested runs longer than the outer run
    - ◊ But with less accurate boundary state
  - Probably only suitable for regional nests
- Nesting no longer requires co-located grids
  - General archive to archive horizontal interpolation (curvilinear)
- Hybrid to fixed vertical grid remapper
  - Allows fixed-coordinate nests inside hybrid coordinate outer domains
    - ◊ HYCOM to (fixed-grid) HYCOM
    - ◊ HYCOM to NCOM

## GoM NESTED TEST DOMAIN

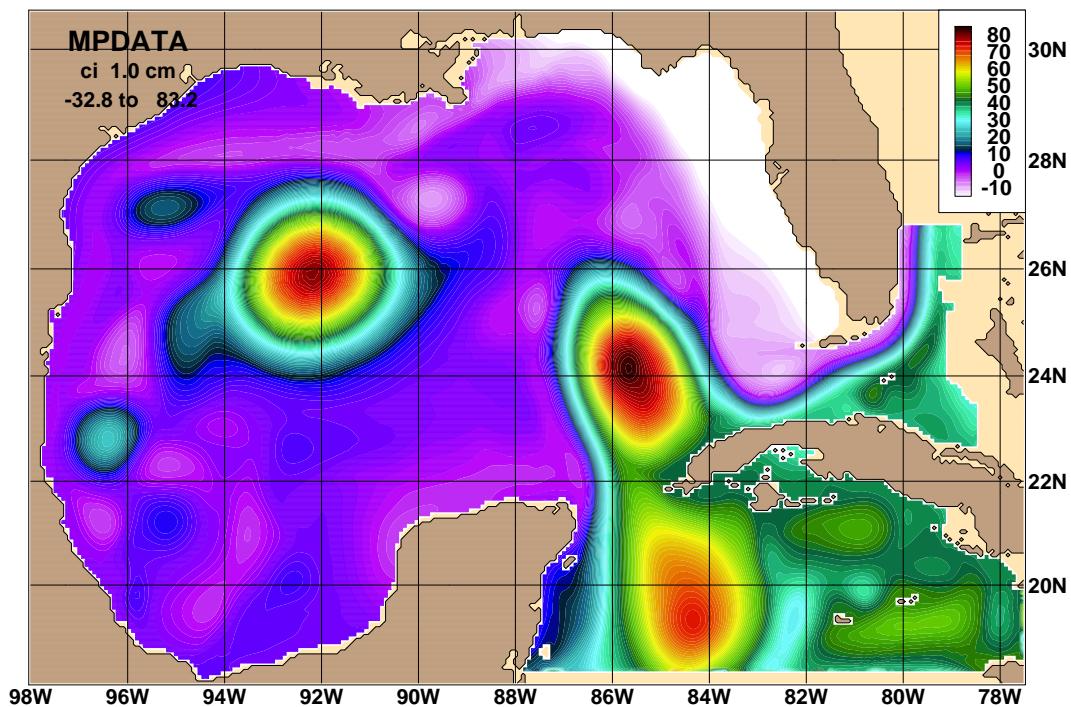
- Same resolution nesting unexpectedly useful
  - No need to rerun large domain
  - Change atmospheric forcing (e.g. use MM5)
  - Change vertical structure
  - Tracer studies (e.g. add biology)
- 1/12°: Gulf of Mexico inside Atlantic
  - Change from 20m to 5m coastline
  - Run for Aug 1999 to equilibrate
  - Run Sep-Nov as standard test case
- Used to test advection schemes
- All needed file are prebuilt
  - <ftp://hycom.coaps.fsu.edu/pub/hycom/GOMd0.08/>
  - Now uses 2.2.18, but 2.1.20 and 2.1.34 are also available
  - Includes a passive tracer
- Also tested (new) climatological nesting
  - Start from monthly mean outer model archive files
  - Climatological nested boundary conditions

# ATLANTIC vs GOM NEST (MPDATA)

sea surf. height Dec 01, 1999 00Z [02.6H]

