Depth Dependent LCS in HYCOM/QG Dipoles

MURI-4D-DS Workshop

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Collaborators:

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- Robert Numrich, CUNY HPCC
- MURI 4D Team

Overview:

- Before tackling full 3D + 1 problem in model data sets:
  - Examine transport geometry of isolated, simplified structures with z dependence included.
  - Examine transport geometry of *large*, *energetic* structures in isopycnal coordinates.
- Identify 'generic' geometric features.
- Test proxy measures for LCS identification.
- Test adaptive-grid algorithms for LCS identification.
- Preliminary results from OGCM indicate prevalence of mixing/transport induced by 3D dipole structures.

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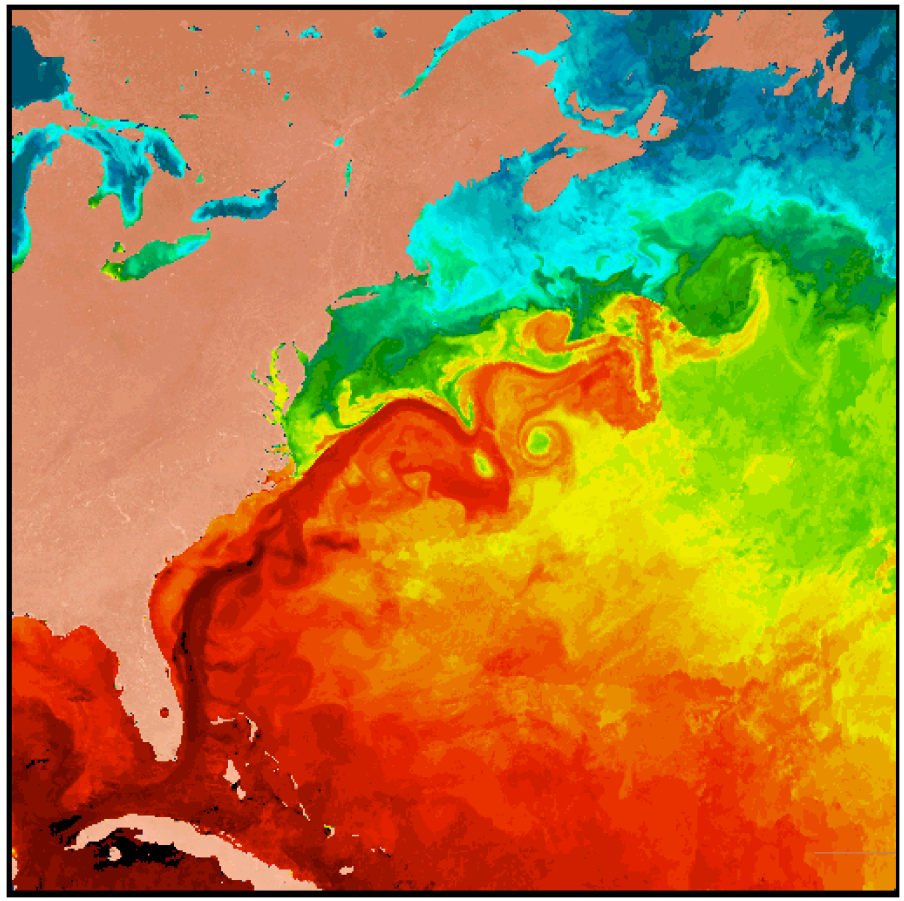
- Preliminary results from OGCM indicate prevalence of mixing/transport induced by 3D dipole structures.
- OGCM's with $\Delta x \sim 1 - 2$ km are 'sub-mesoscale-eddy permitting'.

Overview: Gulf-Stream Rings & HYCOM at 1/50 °

- Depth-dependent advective boundaries/fluxes in large, long-lived, energetic eddies.
- Eddy-Jet and/or Eddy-Eddy?
- HYCOM data-set: $\Delta x \sim 1 - 2$ km.
- Parameterized mixed/boundary layer. 30 isopyncal layers.
- Gulf stream rings with realistic size, strength, frequency.



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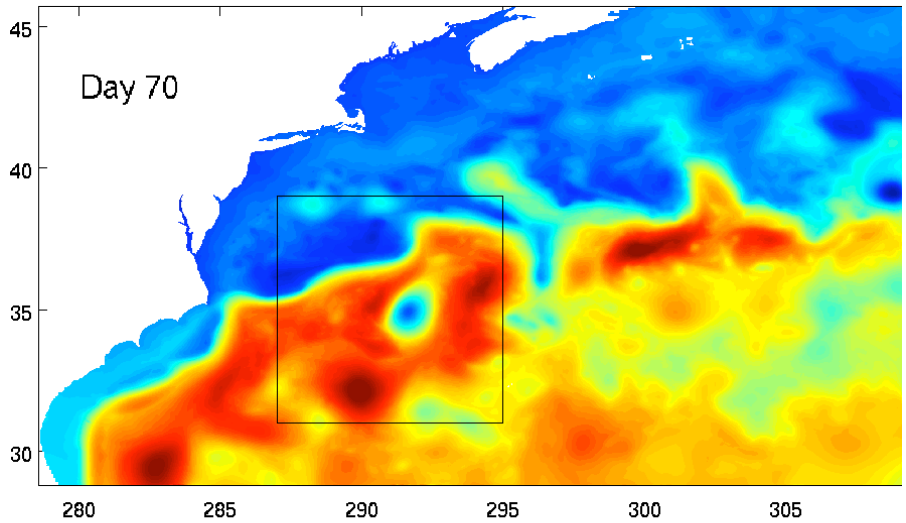
Sea-Surface Height



