HYCOM Model Development, Validation, and Documentation

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HYCOM 2.1.03 (I)

- First public release of HYCOM 2.1
  - September, 2002
- Maintain all features of HYCOM 2.0
  - Requires Fortran 90
  - Can use HYCOM for pure iso-pycnal cases
  - KPP or Kraus-Turner mixed-layer
  - Energy-Loan (passive) ice model
  - High frequency atmospheric forcing
  - New I/O scheme (.a and .b files)
  - Scalability via OpenMP or MPI or both
    - Bit-for-bit multi-cpu reproducibility

HYCOM 2.1.03 (II)

- Orthogonal curvilinear grids
- Fully global domains
  - Near-global Mercator already in HYCOM 2.0
  - Pan-Am grid with closed Bering Strait
    - Open Bering Strait requires a special halo exchange (still not available)
- Multiple tracers
  - Passive
  - Simple biology (NPZ or NPZD)
    - Most of infrastructure in place
    - More work needed on biology and boundary conditions
- Rivers as bogused surface precipitation
  - Annual or monthly climatology

HYCOM 2.1.03 (III)

- Off-line one-way nesting
  - Similar to MICOM
    - Exact b.c. for depth averaged component
    - Relaxation for 3-D T/S/pressure/velocity
      - Based on relaxation to climatology
      - But with addition of velocity relaxation
  - Interpolate to target domain off-line
    - Source domain to target domain archive files
    - Nested model does not “know” about enclosing domain
    - Can discard deep iso-pycnal layers
    - Can remap to new vertical coordinate
  - Get boundary data from input archive files
    - Simplifies scalability
    - At the cost of more I/O and bigger files
- 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)

HYCOM 2.1.03 (IV)

- More general fixed (sigma/Z) vertical coordinate
  - Emulate Z or Sigma or Sigma-Z models
  - HYCOM has partial cells
    - Emulate full cell Z models with the appropriate bathymetry
- Alternative mixed-layer models
  - Mellor-Yamada 2.5
  - Price-Weller-Pinkel
- Explicit support for 1-D and 2-D domains
  - Tiling allows periodic domains
  - 1-D is 2x2 doubly periodic domain
    - Only read/write .b files
  - 2-D is Nx2 periodic domain
    - Infinite f-plane

HYCOM 2.1 (V)

- Region-independent setup and diagnostics
  - Dynamic memory allocation
  - Compile once for all domains
  - Actual model code still domain-dependent
- Restart processing
  - HYCOM from MICOM
  - HYCOM from archive file
  - HYCOM from coarser resolution HYCOM
  - Change land/sea boundary
- Archive processing
  - Add/subtract/merge layers
  - Remap to new vertical coordinate
  - Mean and variability
  - Off-line sampling
    - Vertical profiles
    - Transport sections
  - To netCDF and other file formats
    - All x-y “hycomproc” fields
    - Interpolated to z-space

HYCOM FILE FORMAT

- MICOM's PAKK I/O not efficient or accurate
- HYCOM 2.1 reads/writes ".a and .b" files
  - ".a" is a raw IEEE REAL*4 array file (Fortran direct access)
  - ".b" is a plain-text header file (Fortran formatted)
- This I/O is simple and portable
- It can easily be parallelized
  - Have the N-th processor read/write every N-th 2-D array record
- Convert to netCDF off-line
  - Climate and Forecast (CF) conventions
    - Extension of COARDS conventions
      - Supports curvilinear grids
    - Most existing software is for COARDS only
  - Unlimited time dimension
    - Simplifies time concatenation
  - Safest to have single field per file
    - Avoids all 2GB limits

EQUAL AREA DOMAIN DECOMPOSITION

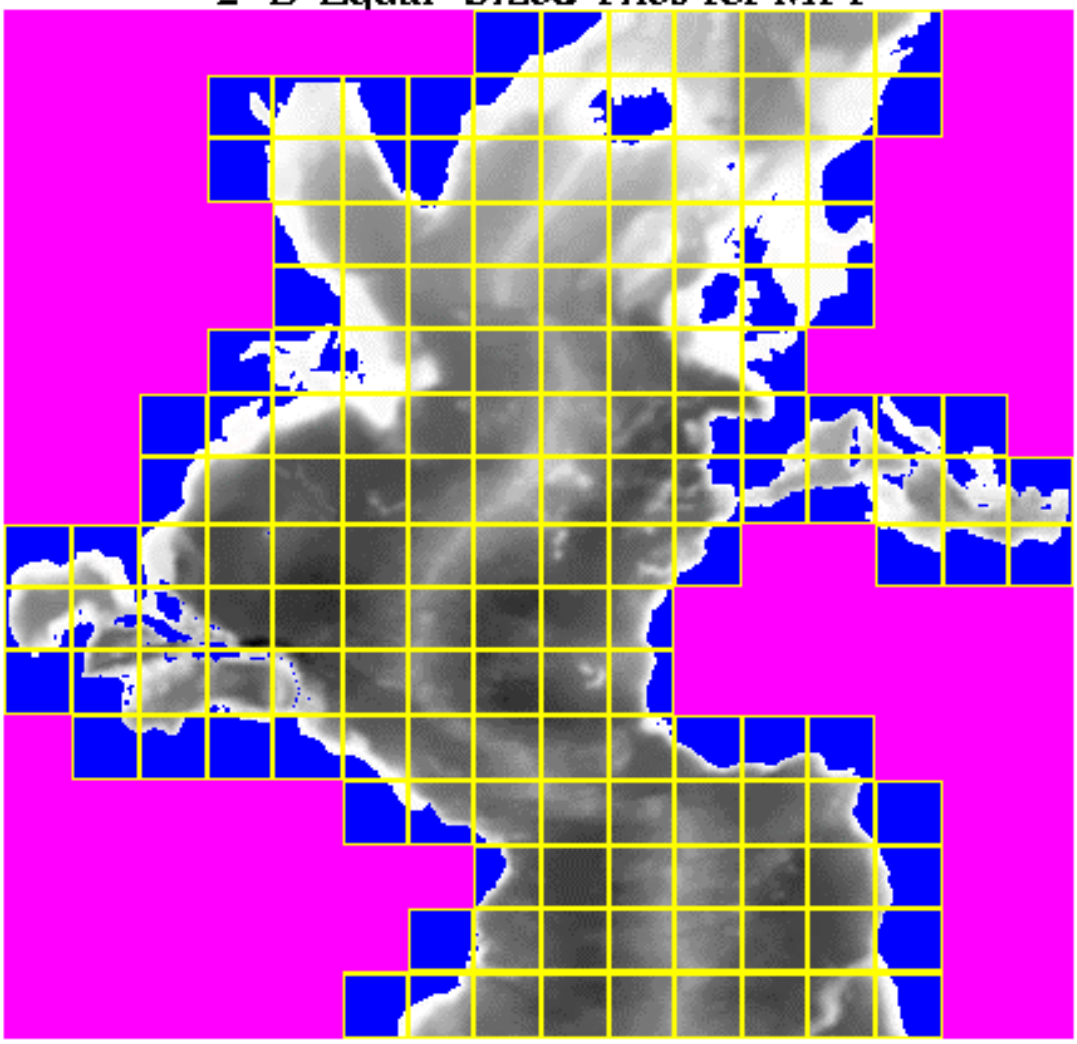
- Simplest domain decomposition is equal-sized rectangular tiles
  - Each tile has four neighbors
    - Eight neighbors including halo corners
- Overall speed controlled by slowest tile
  - Probably have an “all ocean” tile
    - no advantage to avoiding land within a tile
- Discard tiles that are entirely over land
  - Simple to implement
  - Does not discard all land
  - P-MICOM probably first ocean model to do this
  - Should be in all MPI-based OGCM’s

