

HYCOM code development

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HYCOM 2.1.03 (I)

- First public release of HYCOM 2.1
 - September, 2001
- 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
 - * Available “soon”
- 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

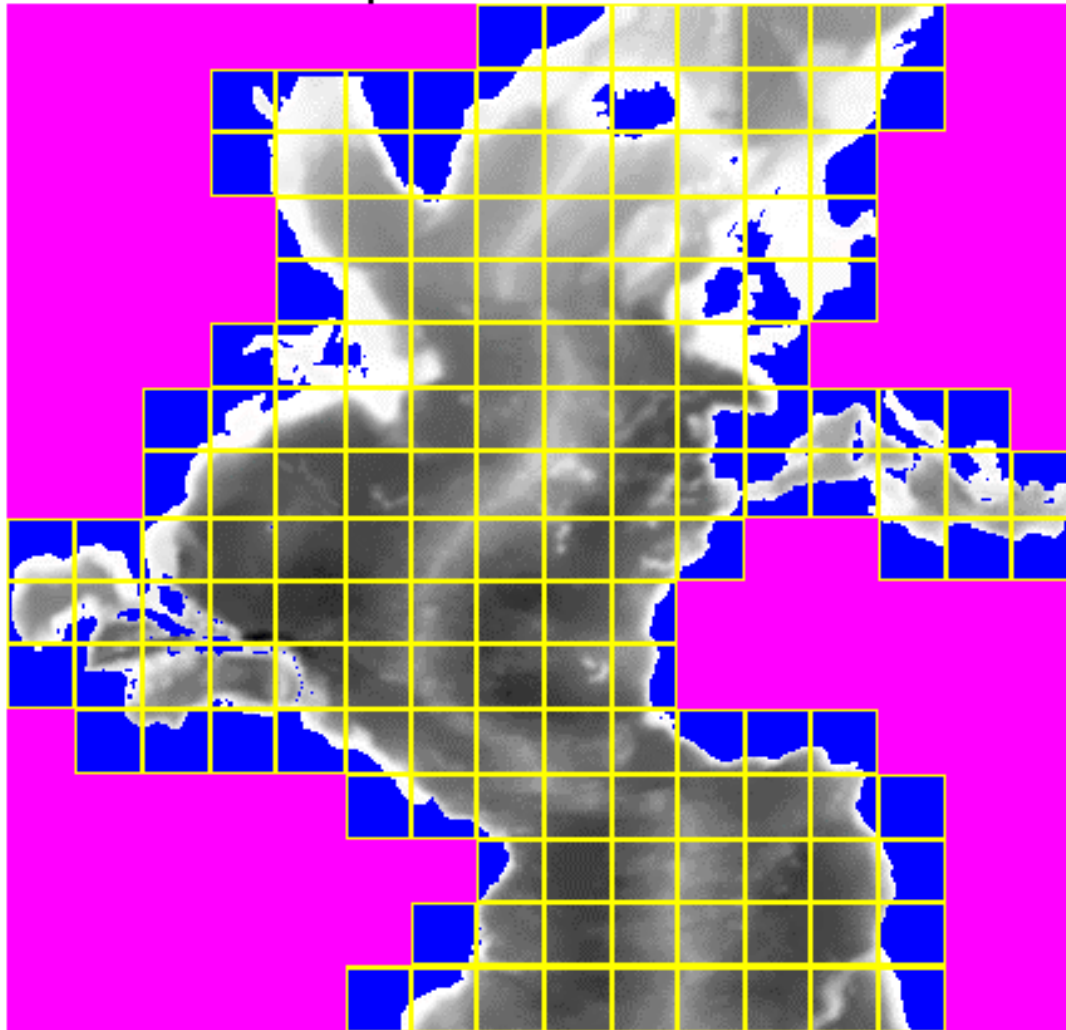
- Simplest domain decomposition is equal-sized rectangular tiles
 - Each tile has four neighbors
 - * Eight neighbors including halo corners
- Overall speed controlled by slowest tile
 - Probably have an “all ocean” tile
 - * no advantage to avoiding land within a tile
- Discard tiles that are entirely 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