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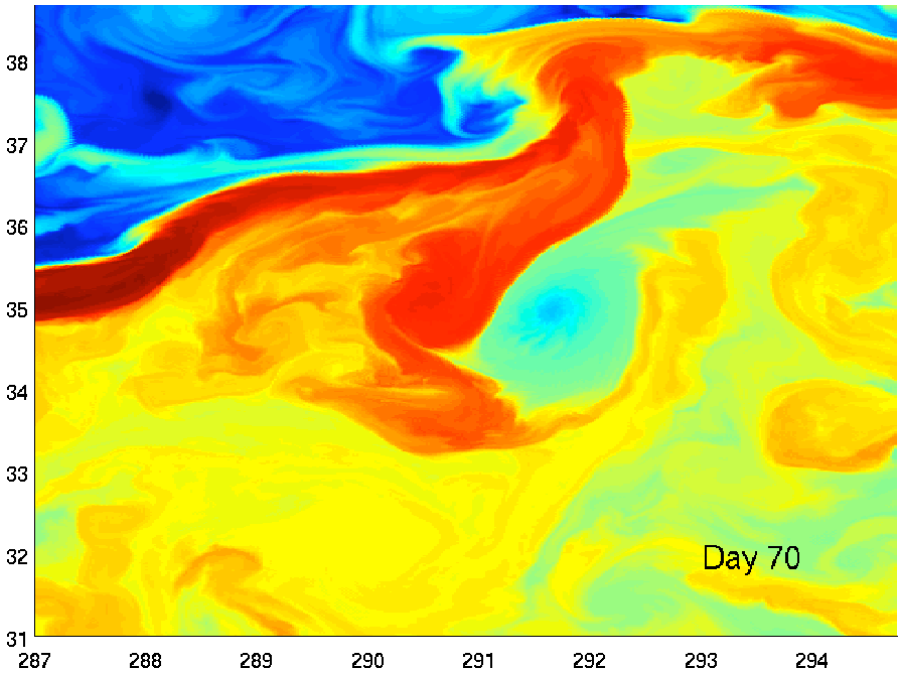
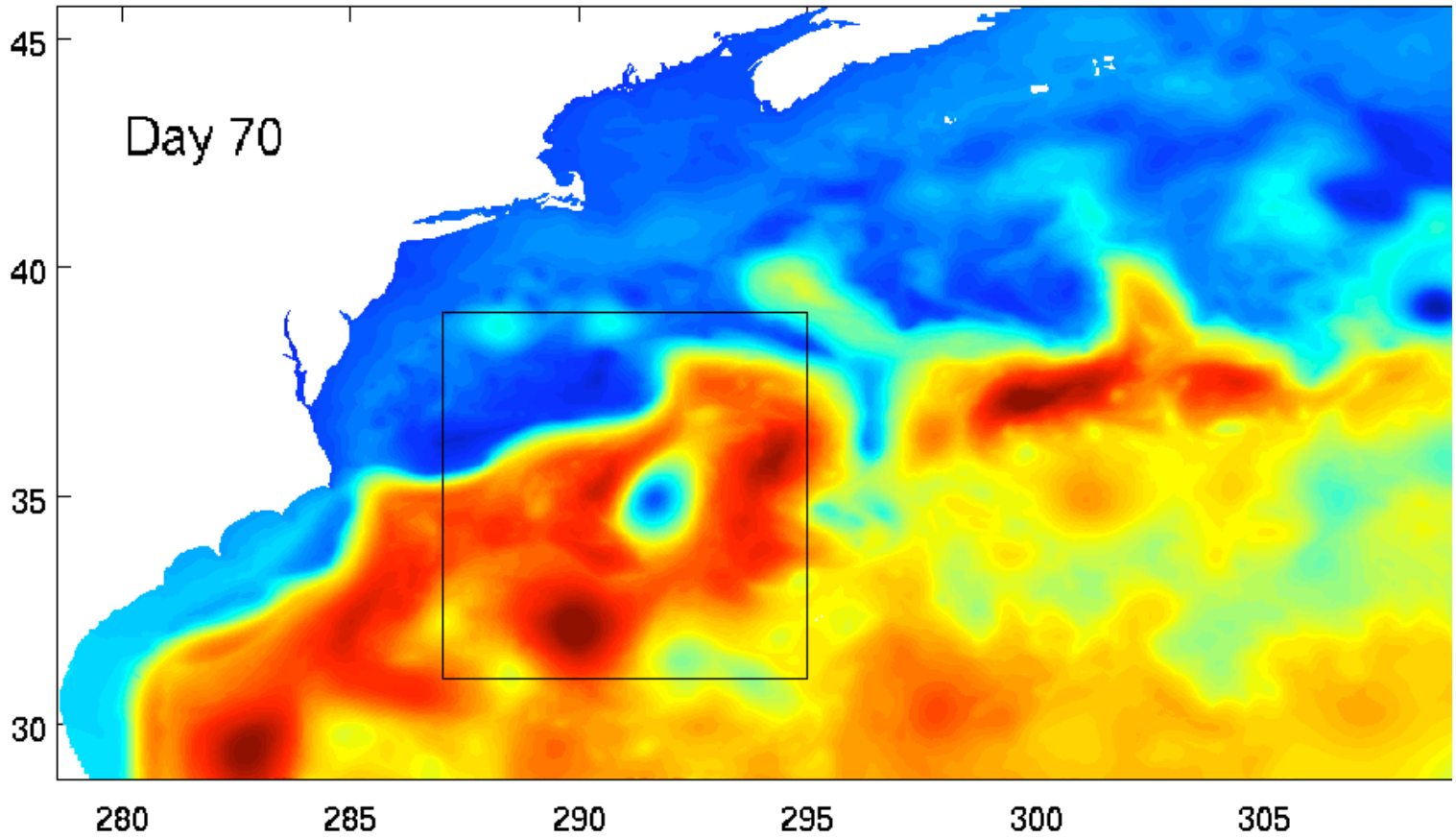
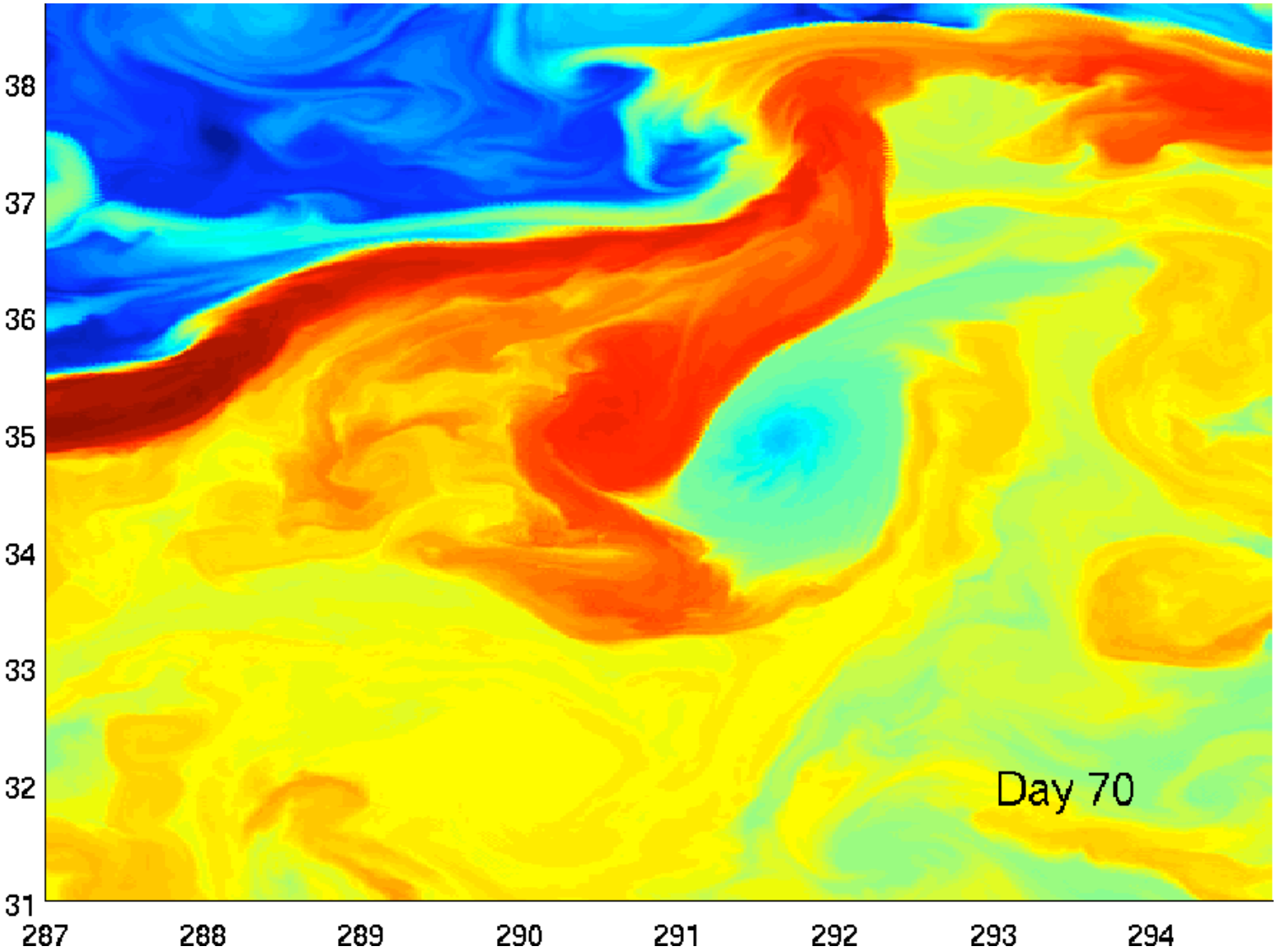


