Overview of HYCOM ALE efforts

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Workshop on Improving ALE Ocean Modeling

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HYCOM'S BASIC ALE APPROACH

- **Solve the layered continuity equation**
  - **Move all the layers**
- **Each time step, remap in the vertical to the "desired" layer structure**
  - **Fluid does not move**
  - **Some layer interfaces are moved (remapped) across the fluid**
  - **Isopycnal layers are not remapped**
  - **Choose interpolation that is conservative, with no new extrema**
  - **Nominally, this does not change the solution but it does add diffusion**
- **Basic algorithm for choosing the new layers (Rainer Bleck)**
  - **1-D in the vertical**
  - **Greedy algorithm, starting at the surface**
  - **Favor isopycnal layers**
  - **Maintain minimum layer thicknesses**
  - **A cushion function transitions between isopycnal and non-isopycnal states**
  - **Unused layers are zero thickness at the bottom**
  - **A too-light deepest inflated layer is a special case**
    - **Can't entrain fluid from below**
    - **Unmix into the layer above**

HYCOM Z-SIGMA-Z

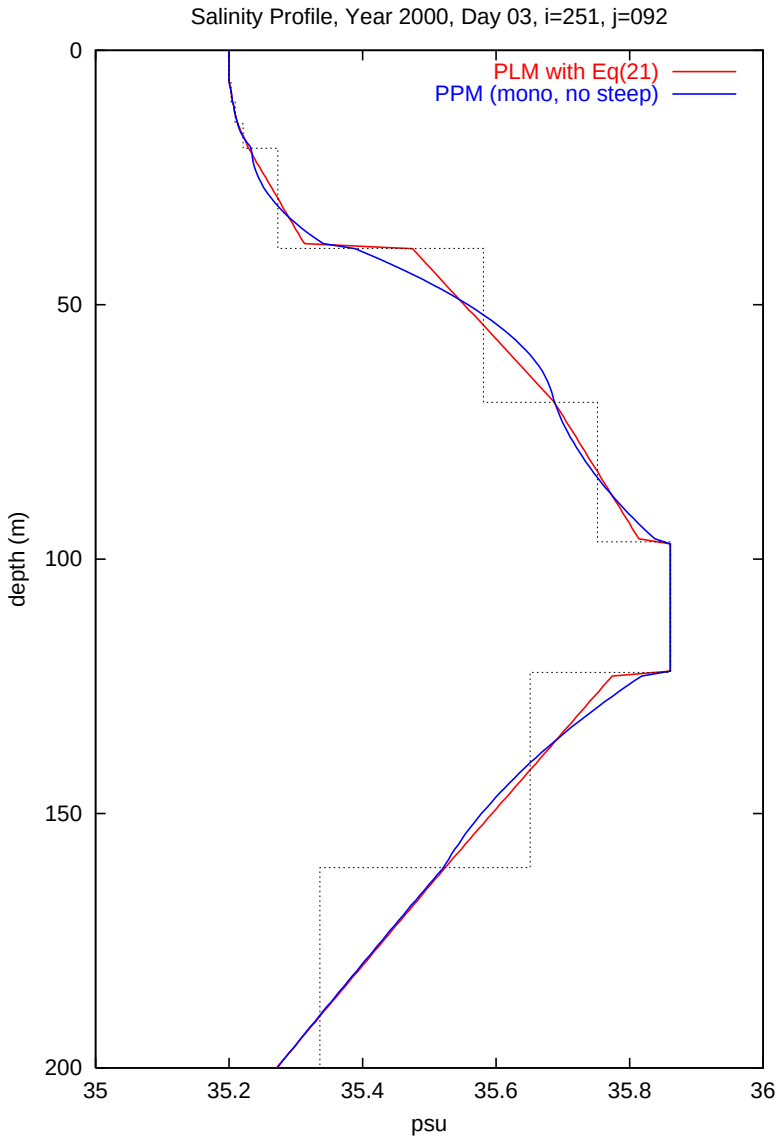
- **HYCOM can emulate z-level (fixed depth) and sigma (terrain following) vertical coordinates, but it always uses the layered continuity equation**
- **Z-levels in HYCOM**
  - **A sequence of minimum thickness layers starting at the surface forms a fixed grid with no horizontal gradients**
  - **Since hybgen works in dp' space, layers are scaled by $(\eta + D)/D$**
- **An actual sigma-coordinate model uses a depth-based transformation to become terrain-following, and a sigma-Z model is terrain-following when shallower than a specified depth but is z-coordinate deeper than that depth**
- **HYCOM has 3 regimes based on bottom depth (Z-sigma-Z):**
  - **Deep constant minimum thickness**
  - **Shallow constant minimum thickness (layers 1 to nsigma)**
  - **Terrain following between "deep" and "shallow" depths**
- **This can emulate sigma or sigma-Z (or Z)**
- **When in fixed coordinates all the way to the bottom, there are typically many deep zero-thickness layers which are included in most calculations but have no effect on the solution**
  - **e.g. layers nsigma+1 to kdm when terrain following**

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**
- **Monotonic Finite Volume approach allows partial separation**
  - **Define a profile across original layers**
    - **Can be discontinuous at layer interfaces**
  - **Use profile in deciding where to put layers**
  - **Integrate this profile to get new layer averages**
- **Original HYCOM approach (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**

EXAMPLE OF INTERPOLATION

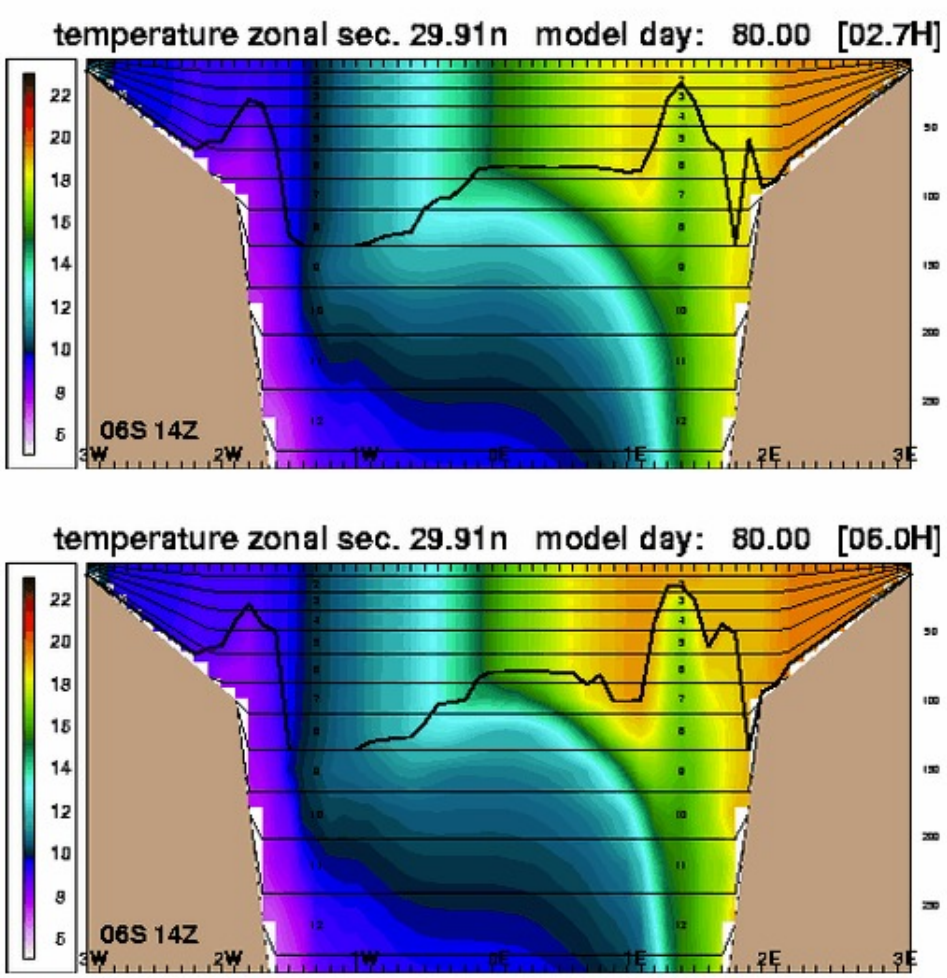
- **Known: layer thickness and layer vertical average value**



