New Numerical Methods in Ocean General Circulation Modeling: Voronoi Tessellations and Floating Vertical Coordinates

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Lessons Learned

Issues related to modeling the vertical (Lagrangian coordinate) is are more difficult to solve than issues related to modeling the horizontal (Voronoi tessellations).

Maintaining an OGCM has much more to do with physics than with dynamics.

And most recently, stratq makes a late arrival into Monterey is a risky proposition. [ABQ, SLC, MRY*, FRS, SLC, MRY]

Outline

Summarizing the problem at hand

An idealized setting: a basin model

A "full-up" ocean simulation

Moving beyond structured Voronoi tessellations

The problem at hand

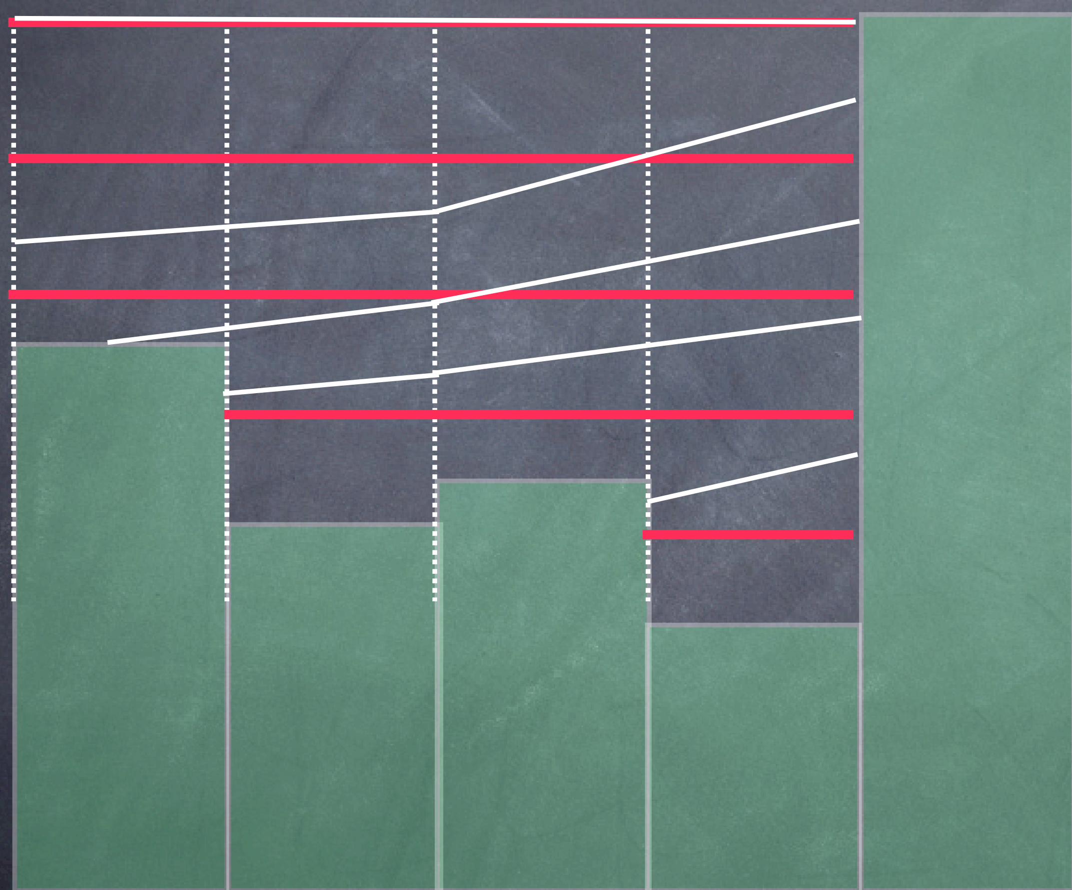
1) Can we model the Earth's ocean system using quasi-uniform, isotropic grids such as Spherical Voronoi Tessellations (SVTs)?

We have used this grid system in SWMs and full AGCMs, so there is precedent.

2) Can we model the Earth's ocean system using a vertical coordinate that better captures observed vertical structure of the ocean?

This requires a move toward Lagrangian vertical coordinates....and has proven to be more challenging than #1.

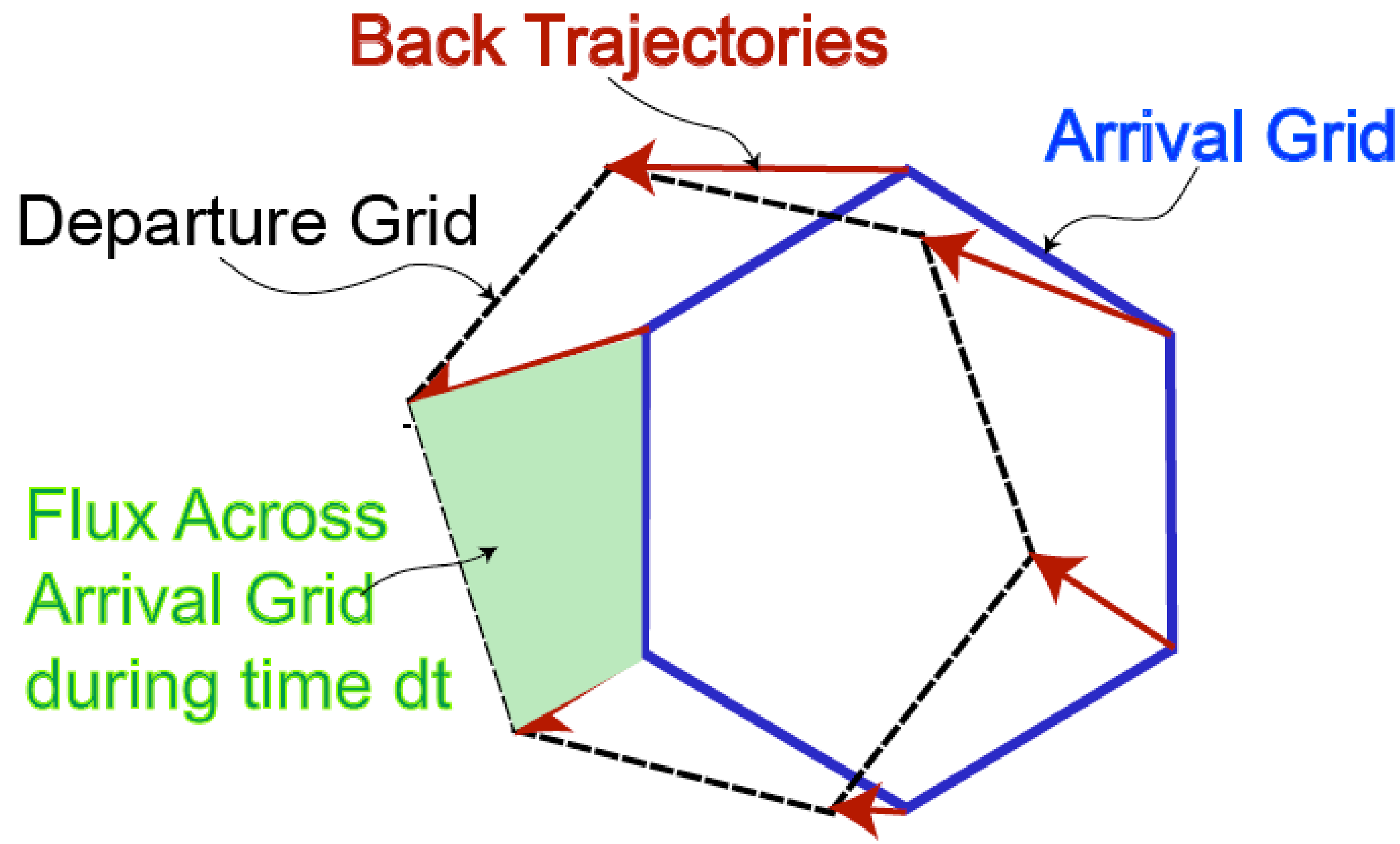
quasi-Lagrangian vertical coodinates impose some new constraints on the modeling of horizontal advection.



Traditionally, ocean models have used a z-level vertical coordinate.