HYCOM: North Atlantic SSH



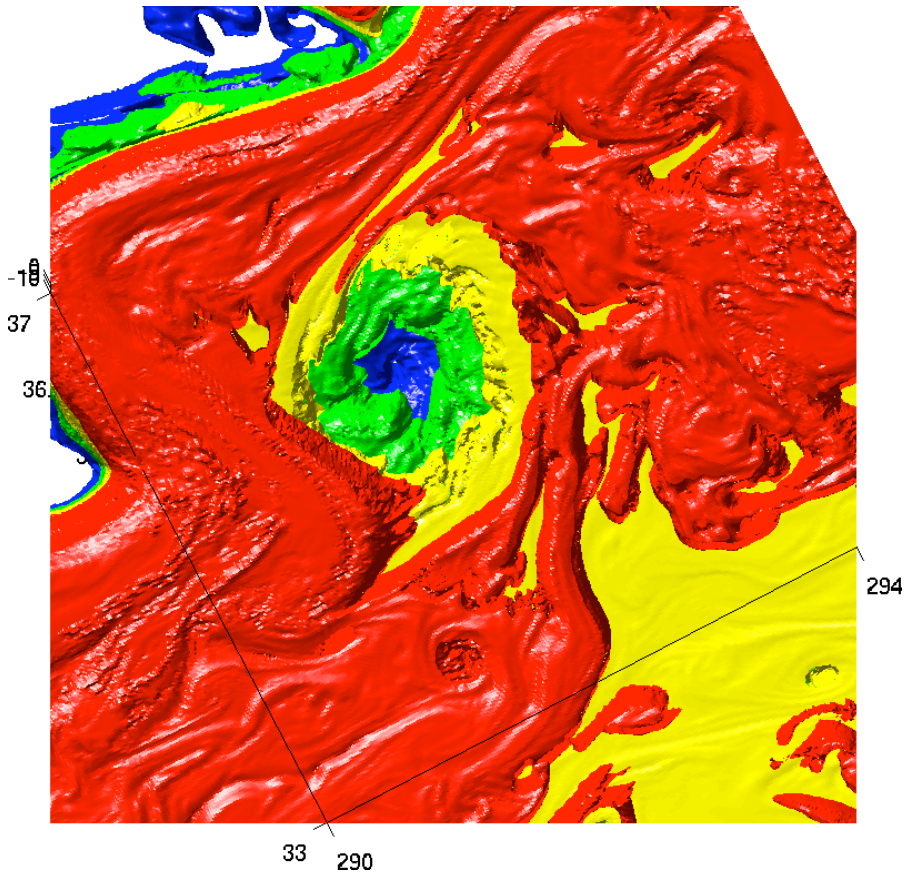
HYCOM: North Atlantic SST



Depth Dependent Stirring/Mixing

- Energy at sub-mesoscales (< 10km) in model.
- Small-scale, fast-time contributions.
- Complex, small-scale vertical structures.
- High resolution HYCOM $\leftrightarrow$ full LES?

Temperature ($\Delta T = 1°$)



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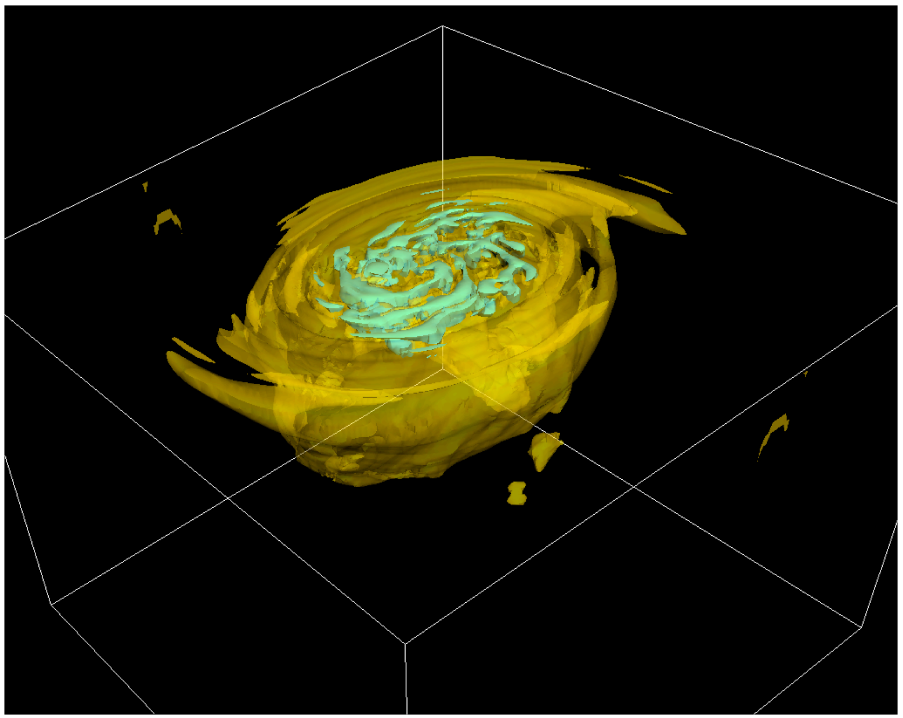
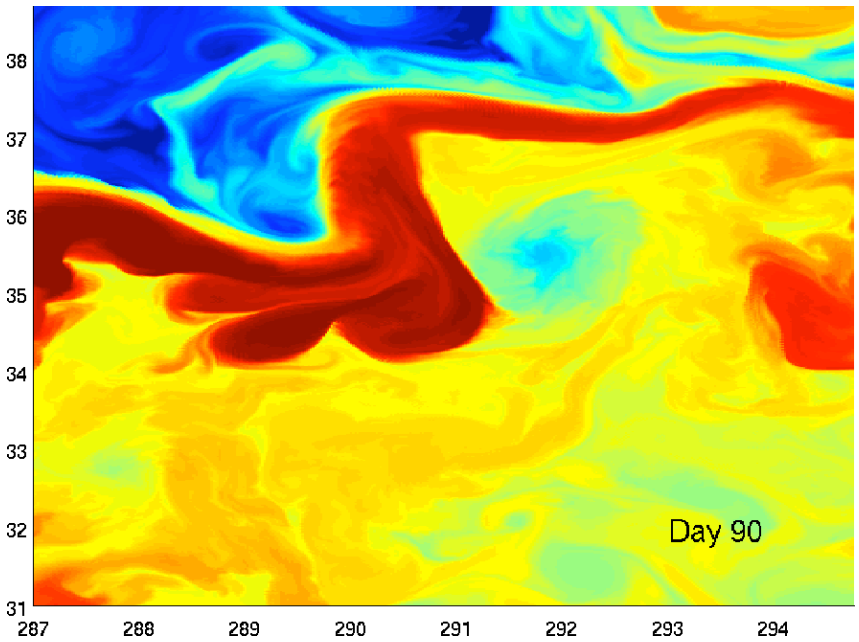
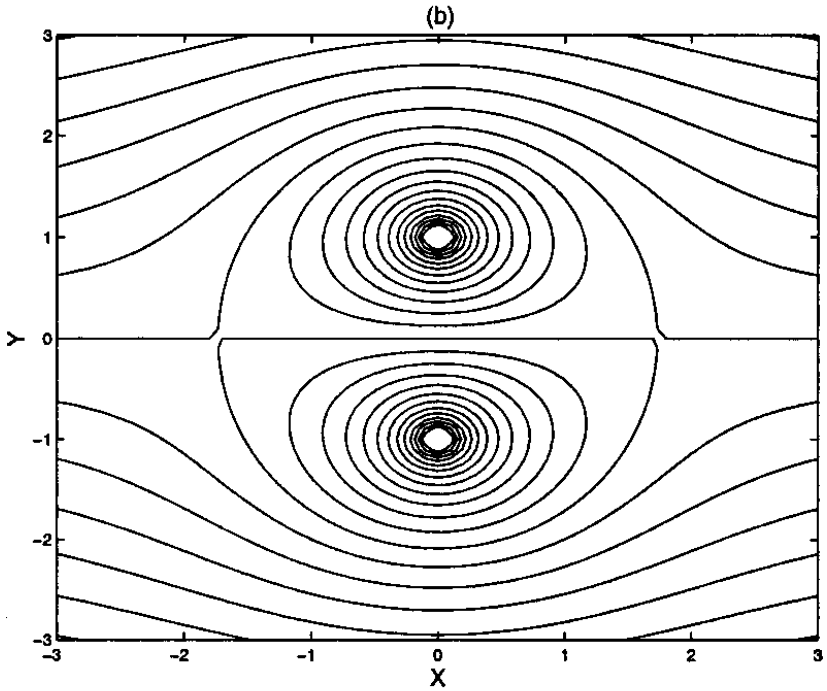
LES - Cylone in Mixed Layer
(Özgökmen)