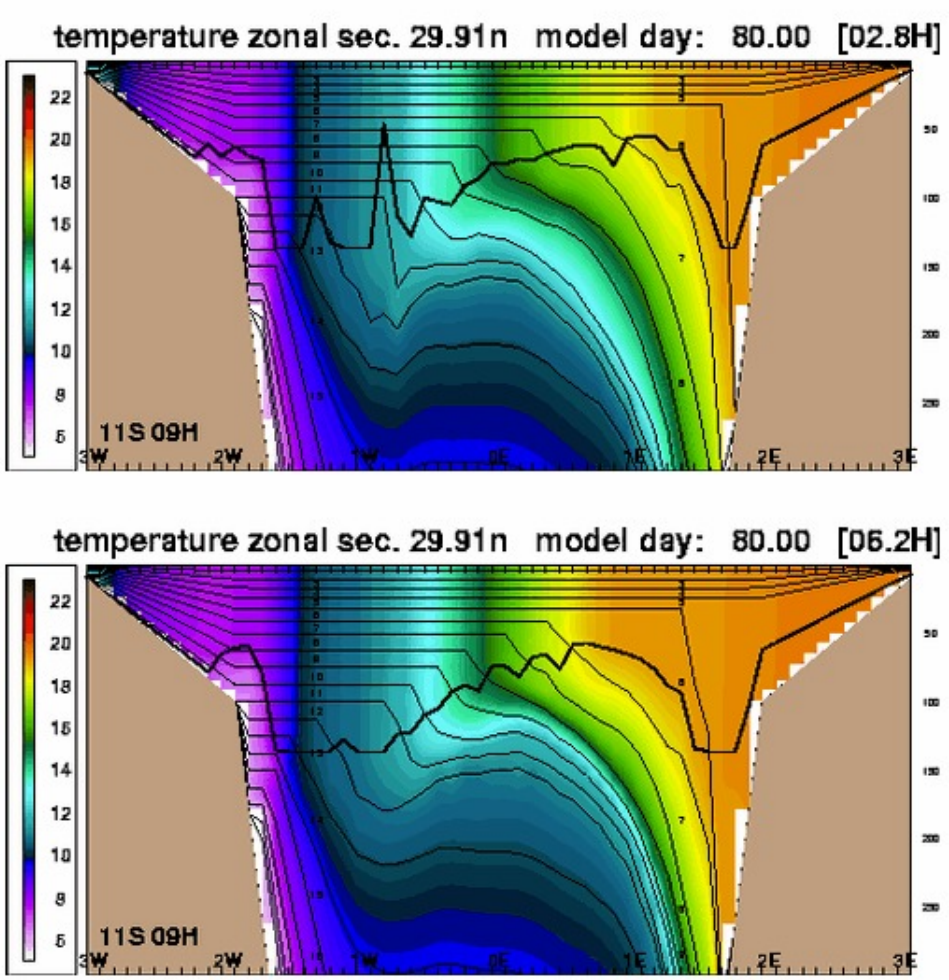
PLM REMAPPING OF FIXED COORDINATE LAYERS

- **In HYCOM, hybgen originally used 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 vertical coordinates**
  - **Fixed layers always move**
  - **PCM is very diffusive**
- **PCM is a special case of PLM (Van Lear)**
  - **PLM with zero slope**
- **1st hybgen upgrade: Use PLM for fixed layers and PCM for iso-pycnals**

UP/DOWN-WELLING TEST - SIGMA-Z
PCM vs PLM



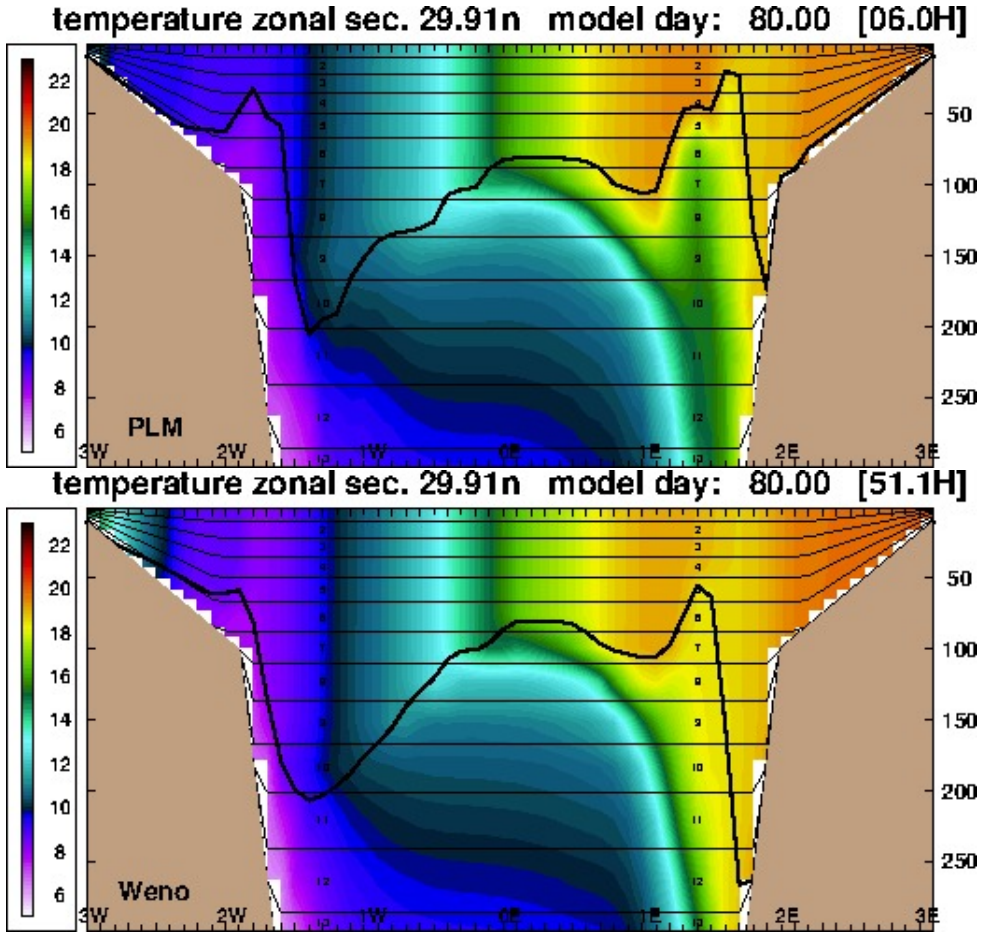
UP/DOWN-WELLING TEST - HYBRID
PCM vs PLM+PCM



