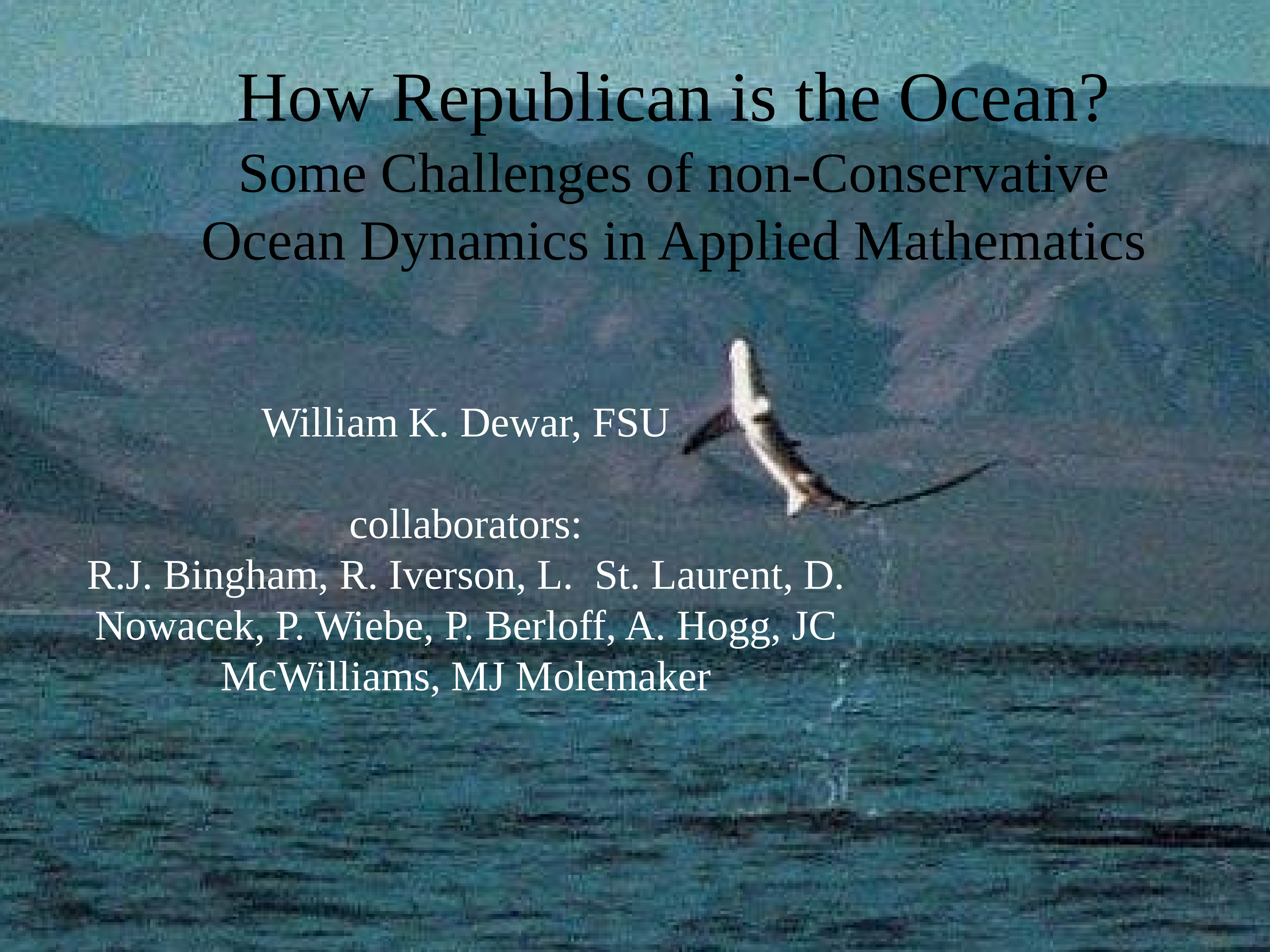


How Republican is the Ocean?

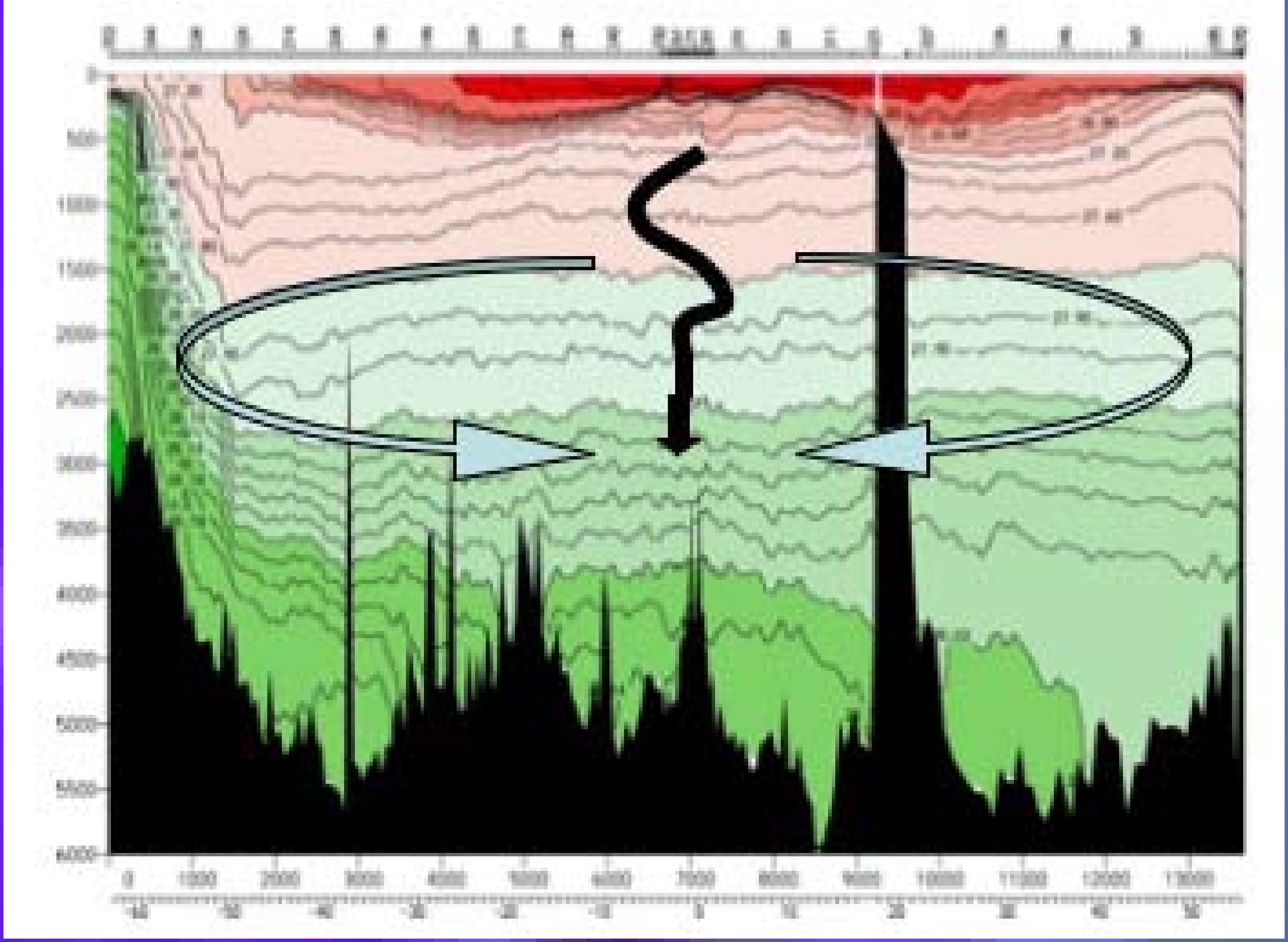
Some Challenges of non-Conservative Ocean Dynamics in Applied Mathematics