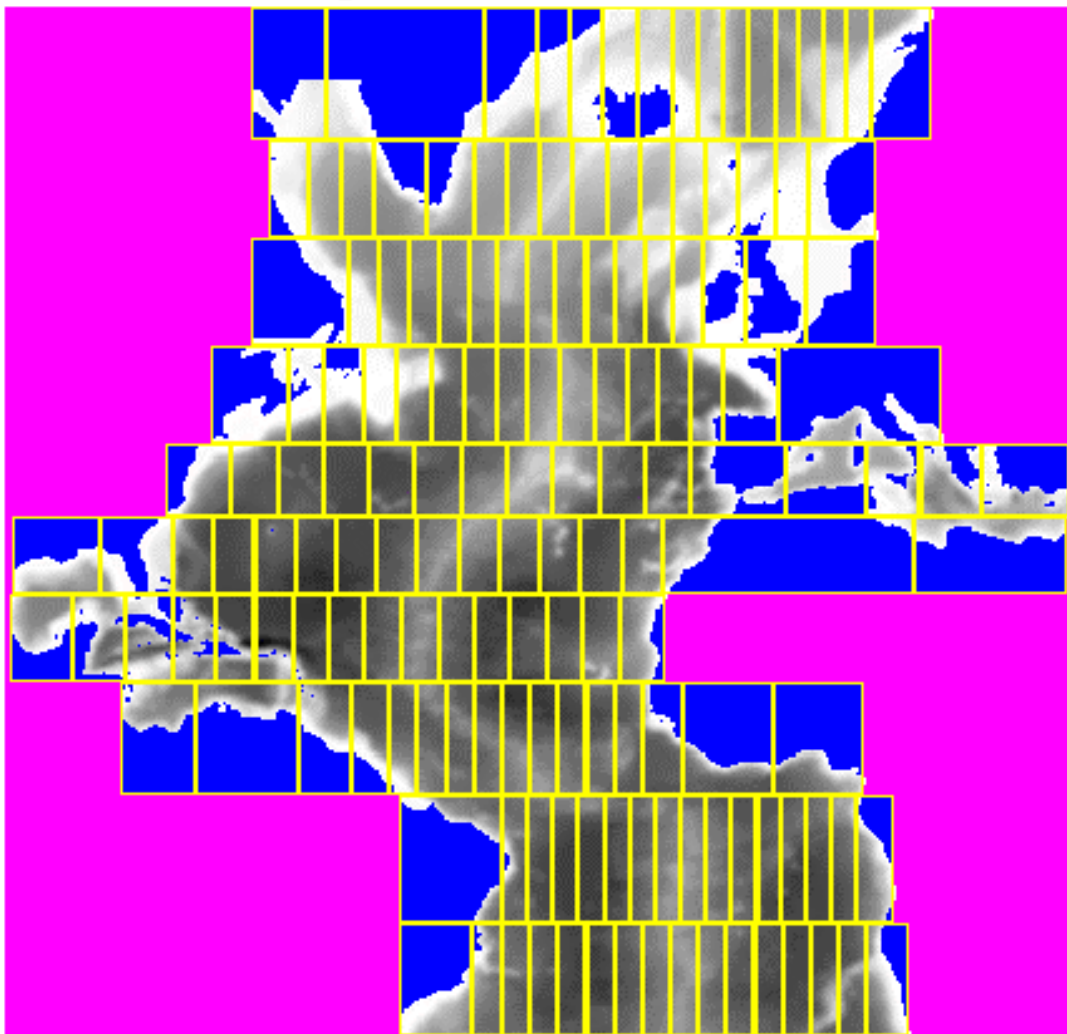
Discard “All-Land” Tiles

$16 \times 16 = 256$ Tiles but only 161 active

Still have significant load imbalance

HYCOM 2-D DOMAIN DECOMPOSITION

2-D “Equal Ocean” Tiles for MPI

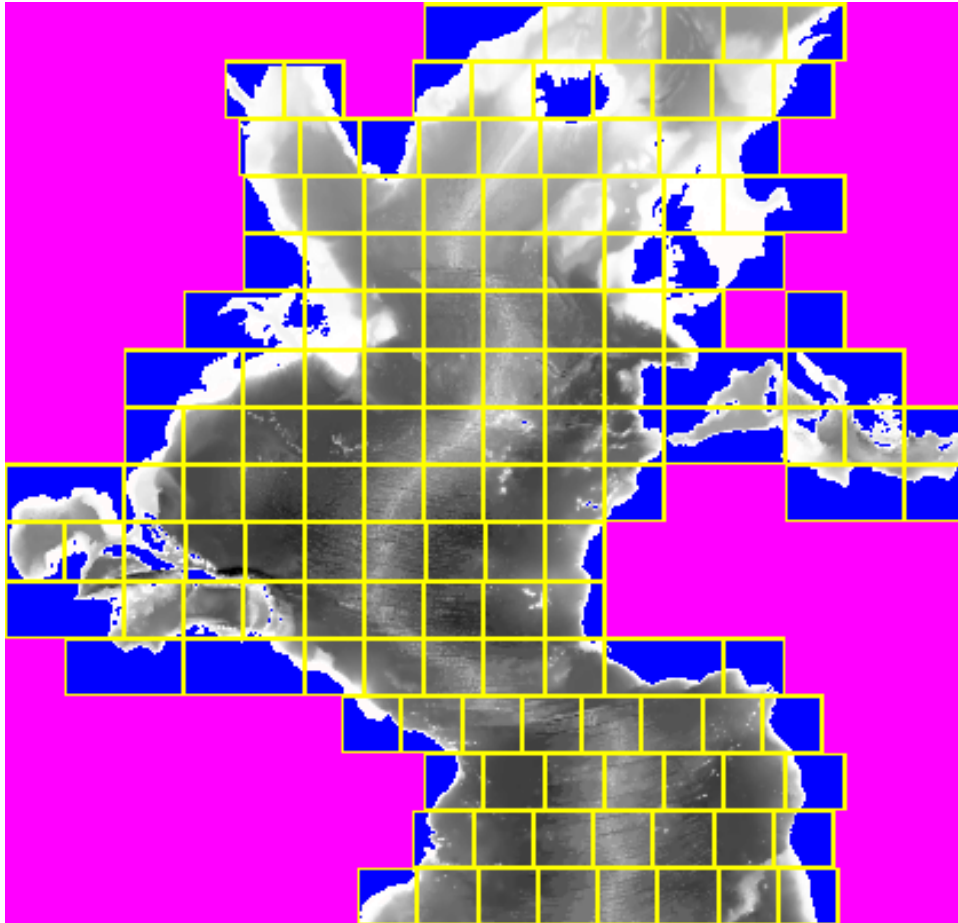


Each tile has 2 E–W neighbors, but many N–S neighbors

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

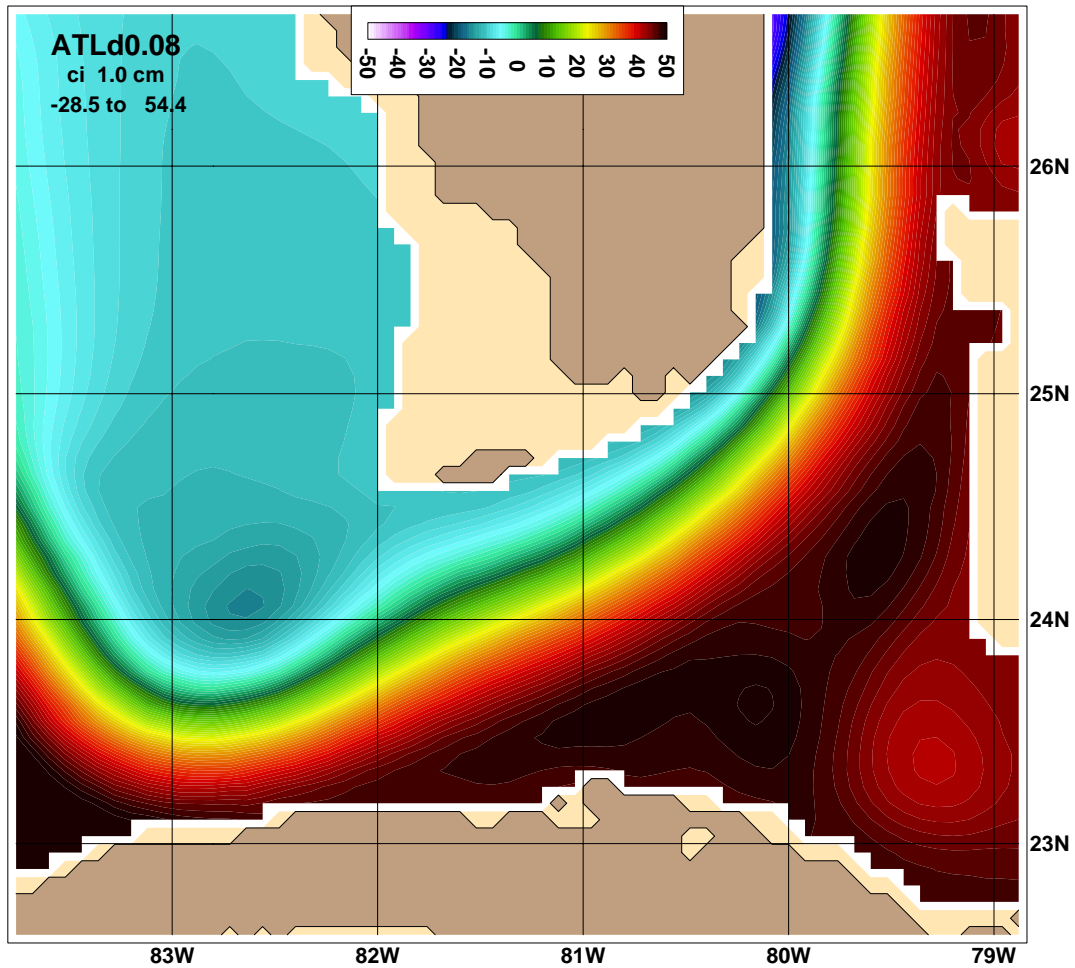


NESTING EXAMPLE

- Extract very small piece of 1/12 degree Atlantic
 - Florida Straits only
 - 1.8 m/s surface intensified flow
 - about 30 Sv total transport
- Same grid resolution
 - Can run on a workstation
 - Intent is to add biological tracers
- Based on previous test cases, started with
 - 1-day depth averaged Atlantic sampling
 - 6-day 3-D Atlantic sampling
 - T/S/p relaxation, with 1-day e-folding
- 1-day e-folding increased 10x
- Added u/v/T/S/p relaxation
- Probably need 1-day 3-D sampling

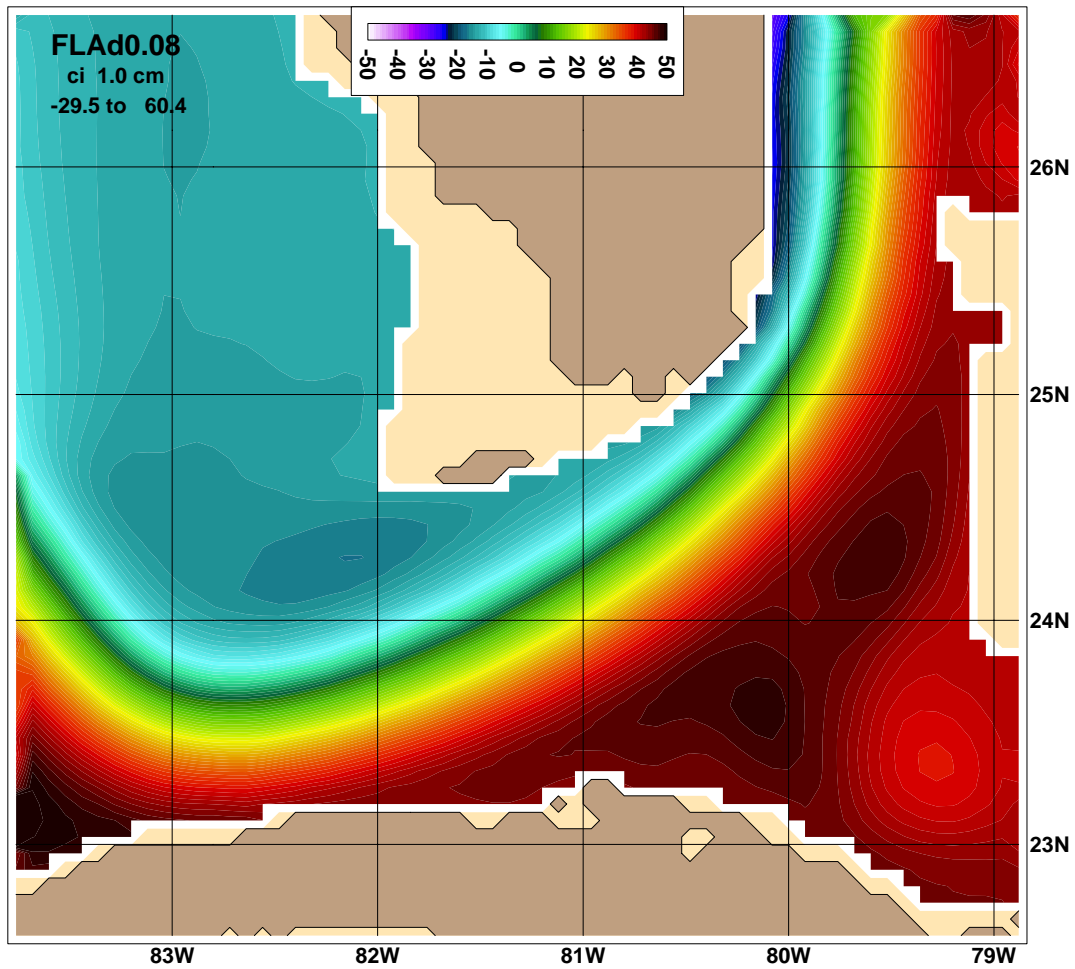
ORIGINAL FSD AFTER 180 DAYS

sea surf. height year 6.50 (jul 16) [02.4H]



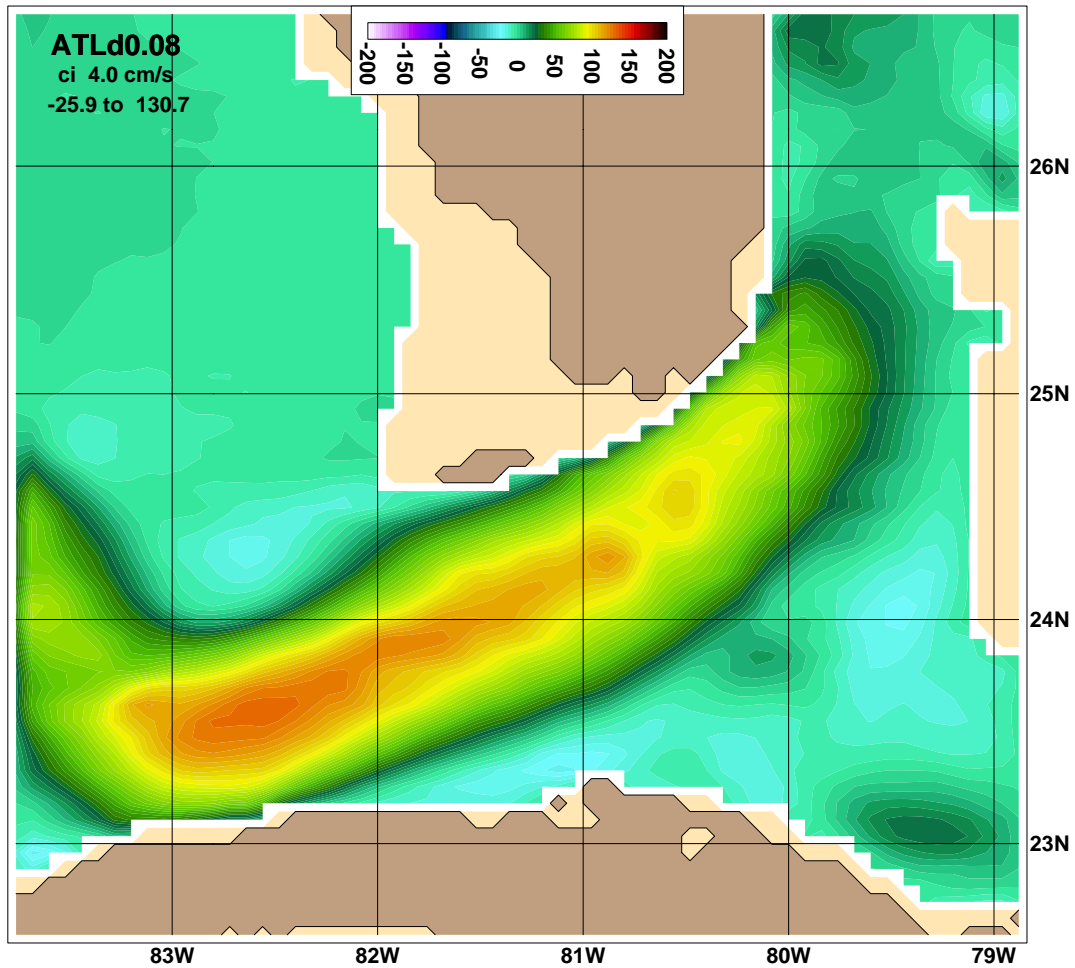
NESTED FSD AFTER 180 DAYS 0.1-DAY E-FOLD T-S-p-u-v RELAX

sea surf. height year 6.50 (jul 16) [01.2H]