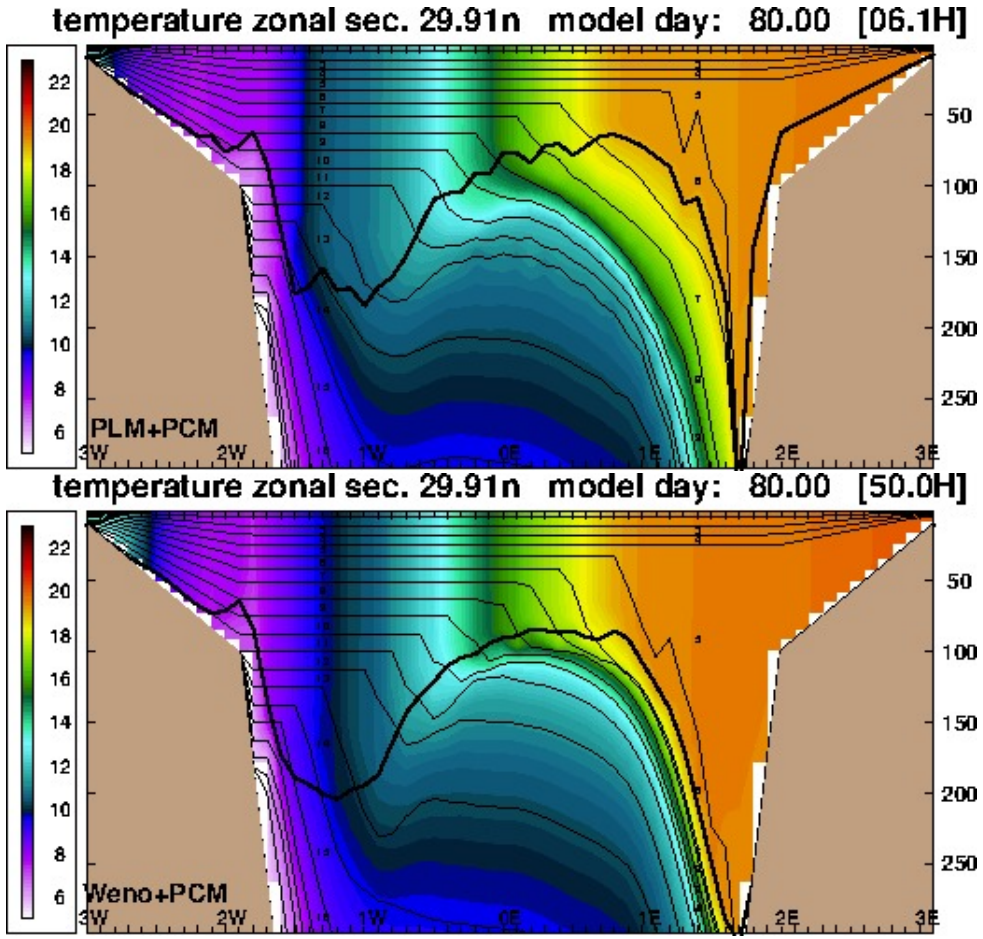
HYCOM v2.2 REMAPPING

- **Spatially varying layer target densities**
  - **Different isopycnal layers in semi-enclosed seas, e.g. Mediterranean Sea**
  - **Fixed (sigma-Z) in isolated regions, e.g. Black Sea and Baltic Sea**
- **Minimum layer thicknesses via a scale factor (v2.1) or a list of thicknesses**
  - **Redefined the specification of deep Z to sigma to shallow Z**
    - **Always fixed coordinates above a specified depth**
    - **Favor isopycnal layers below that depth**
- **Alternative minimum (e.g. dp00i=1m) for all layers when they are 'isopycnal" or "far" from surface**
- **Major re-write of hybgen subroutine by George Halliwell**
  - **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**
    - **PCM is a special case of all these methods**
  - **More layers are identified as non-isopycnal**
  - **Updated logic for two layers (one too dense, other too light)**
  - **Attempts to minimize thick-thin-thick-thin layer structure**
    - **Made worse by greedy algorithm**
    - **Ad-hoc fixes are only partially successful**

UP/DOWN-WELLING TEST - SIGMA-Z
PLM vs Weno
v2.1.05 vs v2.2.98



UP/DOWN-WELLING TEST - HYBRID
PLM+PCM vs Weno+PCM
v2.1.05 vs v2.2.98

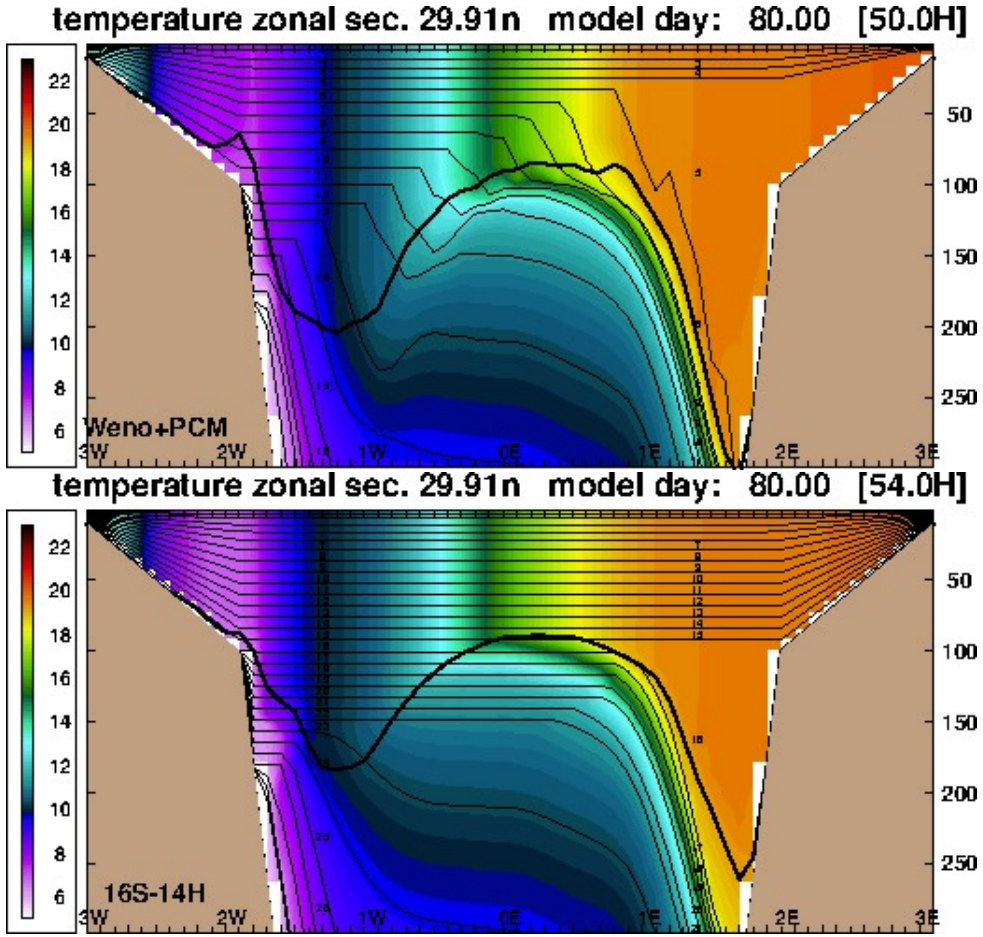


- **dp001=1m (2.2.98) allows tighter isopycnals**

CHOICE OF LAYER STRUCTURE

- **A hybrid vertical coordinate allow a wide choice of layer structure**
- **We have only explored a small fraction of the possibilities**
- **Initial approach**
  - **Choose isopycnals based on water masses**
  - **Add 4-5 thin Z-level layers near the surface to capture a new mixed layer as it forms**
  - **Set all minimum layer thicknesses small, so the maximum Z-level regime covers (say) 0-200m**
- **Current approach**
  - **Choose isopycnals based on water masses**
  - **Add 10-15 thin Z-level layers near the surface that are never isopycnal and extend from 0-100m**
    - **These will also be always fixed depth over the shelf**
    - **Allows velocity shear over the shelf even when T&S are well mixed**
  - **Choose the remaining minimum layer thicknesses so the maximum Z-level regime covers (say) 0-2500m or deeper**
    - **Includes minimum thicknesses of 600m**
    - **However, minimum layer thickness tends to 1m (dp00i) when sufficient layers above are isopycnal**