William K. Dewar, FSU

collaborators:

R.J. Bingham, R. Iverson, L. St. Laurent, D. Nowacek, P. Wiebe, P. Berloff, A. Hogg, JC McWilliams, MJ Molemaker

Consider ‘Mixing’.



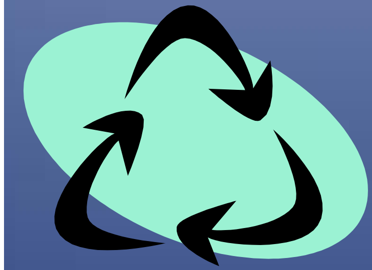
Munk and Wunsch, 1998
Mixing energy (2.4TW) supplied by external sources.

St Laurent and Simmons(2006)

How much energy are we talking about anyway?

How large of a column of the ocean would a typical kitchen mixer mix?

$$\frac{2.4x10^{12}W}{3.5x10^{14}m^2} = \frac{.007W}{m^2} \qquad \frac{200W\ m^2}{.007W} : (200m)^2$$



Point: The Ocean is ‘extremely’ conservative in its properties, but the ‘weak’ non-conservative effects are essential to its dynamics.

Key problem: How to model? Enormous scale disparity, probably requiring parameterization.

Objective: Discuss two examples and outline open questions.

Standard geopotential coordinate models with diffusions fail, with consequences.

Numerical problems associated with capturing this weak level of mixing have prompted novel model constructions.

Ex: MICOM – isopycnals

HYCOM, GOLD – Hybrid MICOM

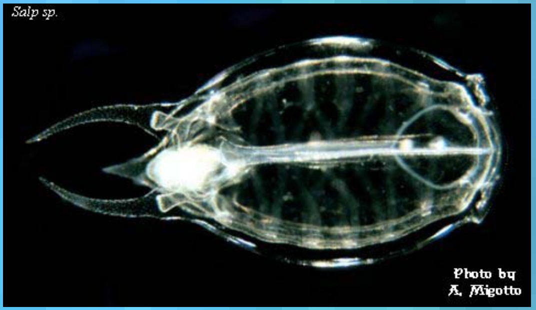
ROMS – Terrain following

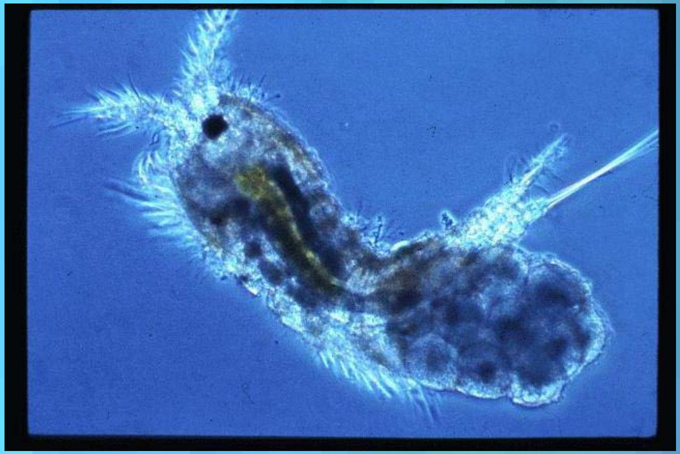
Because of the EOS, what is a good isentropic surface?

Can we numerically close ocean energy budgets?

Physeter Macrocephalus (aka sperm whale)
Architeuthis dux (aka giant squid)