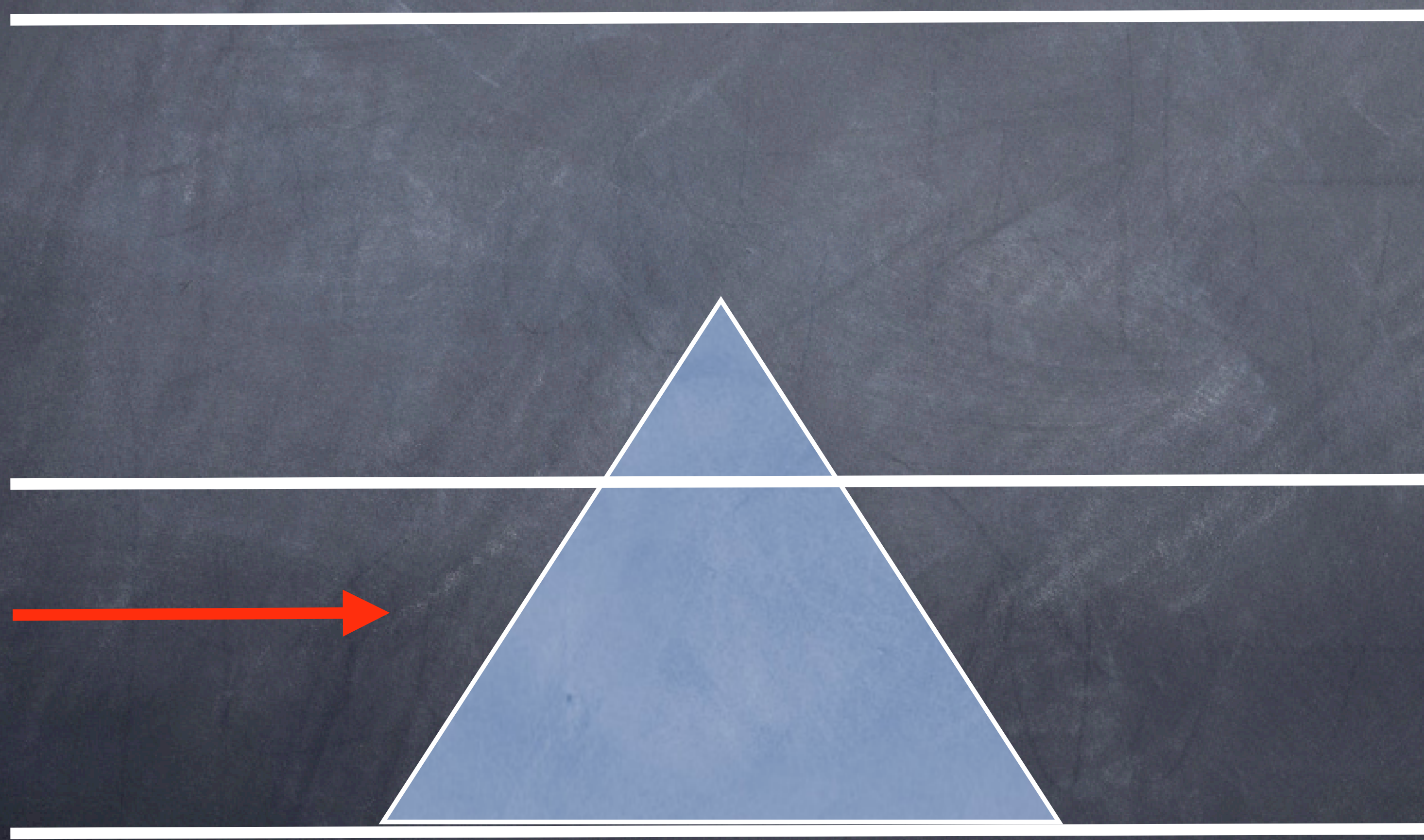
quasi-Lagrangian vertical coordinate lead to massless layers at bottom of column, and maybe in the interior.

Incremental Remapping

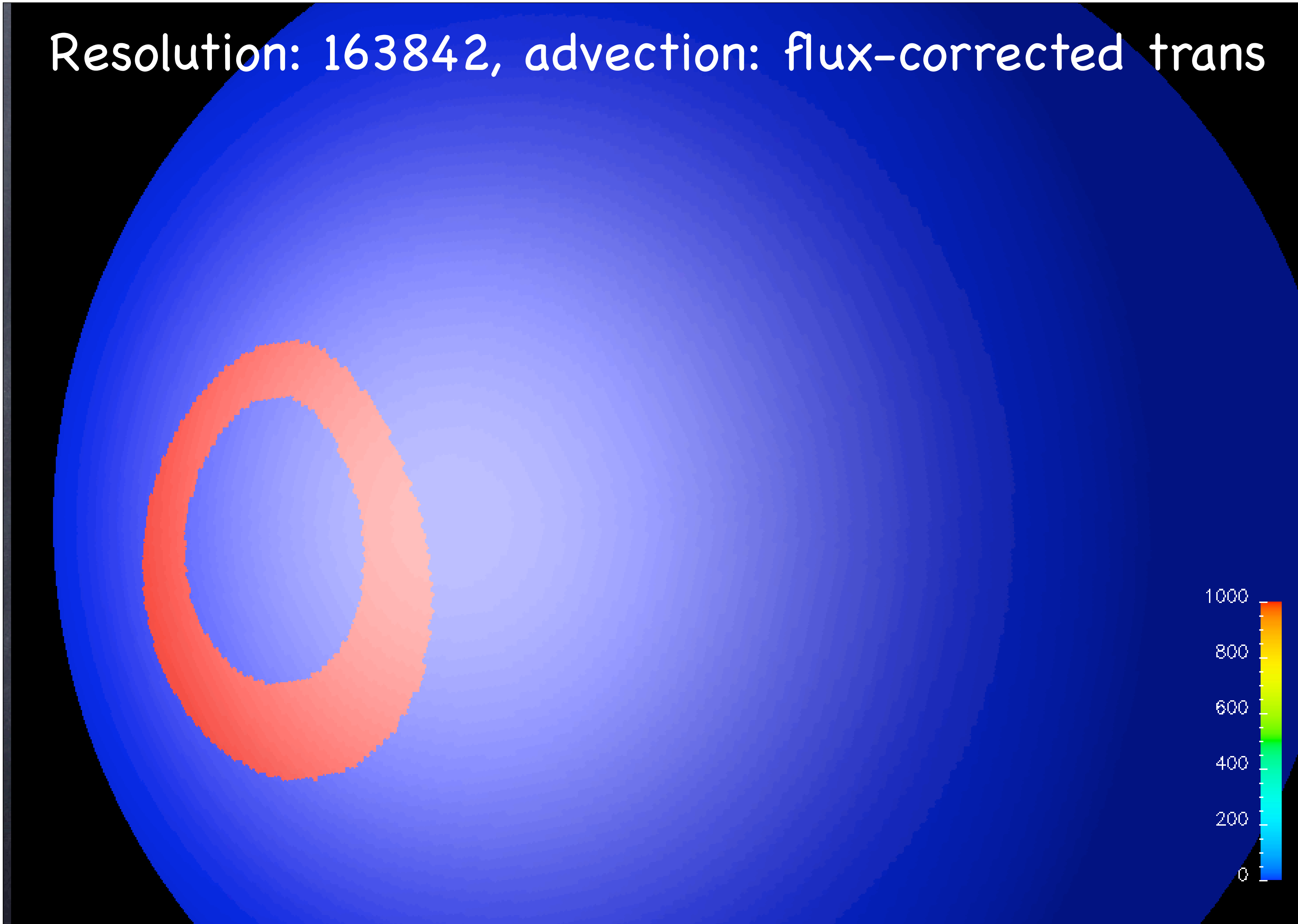


Shallow-water test case #5

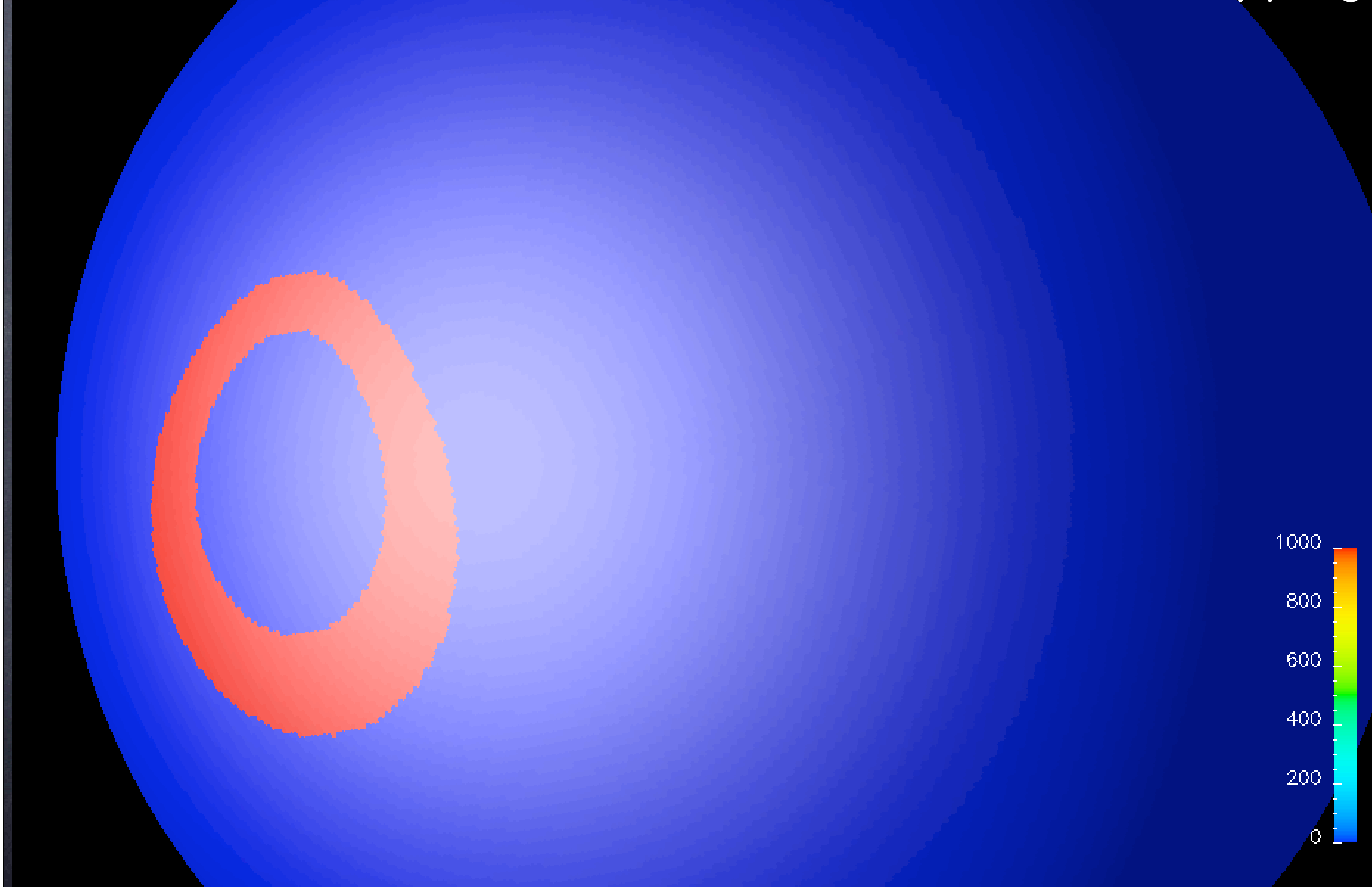
Shallow-water test case #5 -- modified



Resolution: 163842, advection: flux-corrected trans



Resolution: 163842, advection: incremental remapping



What makes this different from the traditional SWTCs? Basically we see "interally-generated" (eddy) structure -- as we increase resolution we see fundamental changes in the flow field.