ORIGINAL U-VELOCITY AFTER 180 DAYS

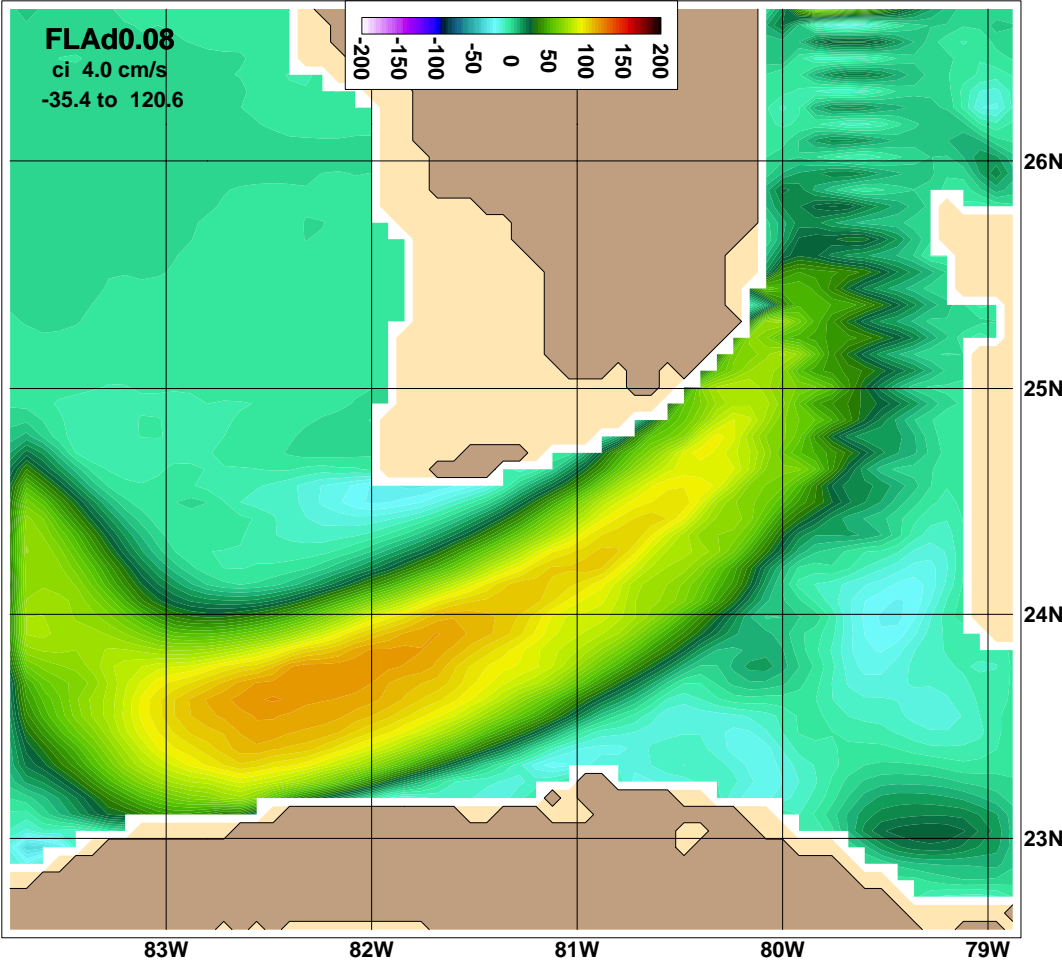
layer=01 u-veloc. year 6.50 (jul 16) [02.4H]



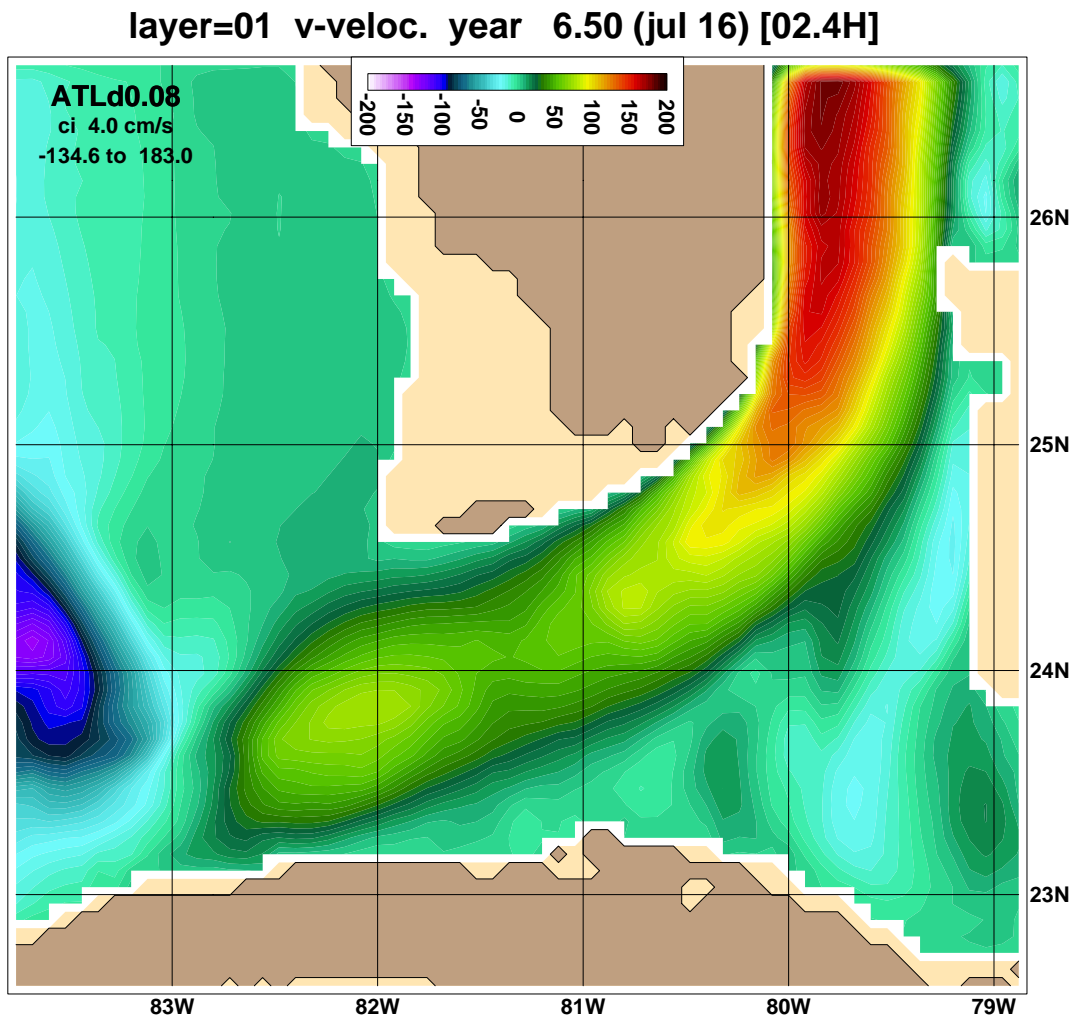
NESTED U-VELOCITY AFTER 180 DAYS

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layer=01 u-veloc. year 6.50 (jul 16) [01.2H]