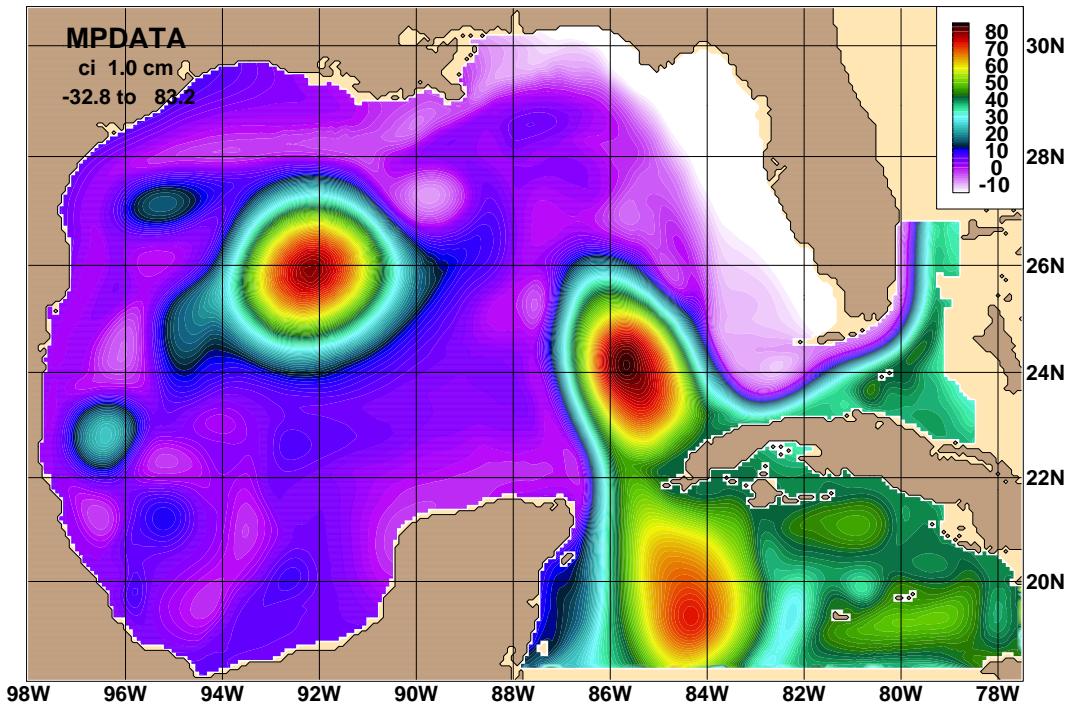


sea surf. height Dec 01, 1999 00Z [02.8H]