IMPROVED DOMAIN DECOMPOSITION

- HYCOM 2.0 and 2.1 allows:
  - Discarded tiles
  - Variable tile size
  - Many North-South neighbors
- Equal-ocean tiling
  - First distribute one axis, then the other
  - Near perfect load balance
  - Some tiles require more memory than others
  - Aspect ratio of rectangle can be large
  - More expensive halo exchange
- Modified equal-area tiling
  - Discard all-land tiles
  - Shift tiles to fit coastline
  - Double-up tiles if less than half ocean
  - Compared to equal-area tiling:
    - Up to 2x the memory requirement
    - More expensive halo exchange
    - Often significantly fewer tiles

MICOM 2–D DOMAIN DECOMPOSITION

2–D Equal–Sized Tiles for MPI



Each Tile has 4 neighbors

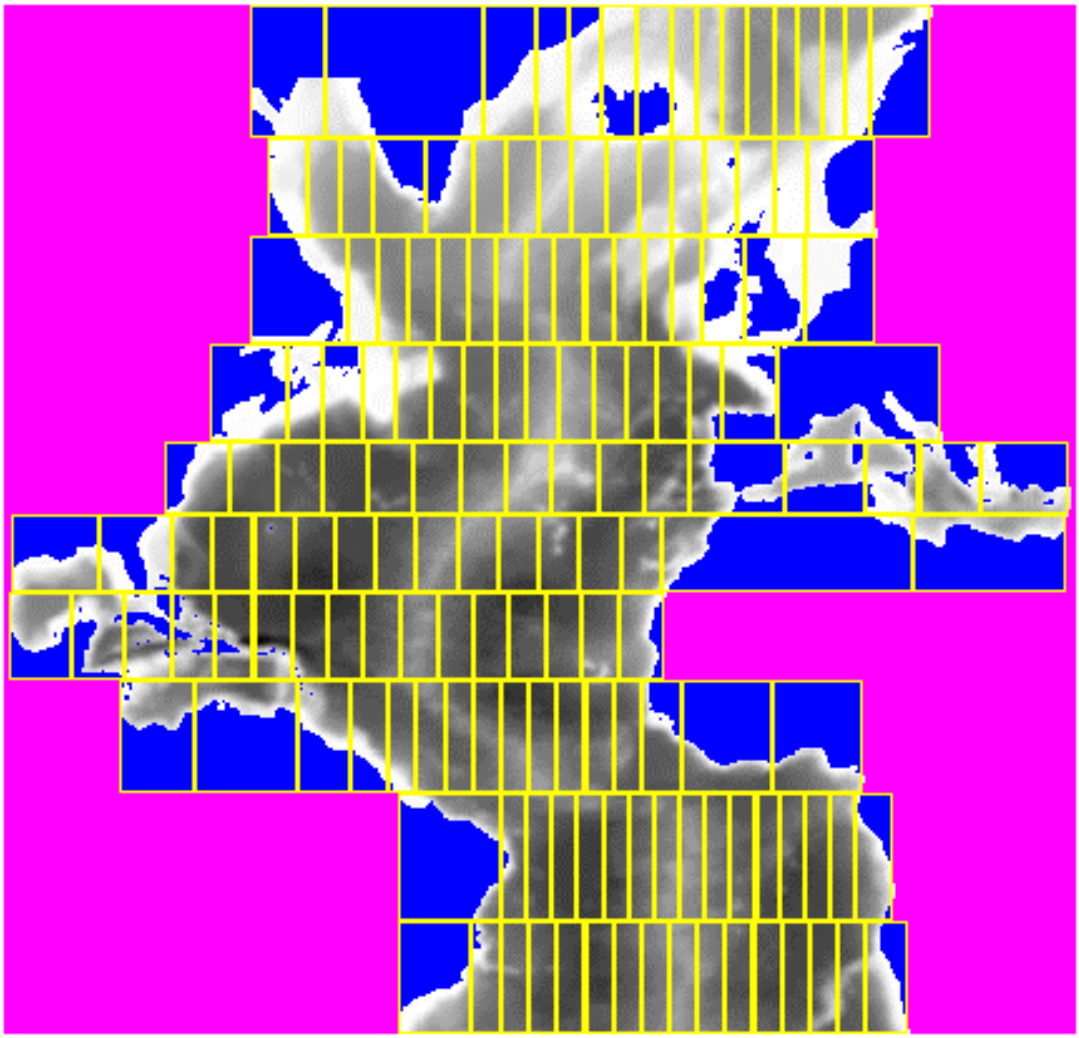
Discard “All–Land” Tiles

16x16 = 256 Tiles but only 161 active

Still have significant load imbalance

HYCOM 2–D DOMAIN DECOMPOSITION

2–D “Equal Ocean” Tiles for MPI



Each tile has 2 E–W neighbors, but many N–S neighbors

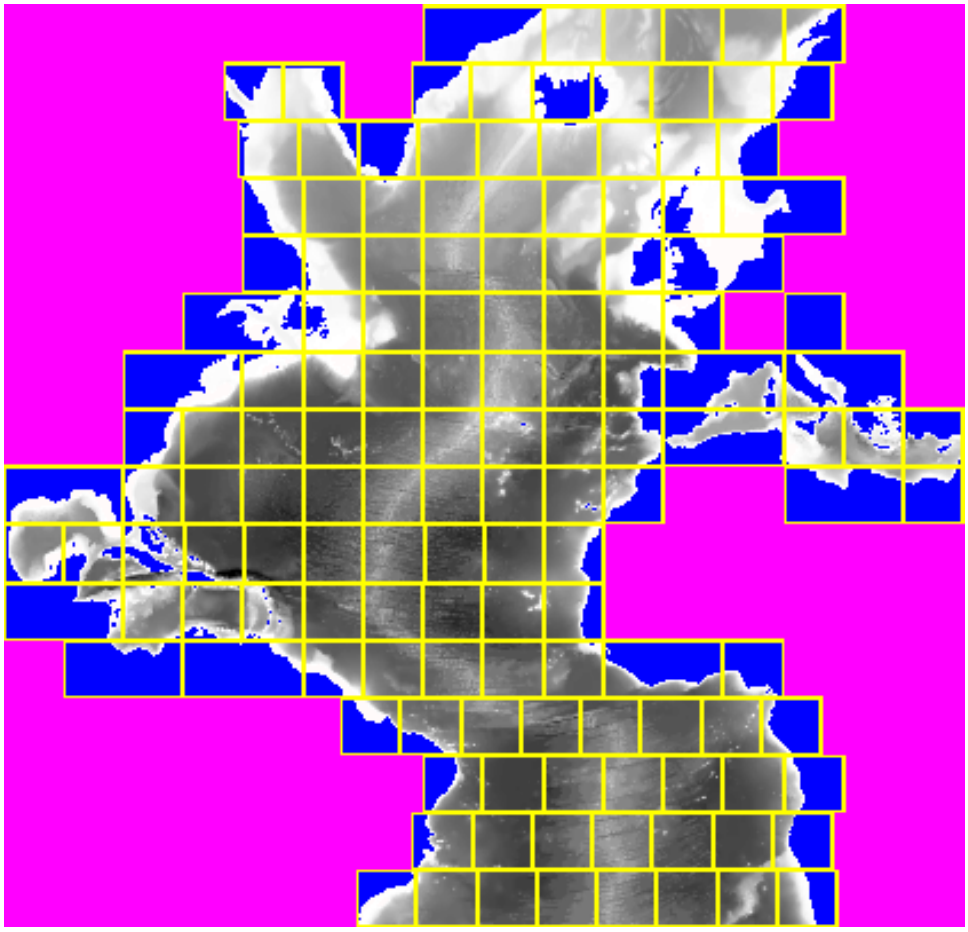
Compared to 16 x 16 “equal – size” decomposition:

30% less work on “worst” tile

larger memory requirement

MODIFIED EQUAL AREA TILING

16x16 = 256 Tiles but only 143 Active
12% fewer than equal area tiling



Improvements since 2.1.03

- Vertical remapping uses PLM for fixed coordinate layers
- Thin deep iso-pycnal layers
- Stability from locally referenced potential density
- GISS mixed layer model
- Black-body correction to longwave flux
- Option to relax to observed SST
- Spatially varying iso-pycnal layer target densities
- Nesting no longer requires co-located grids
  - General archive to archive horizontal interpolation
- Hybrid to fixed vertical grid remapper
  - Allows fixed-coordinate nests inside hybrid coordinate outer domains
    - HYCOM to (fixed-grid) HYCOM
    - HYCOM to NCOM