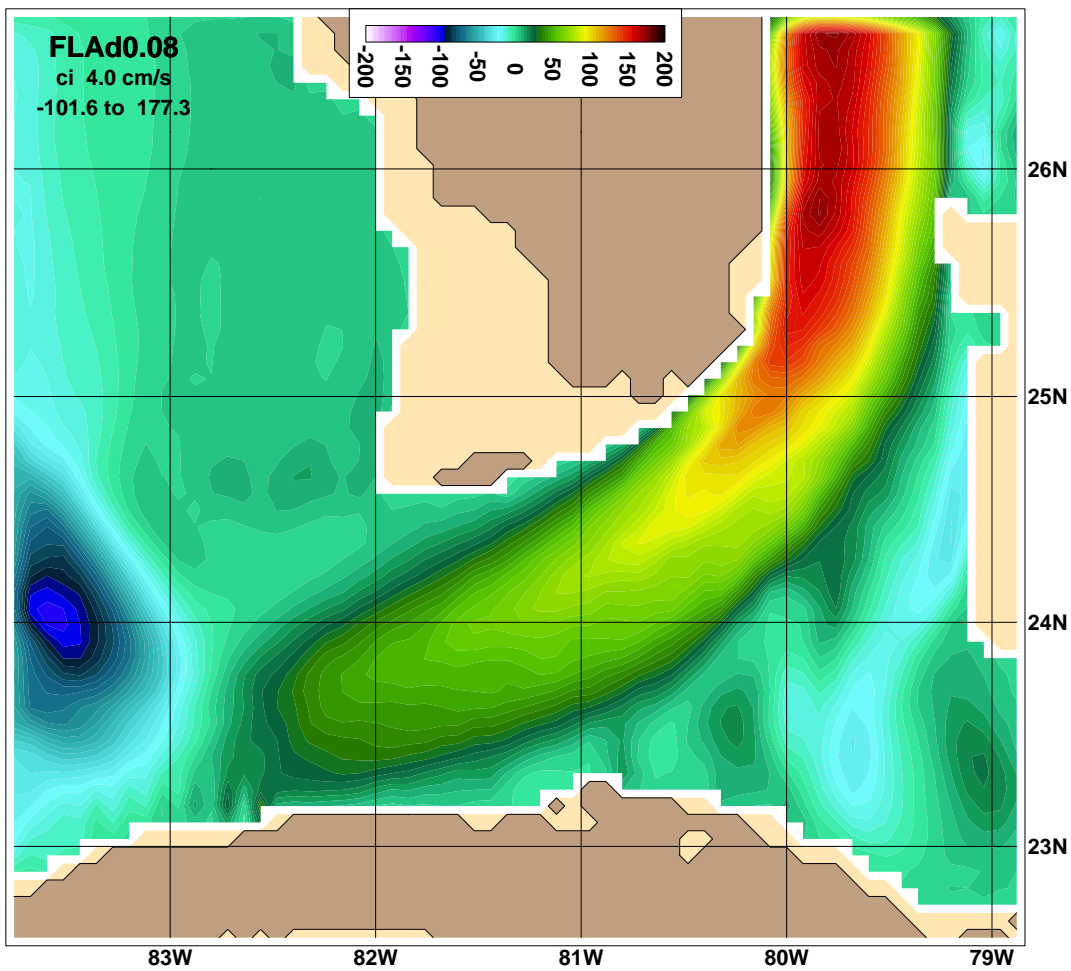
ORIGINAL V-VELOCITY AFTER 180 DAYS



NESTED V-VELOCITY AFTER 180 DAYS

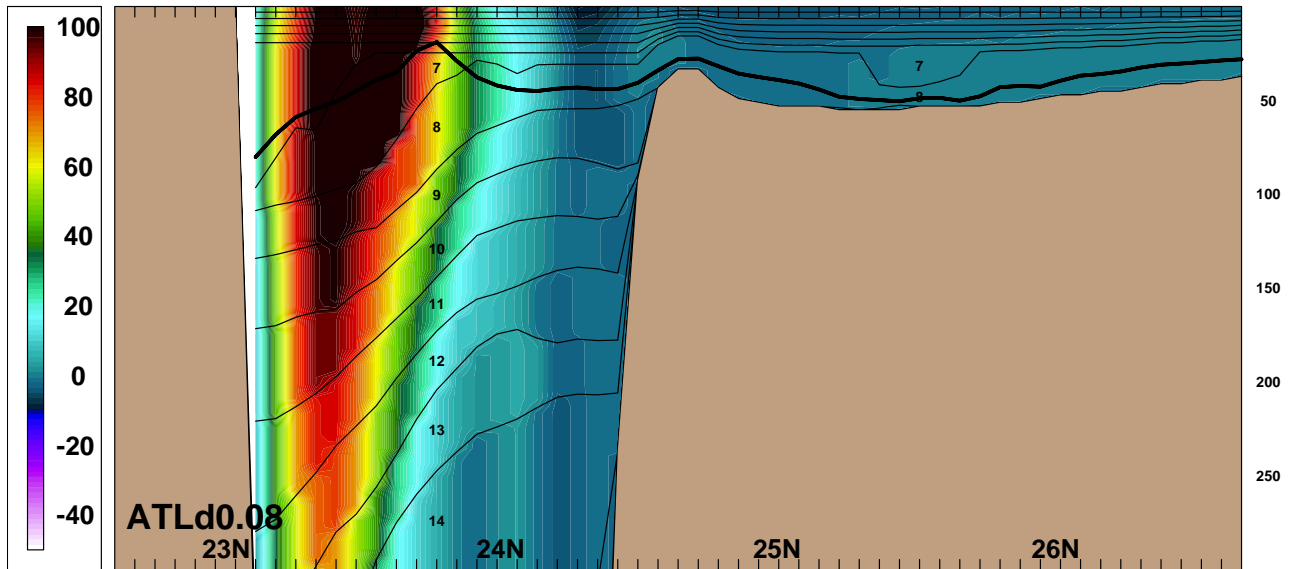
0.1-DAY E-FOLD T-S-p-u-v RELAX

layer=01 v-veloc. year 6.50 (jul 16) [01.2H]

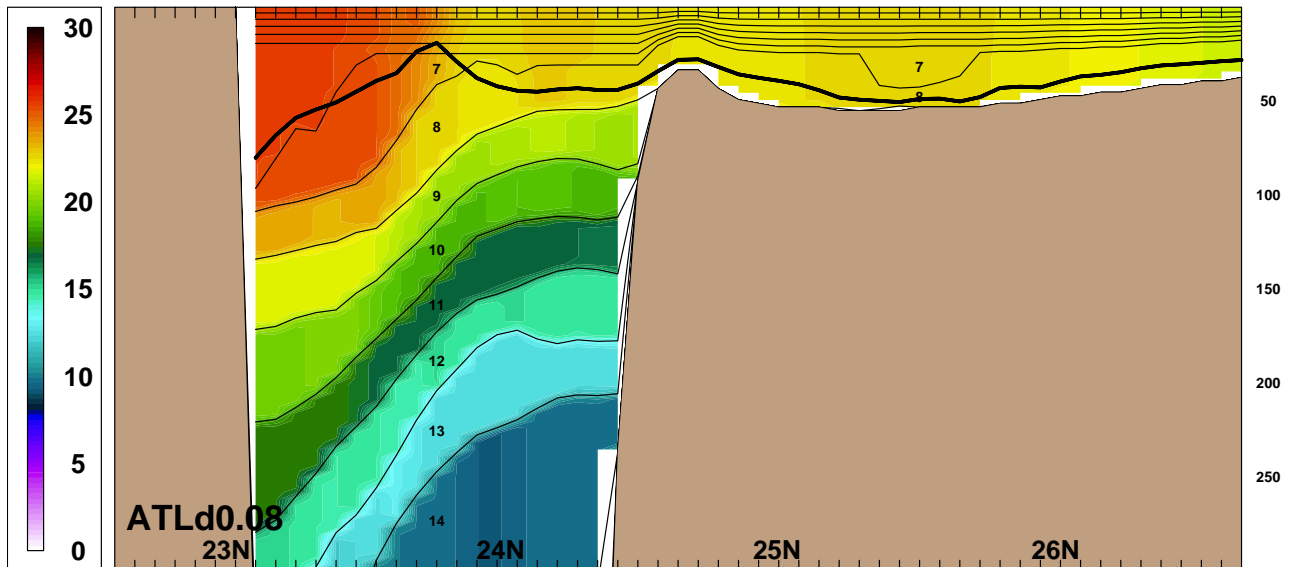


ORIGINAL SECTION AFTER 6 DAYS

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [02.4H]

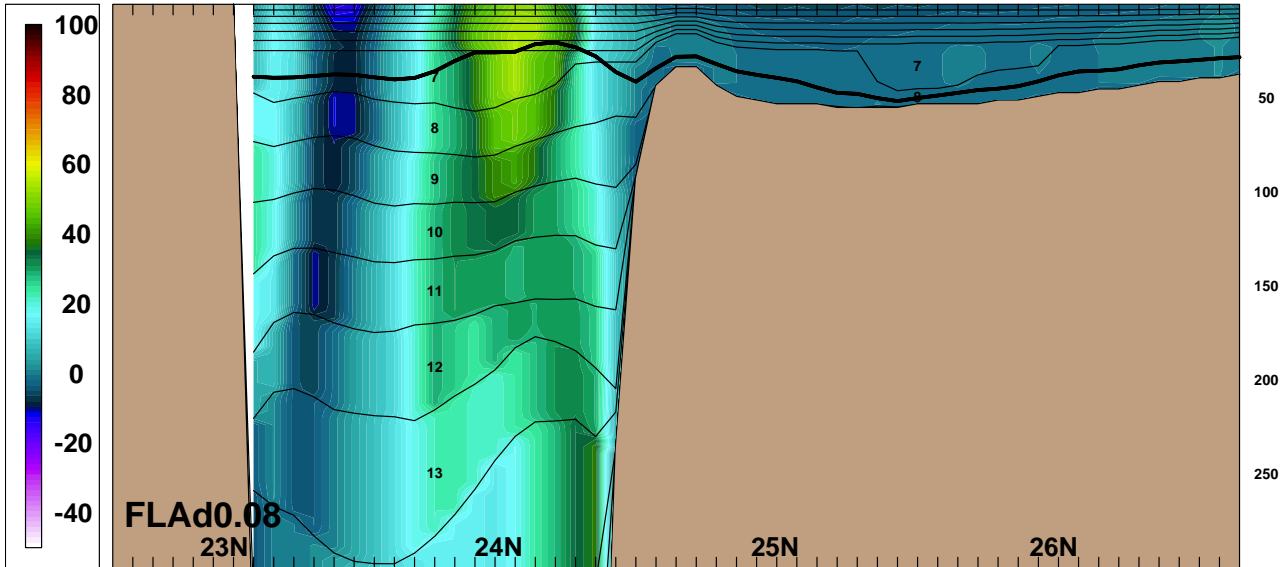


temperature merid.sec. 83.04w year 6.02 (jan 22) [02.4H]