Generic Stuctures: Dipoles/Quadrapoles





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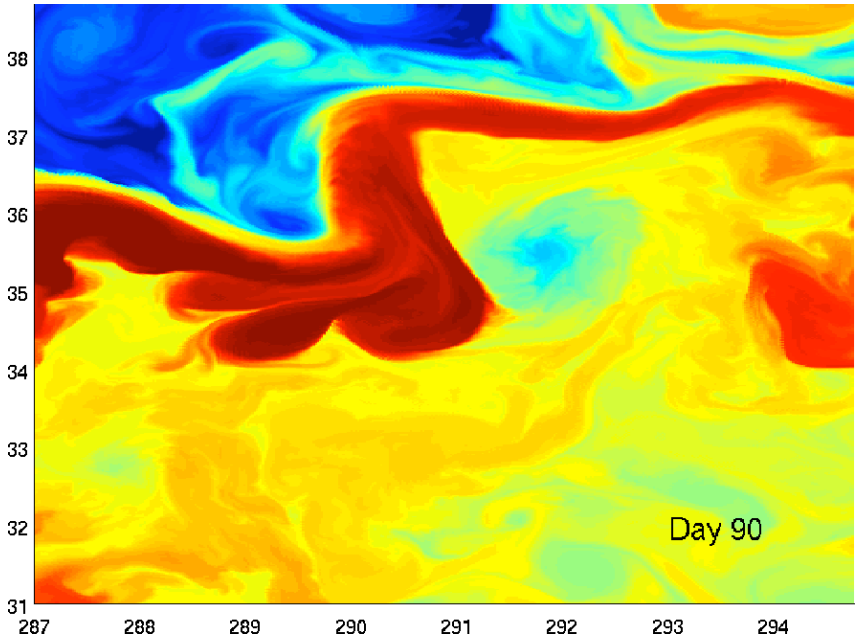
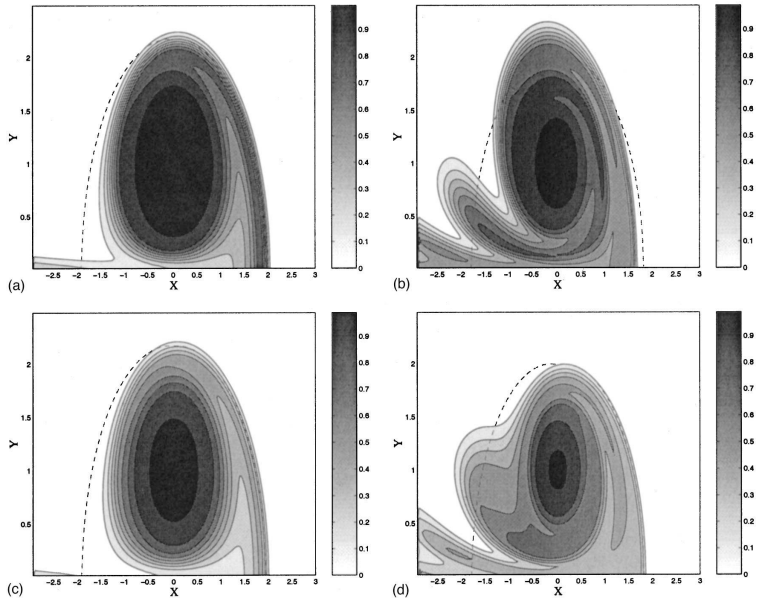




3D Quasi-geostrophic Equations

- Vertically dependent, planar flows:

$$\frac{\partial \omega}{\partial t} + \frac{\partial \psi}{\partial x}\frac{\partial \omega}{\partial y} - \frac{\partial \psi}{\partial y}\frac{\partial \omega}{\partial x} = 0$$

$$\frac{D_H \omega}{Dt} = 0$$

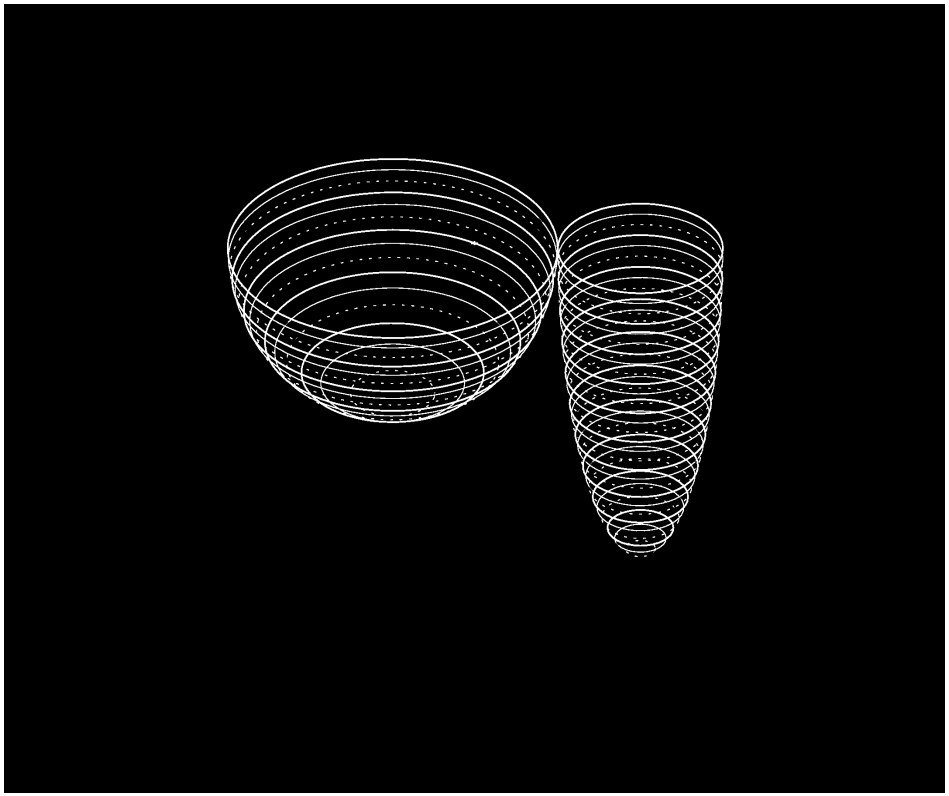
$$\nabla^2_{3D}\psi = \omega$$

- Gridfree: Contour Advection + Contour Surgery. (Dritschel)
- *Trivial* parallelization of particle advection/solver.
- Easily configurable to di-quad-octi-poles.
- No boundaries.