Vertical Remapping

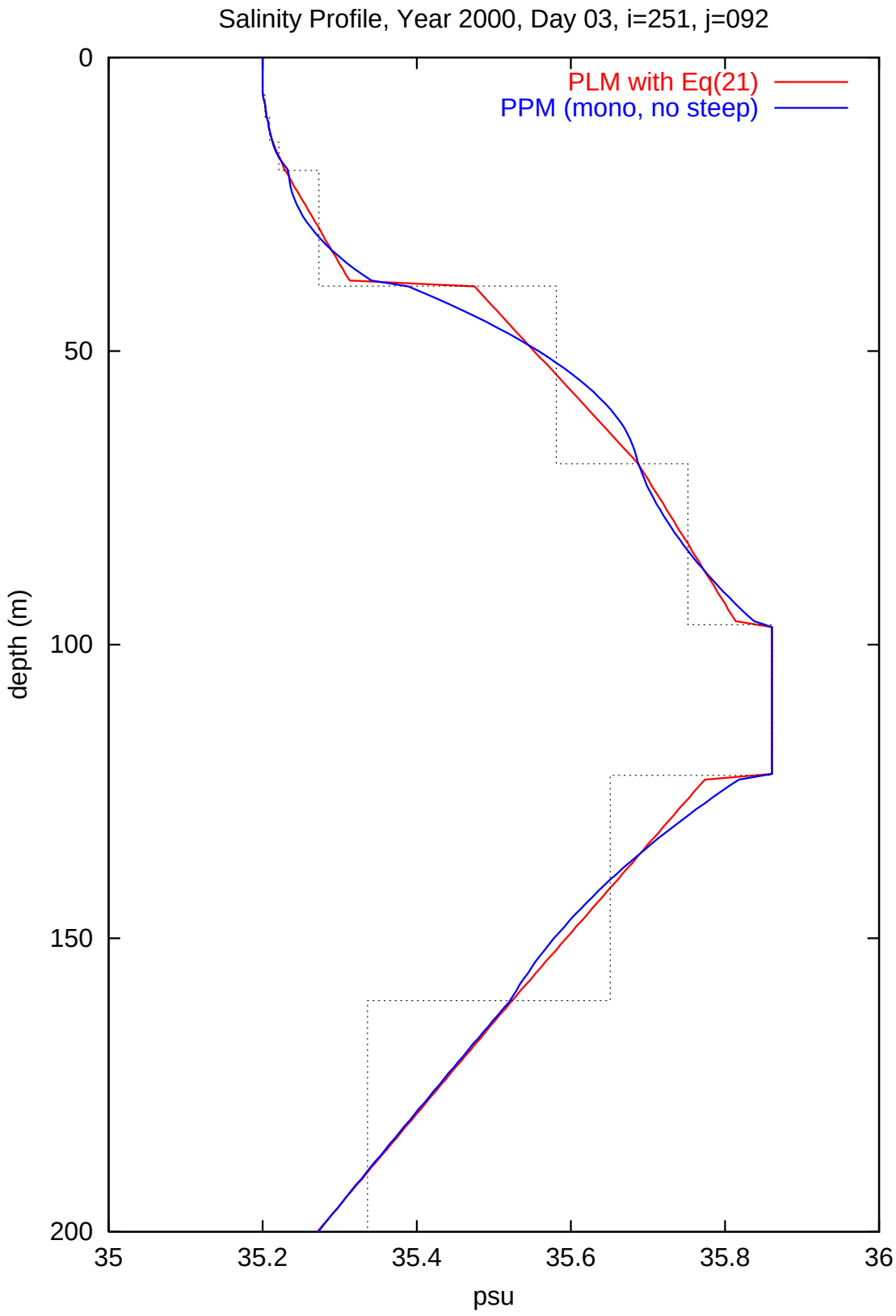
- Vertical remapping has two phases
  - Locating the (new, iso-pycnal) layers
  - Interpolating from old to new layers
- These are not completely separable
  - Can’t locate layers without allowing for interpolation scheme
- Finite Volume approach allows partial separation
  - Define a profile across original layers
  - Use profile in deciding where to put layers
  - Integrate this profile to get new layer averages
- In HYCOM (hybgen)
  - Highly non-uniform layer thicknesses
  - Same number of layers
  - Most (iso-pycnal) layers don’t change
  - Layers don’t move more than one grid length(?)
  - Use PCM (Donor Cell) “advection”
    - Profile is constant across each layer
    - May be only practical scheme for hybgen