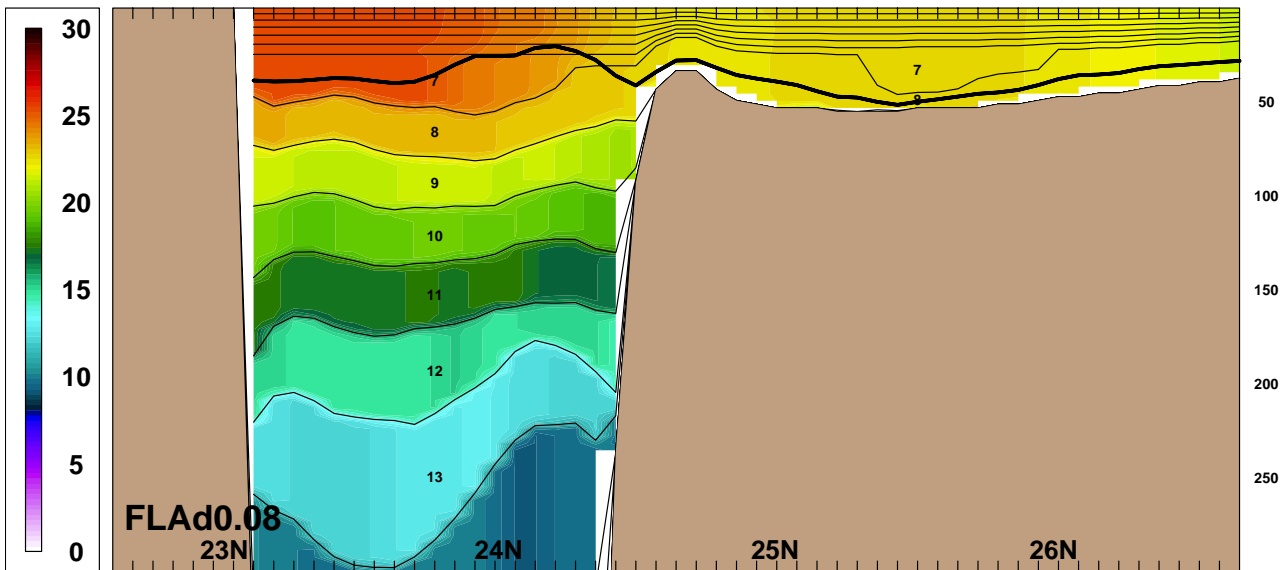


NESTED SECTION AFTER 6 DAYS: 1-DAY E-FOLD T-S-p RELAX

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [01.1H]

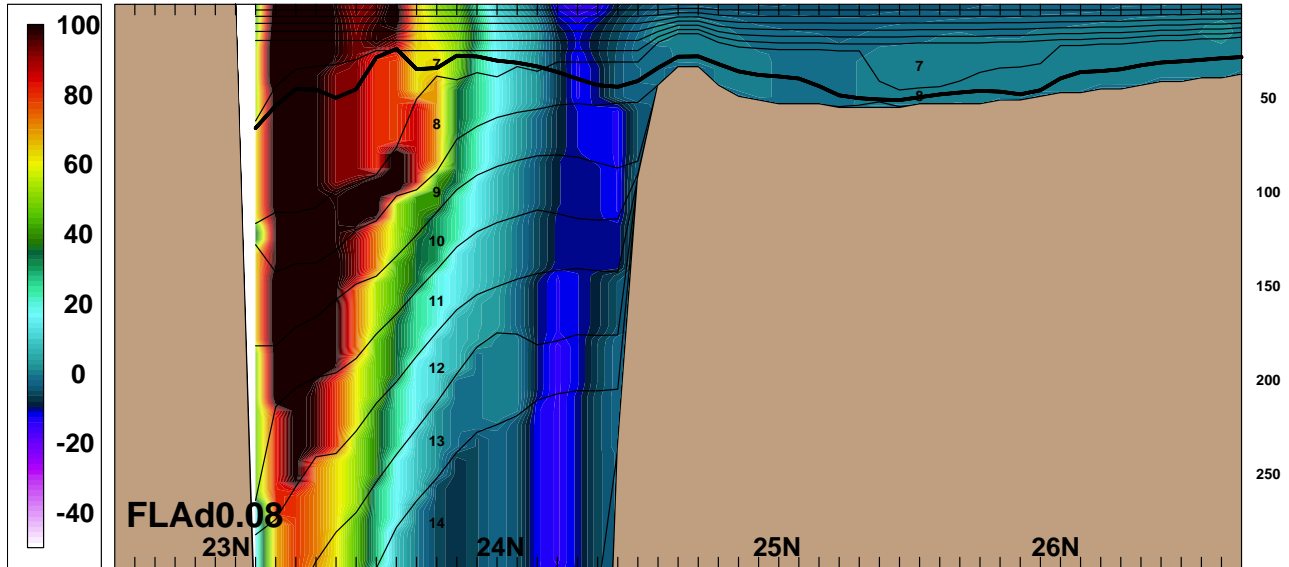


temperature merid.sec. 83.04w year 6.02 (jan 22) [01.1H]

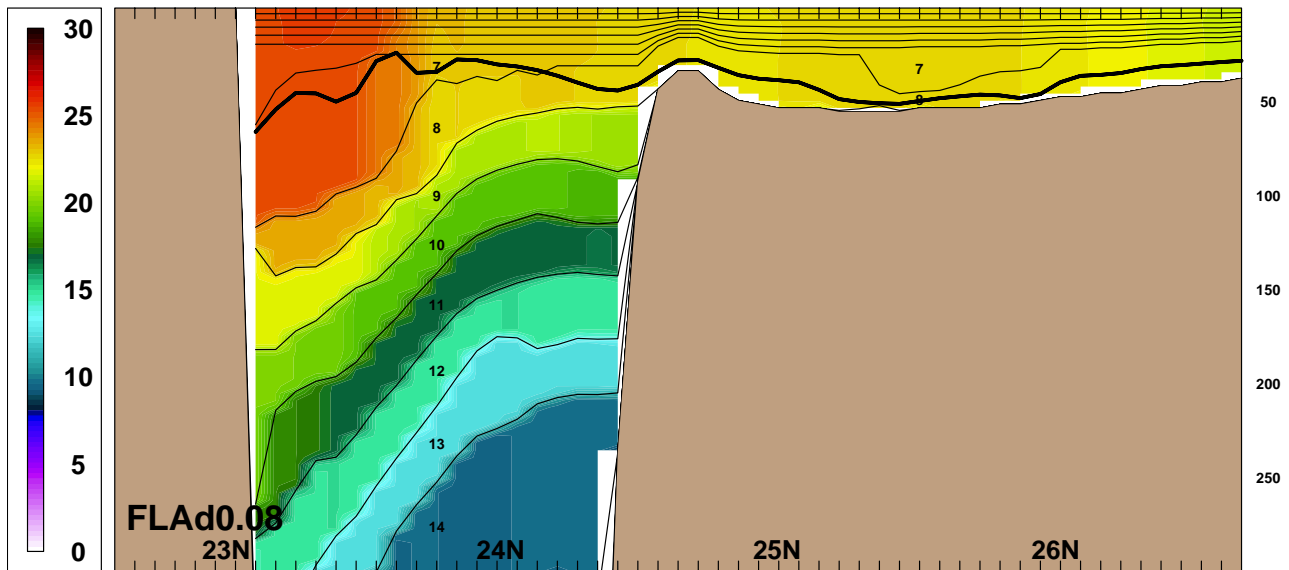


NESTED SECTION AFTER 6 DAYS: 0.1-DAY E-FOLD T-S-p RELAX

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [01.3H]

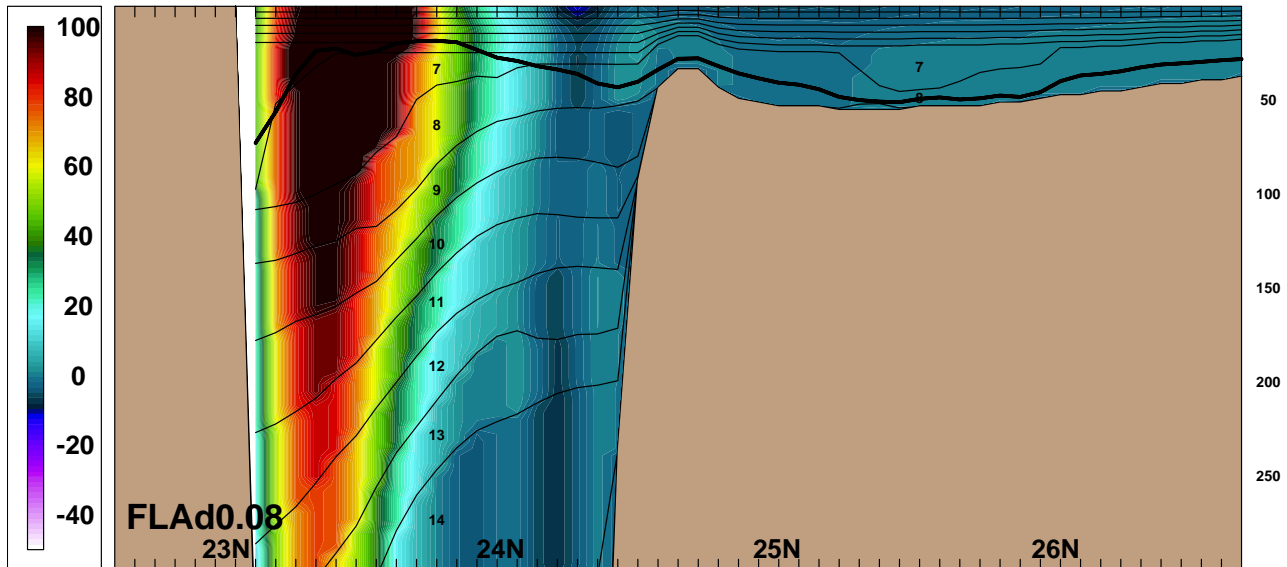


temperature merid.sec. 83.04w year 6.02 (jan 22) [01.3H]