We are considering whether we should expect convergence in this type of test case, and if so, what it would tell us about the advection schemes.

There are fundamental differences between the FCT and incremental remapping that for certain cases (like ocean modeling) differentiates the schemes by more than simply TE and efficiency. (developed by Mats Bensen and detailed on the next slide)

In isopycnal regions we desire d(rho)/dt.

In ALE models, we are required to advect T and S and use EOS [rho = f(T,S)] to derive rho.

$$\beta_S \nabla S \frac{\partial \sigma}{\partial S} + \beta_T \nabla T \frac{\partial \sigma}{\partial T} = 0$$

Where the ratio of the betas is the degree of freedom that can be used to satisfy this constraint.

Tracers must be treated as a group to make this work.

d(rho)/dt .ne. 0 is the same as vertical diffusion in this setting.

The Double-Gyre experiment

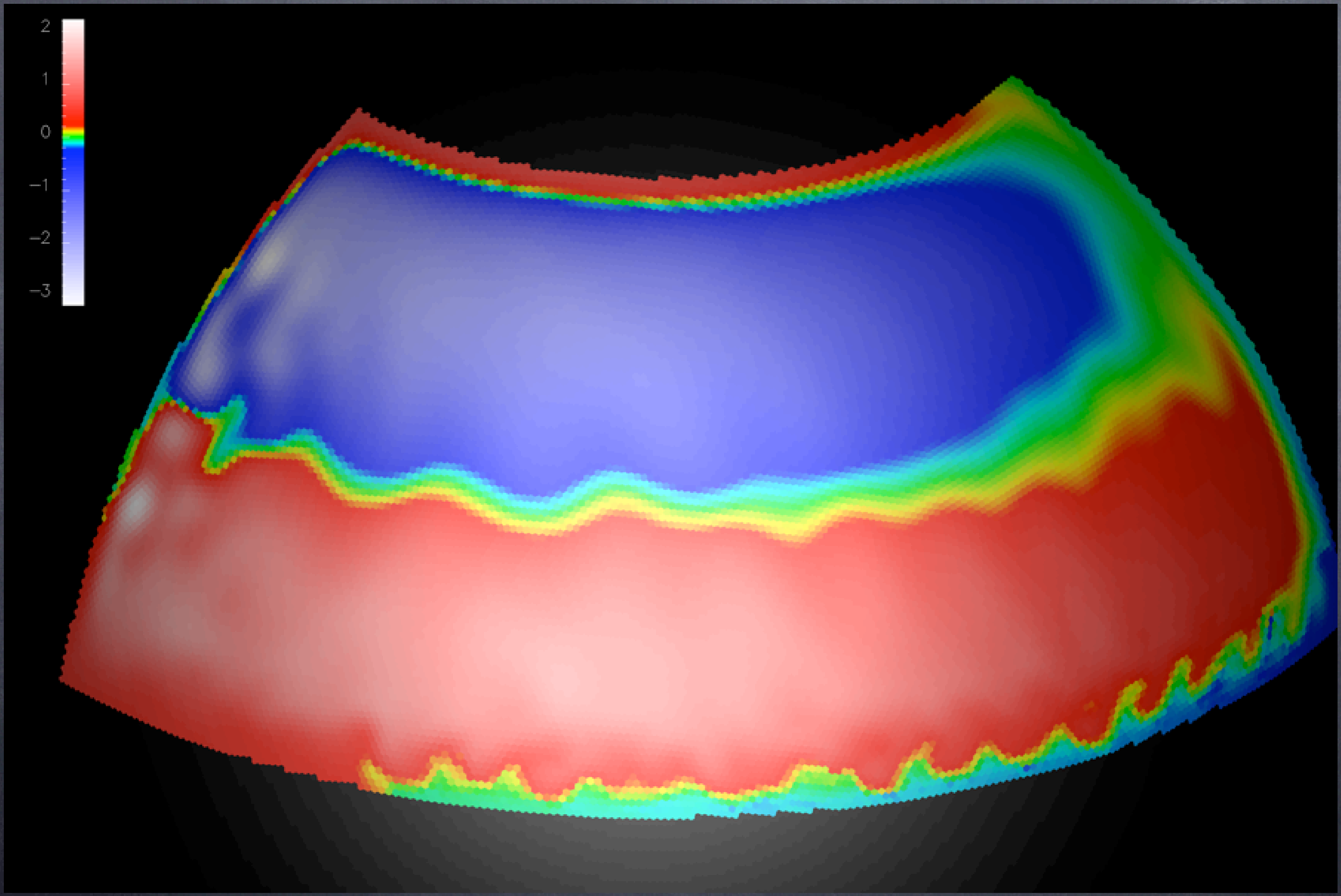
What is it?
A basin with zonal wind stress -- westerlies in mid-latitudes, easterlies in low and high latitudes.

Why?
1) Simplified framework to demonstrate layered model system.

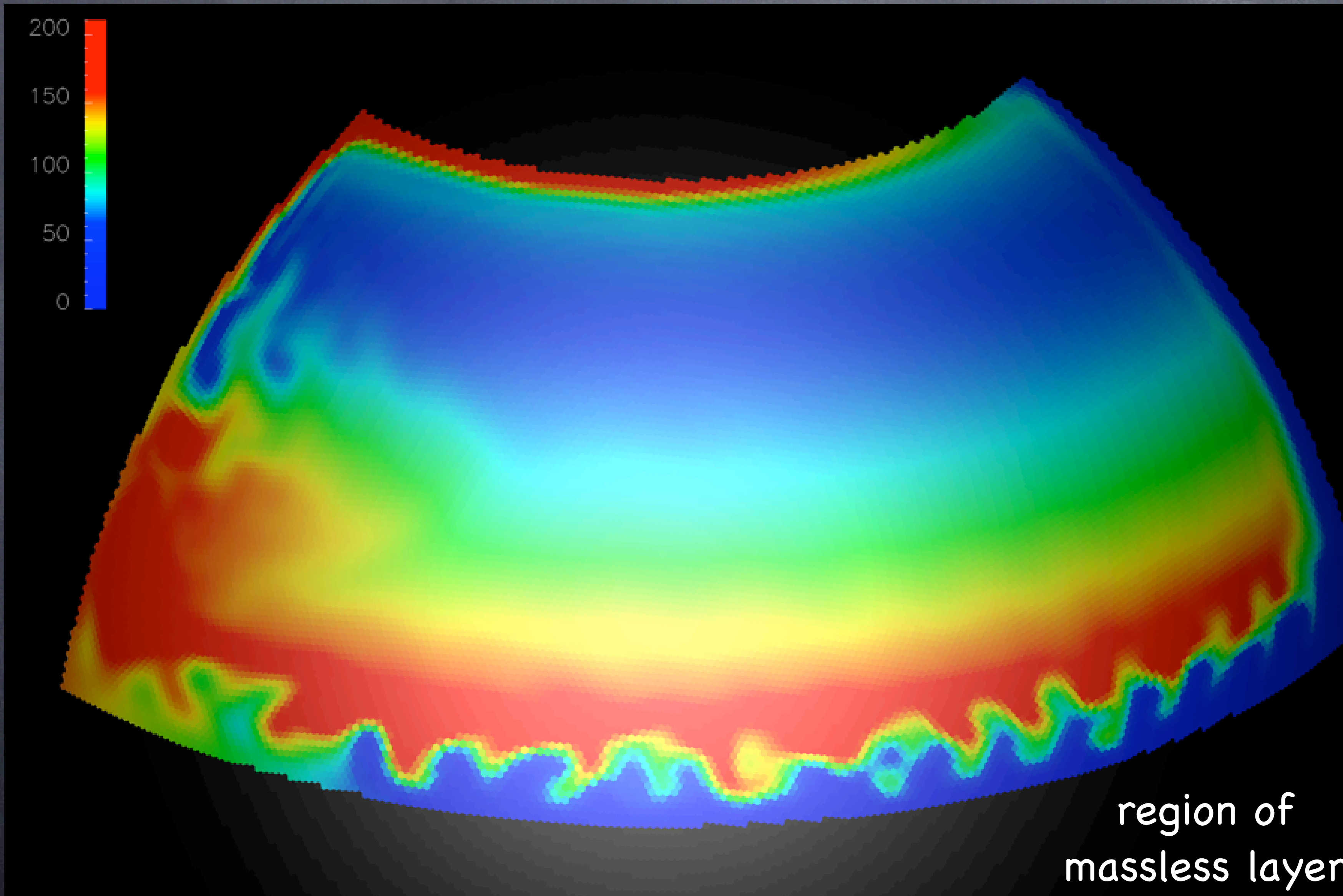
2) Range of "solution spaces." Steady-state solutions at low forcing strength and/or low resolution. Rich variability at high forcing strength when Rossby radius is well-resolved.