UP/DOWN-WELLING TEST - HYBRID
20 layer vs 30 layer

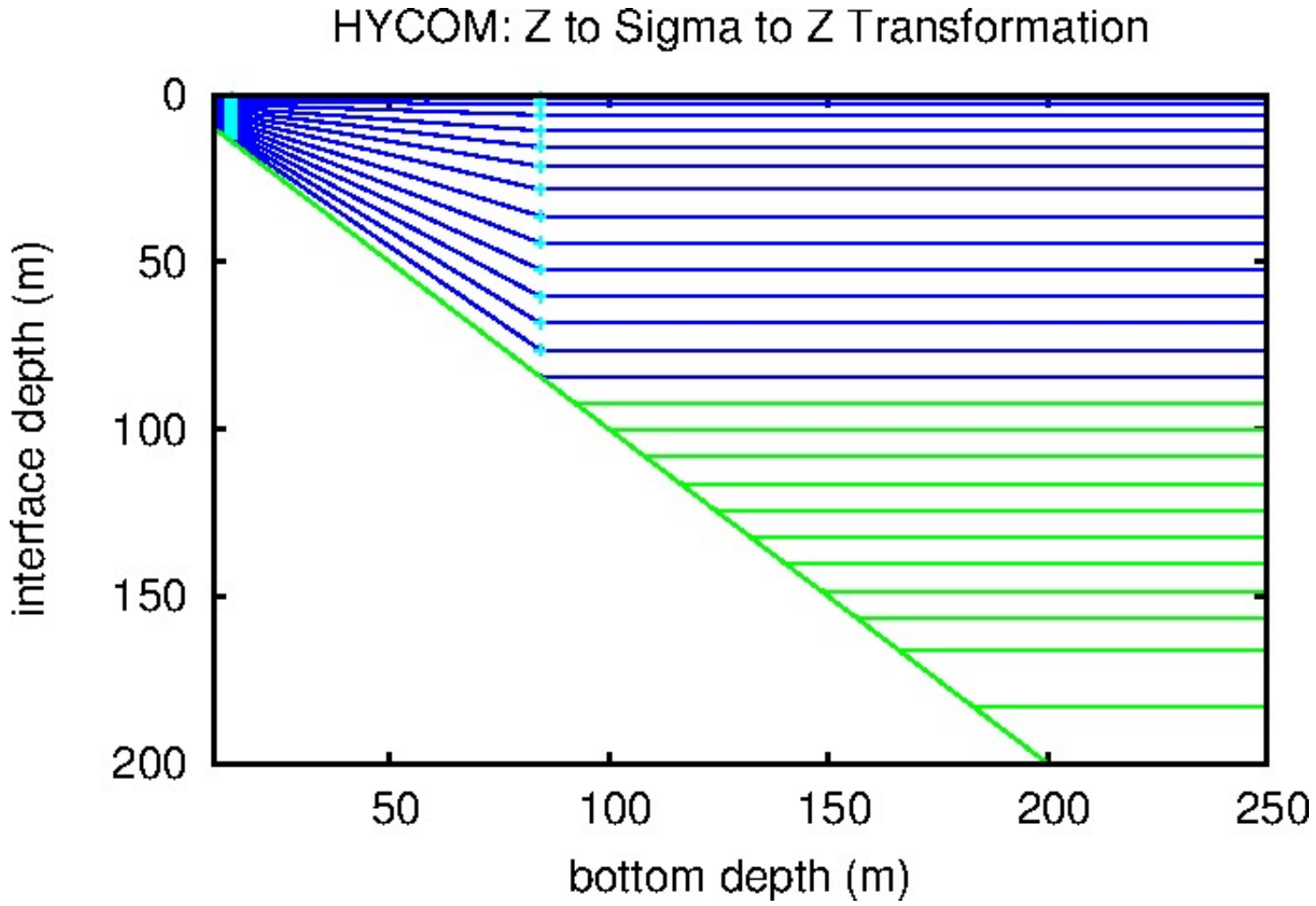


HYCOM Z-SIGMA-Z

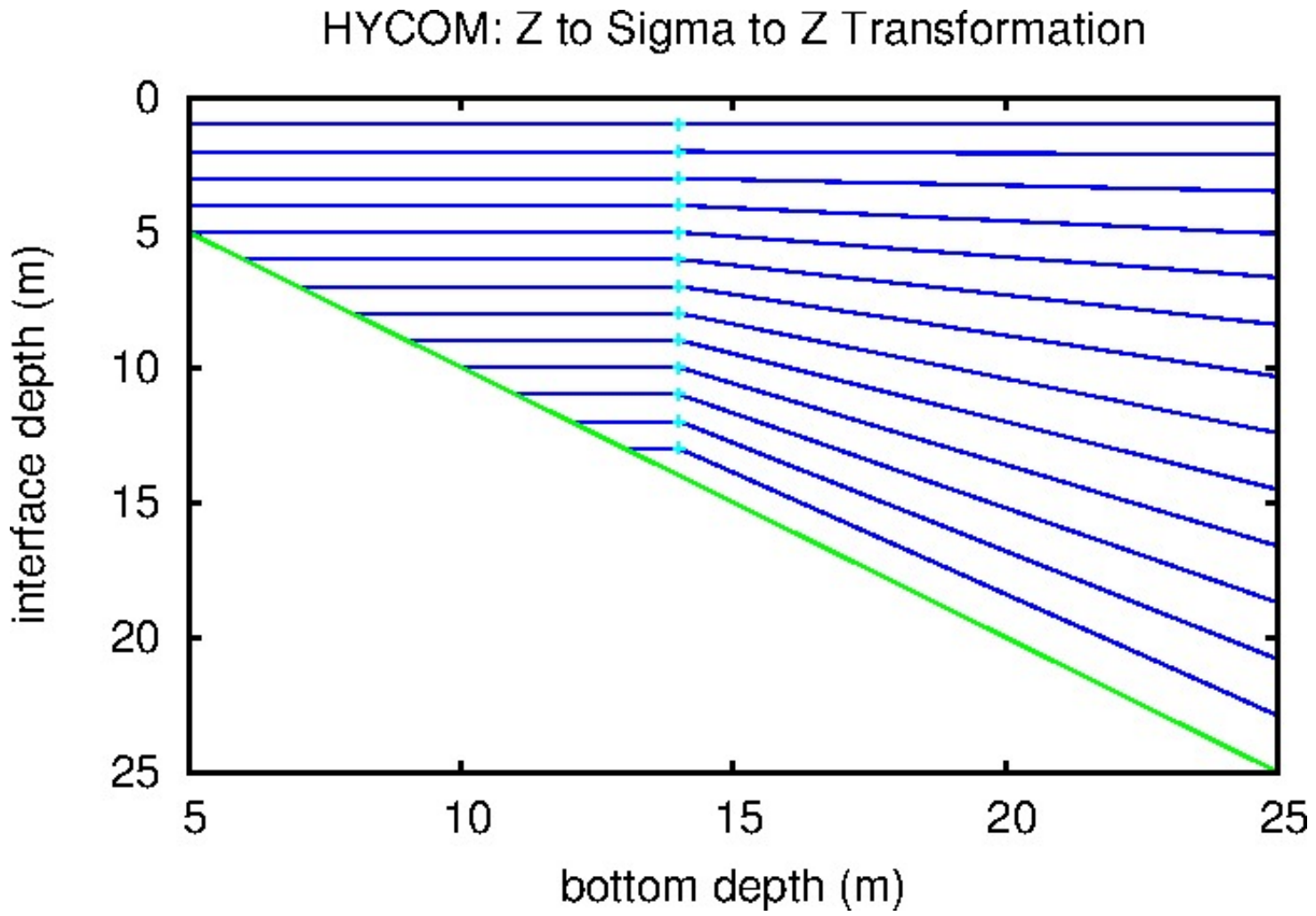
- HYCOM has 3 regimes based on bottom depth (Z-sigma-Z):
  - Deep constant minimum thickness
  - Shallow constant minimum thickness (layers 1 to nsigma)
  - Terrain following between “deep” and “shallow” depths
    - What this means has evolved over time
    - All definitions the same for sigma and sigma-Z, but differ if the ratio of deep to shallow minimum thicknesses is not constant
    - We now linearly connect deep and shallow minimum thicknesses in depth space
- This can emulate:
  - Z (nsigma=0, and so no shallow)
  - Sigma (nsigma=kdm, shallow = small constant fraction of deep)
  - Sigma-Z (nsigma$<$kdm, shallow = small constant fraction of deep)
- For low horizontal resolution cases we use Z
- For high horizontal resolution cases we use Z-sigma-Z, which isn’t an exact emulation of any other vertical coordinate