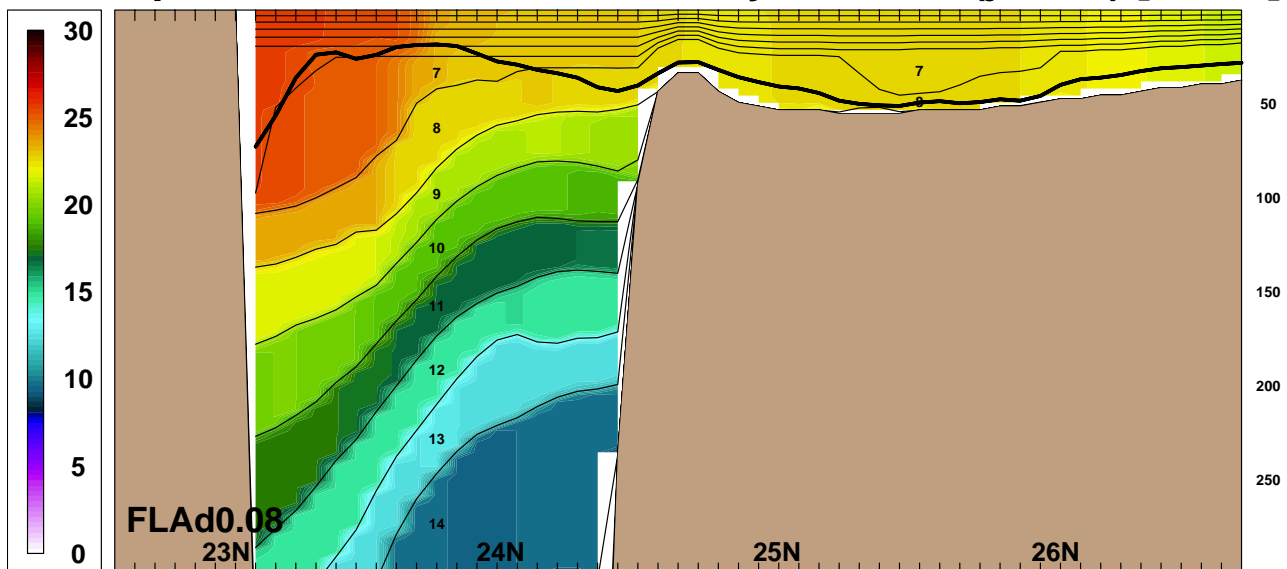


NESTED SECTION AFTER 6 DAYS: 0.1-DAY E-FOLD T-S-p-u-v RELAX

u-velocity merid.sec. 83.04w year 6.02 (jan 22) [01.2H]



temperature merid.sec. 83.04w year 6.02 (jan 22) [01.2H]



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

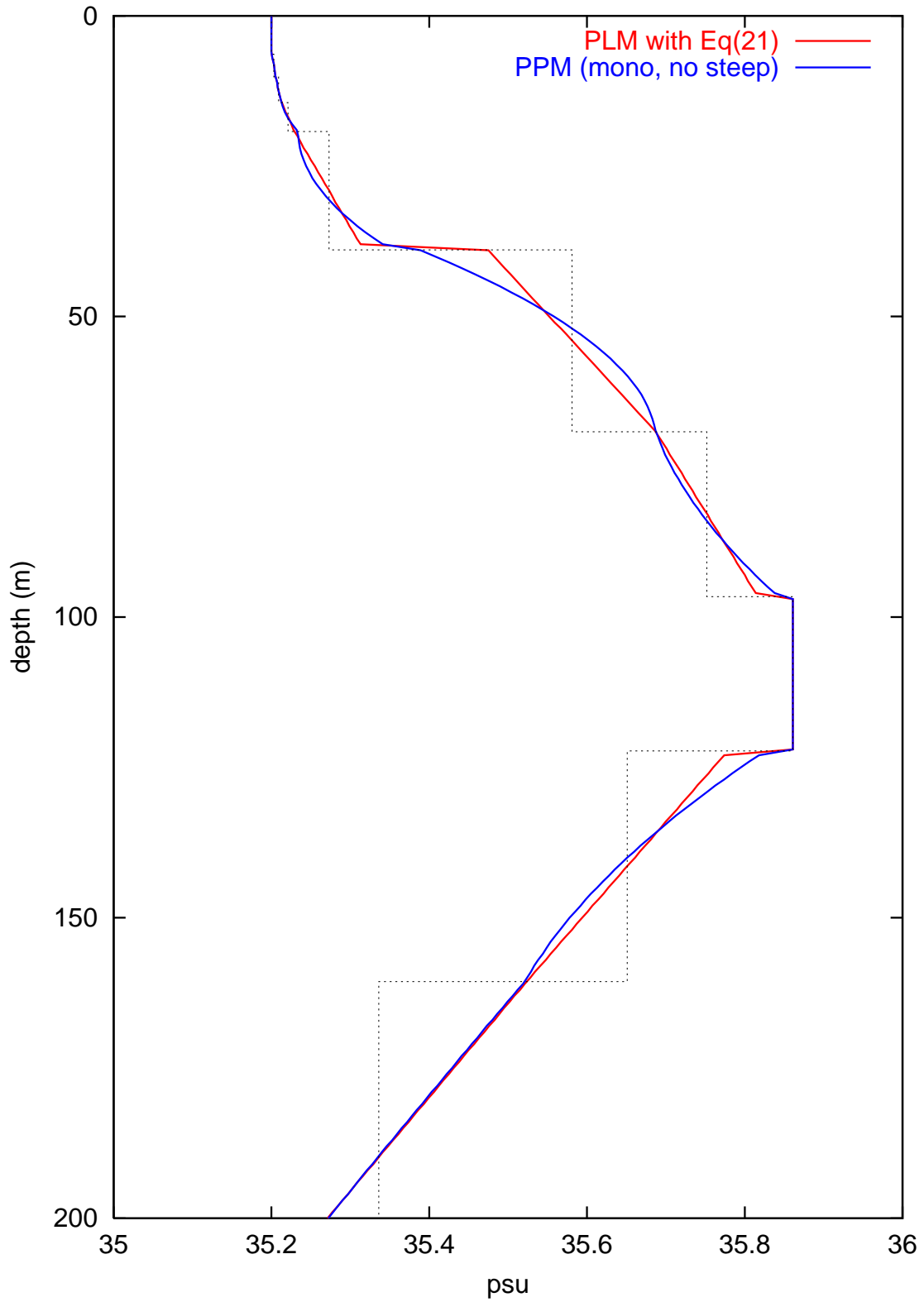
Off-line Vertical Remapping

- 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
 - To “diffusive”
 - Lowest order of a family (PLM/PQM)
- Piecewise Quadratic Method
 - Quadratic across cell
 - Very popular advection scheme
 - Tested it, but probably overkill

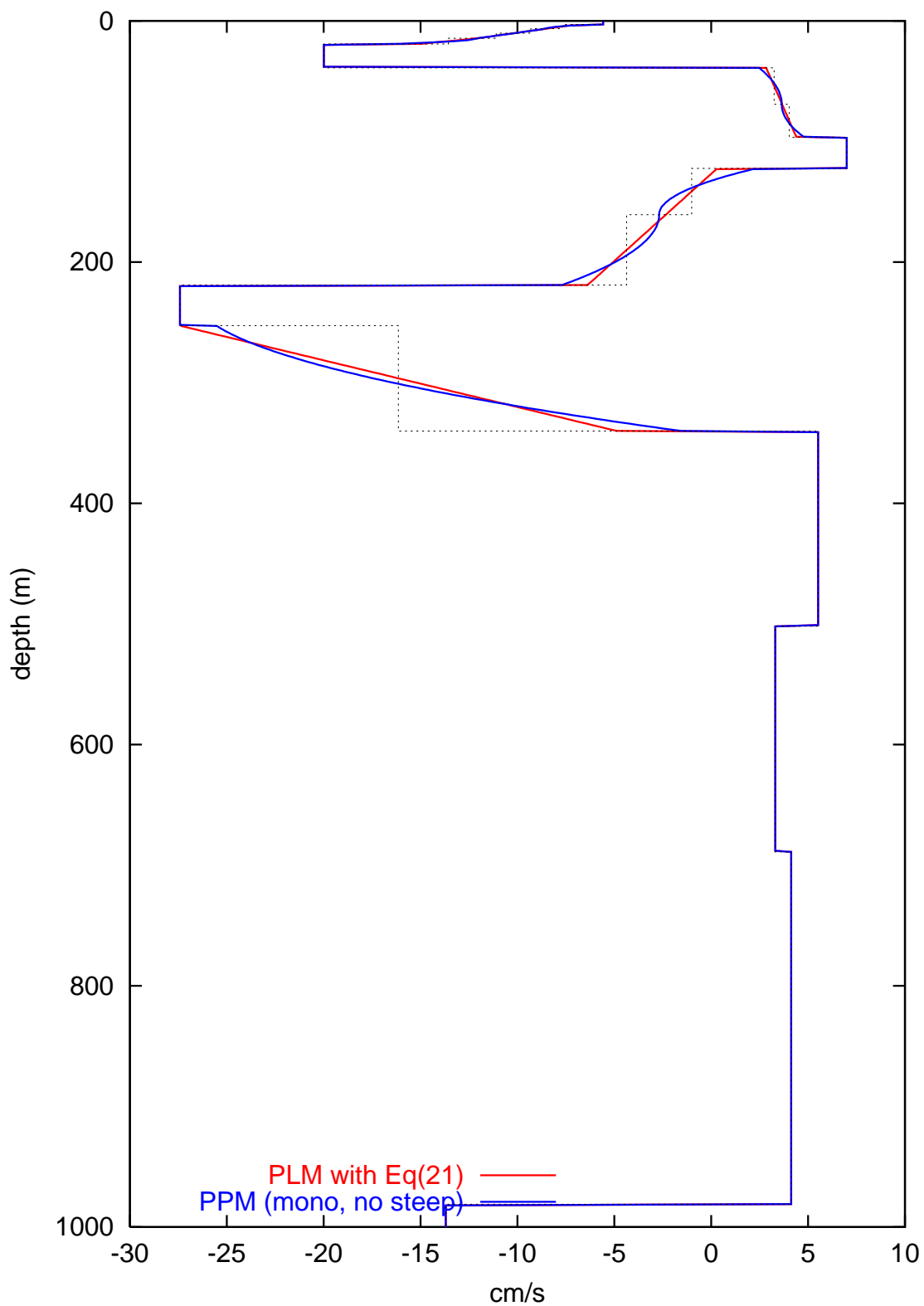
Off-line Vertical Remapping (II)

- 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
 - Working on iso-pycnals and PLM
- 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