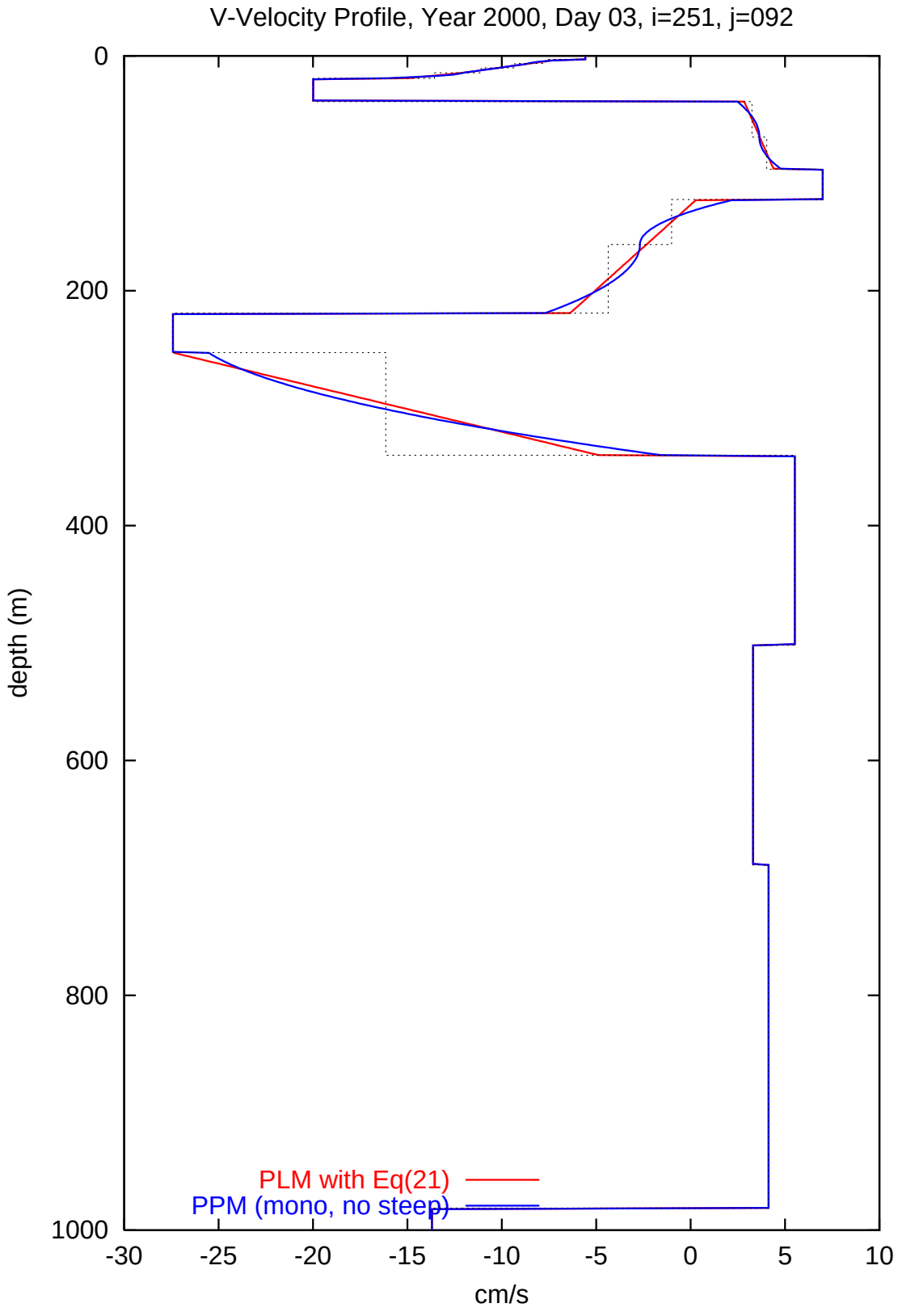
Off-line Vertical Remapping

- Off-line remapping is harder
  - Highly non-uniform layer thicknesses
  - Different number of layers
  - Many layers change location
  - Layers can “move” a long way
- Desirable properties
  - Simple to compute
  - Overall conservation
  - No change if layer is the same
    - Excludes linear between cell centers
  - No new extrema
- PCM
  - Too “diffusive”
  - Lowest order of a family (PLM/PQM)
- Piecewise Quadratic Method
  - Quadratic across cell
  - Very popular advection scheme
  - Tested it, but probably overkill

Off-line Vertical Remapping (II)

- Piecewise Linear Method (Van Leer)
  - Linear profile, mean at cell center