Marine Biosphere impacts ocean mixing as effectively and the winds and tides


Salp sp.
Photo by
A. Migotto

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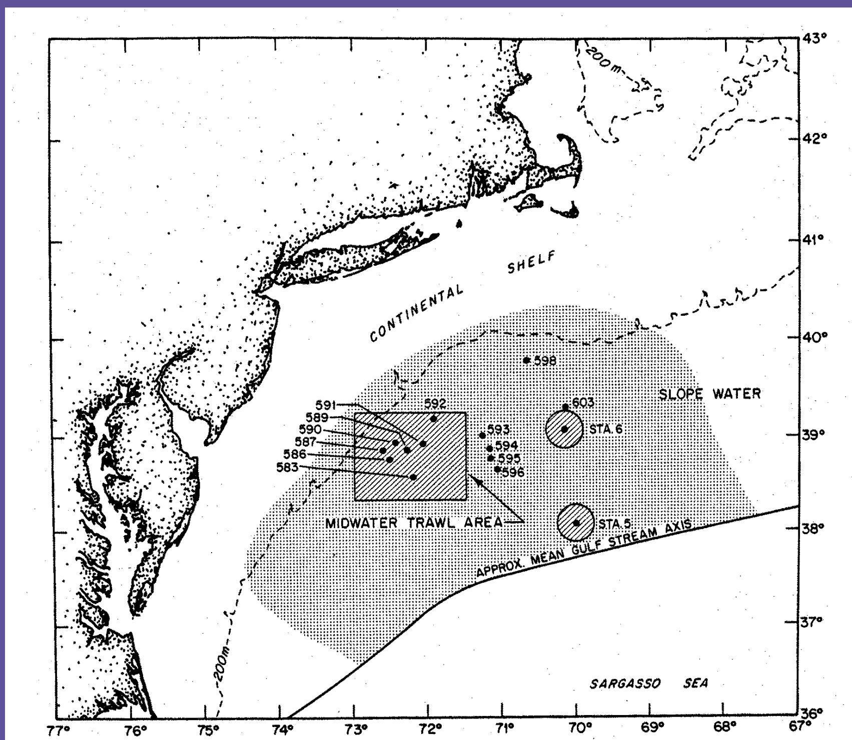
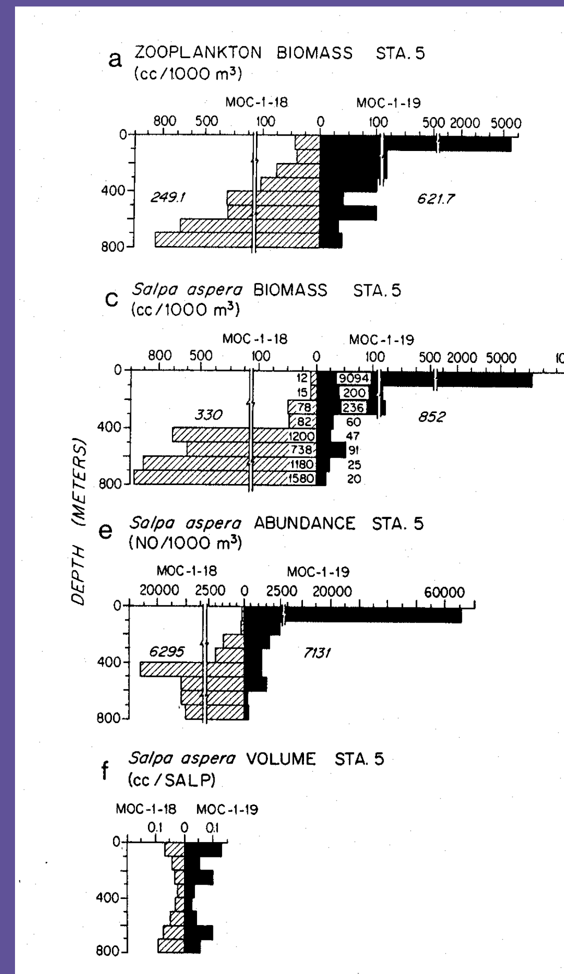
Diel Migrators