V-Velocity Profile, Year 2000, Day 03, i=251, j=092

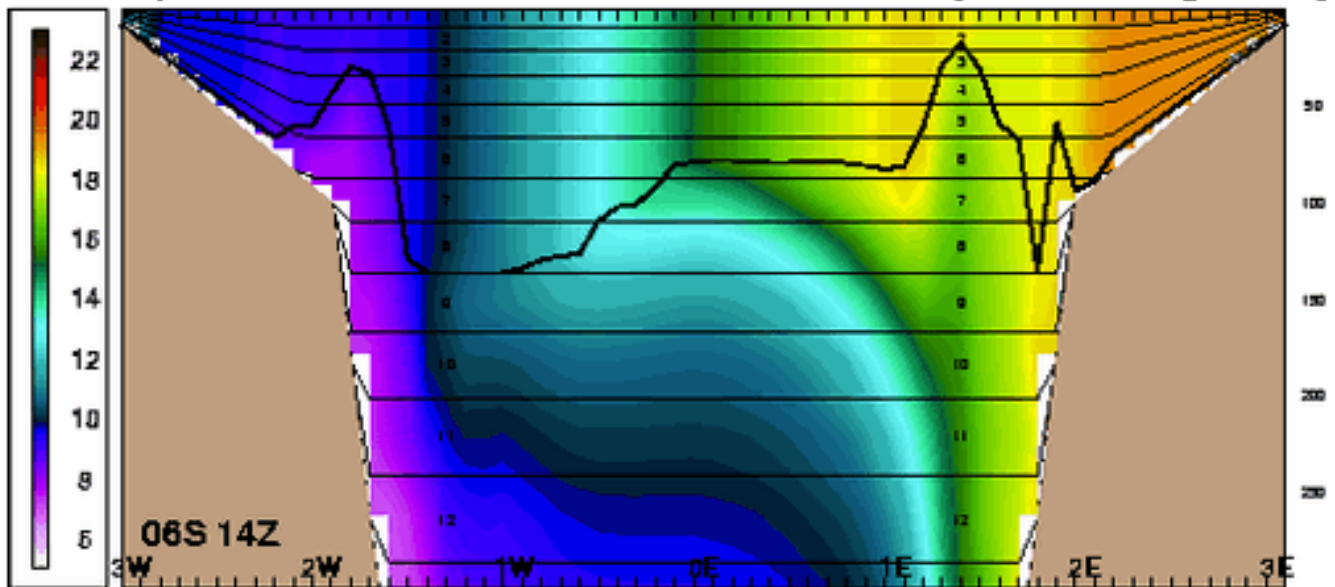


PLM Remapping of Fixed Coordinate Layers

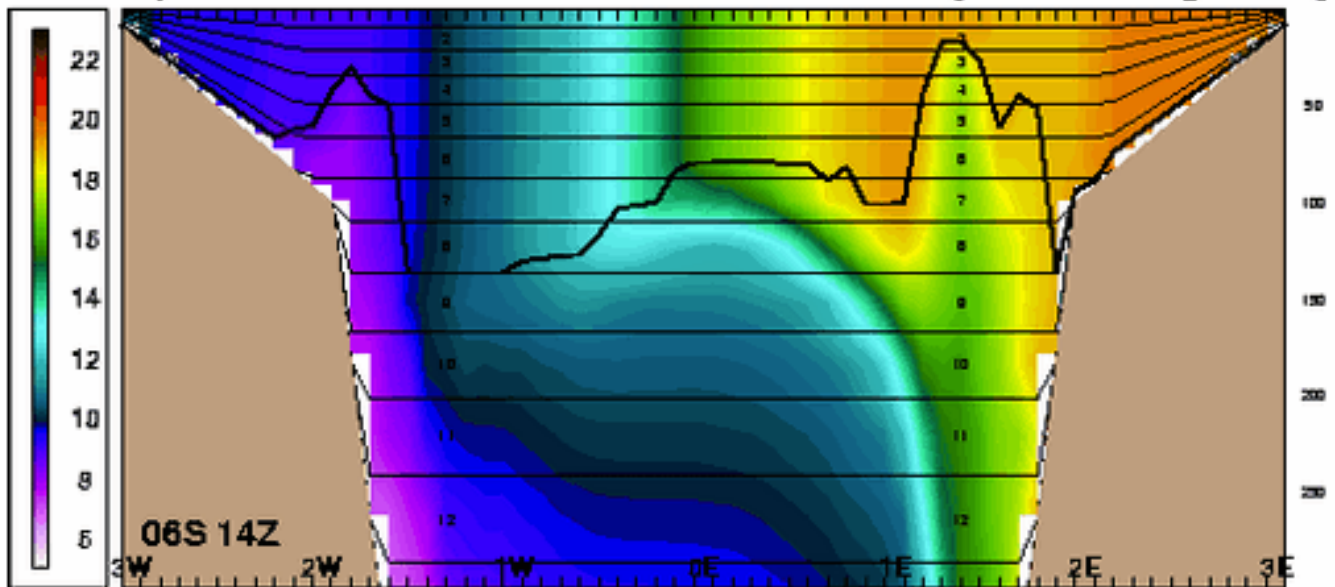
- In HYCOM, hybgen currently uses PCM
- Perfect for iso-pycnal layers
 - Most (iso-pycnal) layers don't change
 - * No remapping, no diffusion
 - Detrainment (thinning) does not change density
 - * Unique to PCM
 - * HYCOM might otherwise be impractical
- Not optimal for fixed coordinates
 - Fixed layers 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 vs PLM

temperature zonal sec. 29.91n model day: 80.00 [02.7H]

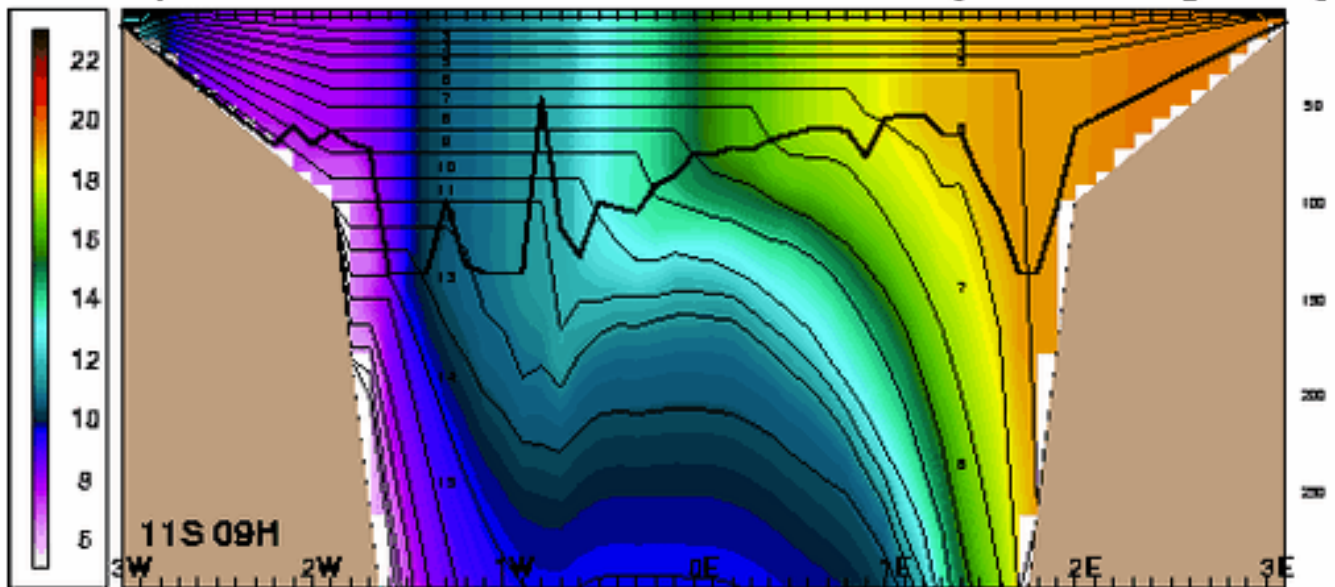


temperature zonal sec. 29.91n model day: 80.00 [06.0H]

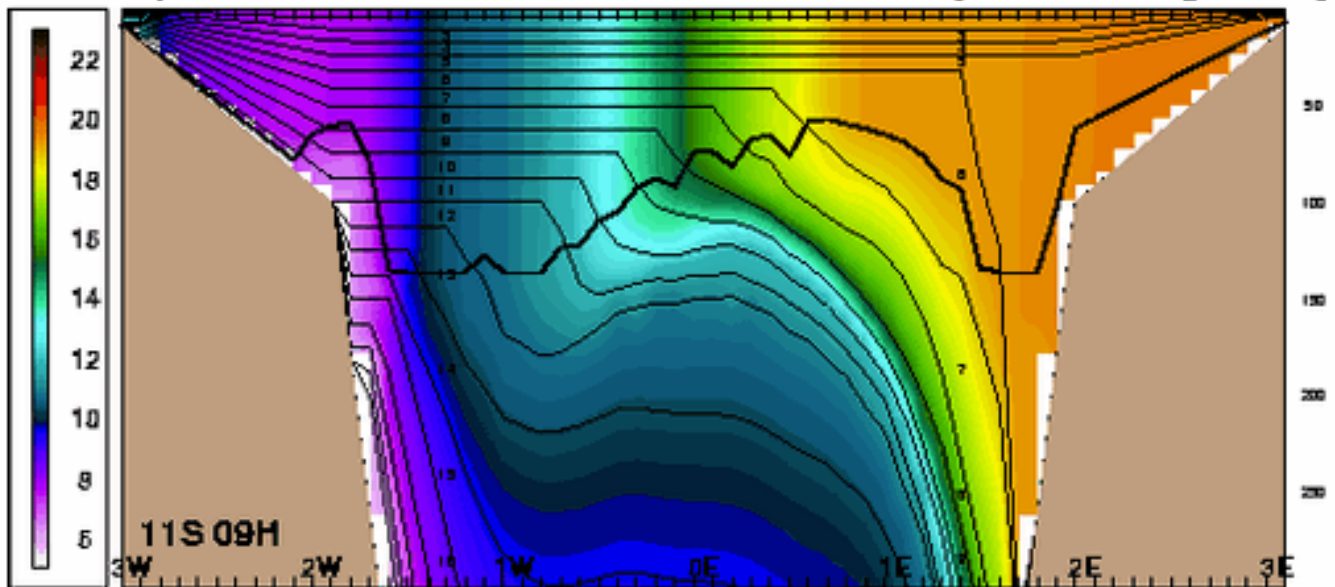


UP/DOWN-WELLING TEST - HYBRID PCM vs PLM+PCM

temperature zonal sec. 29.91n model day: 80.00 [02.8H]