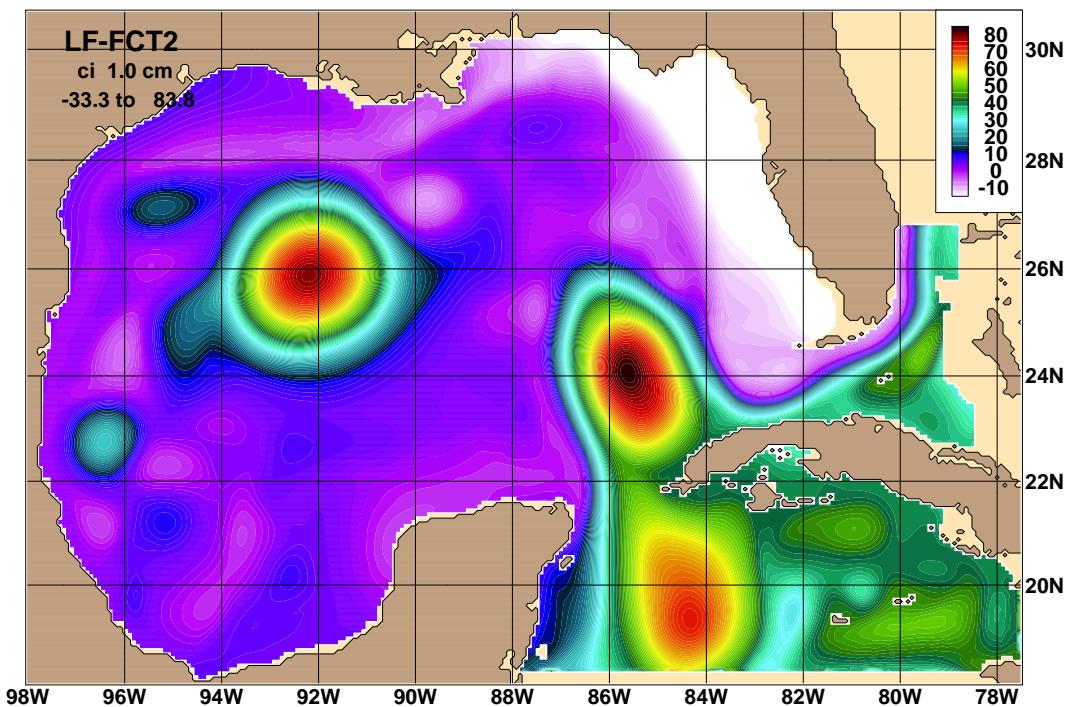


# MPDATA VS LEAPFROG-FCT (SSH)

sea surf. height Dec 01, 1999 00Z [02.8H]

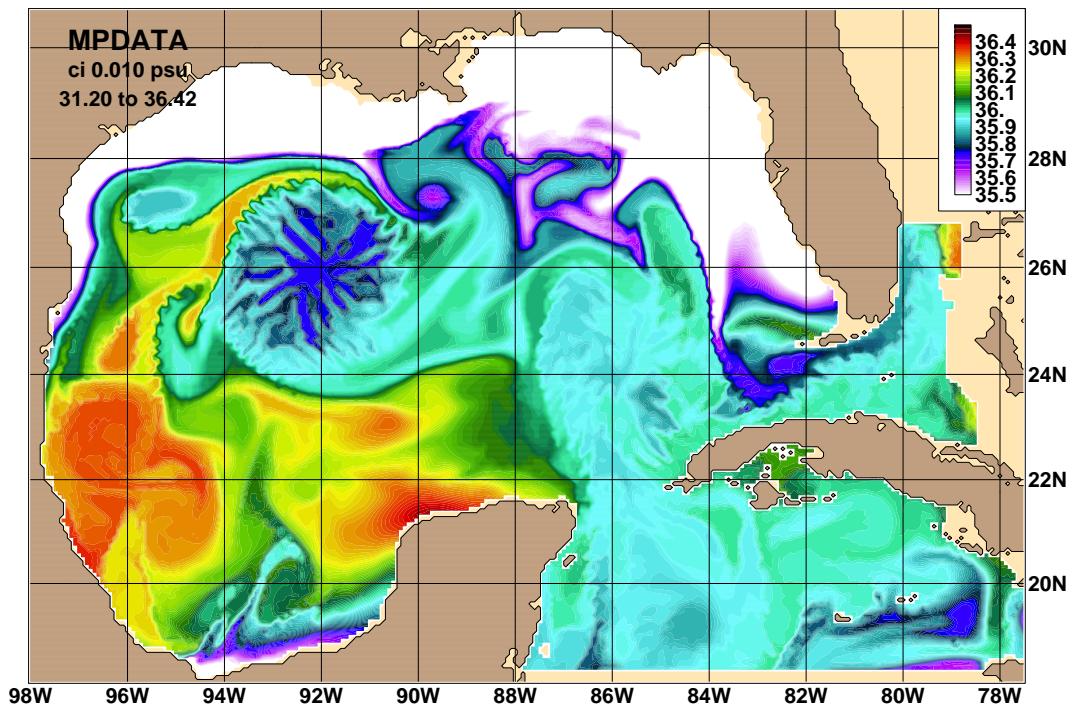


sea surf. height Dec 01, 1999 00Z [03.1H]