EXAMPLE Z-SIGMA-Z SETUP: 0-200M

- **We currently set the top layer 1 m in both deep and shallow, with all (14) shallow minimums at 1 m and deep minimums increasing to 8m at 100m depth**

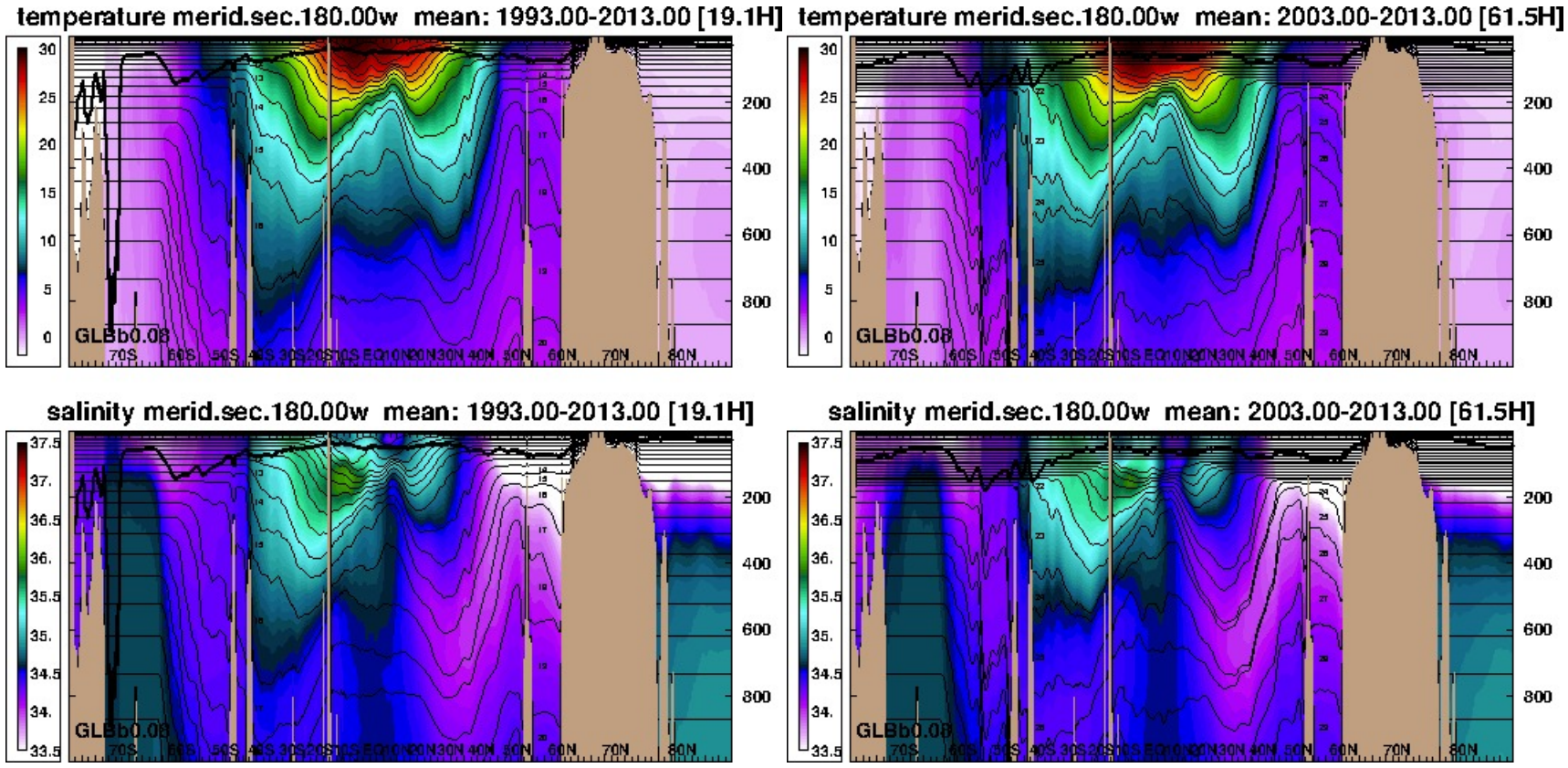


EXAMPLE Z-SIGMA-Z SETUP: 0-25M



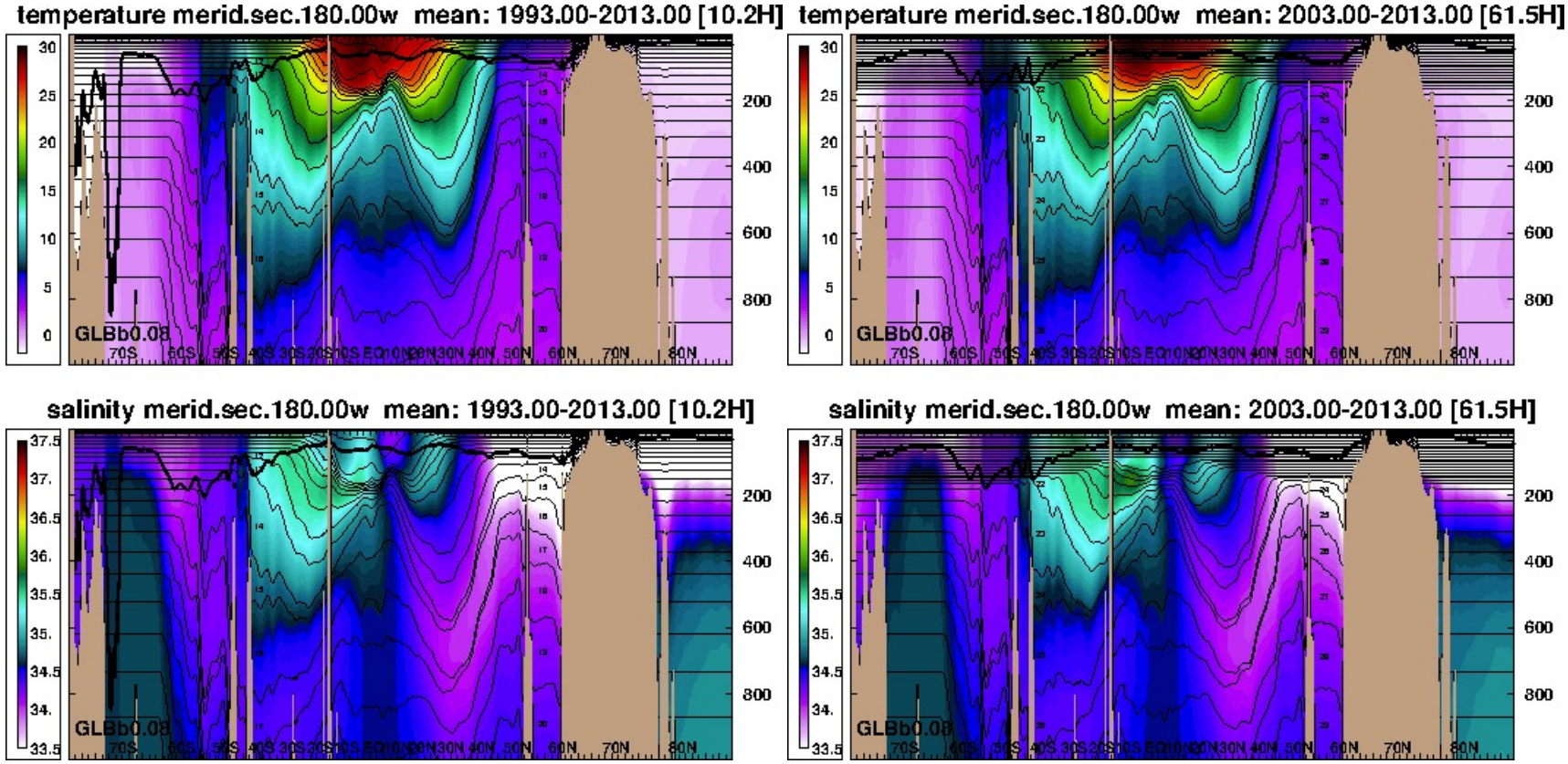
VERTICAL CROSS-SECTION 2003-2012 AT 180E: 0-1000m