  - Discontinuous at cell interfaces
  - Several choices for the slope
  - Tim Campbell developed interpolation variant
    - Non-uniform layer thickness
    - Maximize “smoothness” across interfaces
      - Local optimum, global too much work
- Archive to archive remapper
  - Only for fixed target coordinate
    - Hybrid to sigma-Z
- Archive to data3z
  - Returns fields at fixed depths
  - PCM or linear between cell centers
- Single profile remapper
  - fixed depth version (data3z)
  - fixed cell version (PCM or PLM)

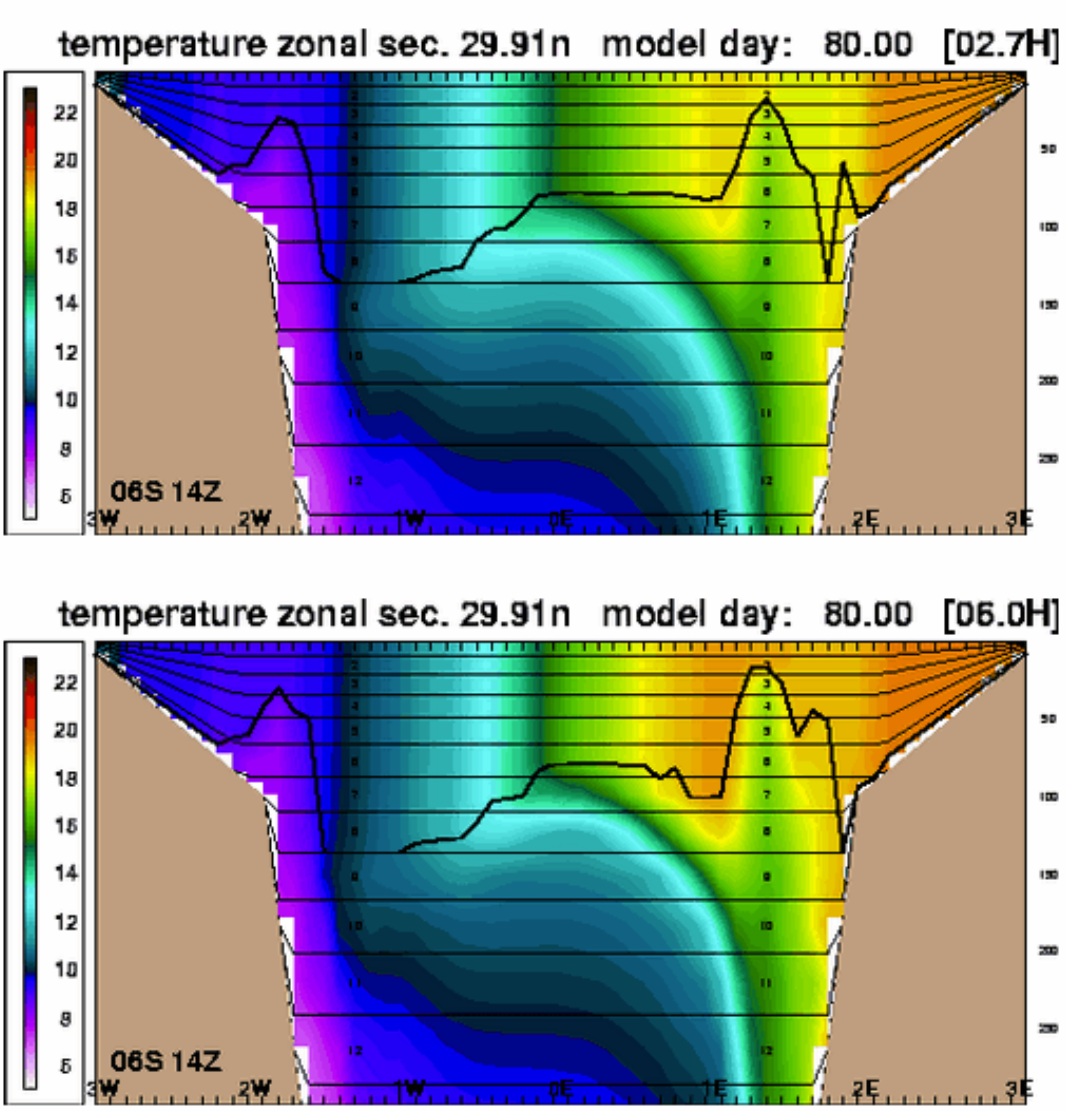

Salinity Profile, Year 2000, Day 03, i=251, j=092
PLM with Eq(21)
PPM (mono, no steep)
depth (m)
0
50
100
150
200
35
35.2
35.4
35.6
35.8
36
psu