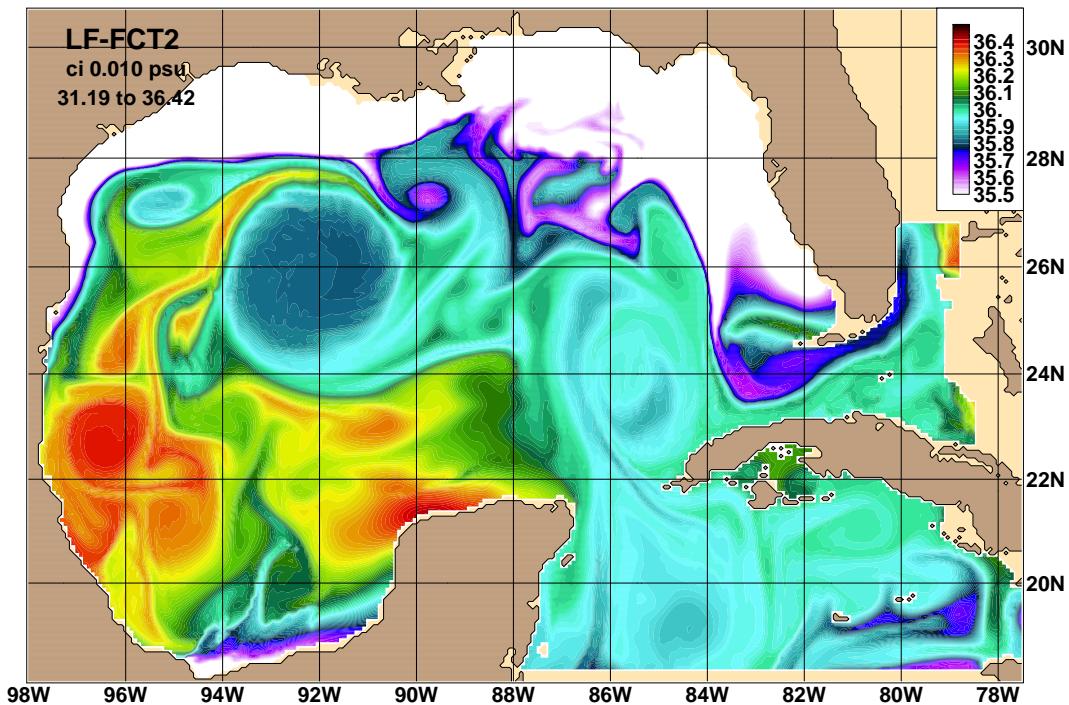


# MPDATA VS LEAPFROG-FCT (SSS)

layer=01 salinity Dec 01, 1999 00Z [02.8H]