Depth Dependent Dipoles

- Constant vorticity, ω_1, ω_2, in two hemi-ellipsoids.
- Configure geometries/strengths of each.
- Symmetry BC at surface.
- Seed with regular particle grid.
- Compute FTLE/FSLE/DLE

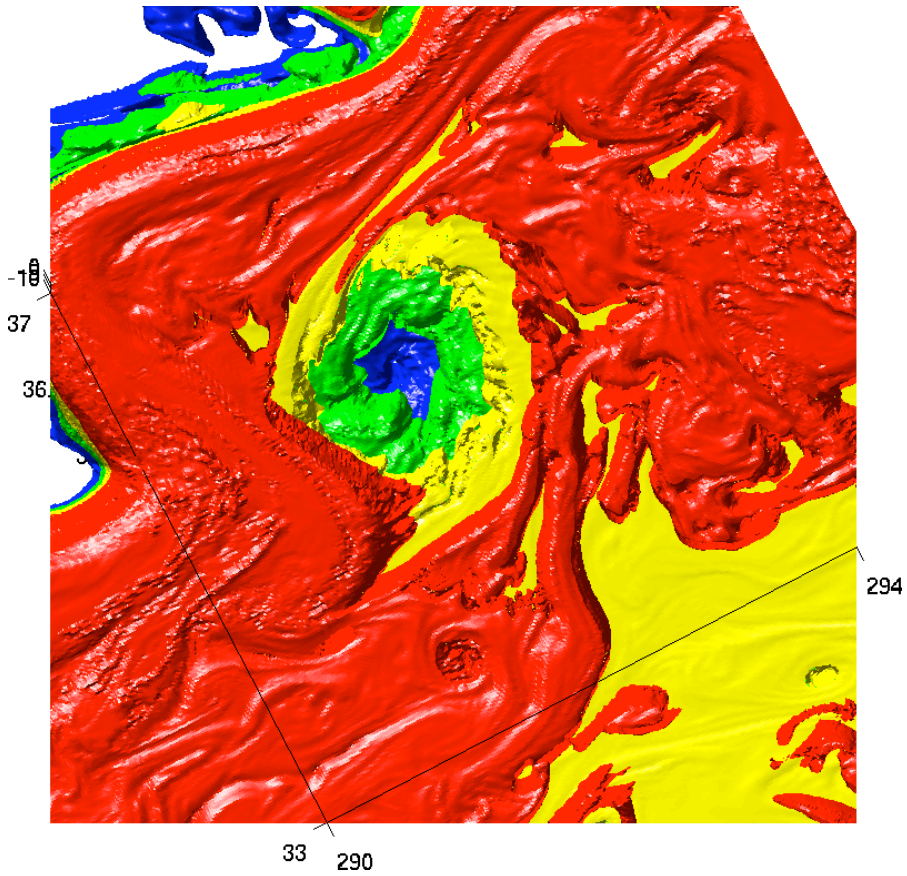
Asymmetric size/strength



Adaptive Mesh Refinement

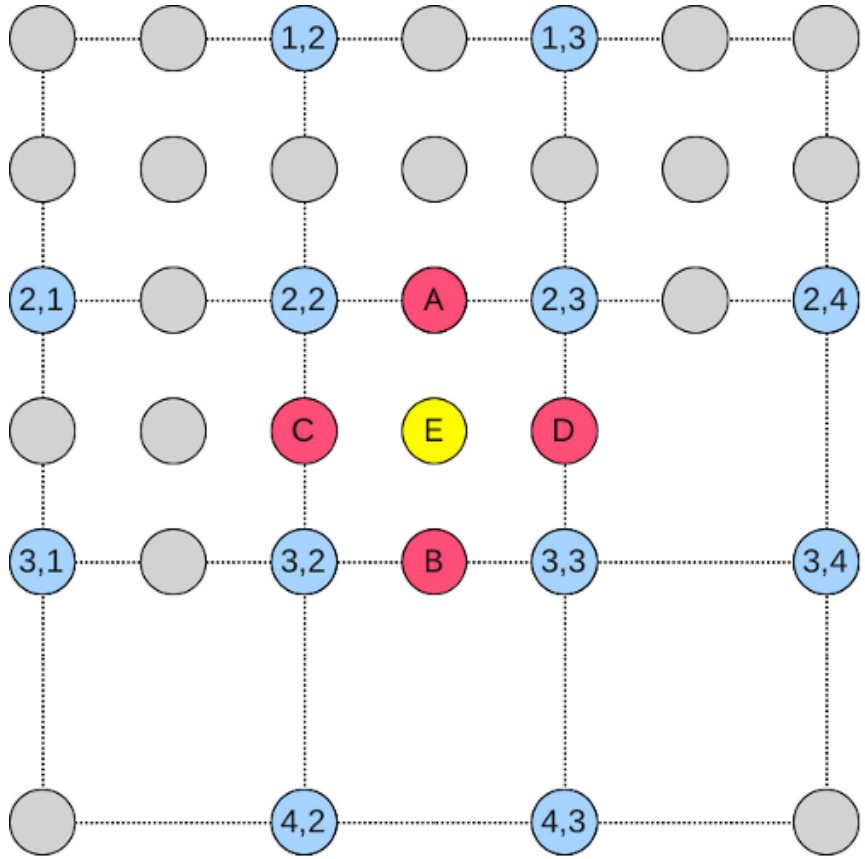
- Complex LCS in highly-resolved OGCM.
- Extremely fine spatial resolution requirements.
- Huge numbers of particles.
- *Garthe: Trans. on Visualization, 2007*

Temperature ($\Delta T = 1°$)



Adaptive Mesh Refinement

- $N \times N \rightarrow 2N \times 2N$ grids.
- Interpolate λ_N onto λ^i_{2N}.
- Compare λ^i_{2N} to λ_{2N}.
- If difference $< \epsilon$, use interpolation for all finer grids.
- If difference $> \epsilon$, compute λ on finer grids.



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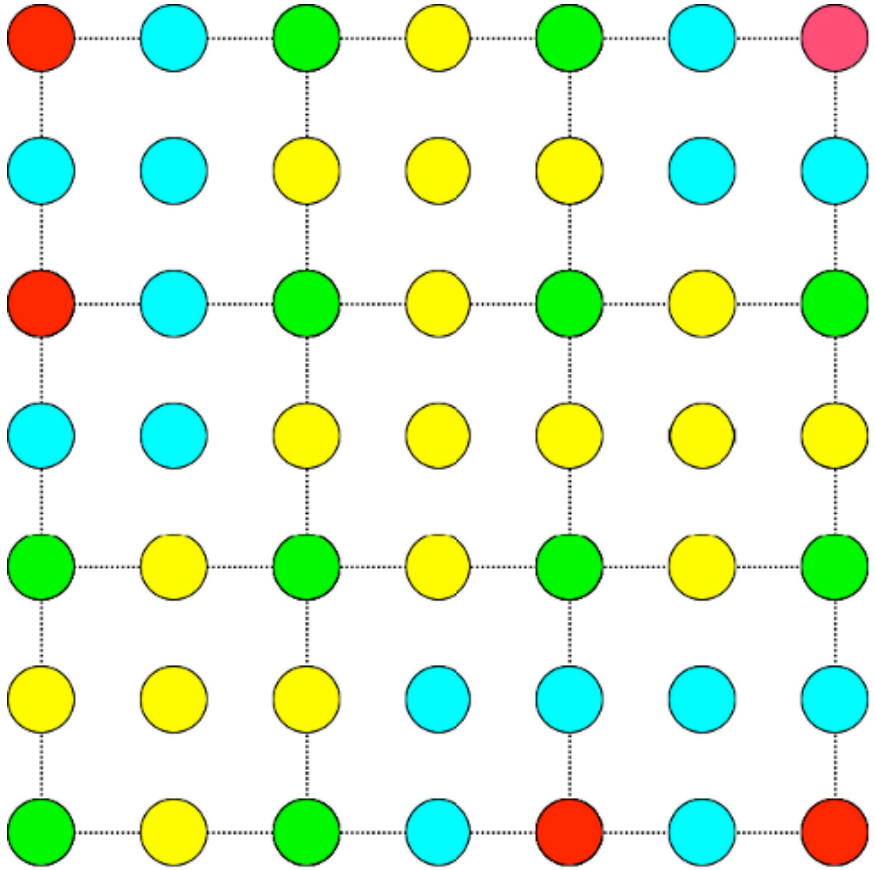