V-Velocity Profile, Year 2000, Day 03, i=251, j=092
depth (m)
0
200
400
600
800
1000
-30
-25
-20
-15
-10
-5
0
5
10
cm/s
PLM with Eq(21)
PPM (mono, no steep)

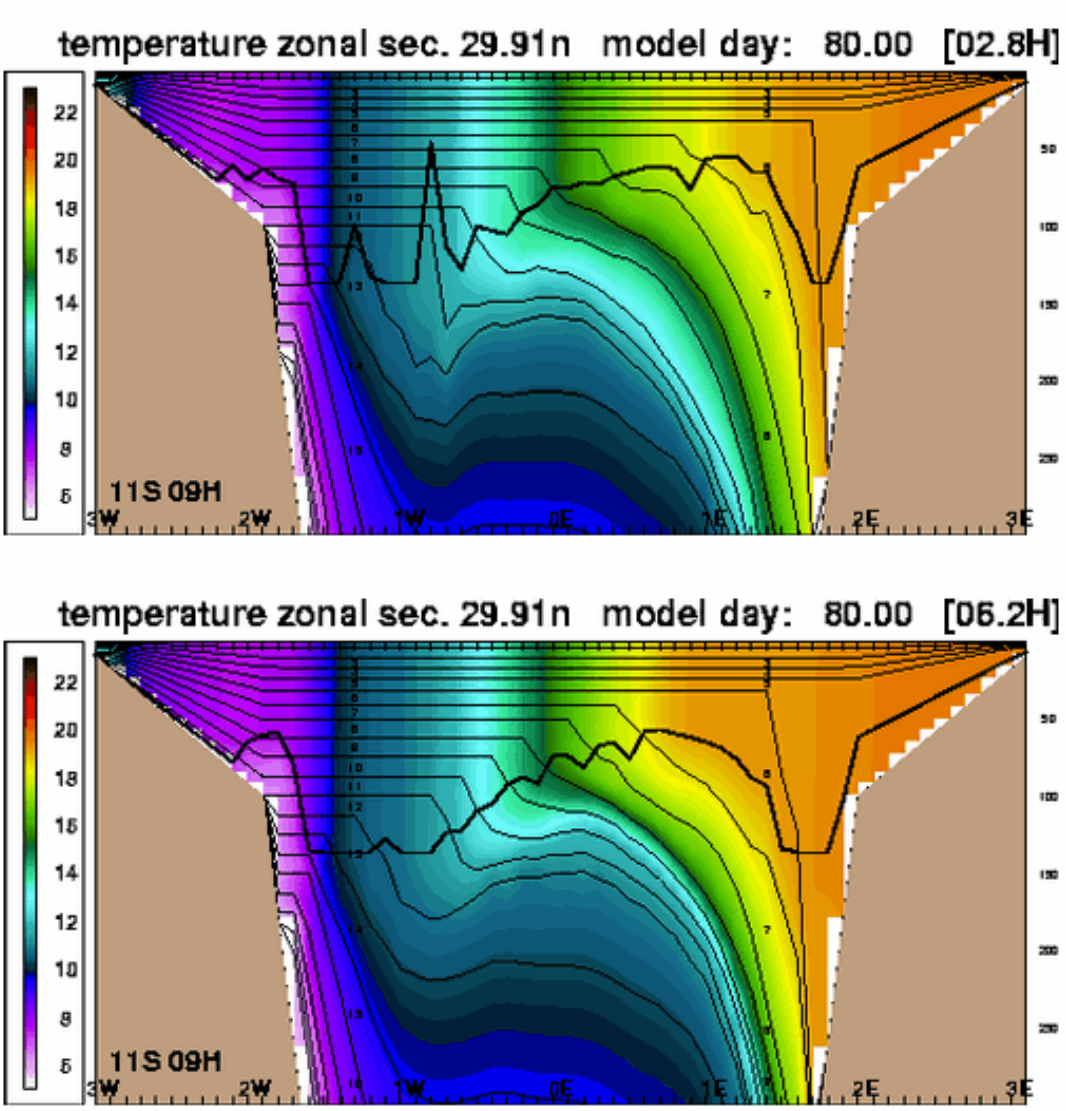
PLM Remapping of Fixed Coordinate Layers

- In HYCOM 2.1.03, hybgen uses PCM
- Perfect for iso-pycnal layers
  - Most (iso-pycnal) layers don’t change
    - No remapping, no diffusion
  - Detrainment (thinning) does not change density
    - Unique to PCM
    - HYCOM might otherwise be impractical
- Not optimal for fixed coordinates
  - Fixed layers always move
  - PCM is very diffusive
- PCM is a special case of PLM
  - PLM with zero slope
- Use PLM for fixed layers and PCM for iso-pycnals
  - Currently using same scheme for all variables
  - Could use PCM+PLM for density only, or density and salinity only