- **19.1 is 0.08° global 32 layers with data assimilation**
  - **DA explicitly corrects for thick-thin-thick-thin layer structure**
- **61.5 is 0.08° global 41 layers without data assimilation**



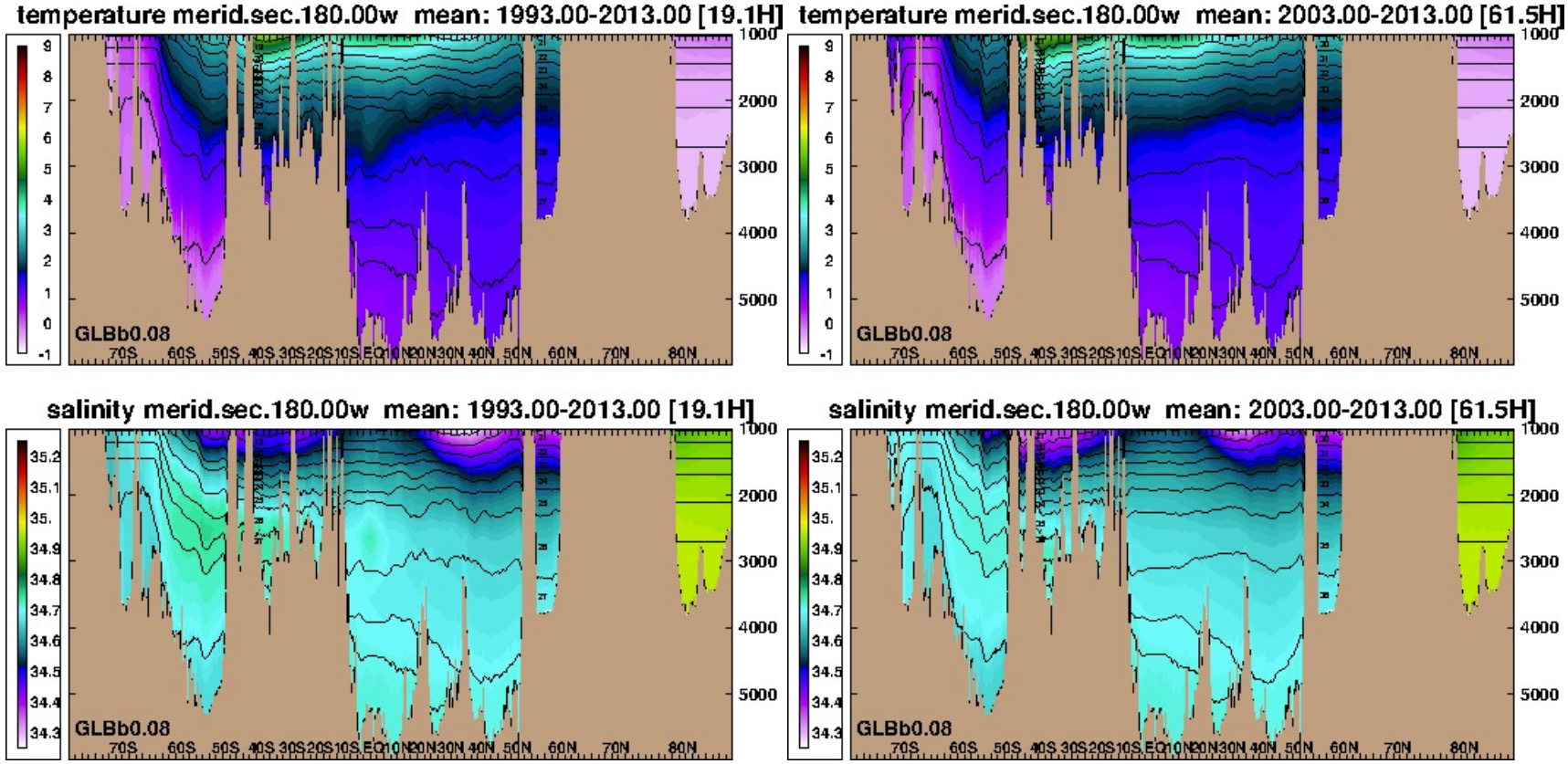
VERTICAL CROSS-SECTION 2003-2012 AT 180E: 0-1000m

- 10.2 is 0.08° global 32 layers without data assimilation
- 61.5 is 0.08° global 41 layers without data assimilation



