Geometry of 3D Dipole Interactions: Painting HYCOM

MURI-4D-DS Workshop

Wilmington Delaware

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Collaborators:

- MURI Crowd
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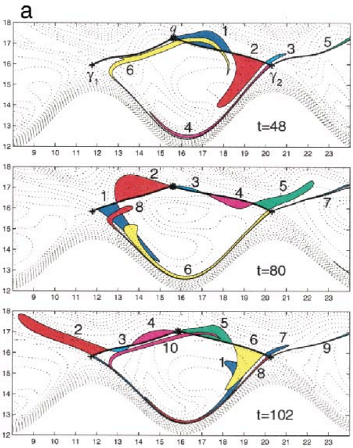
- Lucas Garber, CUNY

Overview: 'Paradigm' 3D Ocean Structures?

- 2D Coherent Structures:
  - Classical phase space pictures:
  - Hetero-clinic orbits: Cat's Eye
    - ★ Meandering Jet
    - ★ Eddy-eddy interaction
    - ★ Dipoles
  - Homoclinic Orbits:
    - ★ Eddy-pinchoff
    - ★ Eddy-jet interaction



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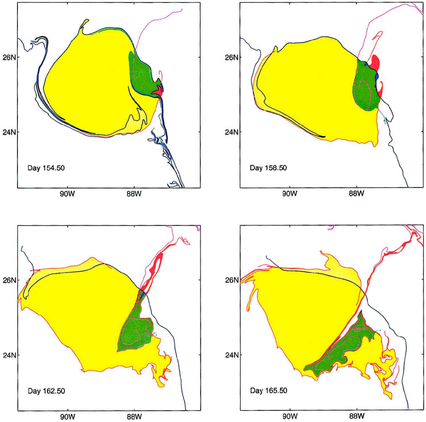

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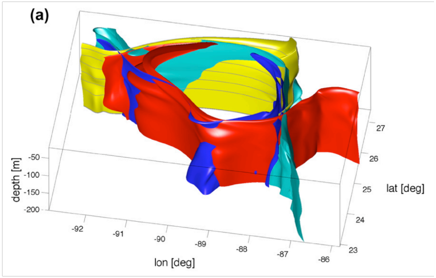
  - 2D + 1
    z-dependent 2D structures
    $\mathbf{u} = (u(x,y,z), v(x,y,z))$
  - 3D + symmetry
    $\mathbf{u} = (u(r,\theta), v(r,\theta), w(r,\theta))$
  - Fully 3D? Role of w component?
    - ★ Isopycnal advection.
    - ★ Diagnose w in cartesian coordinates.



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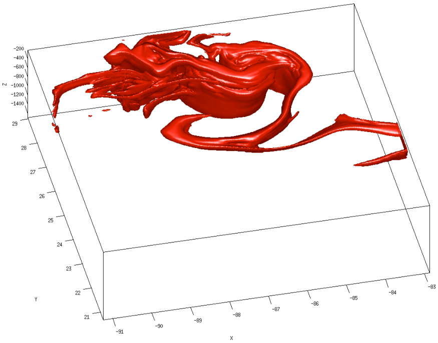

Goal: Tool for quickly visualizing 3D advective pathways in available model data sets.

Eulerian Approach to LCS

- Trouble: Proxy measures rely on differencing gridded trajectories w.r.t. initial conditions.
- Time dependent 3D structures $\rightarrow$ *many* particles.
- Look instead at a differentiable scalar field:

$$\frac{\partial \phi}{\partial t} + (\mathbf{u} \cdot \nabla)\, \phi = \kappa \nabla^2 \phi + S(\mathbf{x}, t)$$

$$\phi(\mathbf{x}, 0) = \phi_0(\mathbf{x})$$

κ and S prescribed
$\mathbf{u}(\mathbf{x}, t)$ given ($\mathcal{I}(\mathbf{u}_{ijkl})$)

- 'Judicious' choice of S and/or $\phi_0(\mathbf{x})$ ....
- Computationally minimal κ ensures differentiable ϕ.
- Backwards in time evolution with $\mathbf{u} \rightarrow -\mathbf{u}$.

Advection-Diffusion + HYCOM

$$\frac{\partial \phi}{\partial t} + (\mathbf{u} \cdot \nabla)\, \phi = \kappa \nabla^2 \phi + S(\mathbf{x}, t)$$

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- Standard conservative, explicit 2nd order finite-differences.
- 2-pass MPDATA for advection.
  - Upwind + Anti-Diffusive.
  - Stable w/no explicit diffusion.
- Dufort-Frankel diffusion.
- Interpolation:
  - cubic in space.
  - linear in time.

- *Fancy* CAF Code (F2008)
- User-defined grid

$$\Delta x < \Delta x_{\mathrm{Model}}$$

- Split diffusion:

$$\kappa \nabla_h^2 \phi + \alpha \frac{\partial^2 \phi}{\partial z^2}$$

Advection-Diffusion: HYCOM Results

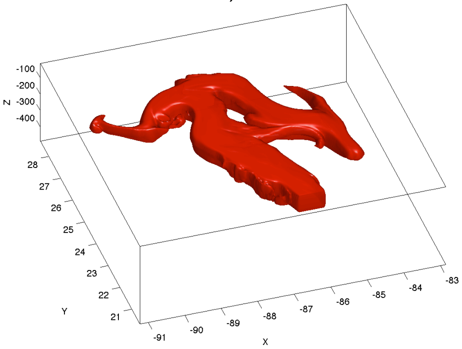
HYCOM - GOM30.1

- HYCOM GOM: $1/25$ Degree, 2010 archive.
- Daily output, Cartesian grid.
- w available.