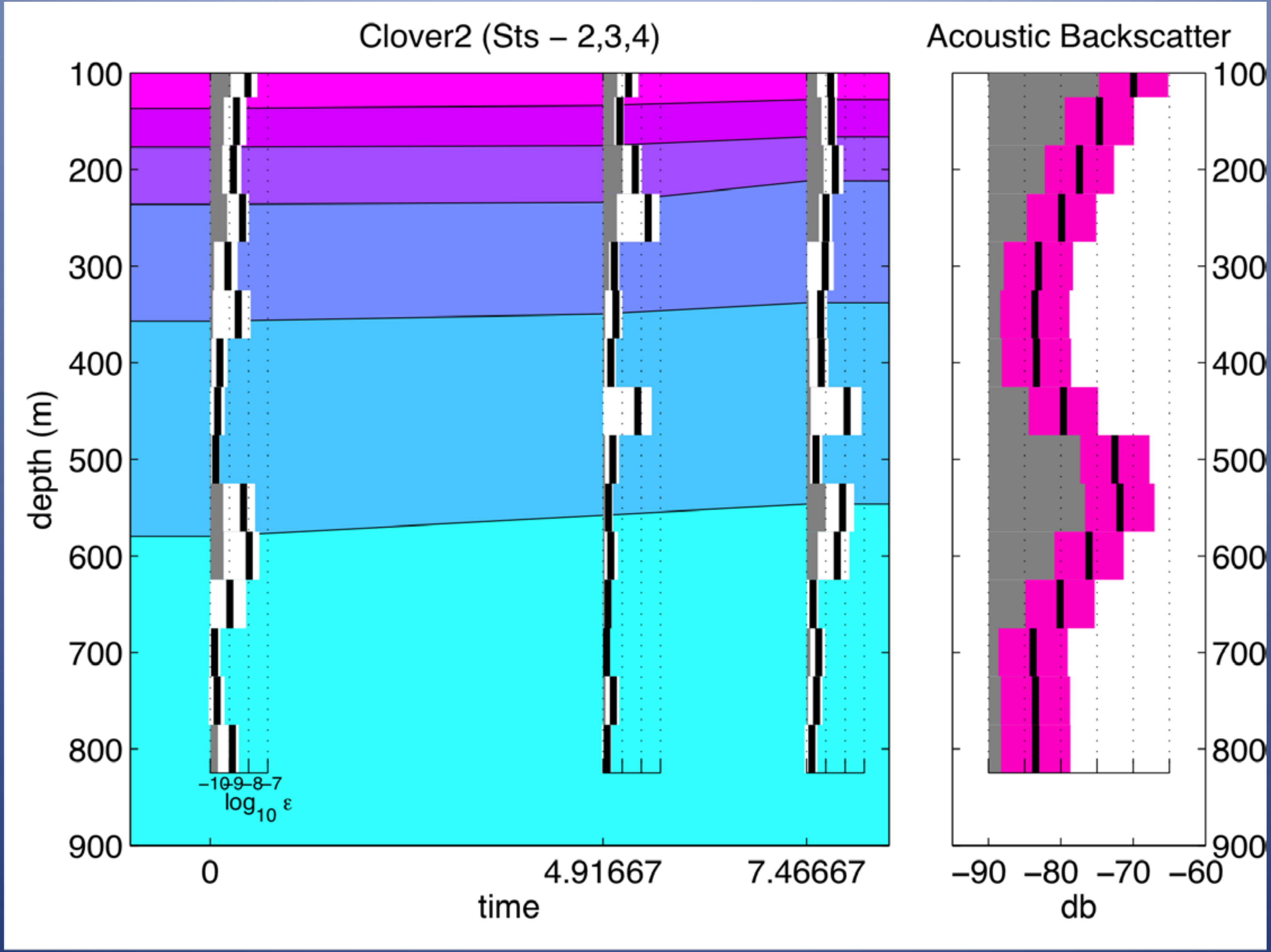


Wiebe, 1979

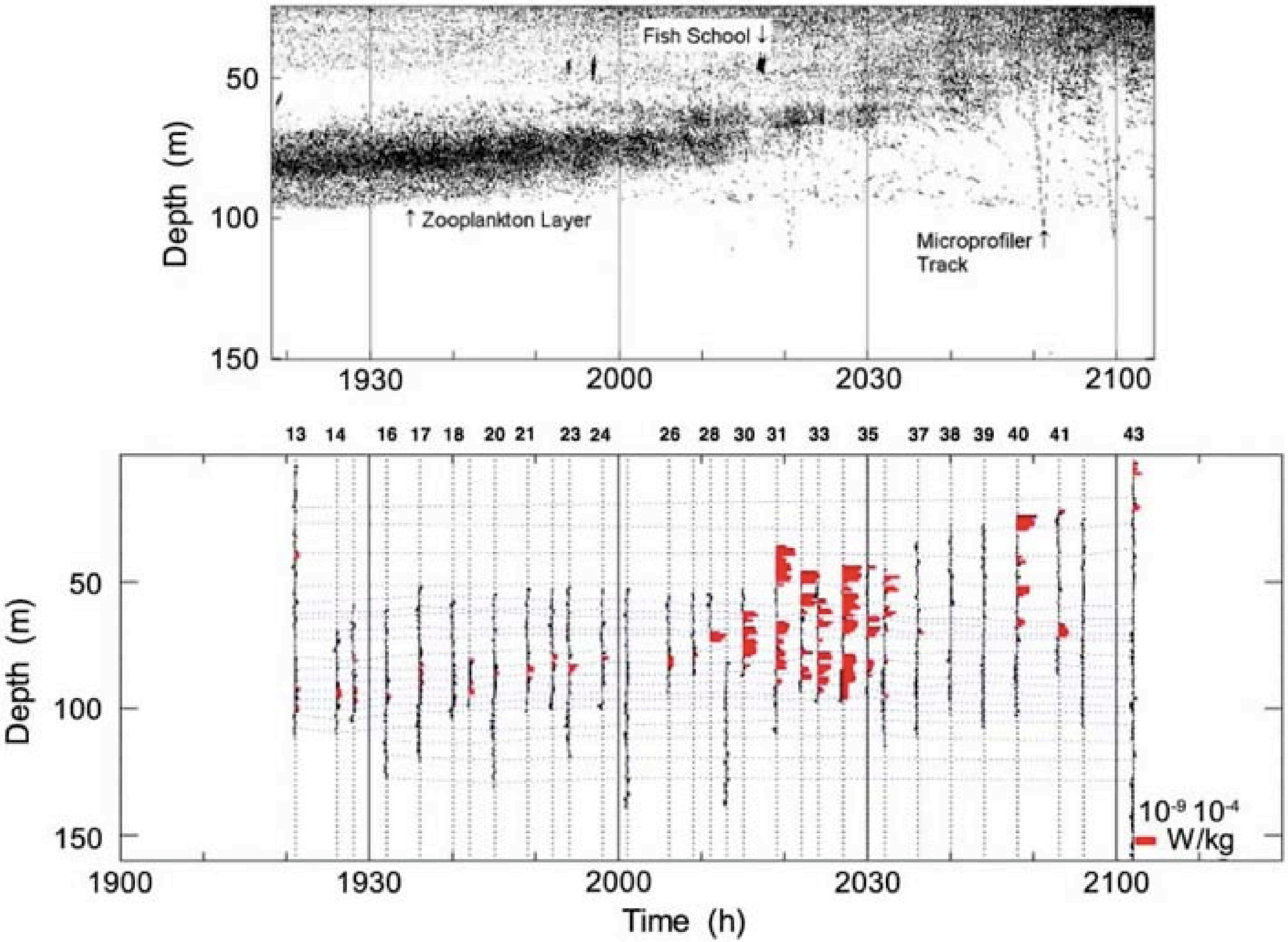
Recent Efforts – work in progress

Tongue of the Ocean

Principles:
Nowacek
St. Laurent



Clover2 (Sts – 2,3,4)
Acoustic Backscatter
depth (m)
100
200
300
400
500
600
700
800
900
−10 −9 −8 −7
log10 ε
0
4.91667
7.46667
time
−90 −80 −70 −60
db



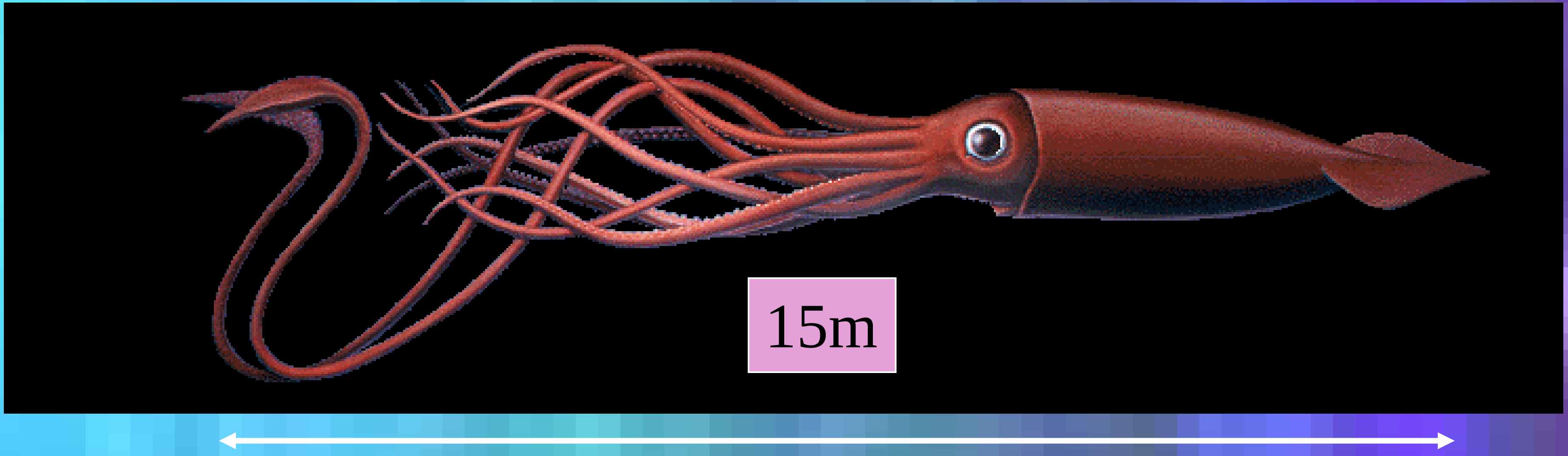
Fish School ↓
↑ Zooplankton Layer
Microprofiler ↑
Track
Depth (m)
50
100
150
1930
2000
2030
2100
13
14
16
17
18
20
21
23
24
26
28
30
31
33
35
37
38
39
40
41
43
1900
Time (h)
10^{-9} 10^{-4}
W/kg