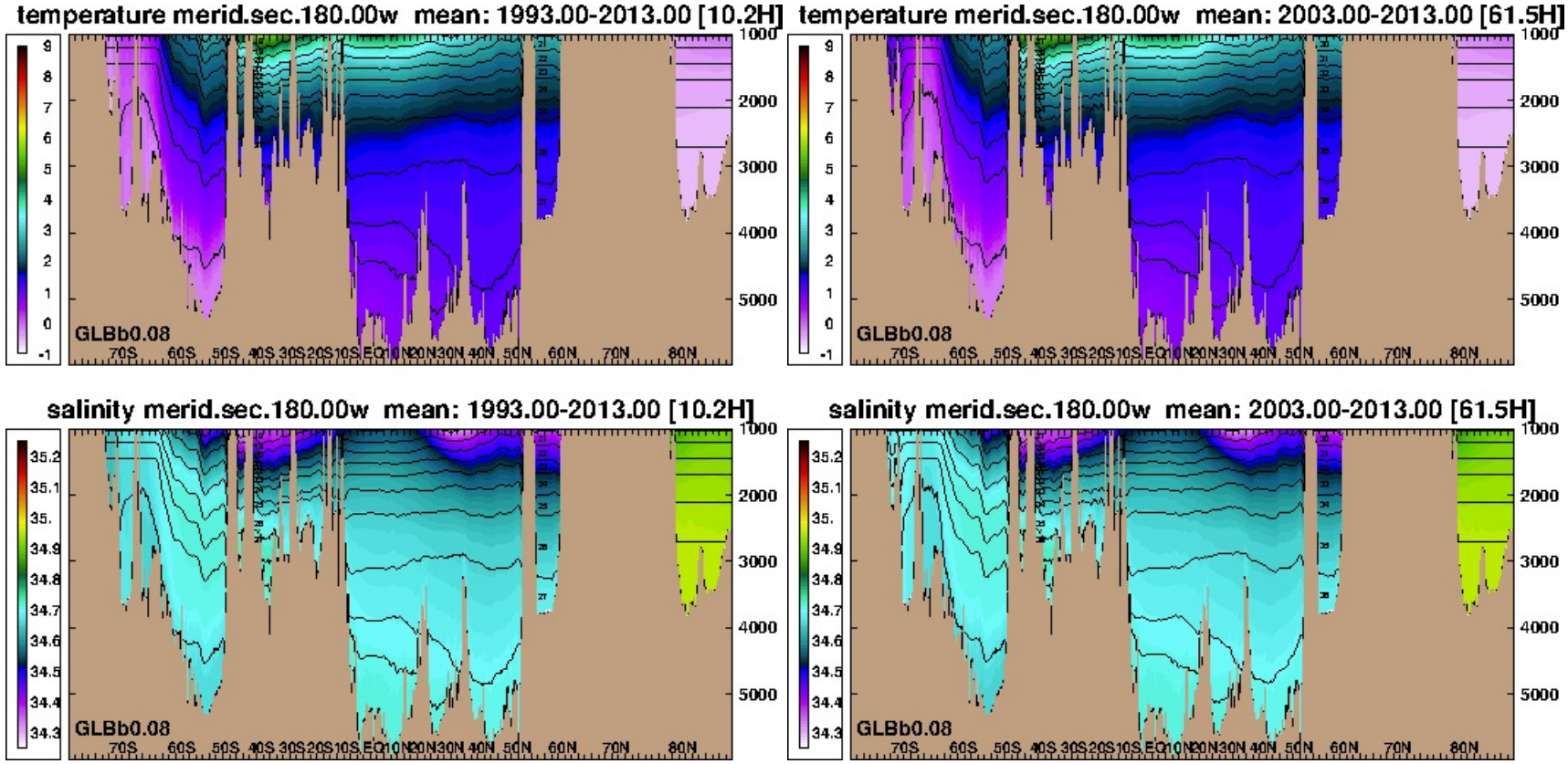
VERTICAL CROSS-SECTION 2003-2012 AT 180E: 1000-6000m

- 19.1 is 0.08° global 32 layers with data assimilation
- 61.5 is 0.08° global 41 layers without data assimilation



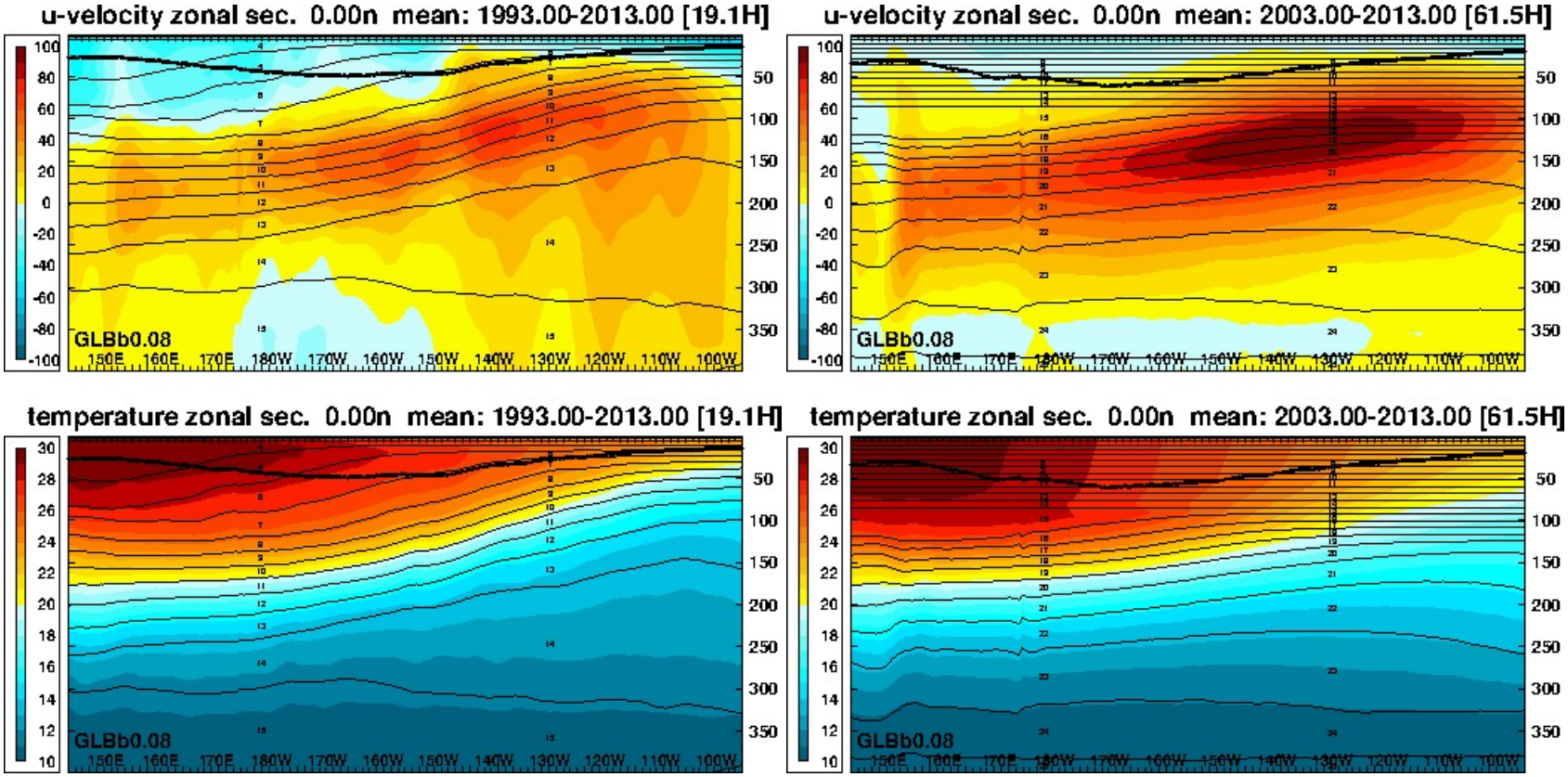
VERTICAL CROSS-SECTION 2003-2012 AT 180E: 1000-6000m

- 10.2 is 0.08° global 32 layers without data assimilation
- 61.5 is 0.08° global 41 layers without data assimilation