UP/DOWN-WELLING TEST - SIGMA-Z
PCM (top) vs PLM

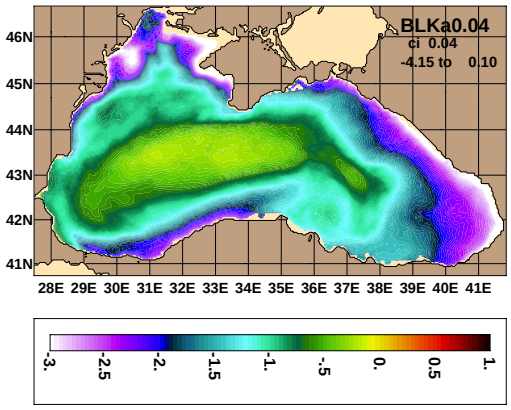


UP/DOWN-WELLING TEST - HYBRID
PCM (top) vs PLM+PCM

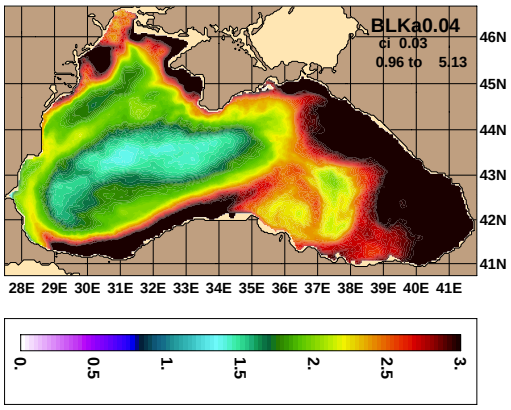


BLACK SEA SST STATISTICS: PCM

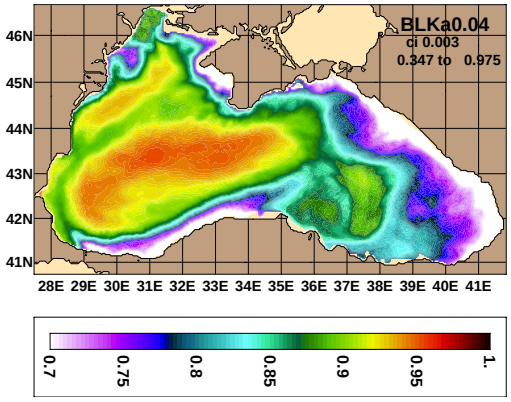
09.1 vs Pathfinder : SST Mean Error (deg C)



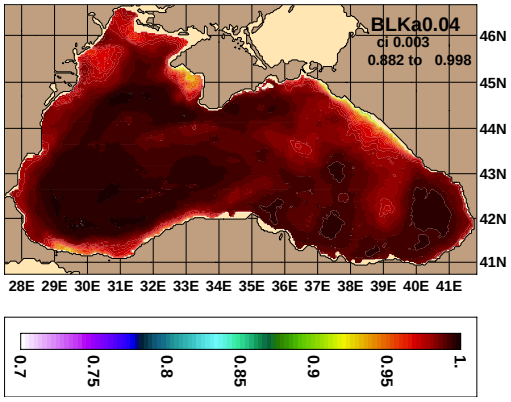
09.1 vs Pathfinder : SST RMS Error (deg C)



09.1 vs Pathfinder : SST Skill Score

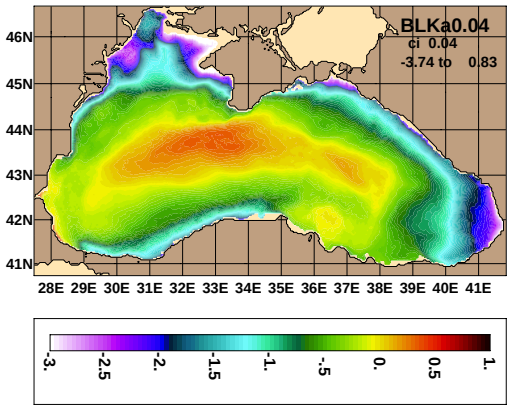


09.1 vs Pathfinder : SST Correlation Coeff.

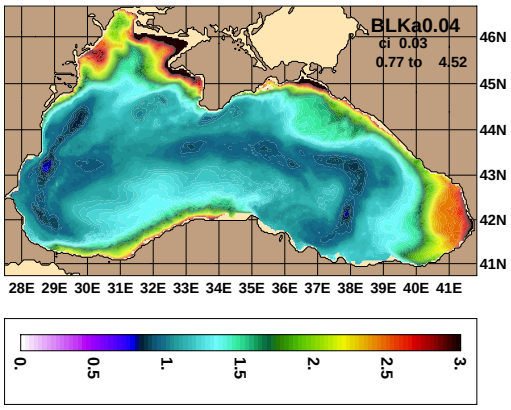


BLACK SEA SST STATISTICS: PLM+PCM

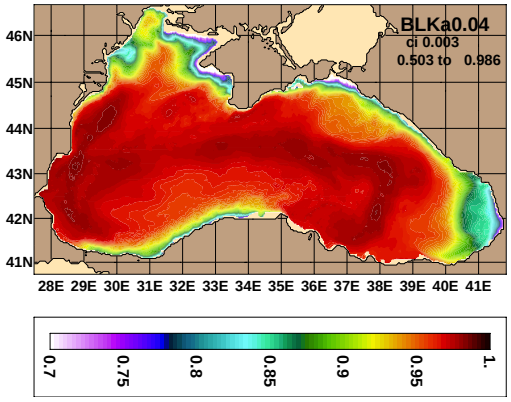
09.5 vs Pathfinder : SST Mean Error (deg C)



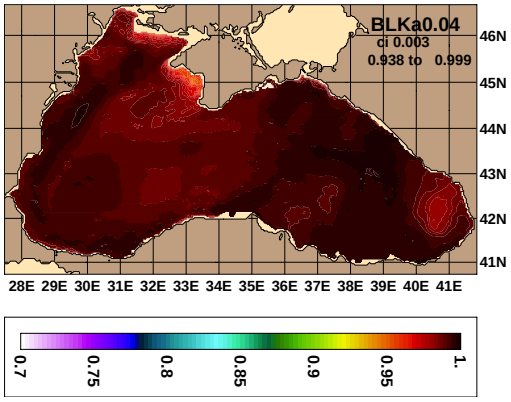
09.5 vs Pathfinder : SST RMS Error (deg C)