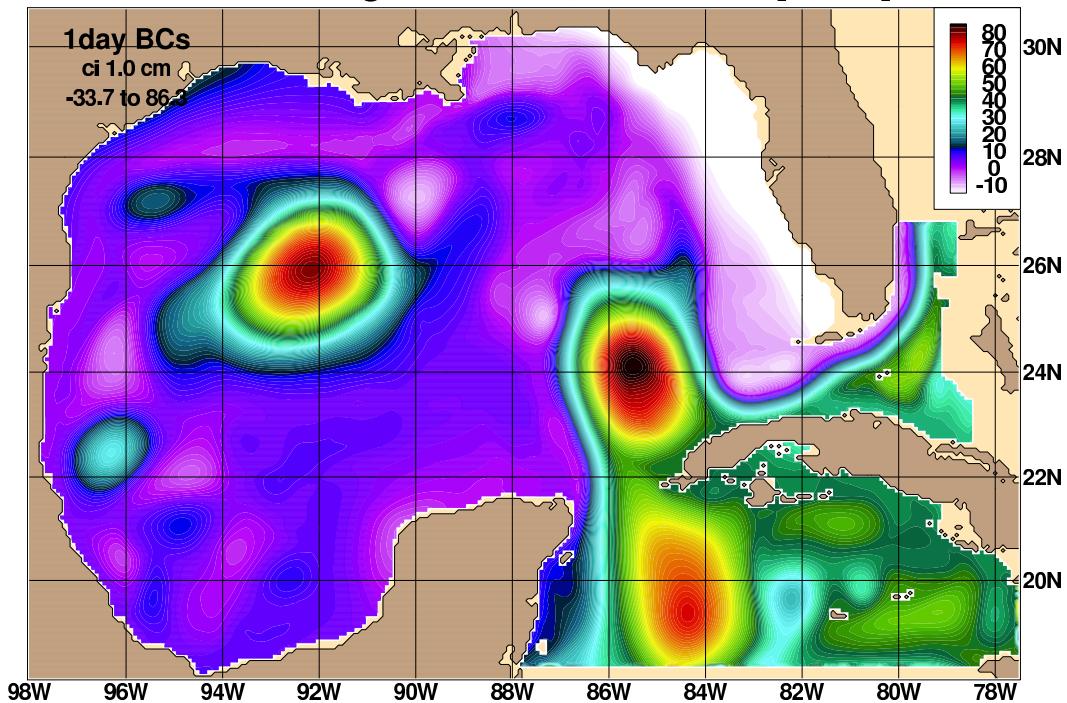
layer=01 salinity Dec 01, 1999 00Z [03.1H]



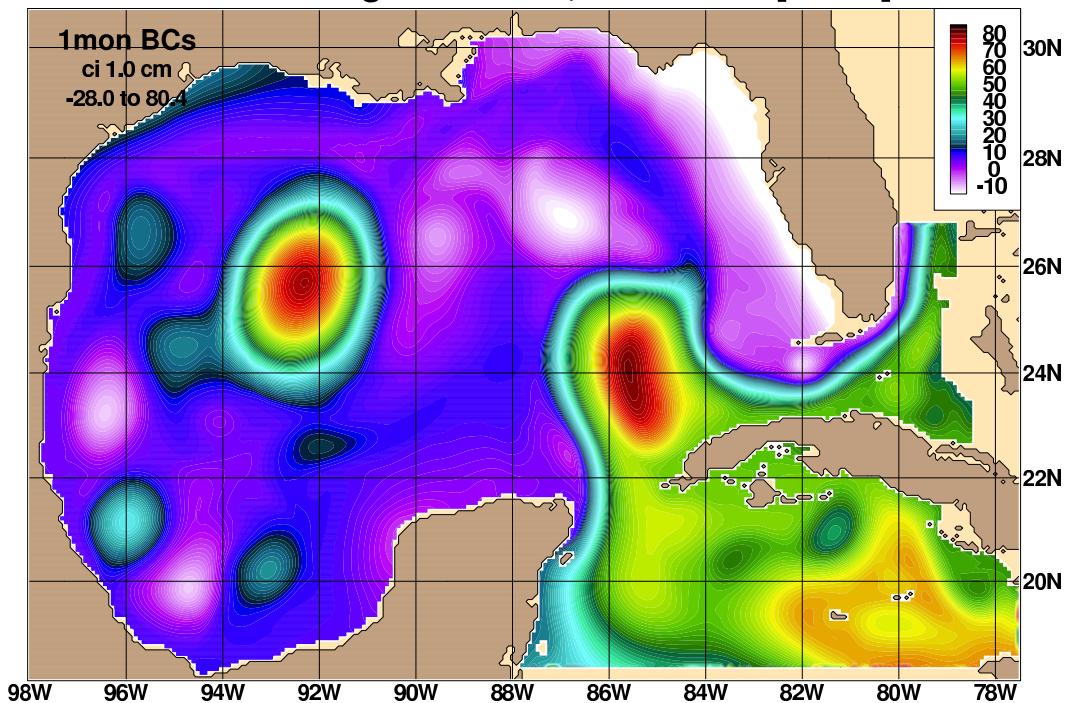
# DAILY VS MONTHLY NESTING

## SSH after 3 Months

sea surf. height Dec 01, 1999 00Z [06.1H]



sea surf. height Dec 01, 1999 00Z [11.1H]