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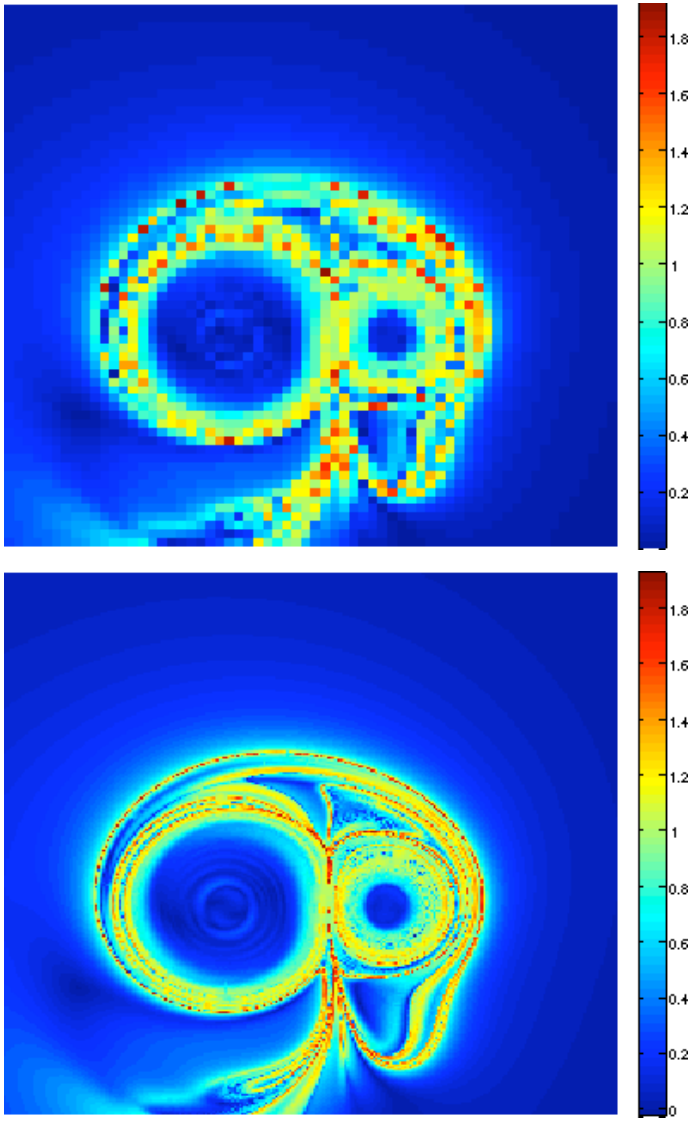

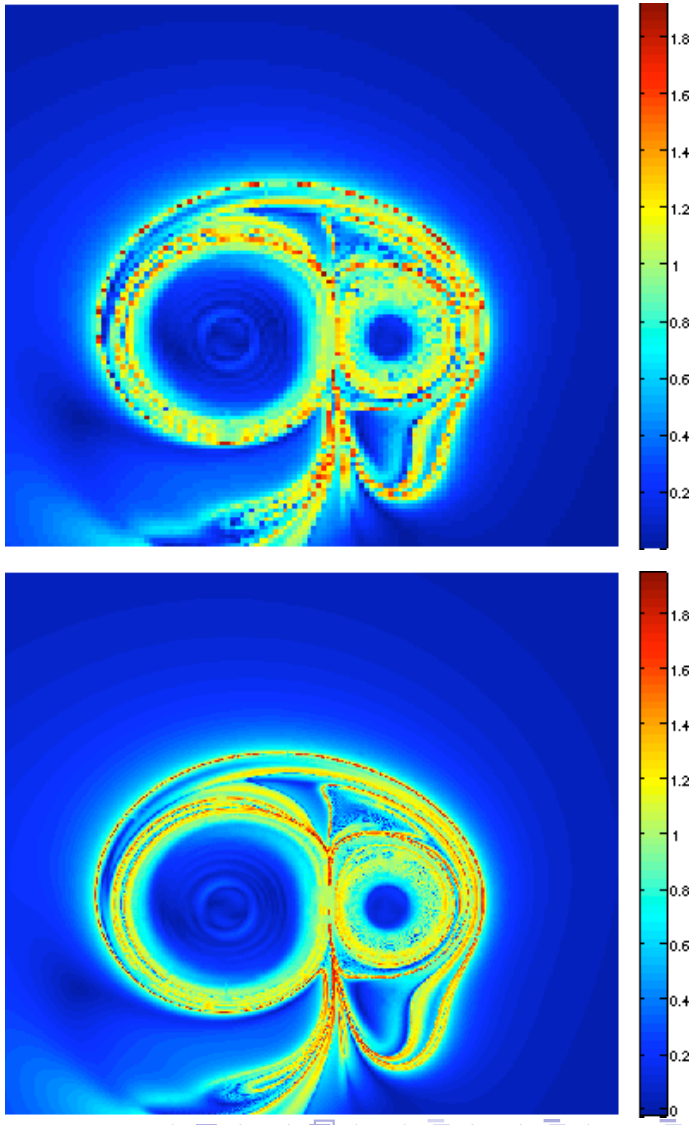

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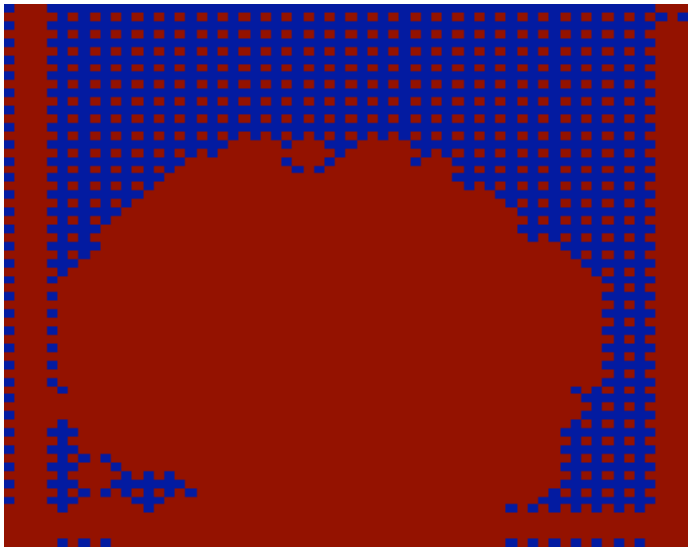
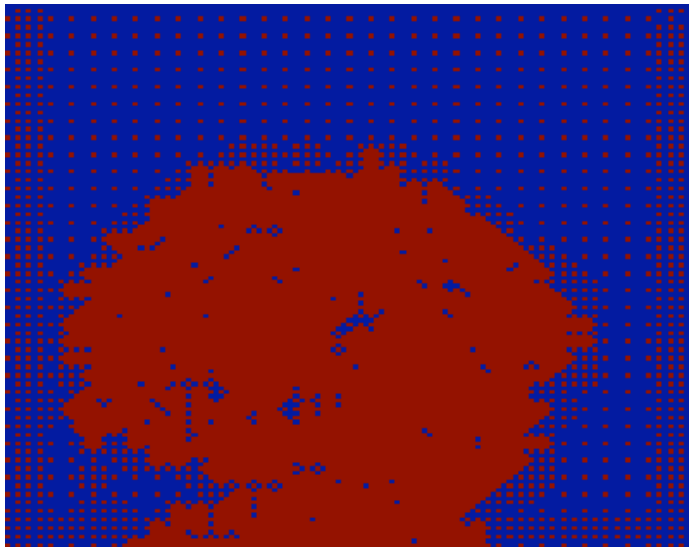
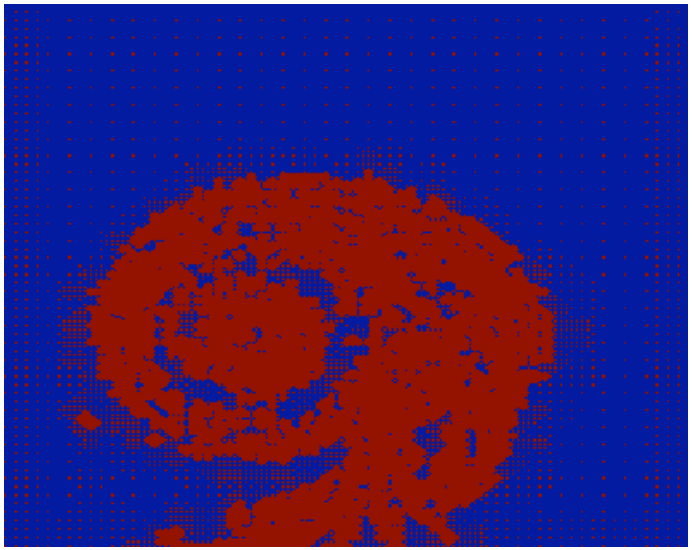
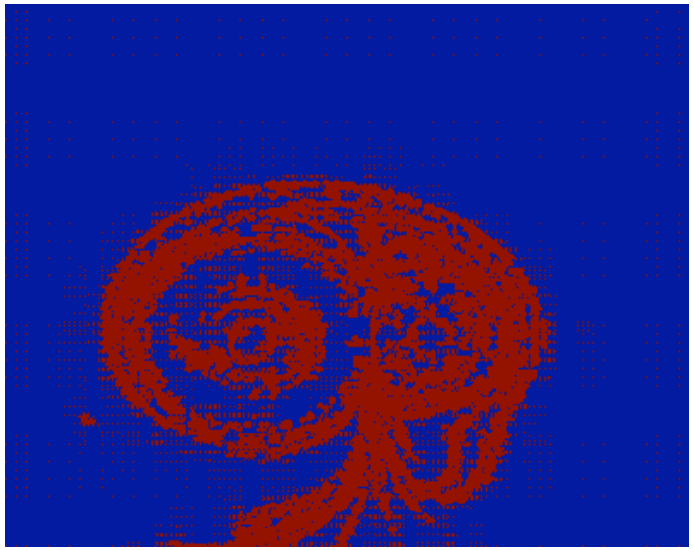