Case 1: Plane Source

- Loop Current Dynamics:
- $S(\mathbf{x}, t) =$ constant on $x - z$ plane at inflow
- $\Delta x = 0.75 \Delta x_{HYCOM}$
- Regrid: $\Delta z = 25$m
- $\sim$ 5 minutes for 50 days $(300 \times 300 \times 20 layers)$

$w = 0, \alpha \neq 0$



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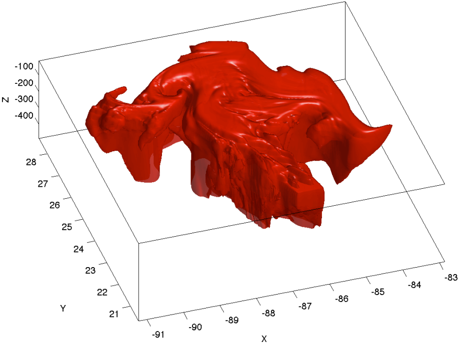
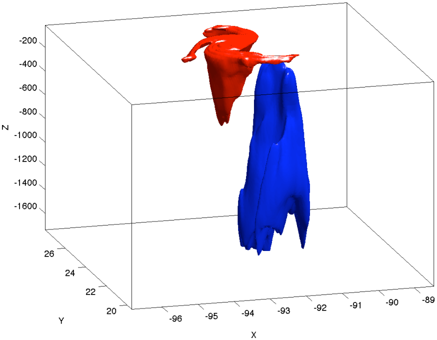
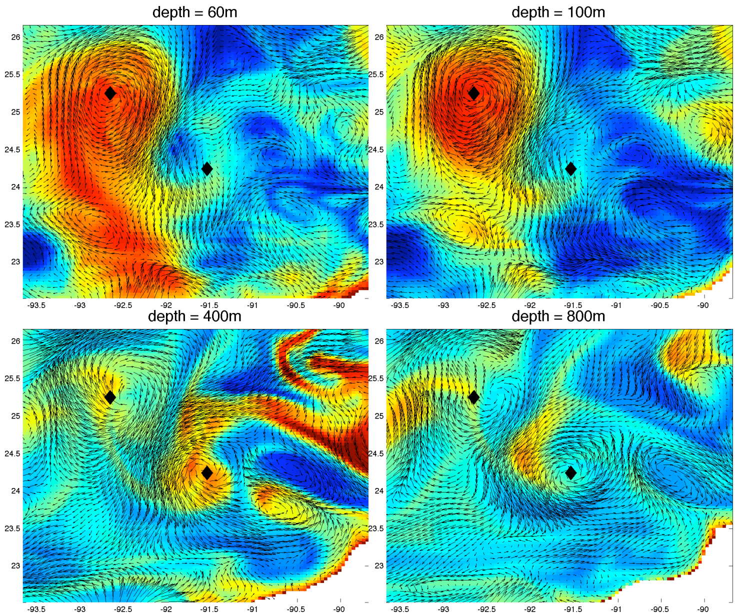


Case 2: Isolated Structures

- Deep-water, western Gulf.
- One (of many) multi-pole pairs.
- $\phi_0(\mathbf{x}) =$ constant in z dependent cycolone-anticyclone.
- Strong vertical component.

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depth = 100m
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26
25.5
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23.5
23
-93.5
-93
-92.5
-92
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-90

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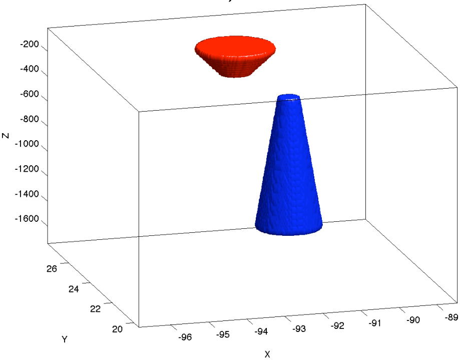

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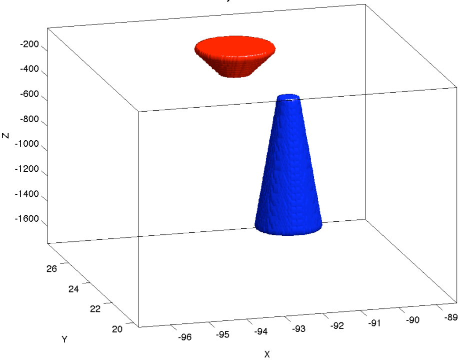
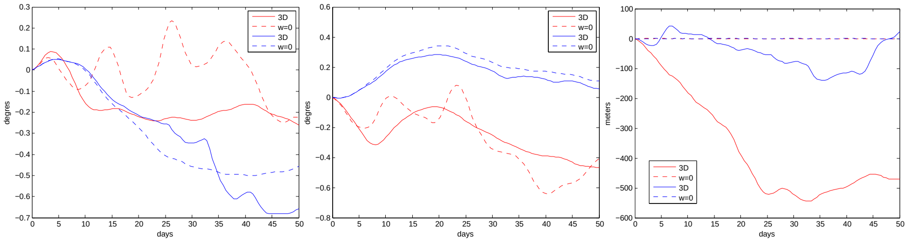


Advection-Diffusion: HYCOM Results

Center of Mass:

$$M_i(t) = \iiint x_i \phi(\mathbf{x}, t) \mathrm{d}V$$



To Do List:

- Compare scalar/LCS proxies
- Raw HYCOM output:
  - $\Delta t \sim 1$ hour
  - Isopycnal coordinates:

$$\frac{\partial h\phi}{\partial t} + (\mathbf{u} \cdot \nabla)\, h\phi = \nabla \cdot \kappa h \nabla \phi + \tilde{S}(\mathbf{x}, t)$$

- High Res HYCOM North Atlantic.
- Extend to other OGCM data bases.