3) Test the Lagrangian limit of the vertical coordinate system.

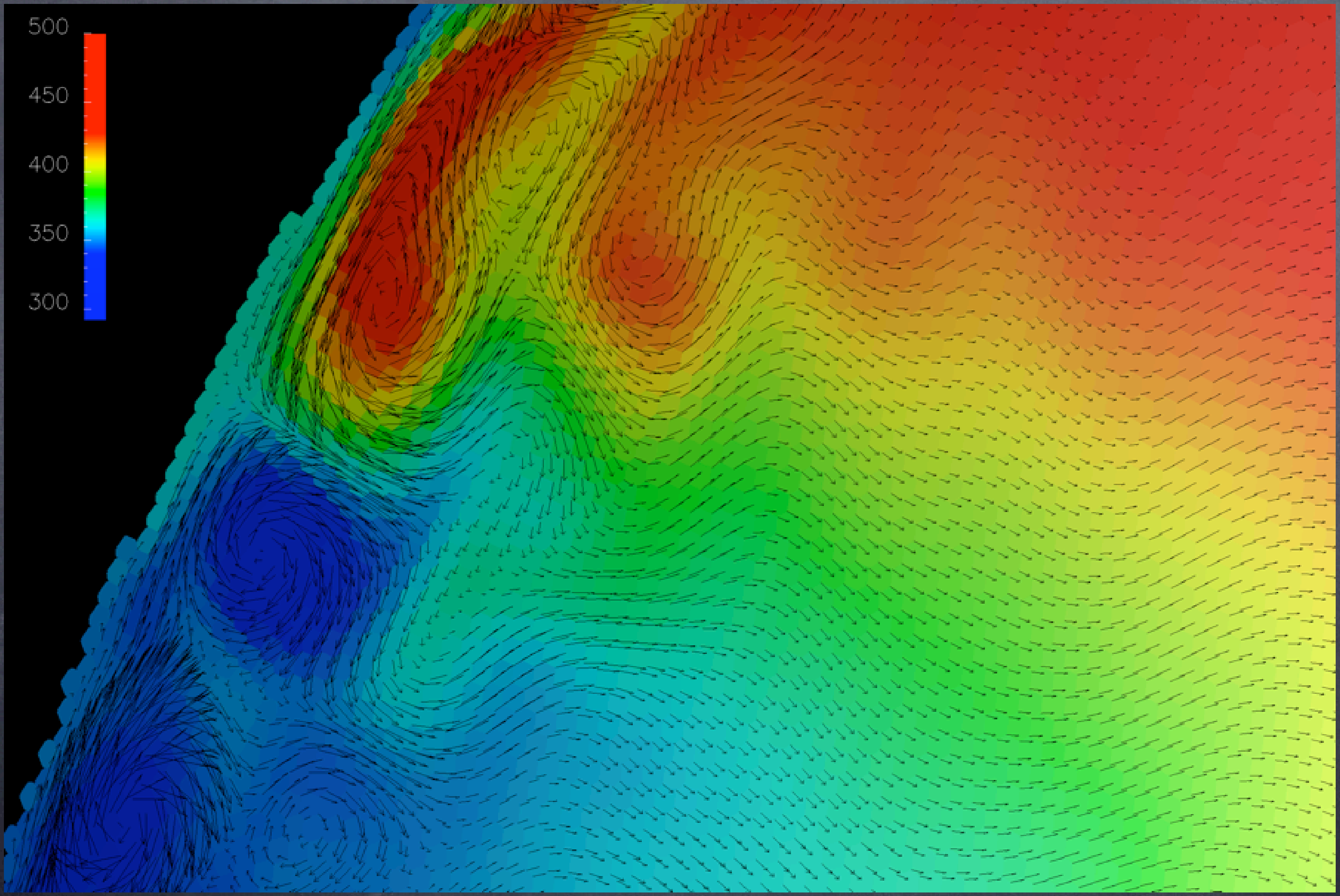
Sea-surface height (m)



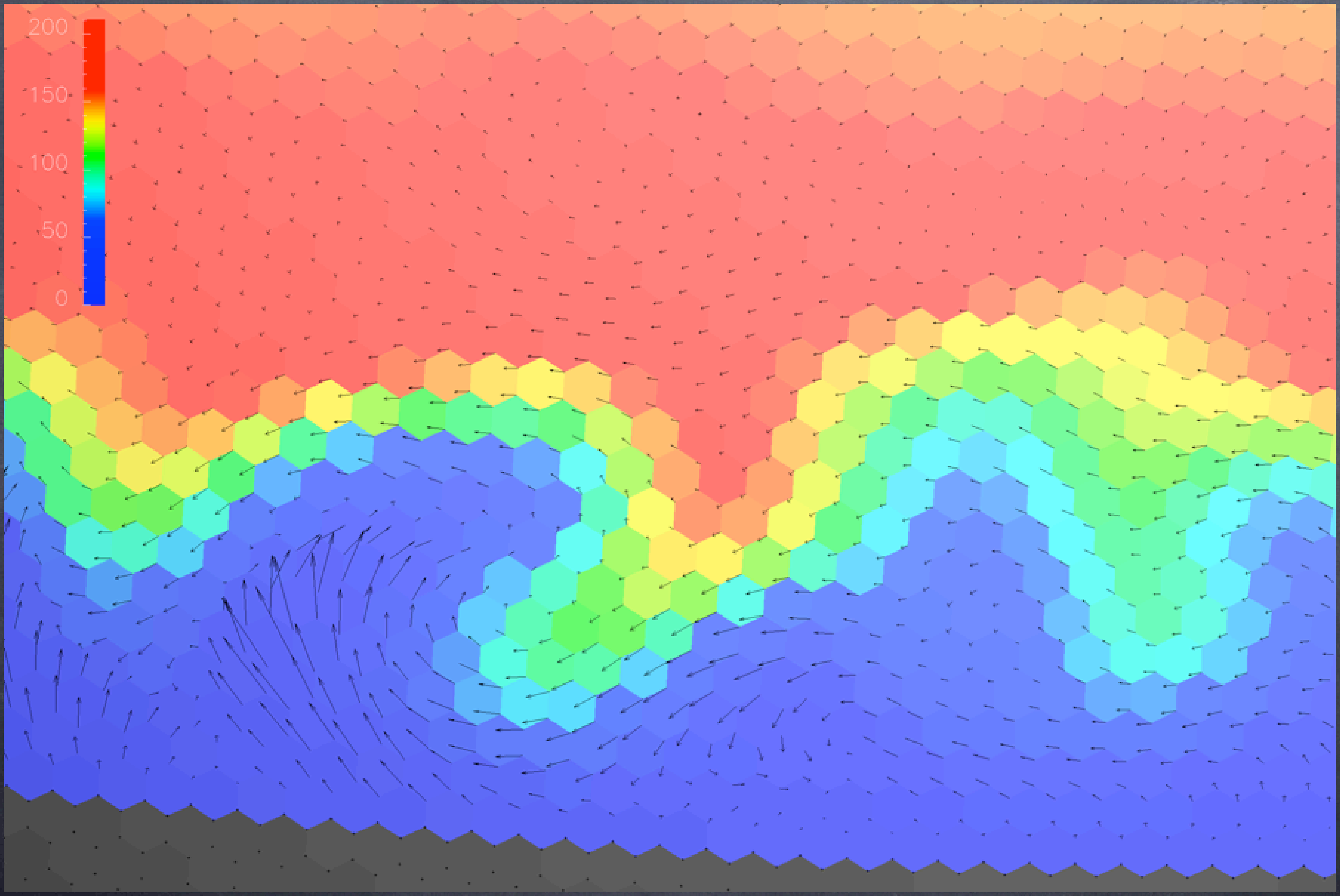
upper-layer thickness (m)



Close-up of western boundary current



Close-up of "equatorial tropical waves"