- This is a poorly studied problem in turbulence
- There are at least three length scales in this problem
  1. individual
  2. inter-cloud separation
  3. cloud scale (actually two of these)

Catton, Webster and Yen (OS, 2008), in tank experiments, conclude krill aggregations define the effective length scale of their mixing.

Can the cloud mixing ‘efficiency’ be computed?
Can we apply to schools of fish?
What about direct fluid transport ala Dabiri/Katija?

But, beware: its not all zooplankton!



Q: How many giant squid are there?

A: 1 Billion

10^9 A. dux/3.5 x $10^8 km^2$ = 3 per square km

Run of the Mill TMR is easily 1W/kg
Swimming inefficiency of 10%
~30W/sqkm

Can we develop a swimming theory for cephalopods like that for thunniforms?

Mesonychoteuthis

Part II: Balanced Energetics

Turn on a global ocean model and what do you see?

http://www7320.nrlssc.navy.mil/GLBhycom1-12/navo/globalsss_nowcast_anim30d.gif

What do I mean by 'Balanced' Flow?

Many definitions exist, but all have diagnostic momentum equations.

$$\cancel{u_t} + uu_x + vu_y + wu_z + fv = -p_x$$

$$\cancel{v_t} + uv_x + vv_y + wv_z - fu = -p_y$$

The simplest example is geostrophy:

$$fv = p_x$$

$$fu = -p_y$$

Tend to large scales and subinertial frequencies.

More formally, balanced flows have a 'potential vorticity' that is diagnostically linked to the dynamical fields:

$$\nabla^2 p = q$$

<u>A consequence</u>: difficult for these flows to dissipate. Energetics budgets in models?

McKiver and Dritschel, 2006

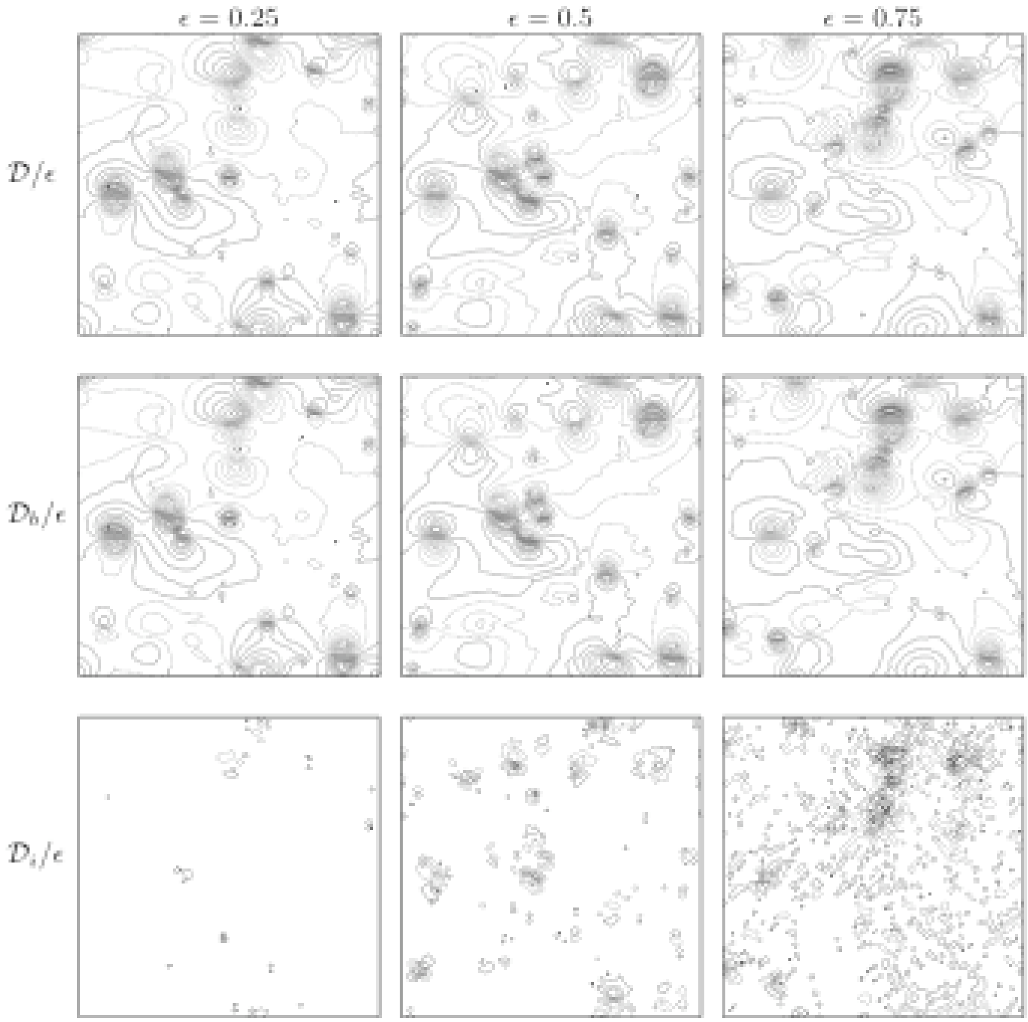
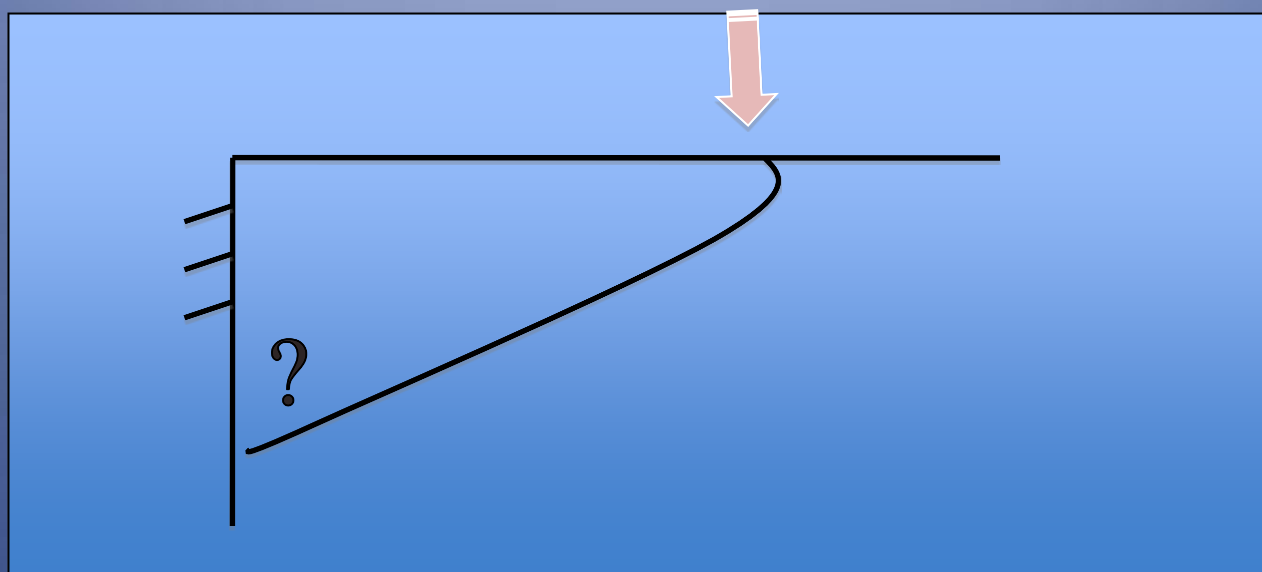