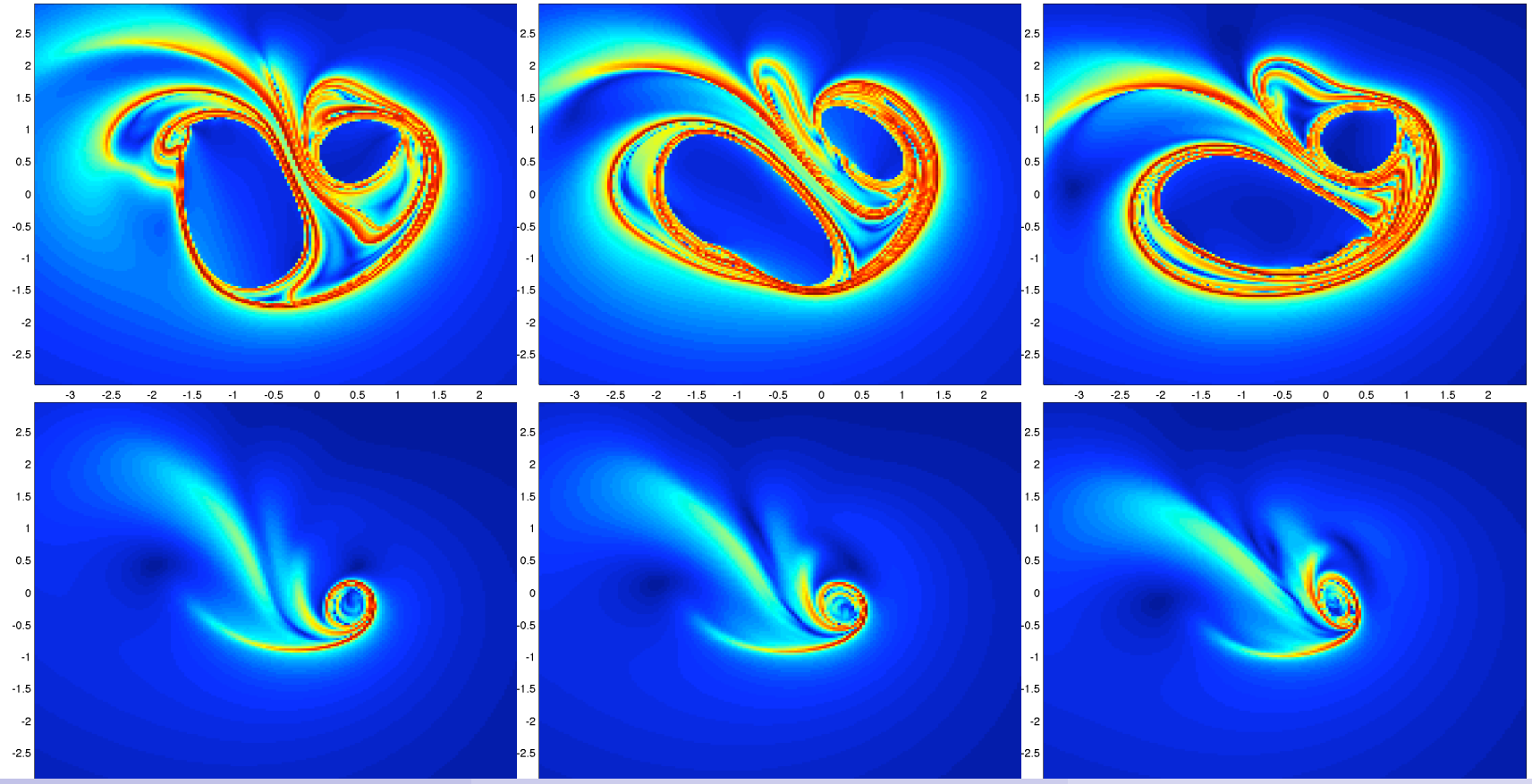


LCS Results: QG Dipole

Metric: Direct Lyapunov Exponent

$$\lambda(\mathbf{x}, t; \tau) = \frac{1}{\tau} \ln \sigma(\mathbf{x}, t, t + \tau)$$

$t = 2.0$ $t = 3.0$ $t = 4.0$



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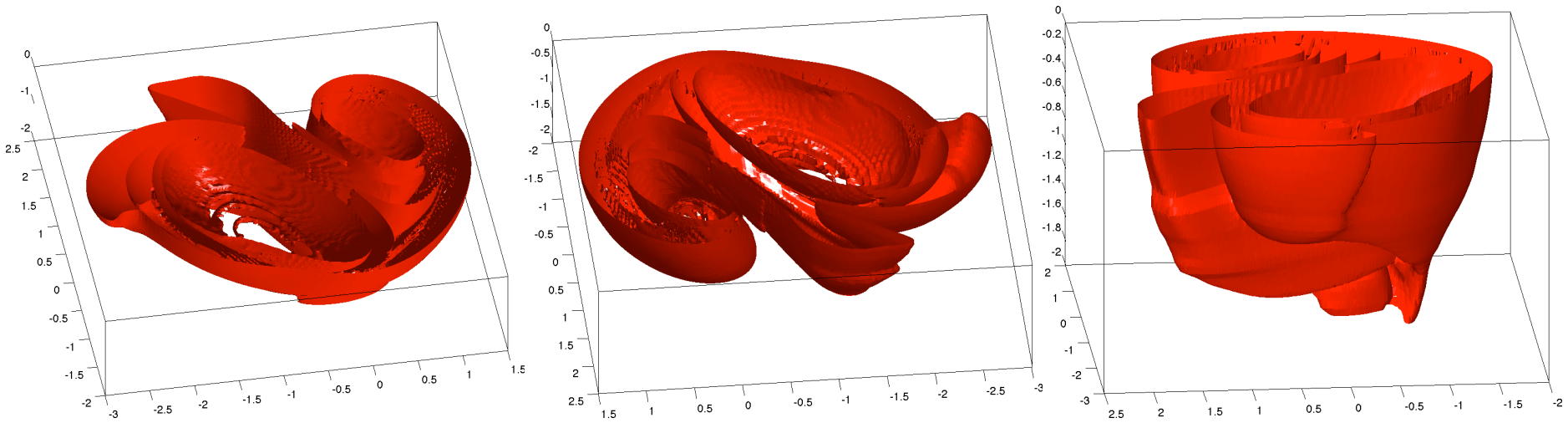