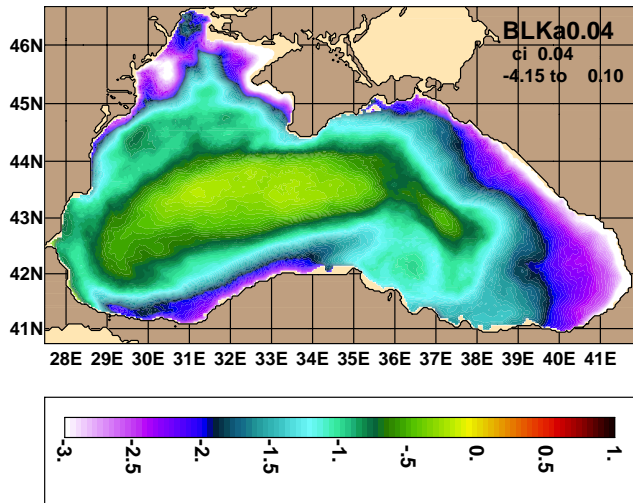


temperature zonal sec. 29.91n model day: 80.00 [06.2H]

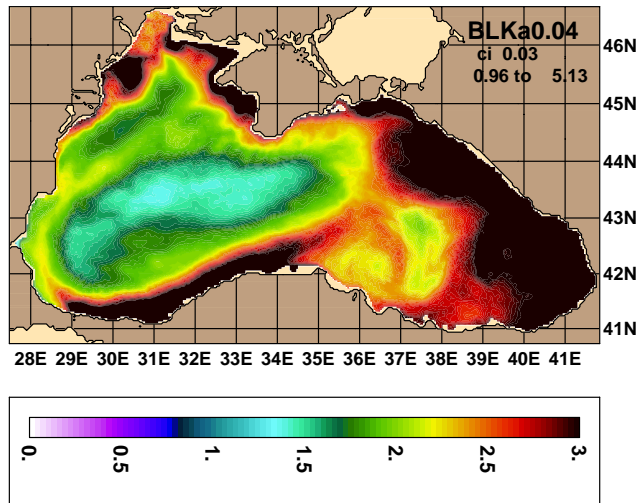


BLACK SEA SST STATISTICS: PCM

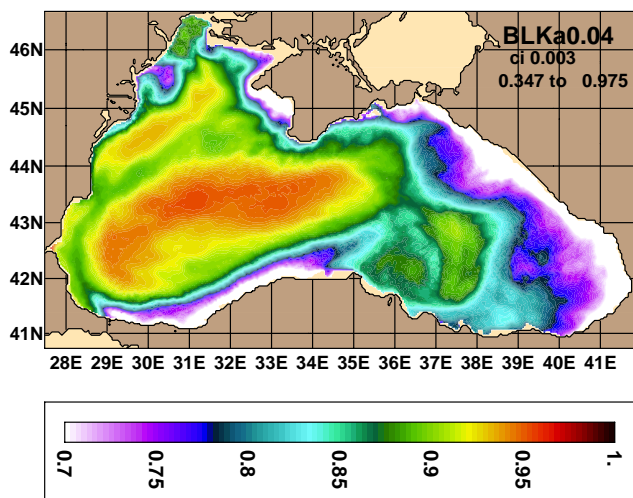
09.1 vs Pathfinder : SST Mean Error (deg C)



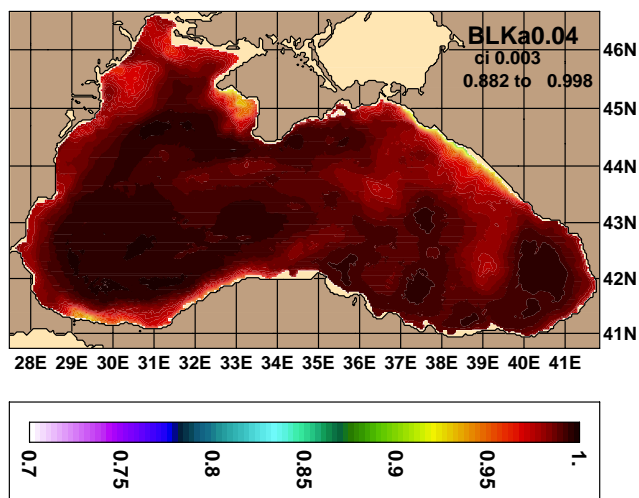
09.1 vs Pathfinder : SST RMS Error (deg C)



09.1 vs Pathfinder : SST Skill Score

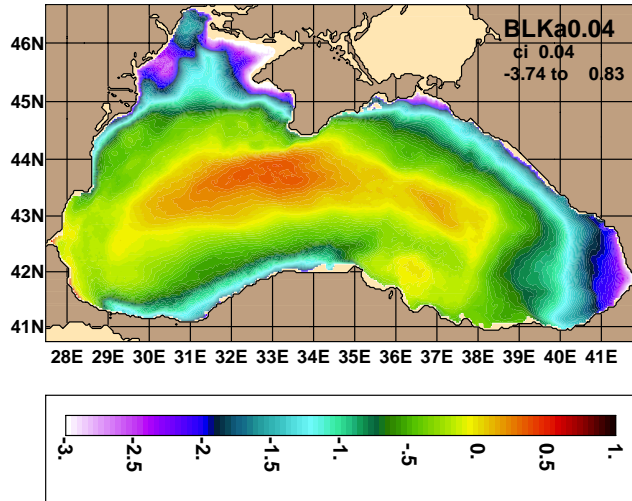


09.1 vs Pathfinder : SST Correlation Coeff.

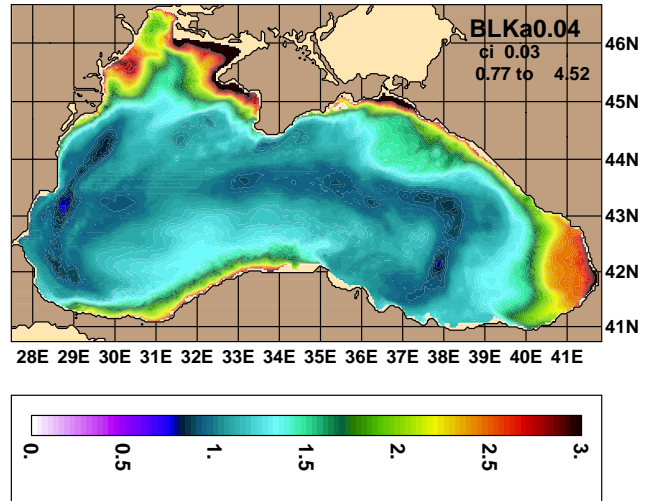


BLACK SEA SST STATISTICS: PLM+PCM

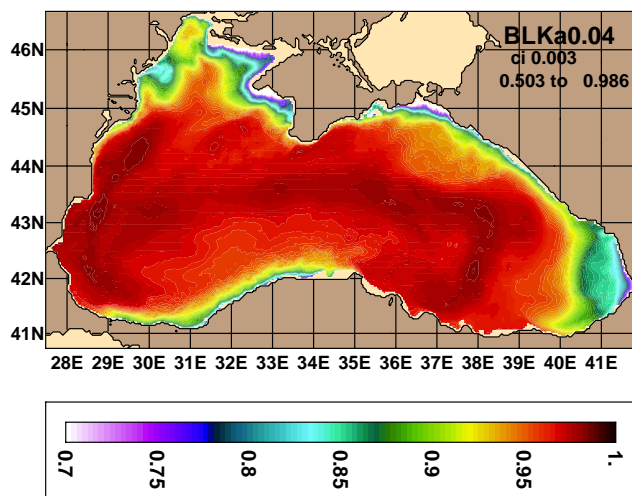
09.5 vs Pathfinder : SST Mean Error (deg C)



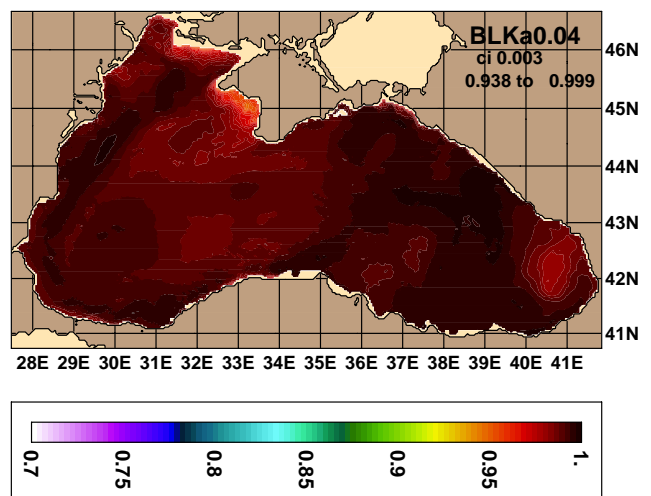
09.5 vs Pathfinder : SST RMS Error (deg C)



09.5 vs Pathfinder : SST Skill Score



09.5 vs Pathfinder : SST Correlation Coeff.



NEW FEATURES OF NEXT RELEASE

- Fully region-independent
 - Compile once, run on any region and any number of processors
- PLM remapping of fixed coordinate layers
- Spatially varying iso-pycnal layer target densities
- GISS mixed-layer model
- Bottom boundary layer in KPP
- Within HYCOM:
 - Drifters
 - Moored buoy sampling
 - Transport section sampling
- NCAR's CCSM Coupler
 - CICE sea-ice model
 - Coupled air-ocean-ice

WISHLIST FOR HYCOM (I)

- Tidal forcing
- Even more mixed-layer models
- Support for data assimilation
- Comprehensive tracer support
 - Within HYCOM and off-line
 - In z-space?
- Use WRF framework for parallelization
 - Weather Research and Forecast model
<http://www.wrf-model.org>
 - Future of all US operational weather centers
 - Automatic compatibility with NASA's ESMF
 - Flexible and asynchronous I/O
- Extended coupler support
 - Alternatives to NCAR's CCSM coupler (ESMF)
 - Bio-geochemical/ecosystem model?
 - Asynchronous I/O?

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?
- Atmospheric pressure forcing?
- Rivers (and surface E-P) as mass exchange?