"Full-Up" Ocean Experiment

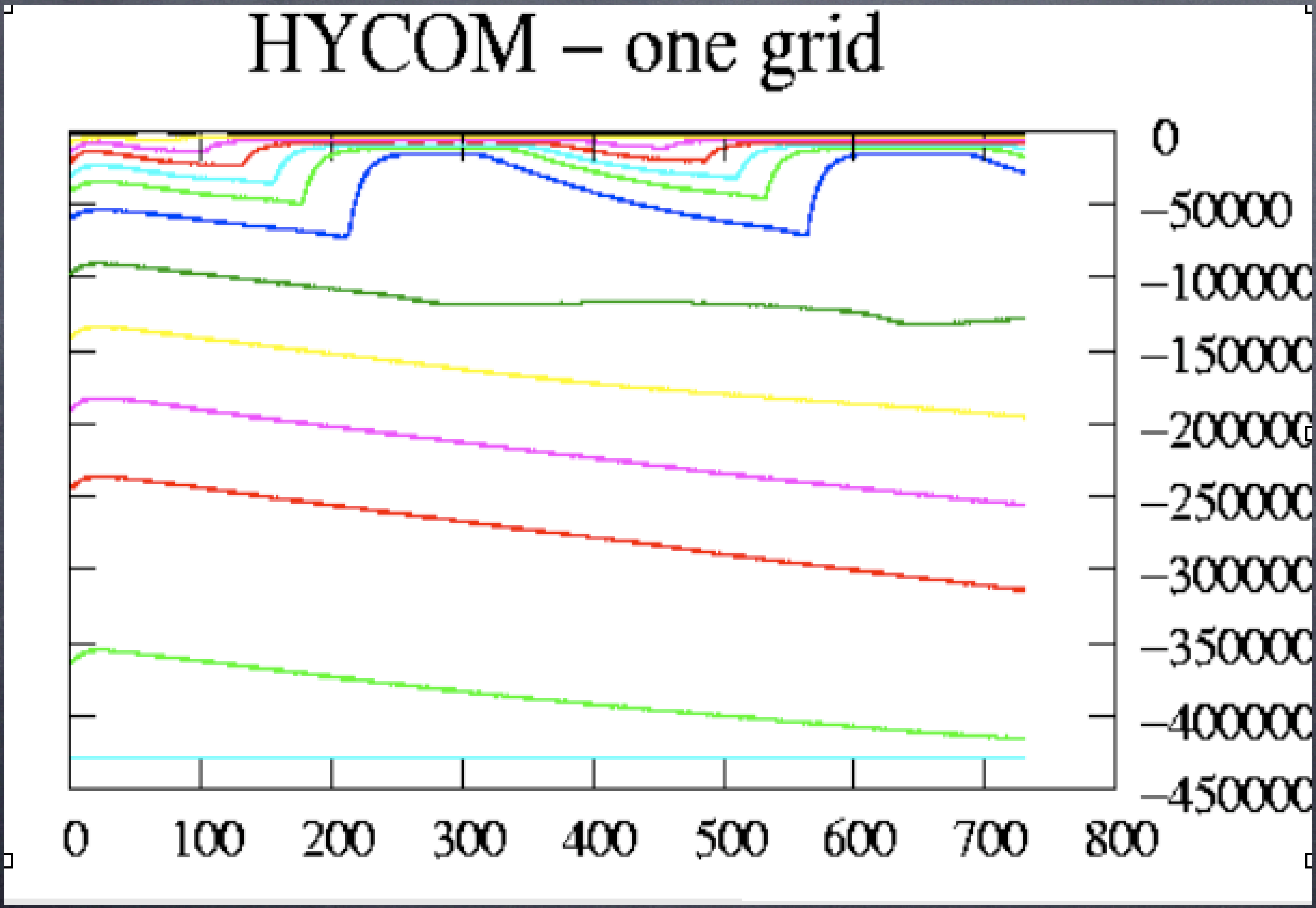
Horizontal: 40962 grid cells
Vertical: 33 vertical layers

ALE vertical coordinate - fixed thickness in upper layers, isopycnal at depth.

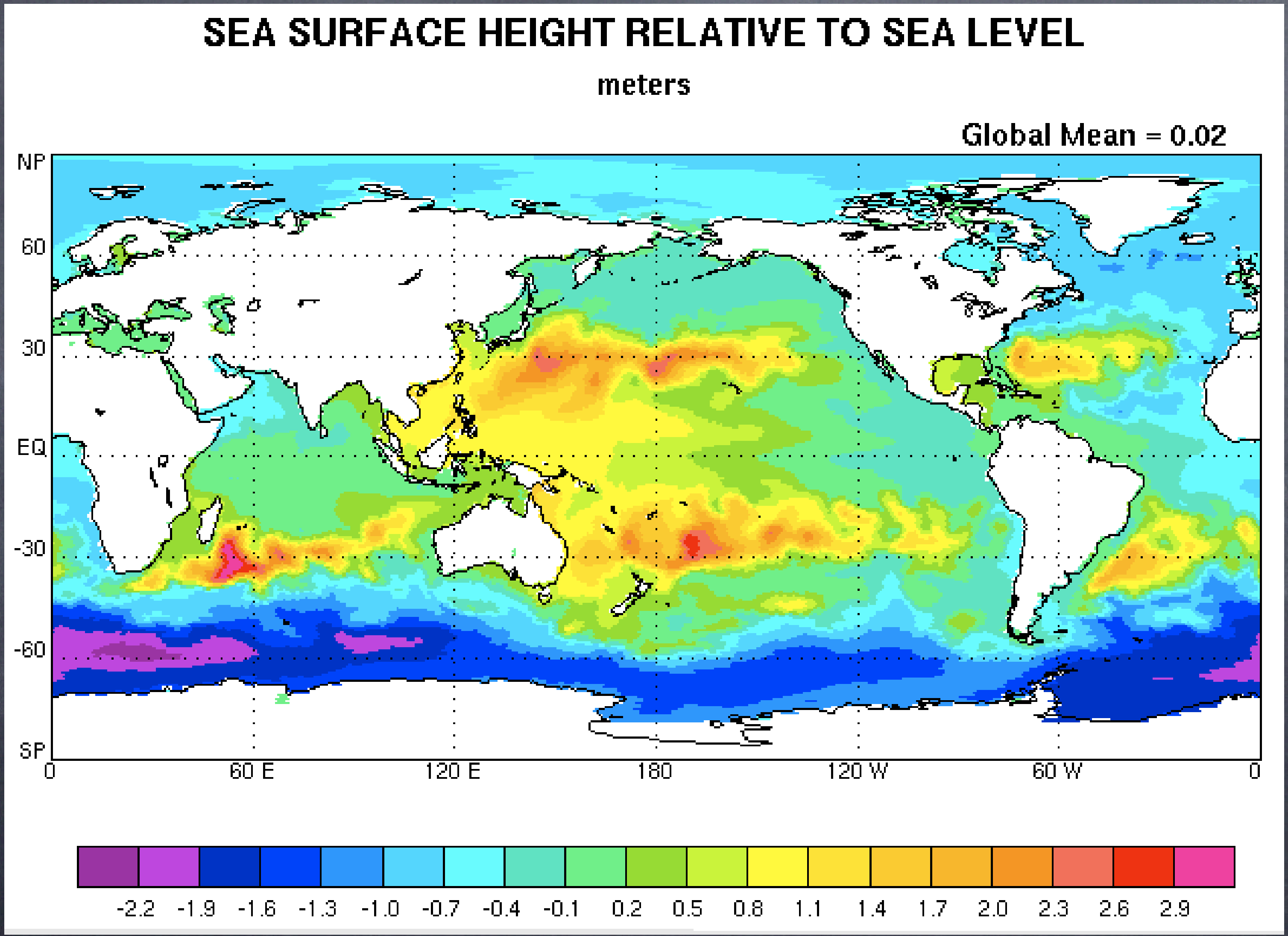
Real bathymetry.

Forcing: monthly mean NCEP wind-stresses and freshwater fluxes, restoring to NCEP Tsfc.

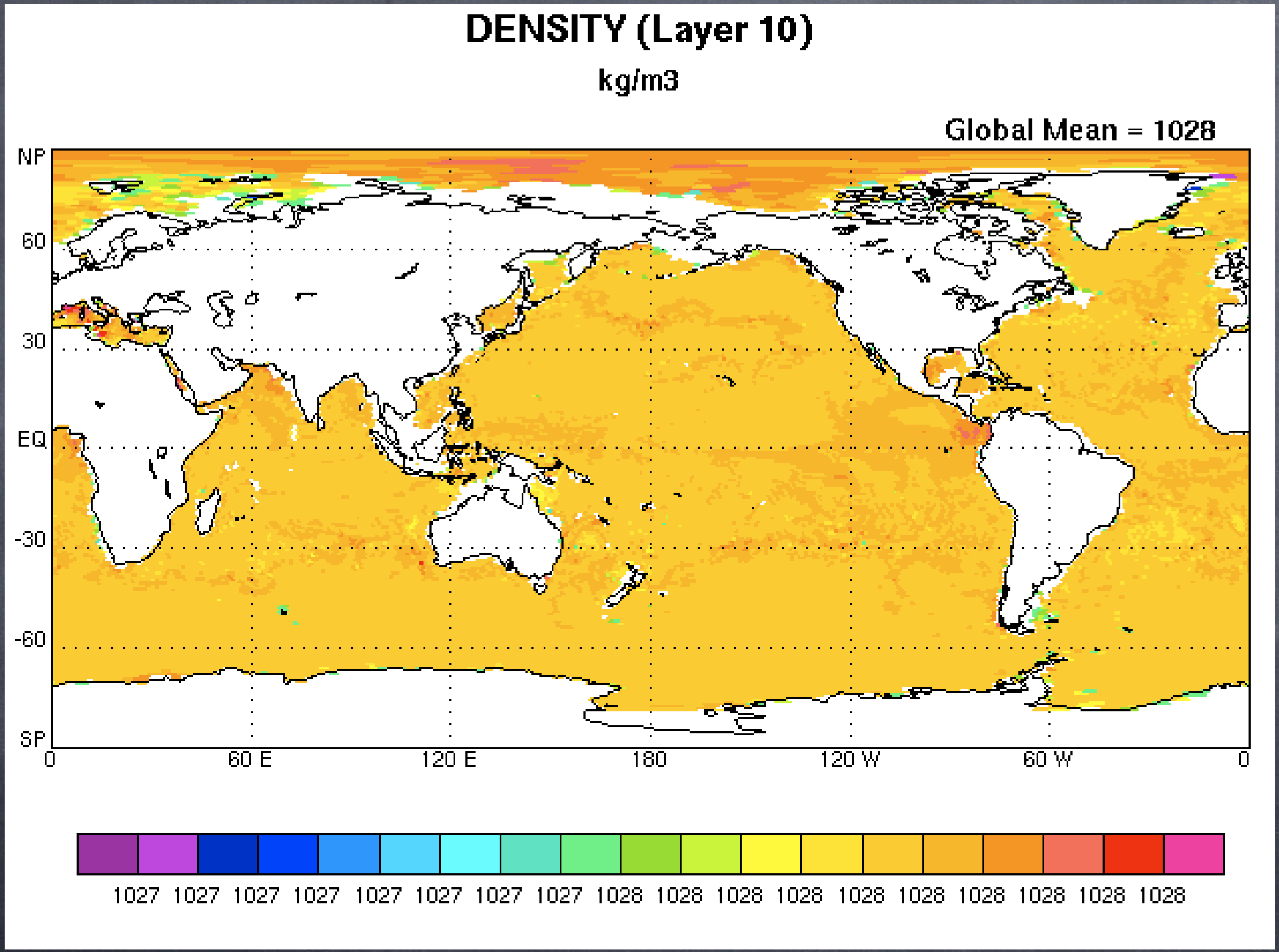
ALE vertical coordinates and KPP... from Beth Wingate at LANL.