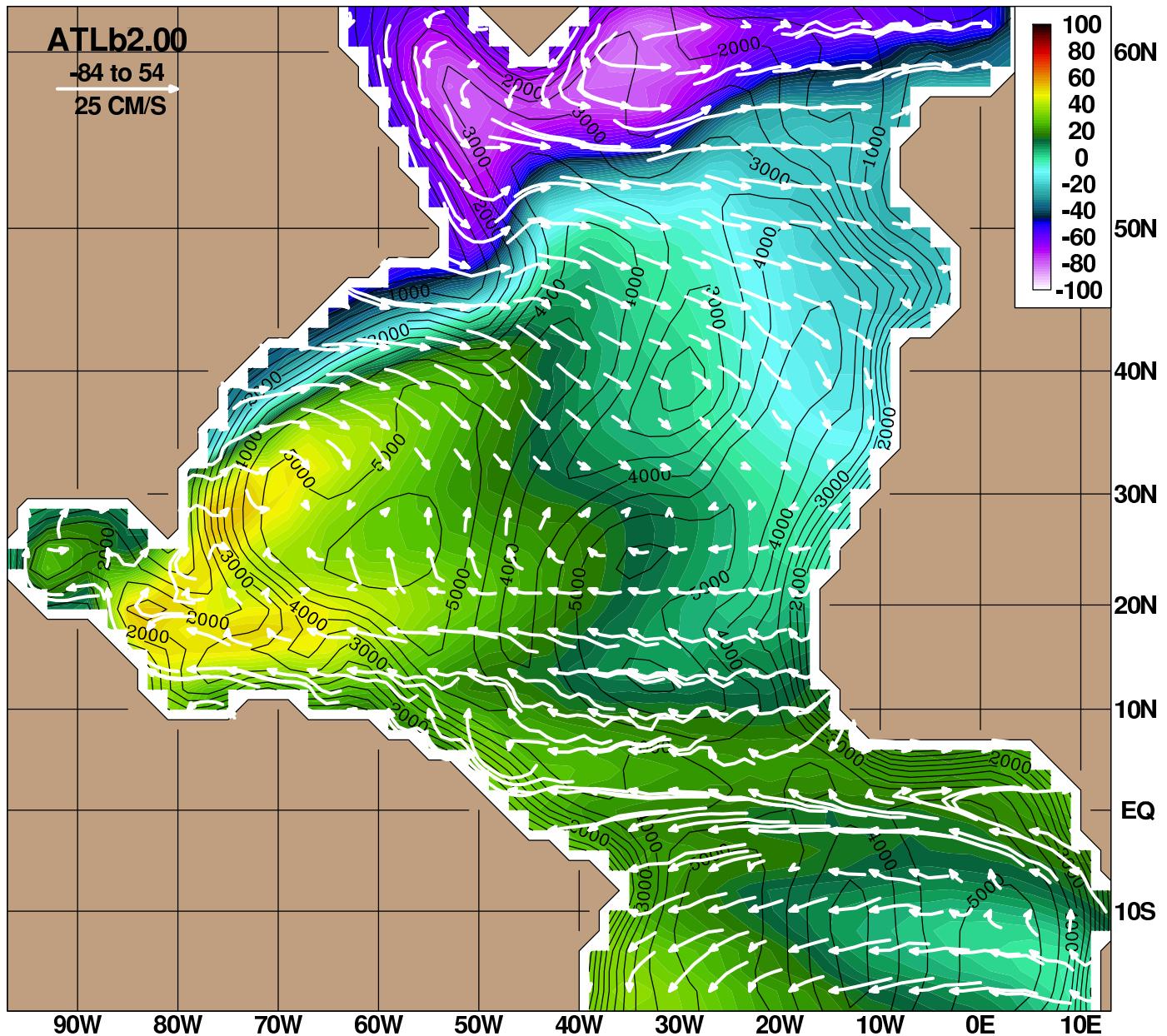


## **HYCOM 2.2 (V)**

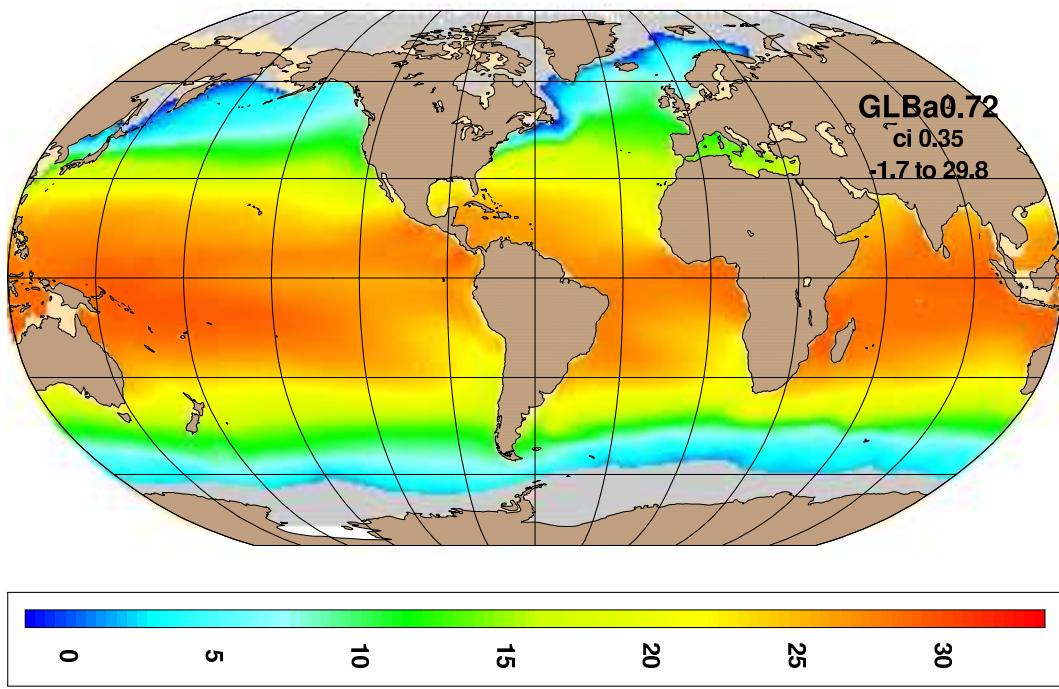
- Enhanced hycomproc and fieldproc
  - NCAR-graphics based
  - Many more color palette options
    - ◊ Can read in an arbitrary palette
  - Mark locations, and draw tracks, on plot
  - Plot diffusion coefficients and tracers (hycomproc)
  - Overlay vector and line-contours (fieldproc)
    - ◊ Vectors 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