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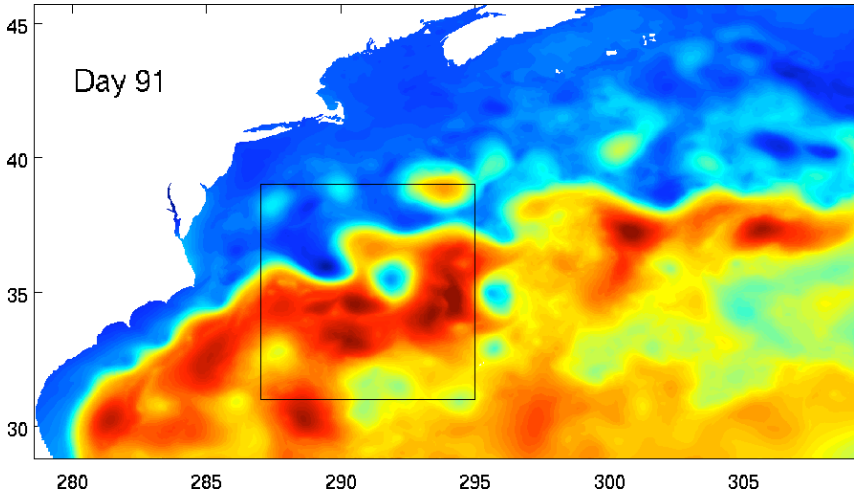

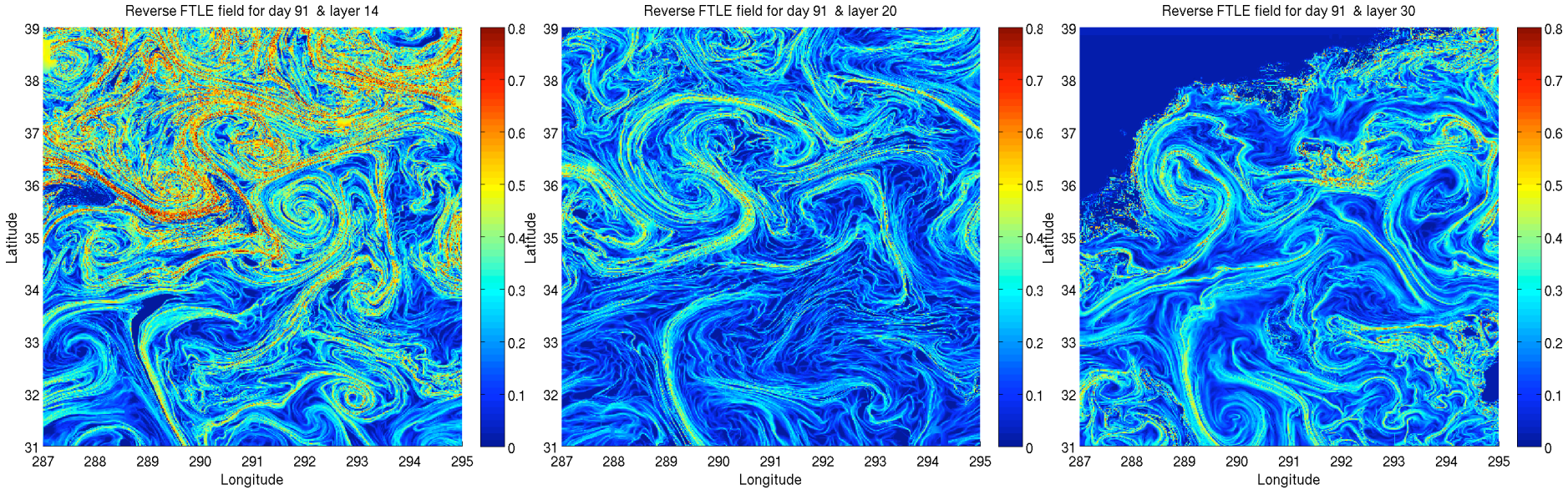

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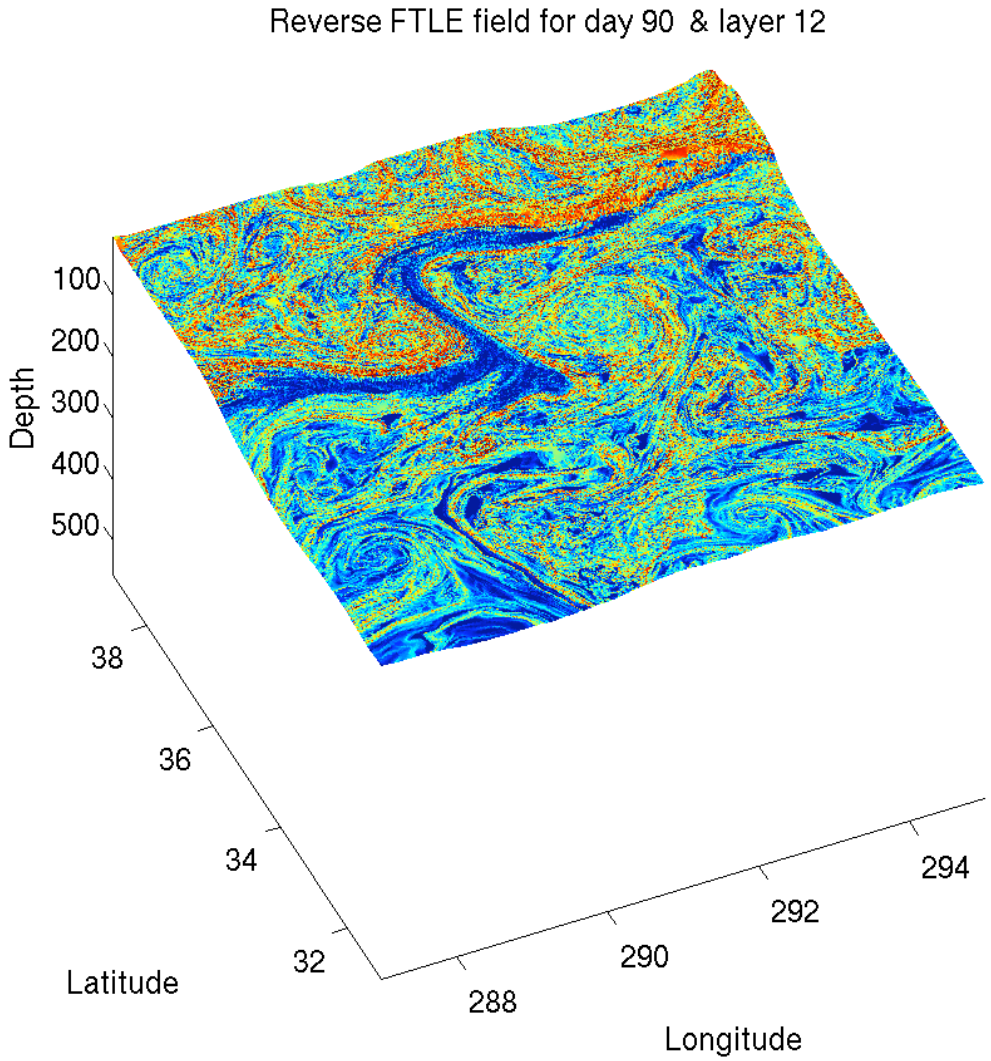

Conclusions:

- Depth/density dependent LCS in high-res OGCM.
  - Adpative sampling for LCS.
  - Persistent mesoscale structures - but significant sub-mesoscale contributions.
  - Transport via eddy-eddy interaction.
  - Strong bathymetric control.
- Details (to do):
  - Adaptive/depth dependent time-scale in LCS computations.
  - Temporal resolution (12 hr velocity fields?).
  - Spatial filtering (eliminate SMS?).
- Analysis:
  - QG+ Add vertical velocity to Dritschel's QG Dipoles. (Stephan/Cecily?)
  - Closer comparison of isopycnal/hydrostatic structures in OGCM to 3D/nonhydrostatic LES process model. (Tamay?)