Eddies are present, but are not very energetic



At depth, layer interface follows isopycnals



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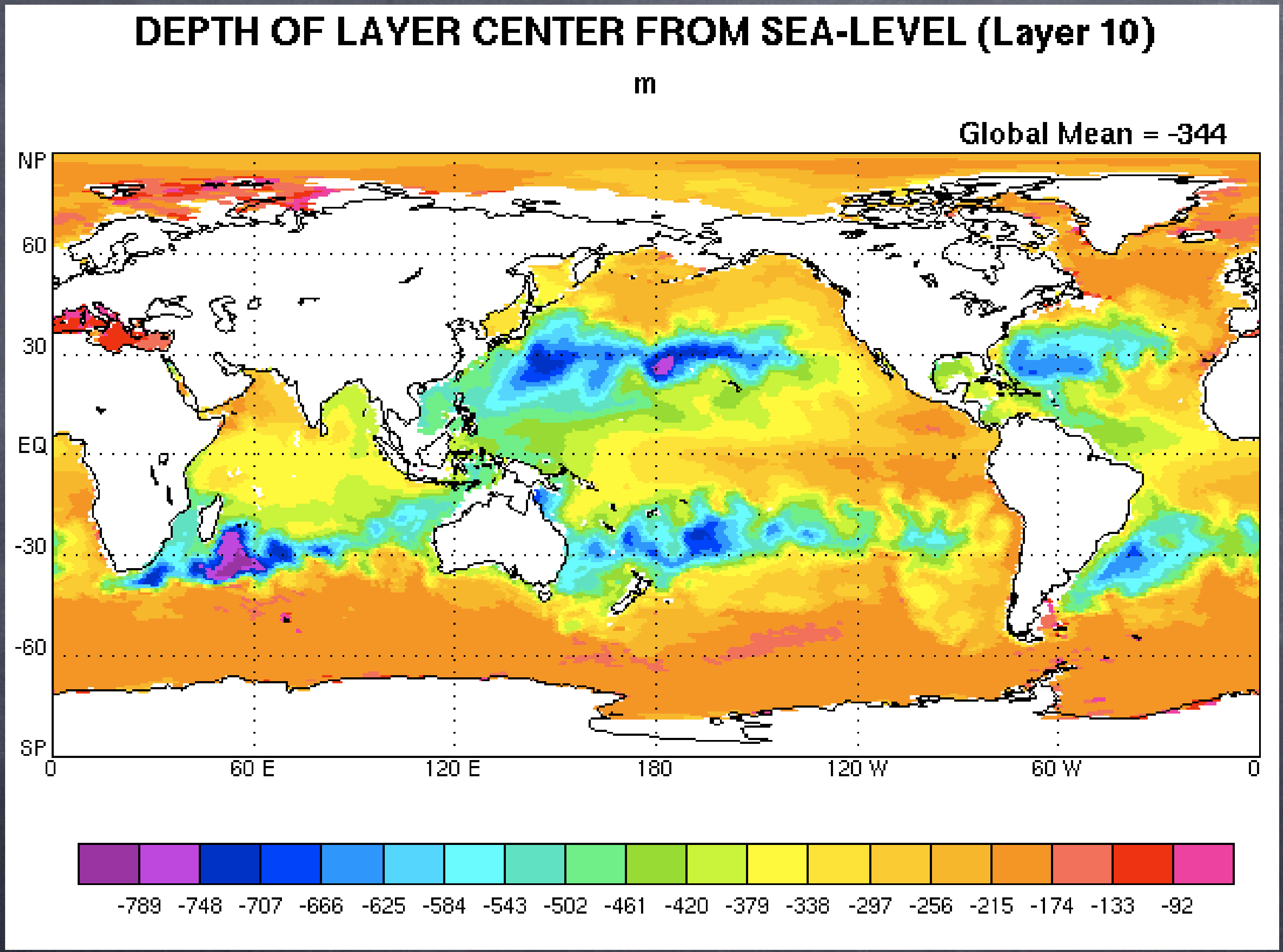
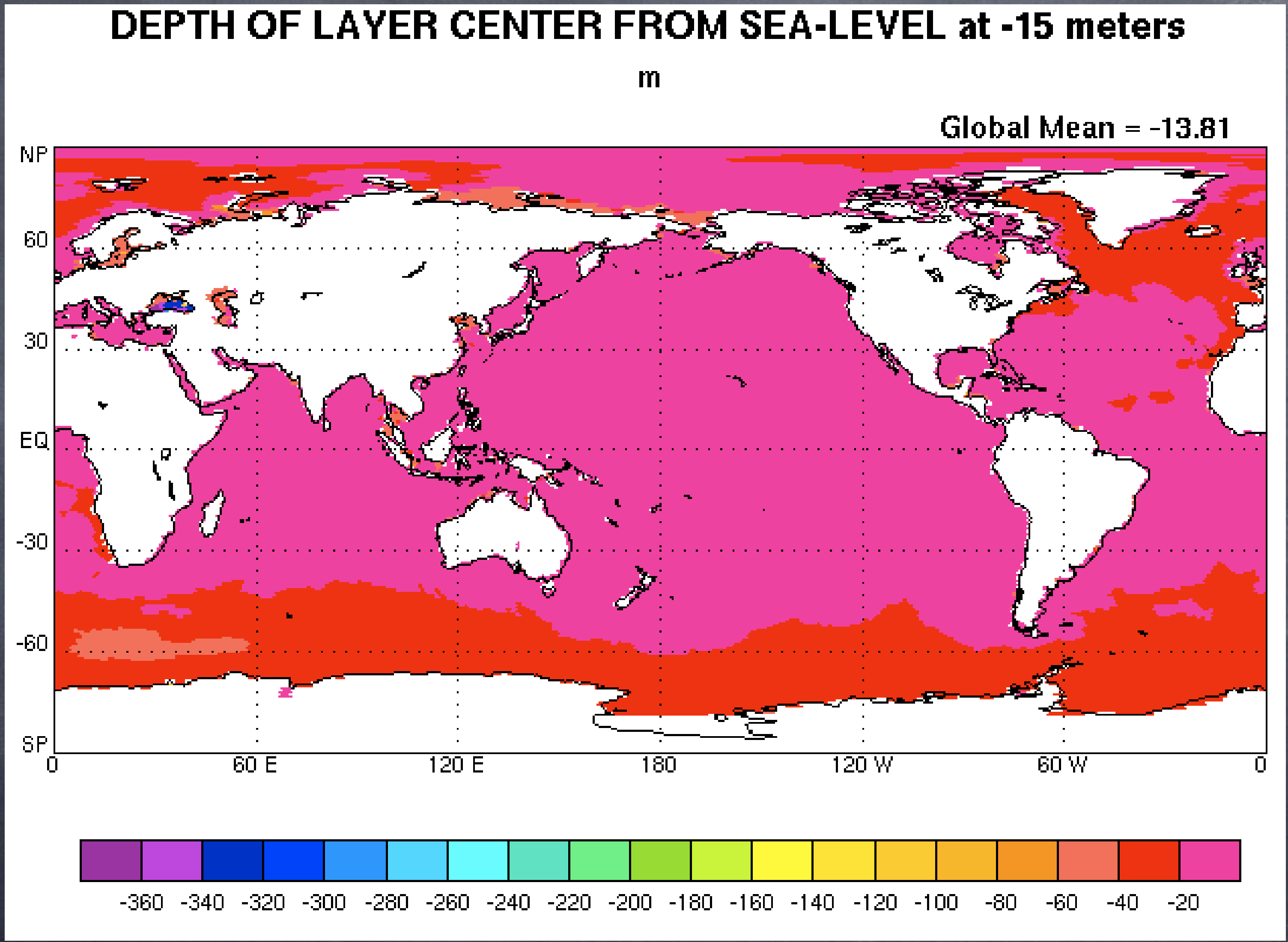
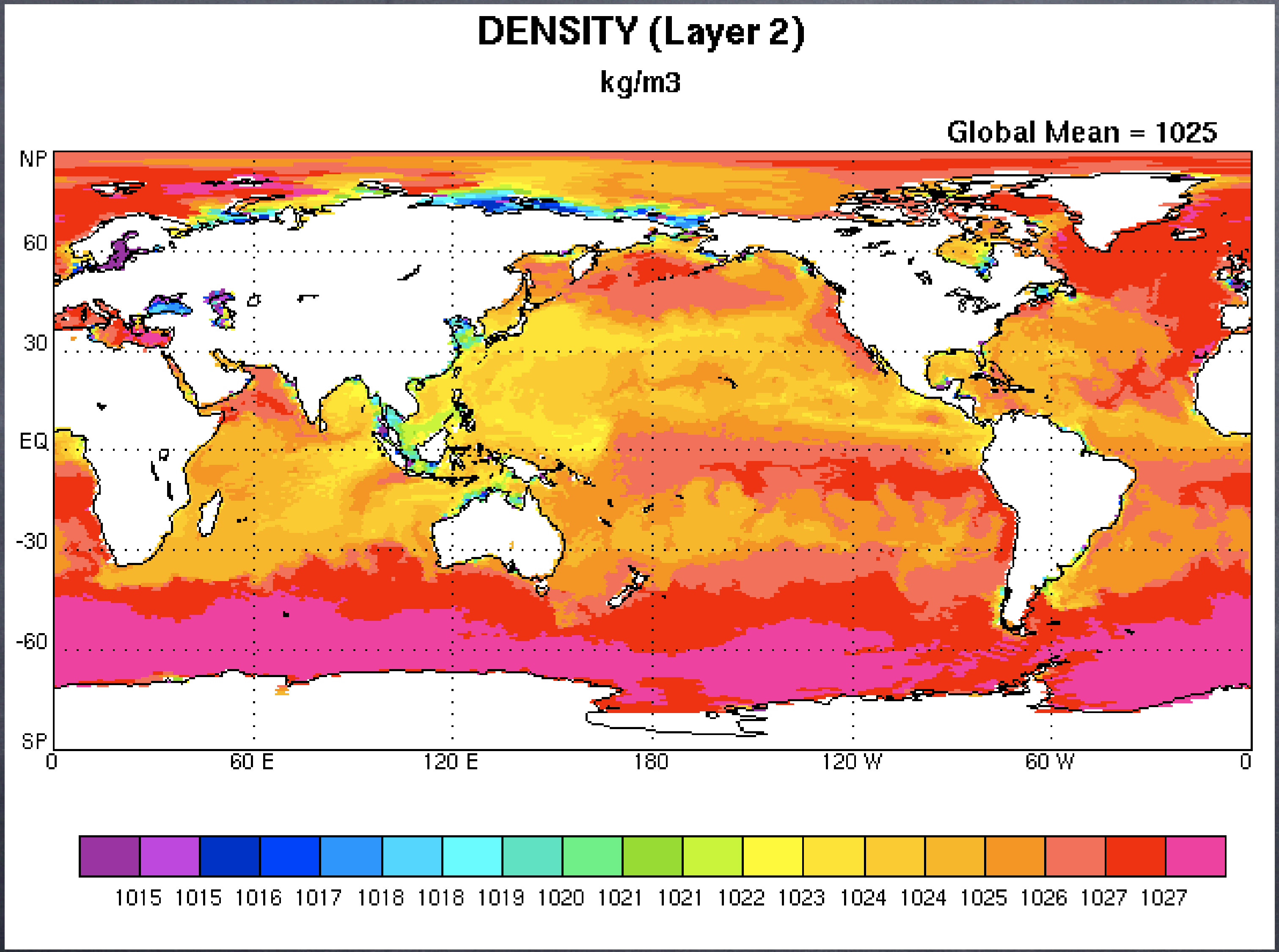