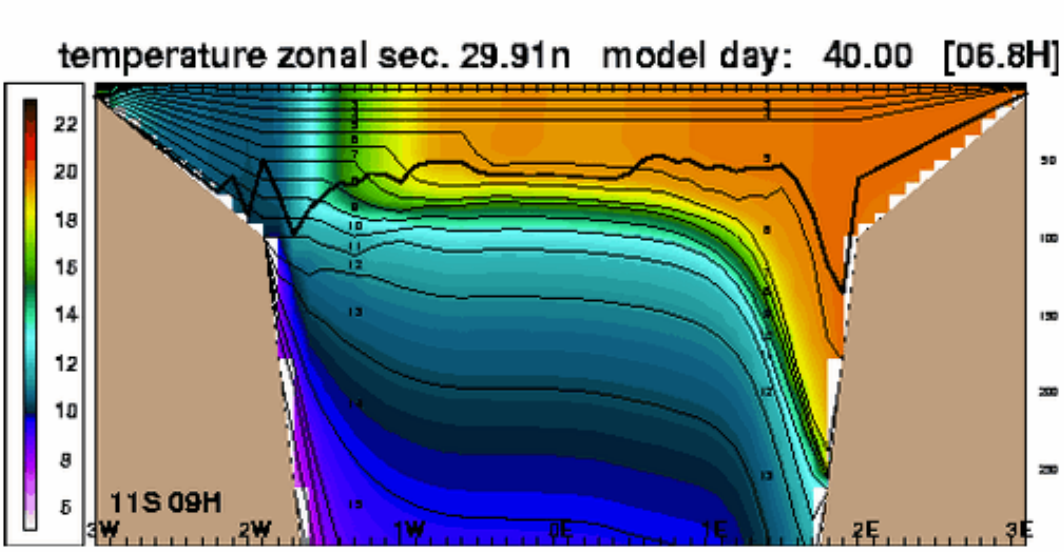
09.5 vs Pathfinder : SST Skill Score

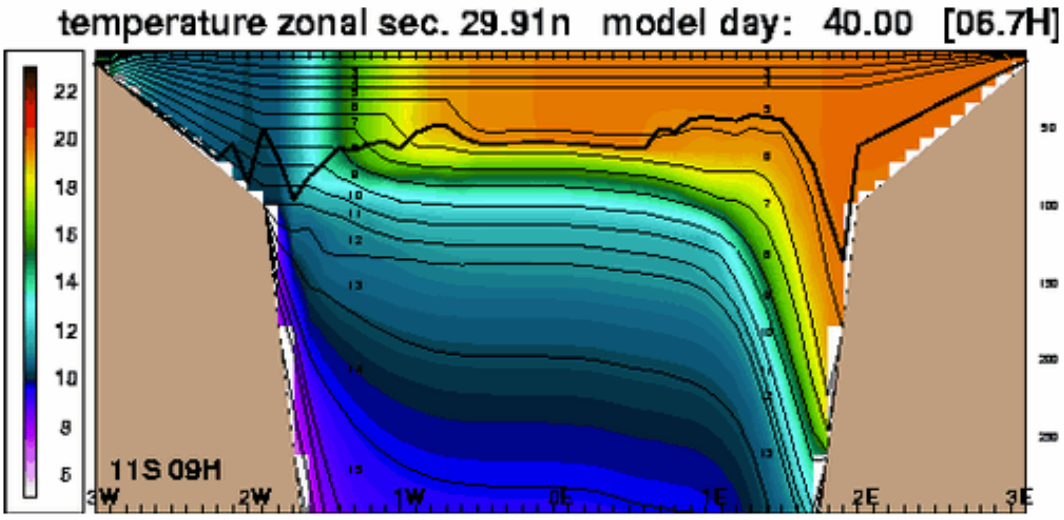


09.5 vs Pathfinder : SST Correlation Coeff.



UP/DOWN-WELLING TEST
THIN DEEP ISO-PYCNAL LAYERS





OTHER NEW FEATURES OF NEXT RELEASE (SEPTEMBER?)

- Arctic bi-polar patch with open Bering Strait
  - For 0.24 degree global domain
- Bottom boundary layer in KPP
- Diagnostics within HYCOM:
  - Time-averaged fields (archive files)
  - Drifters
  - Moored buoy sampling(?)
  - Transport section sampling(?)
- Is anything else needed immediately?

WISHLIST FOR HYCOM (I)

- Fully region-independent
  - Compile once, run on any region and any number of processors
- Tidal forcing
- Even more mixed-layer models
- Support for data assimilation
- Comprehensive tracer support
  - Within HYCOM and off-line
  - In z-space?
- NCAR's CCSM Coupler
  - CICE sea-ice model
  - Coupled air-ocean-ice
- ESMF compatibility
  - Earth System Modeling Framework **http://www.esmf.ucar.edu/**
  - Alternative to CCSM
  - Much broader support
  - Might allow asynchronous I/O
  - Use ESMF for parallelization(?)

WISHLIST FOR HYCOM (II)

- Improved/Alternative hybrid remapping (hybgen)?
- Improved/Alternative advection (tsadvc)?
- Improved/Alternative split-explicit time scheme?
- Alternative free surface formulation?
  - Currently assume free surface is a small fraction of the total depth
    - Does this work for coastal domains?
    - Includes steric effects, but does not exactly conserve either mass or volume
- Atmospheric pressure forcing?
- Rivers (and surface E-P) as mass exchange?
- Balance E-P via land precip runoff?