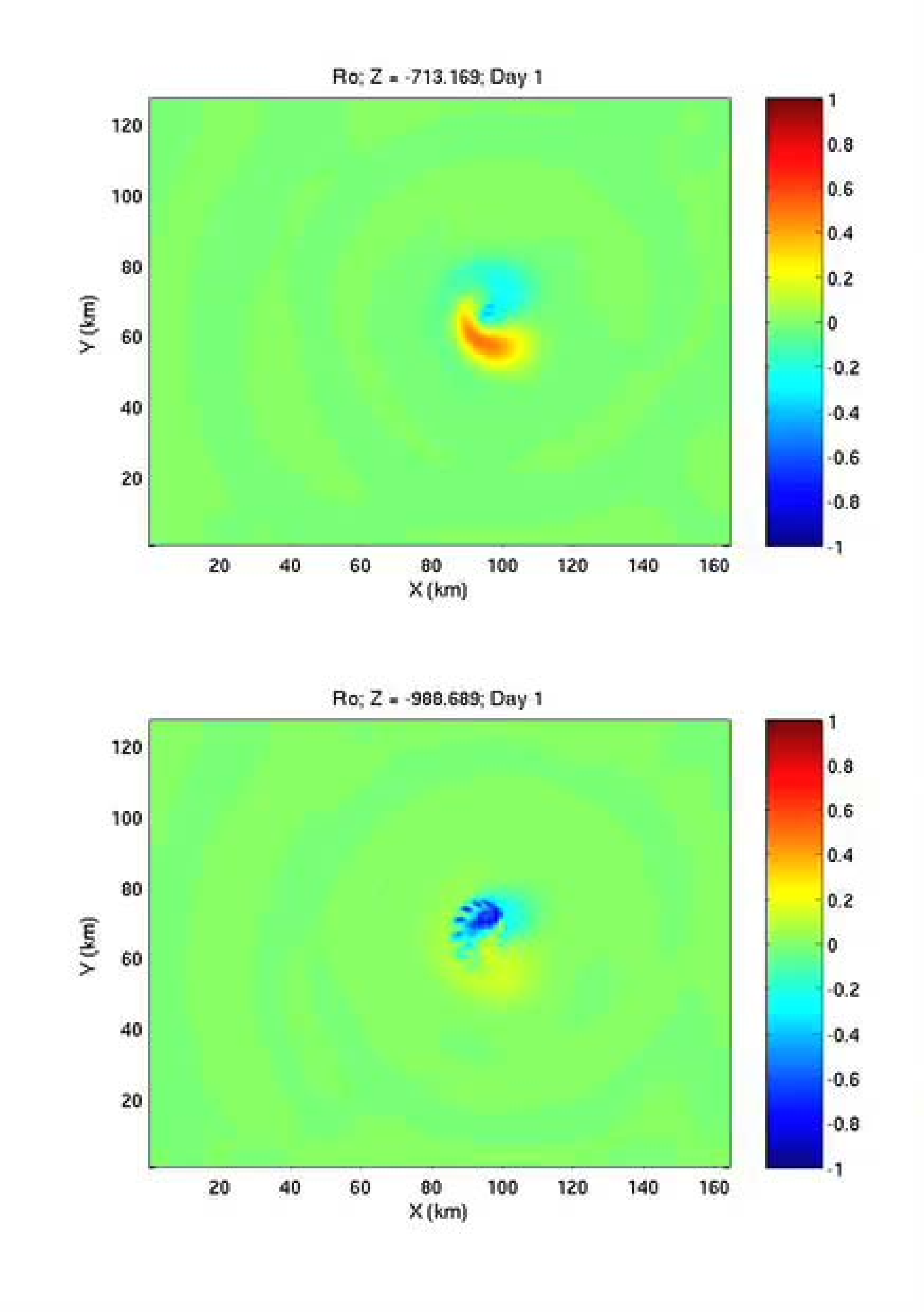
FIGURE 8. Comparison of the full (top), balanced (middle) and unbalanced (bottom) components of the displacement field (in a $y = 0$ cross section) at 20 QG time units for $c = 10$ and for the effective Rossby numbers indicated. The contour intervals for the full and balanced fields are $\Delta = 0.008$. The unbalanced contour intervals are 1/50th of the balanced contour intervals.