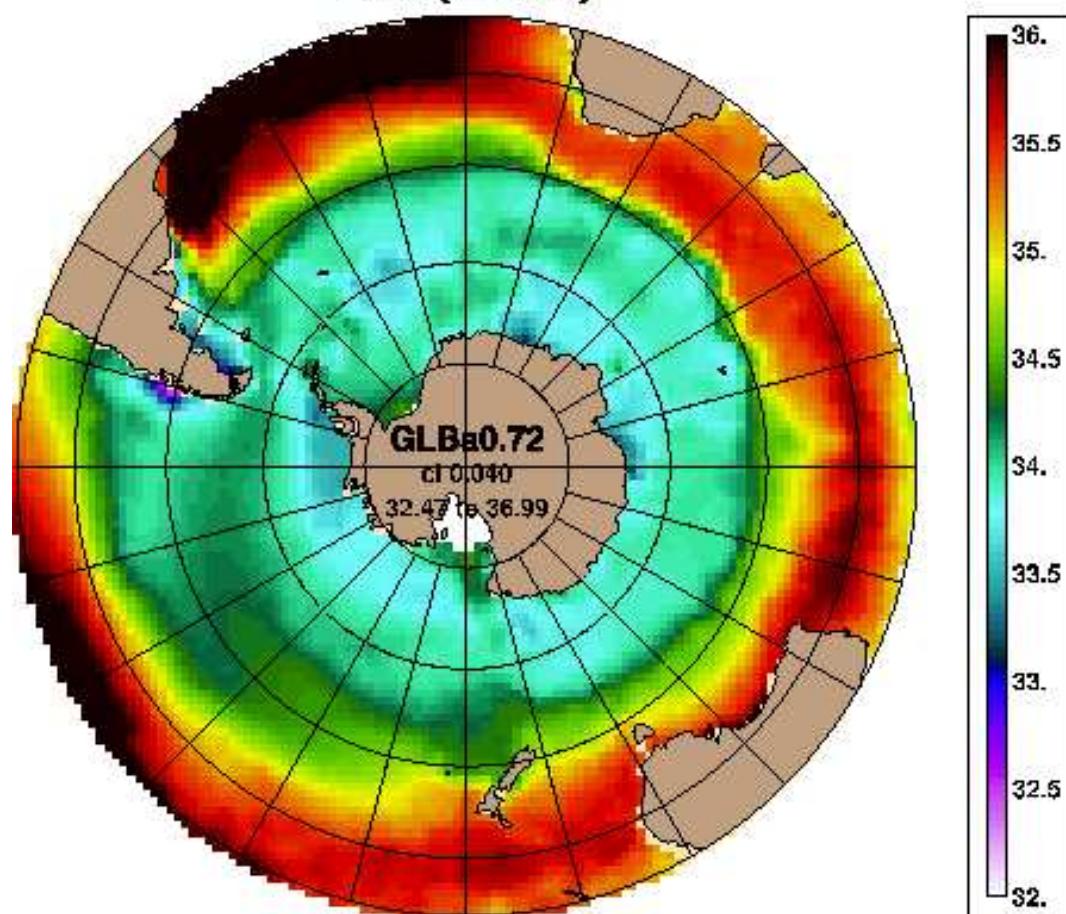
FSD (cm) and V.1 - Jan Year 20



ERA-15 SST: Feb



SSS (hour 0)



## **HYCOM 2.2 (VI)**

- Diagnostic fields to netCDF and other file formats
  - 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 input fields
    - ◊ Time axis depends on “.b” file format
    - ◊ Any “.a” file with the right “.b” file structure can be converted to netCDF
  - Fields binned into lon-lat cells

## **HYCOM CURVILINEAR GRIDS and NetCDF**

- Most basin-scale cases use a Mercator grid
  - 1-D lat & lon axes (rectilinear)
  - Handled well by many netCDF packages
- Global HYCOM's tripole grid is curvilinear
- HYCOM netCDF use the CF-1.0 conventions, which support curvilinear grids
  - If latitude and longitude are 2-D grids
    - ◊ 1-D axes are array indexes
    - ◊ Longitude and latitude arrays are also in the file and identified as alternative coordinates
    - ◊ Velocity rotated to eastwards and northwards
      - Optionally output native x\_velocity & y\_velocity
- Most netCDF packages are not CF-1.0 aware
  - Bin into uniform lon-lat cells off-line
  - Interpolate to a 1-D latitude and longitude grid off-line
    - ◊ General archive (field) to archive (field) horizontal interpolation
- Archive to archive remapper can also be used to support standard (non-native) grids, e.g. MERSEA

## CANDIDATE FEATURES FOR HYCOM 2.3

- Wind drag coefficient based on model SST
- Regional tides and Browning-Kreiss nesting
- Wetting and Drying
- 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
- Enhanced support for ESMF
  - HYCOM+CICE on global tipole grid