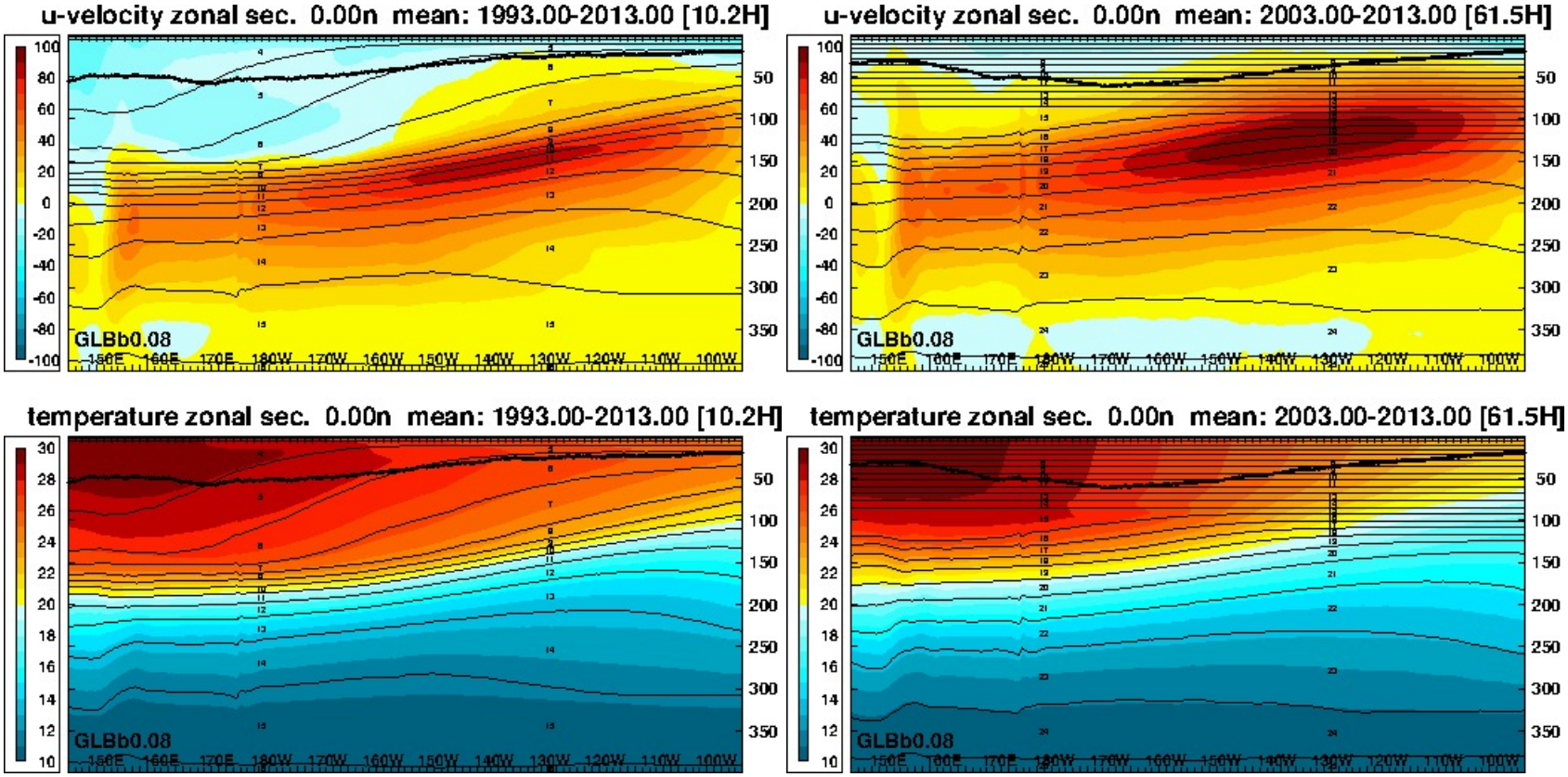
VERTICAL CROSS-SECTION 2003-2012 EQUATORIAL PACIFIC

- **19.1 is 0.08° global 32 layers with data assimilation (no velocity assim.)**
- **61.5 is 0.08° global 41 layers without data assimilation**



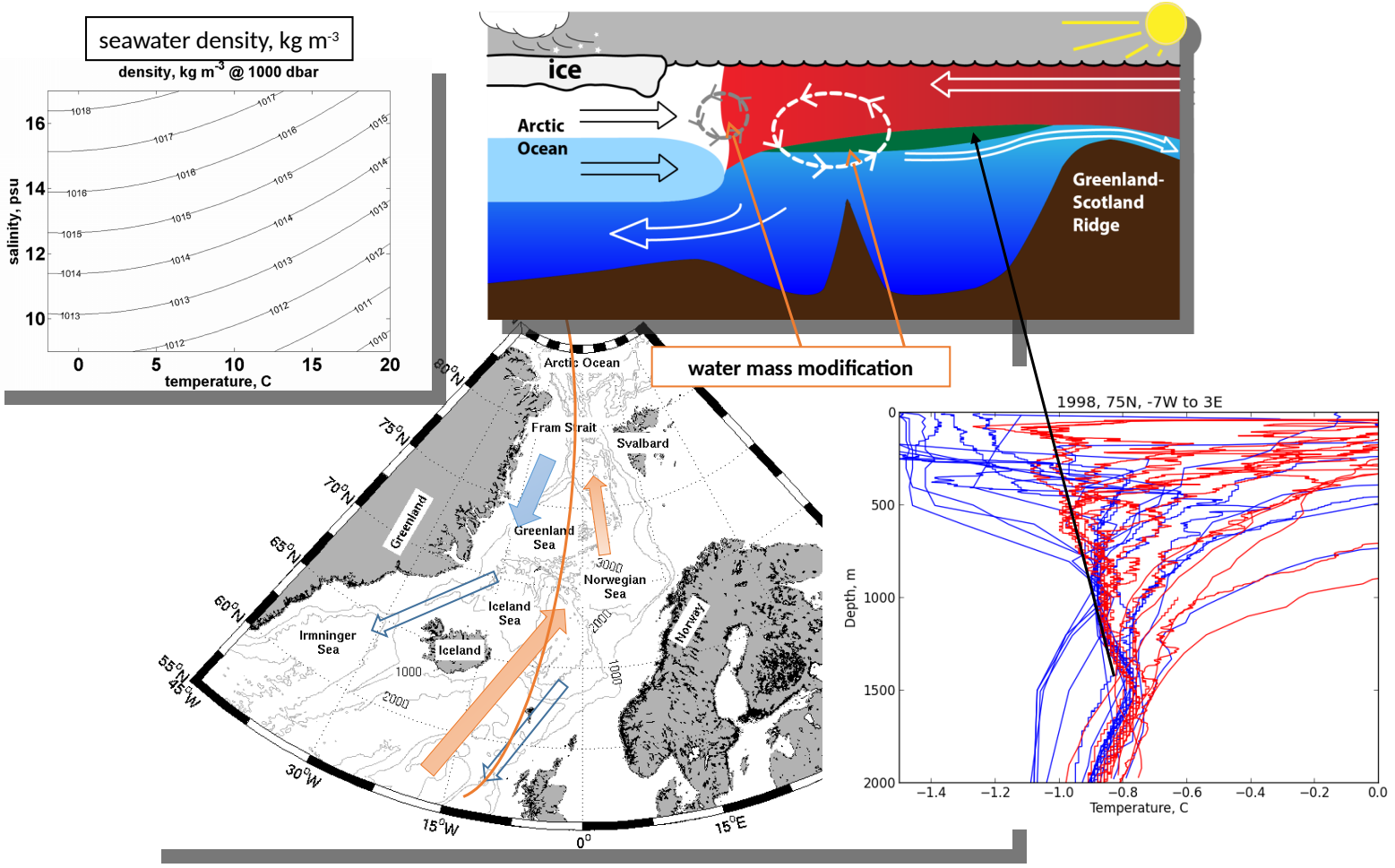
VERTICAL CROSS-SECTION 2003-2012 EQUATORIAL PACIFIC

- **10.2 is 0.08° global 32 layers without data assimilation**
- **61.5 is 0.08° global 41 layers without data assimilation**



WATER MASSES IN THE NORDIC SEAS

- **NRL basic science (6.1) project that will explore thermobaricity, hybrid vertical grid and other issues in HYCOM**
- **Nordic Seas is an area where many processes are significant**



SUMMARY

- **The hybgen subroutine has proved reasonably successful at defining a robust hybrid vertical coordinate**
- **The latest version is much more complicated that the original, and not all the added complexity is a good thing**
- **Difficult to debug and change because effects can vary by region**
- **A recurring issue is deep isopycnal layers shrinking/disappearing over time**
  - **Suggests that "unmixing" may need an overhaul**
- **Can still get thick-thin-thick-thin layer structure**
  - **Data assimilation (via incremental insertion) used to make this worse**
  - **Now explicitly correct this during data assimilation**
- **Making hybgen a column routine has obvious advantages, but it relies on interface diffusion and the continuity of the model equations to preserve the spatial distribution of layer thickness**
  - **Data assimilation via direct/incremental insertion, and relaxation or nesting, act against layer thickness continuity and can cause problems for hybgen**