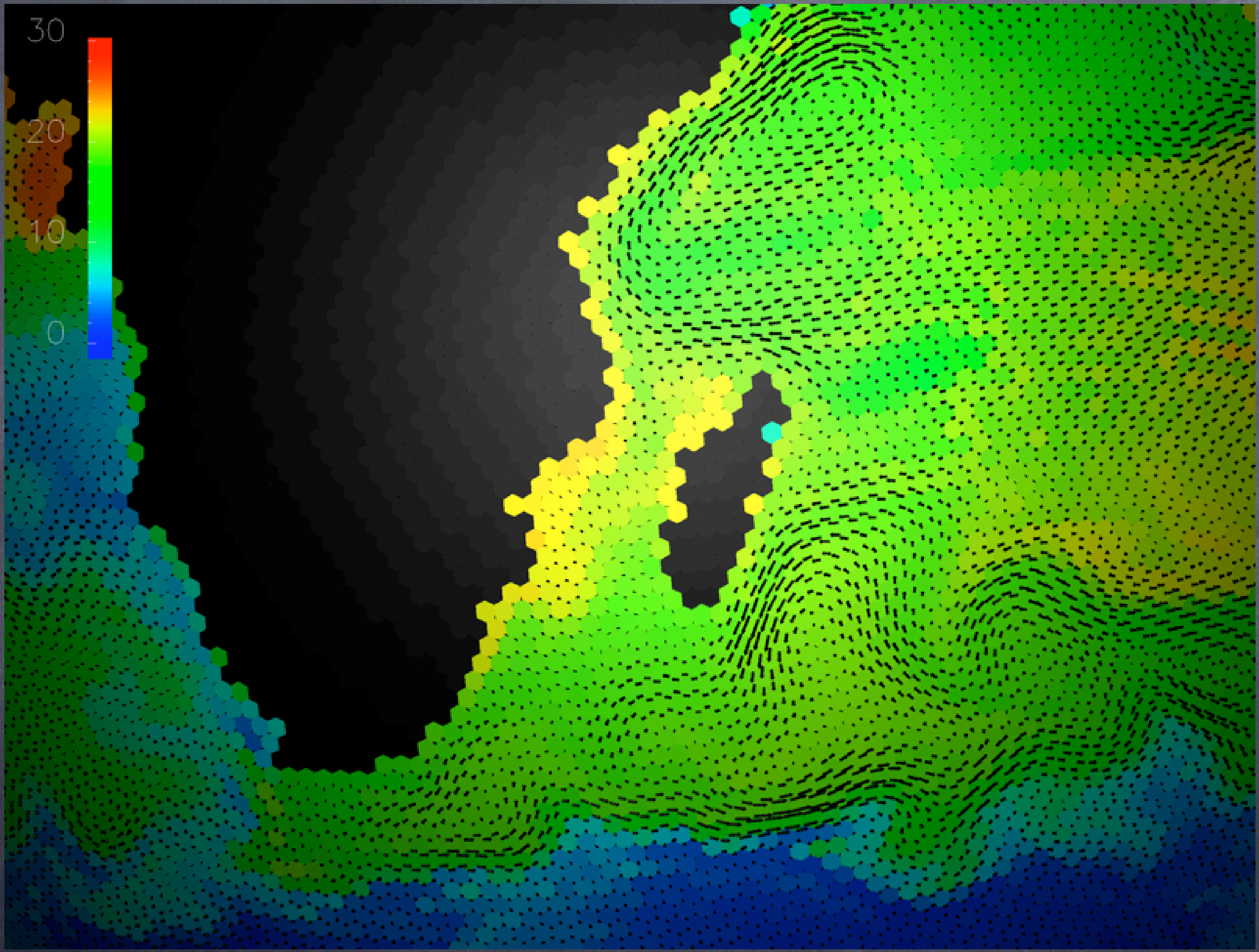
Near sfc, layer interface follows z-levels



Near sfc, layer interface follows z-levels



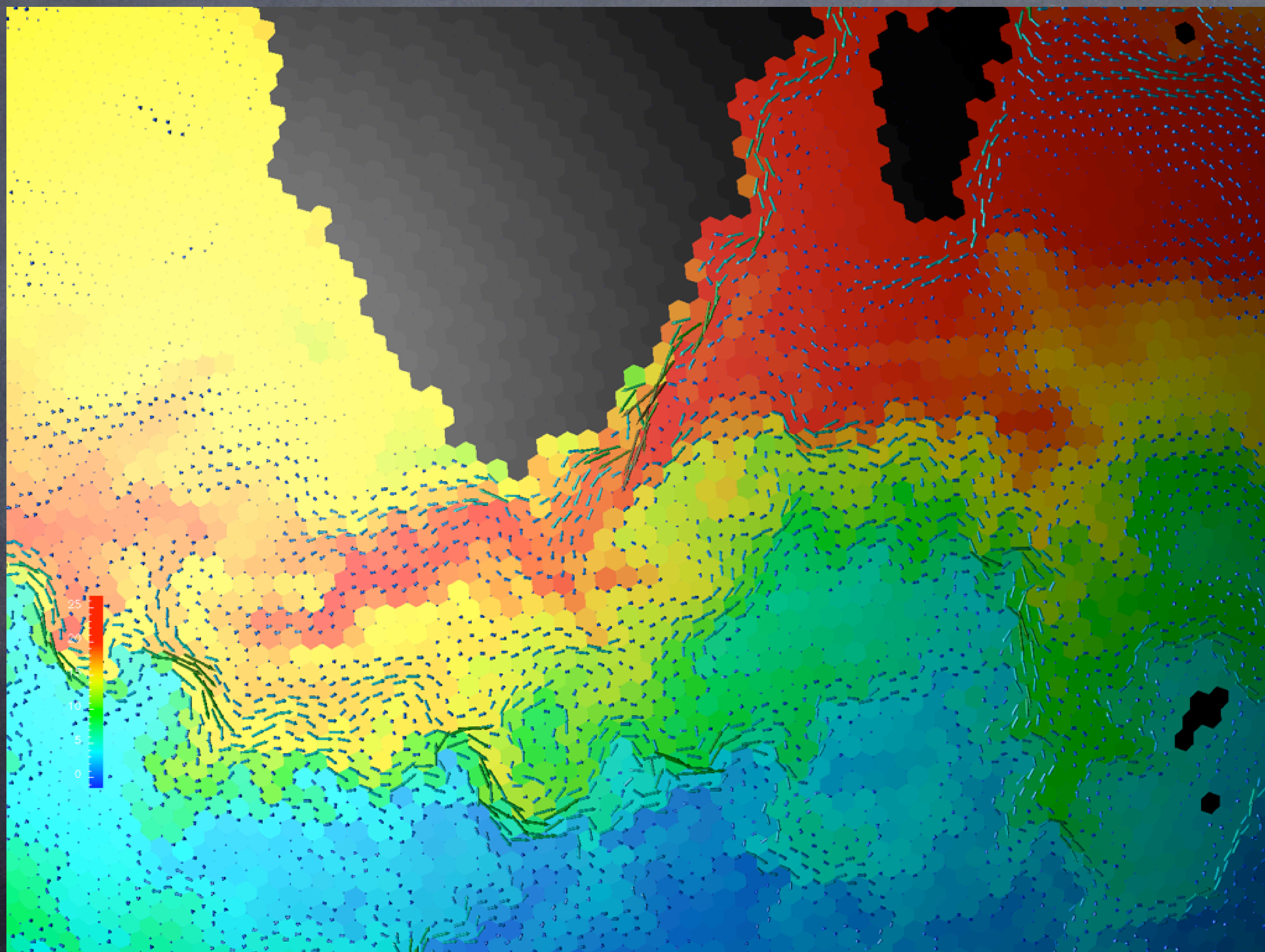
Algulhas and ACC....