Comparable pv question:

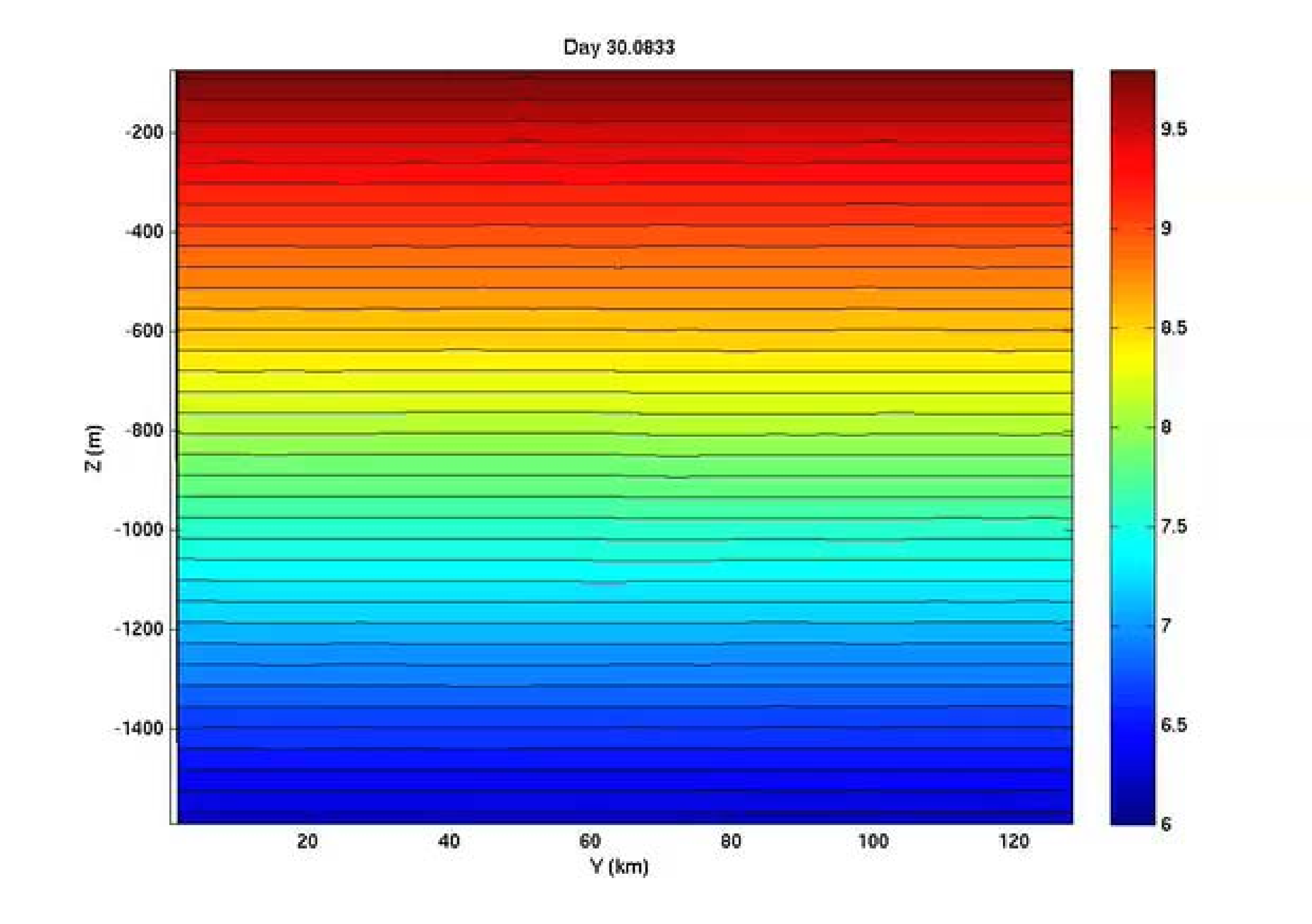


$$\frac{\partial}{\partial t} q = -\nabla \cdot \vec{F}; \; \vec{F} = \vec{u} q - X x \nabla \rho - \omega \vec{H}$$

What about external effects, eg topography



Temperature at western wall



A Theory of Wall Interaction

$$u_t + uu_x + vu_y - fv = -M_x$$

$$v_t + uv_x + vv_y + fu = -M_y$$

$$M = p + \rho gz$$

$$q_t + uq_x + vq_y = 0; \quad q = (f + v_x - u_y) / z_\rho$$

EOMs in density coordinates

At the wall, normal flow vanishes

$$\cancel{u_t} + \cancel{u u_x} + \cancel{v u_y} - fv = -M_x$$

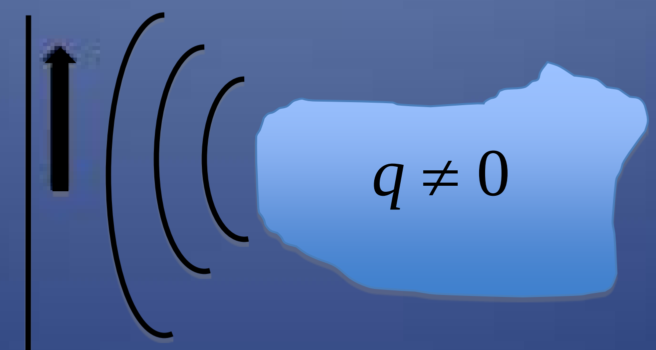
$$v_t + \cancel{u} v_x + v v_y + \cancel{fu} = -M_y$$

$$M_\rho = gz$$

$$M = p + \rho g z$$

$$q_t + \cancel{u} q_x + v q_y = 0; \quad q = (f + v_x - \cancel{u_y}) / z_\rho$$

u=0



$$f(v_g + v') = M_{gx} + M'_x$$

$$v'_t + \left(\frac{v'^2}{2}\right)_y + (v_g v')_y + M'_y = -v_{gt} - v_g v_{gy} - M_{gy}$$