[From the last PDEs - the z-level version]

Snapshot of ocean model state after 12 years of spinup

Agulhas Current and ACC [Temperature and Velocity, 175m depth]



Where does the full-up simulations stand? Robin Tokmakian from NPS is analyzing the structure of the near-sfc ocean currents -- that analysis will include a comparison of the z-level and ALE versions of the model.

Future Work with this Ocean Model
1 to 3 year time frame

-Summarize this work in a manuscript.

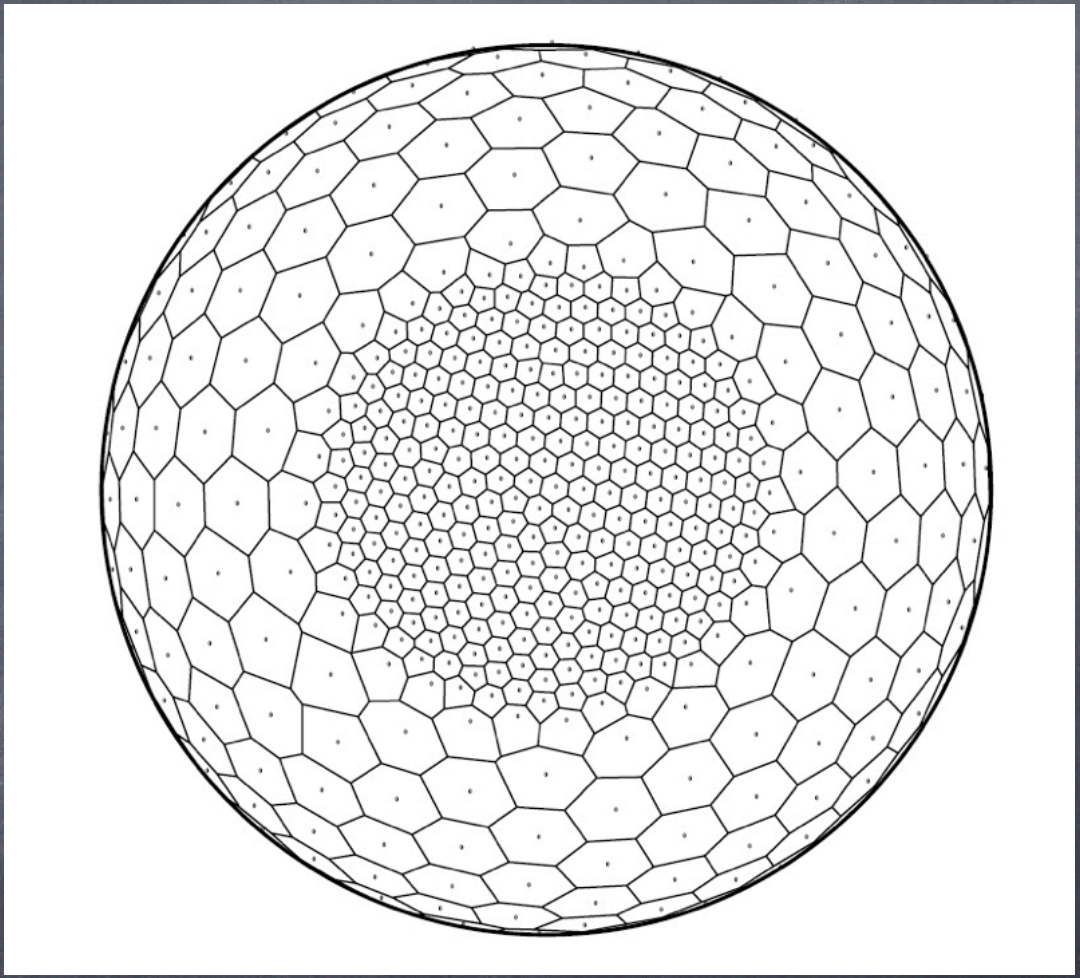
-Develop an unstructured, variable resolution Voronoi tessellation grid.

-Modify the Parallel Ocean Program (POP) to support unstructured grids (and, thus, accommodate these Voronoi tessellations).

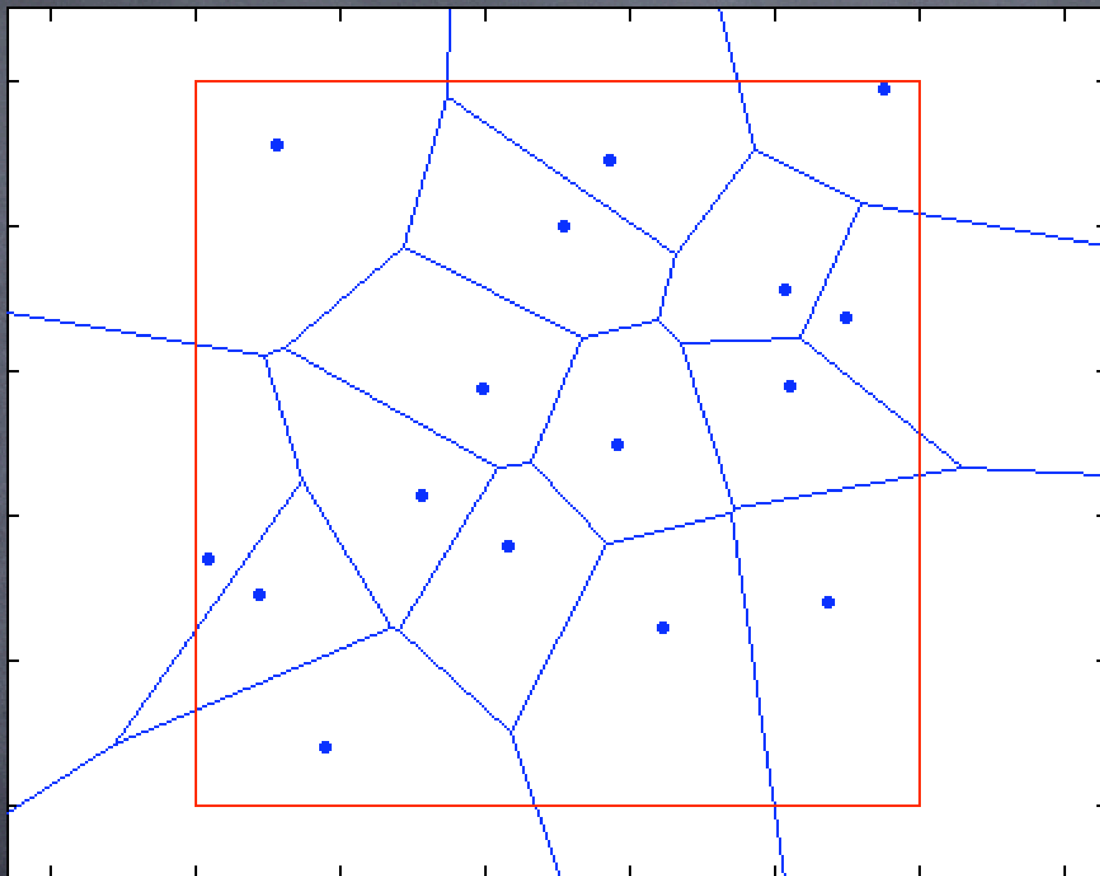
A 1D (linear) data structure opens doors that allow the quick exploration of many ideas.

For example, variable resolution grids -- spherical centroidal Voronoi tessellations.

Finite-volume methods map naturally to the primary grid, spectral element methods map naturally to the dual (triangular) grid.



Du and Gunzburger



In collaboration with Max Gunzburger