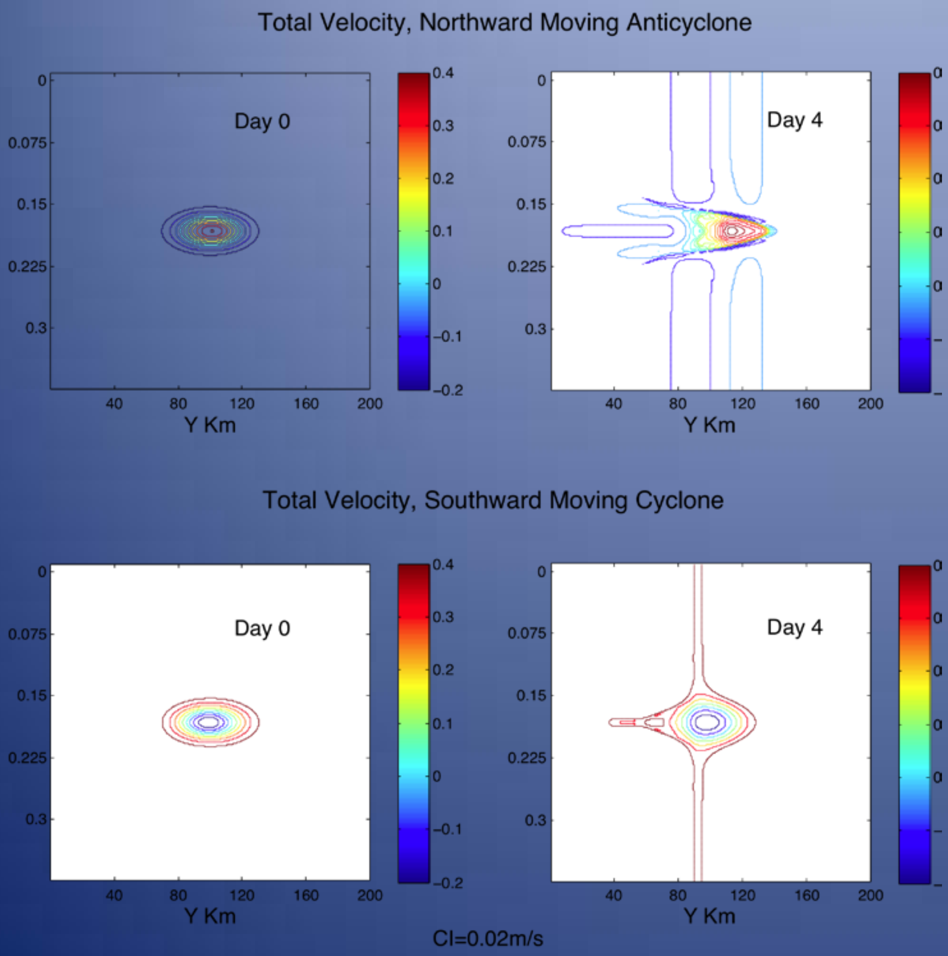
Exact pv solution

$$\frac{(f - v_x)}{z_\rho} = q(x,y,\rho,t) = q(0,y_o,\rho,0) = \frac{fg}{\overline{\overline{M}}_{\rho\rho}}$$

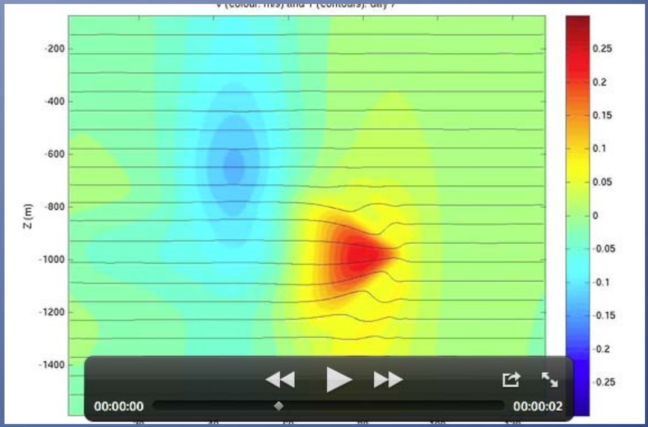
$$M'_{xx} = \frac{f^2}{\overline{\overline{M}}_{\rho\rho}} M'_{\rho\rho}$$

The only assumption: hydrostatics!

Solutions:



MITgcm



$$v'_t + \left(\frac{v'^2}{2}\right)_y + (v_g v')_y + M'_y = -v_{gt} - v_g v_{gy} - M_{gy}$$

$$M'_{xx} = \frac{f^2}{M_{\rho\rho}} M'_{\rho\rho}$$

When linearized, above set has yielded much useful information about quasi-1d cases:

$$v_g = v_g(\rho)$$

$$v_g = v_g(y)$$

and the interesting nonlinear eigenvalue problem

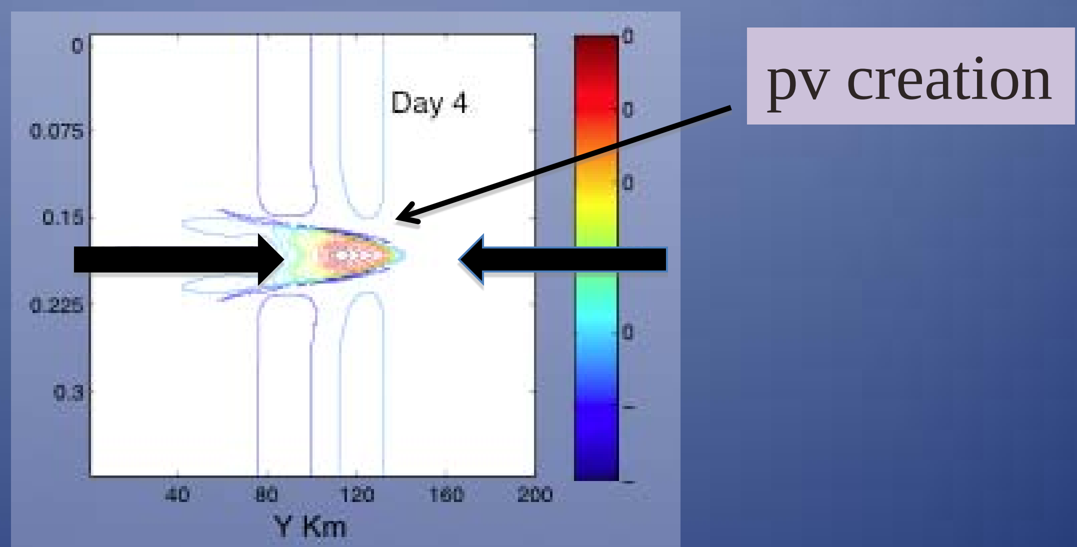
$$M'_{\rho\rho} + \lambda^2 \frac{1}{\sqrt{1 - \frac{2M'}{c^2}}} = \lambda^2$$

$$M'_\rho = gz'(x, y, \rho, t) = 0 \text{ at } \rho = \rho_b,\ \rho_s$$

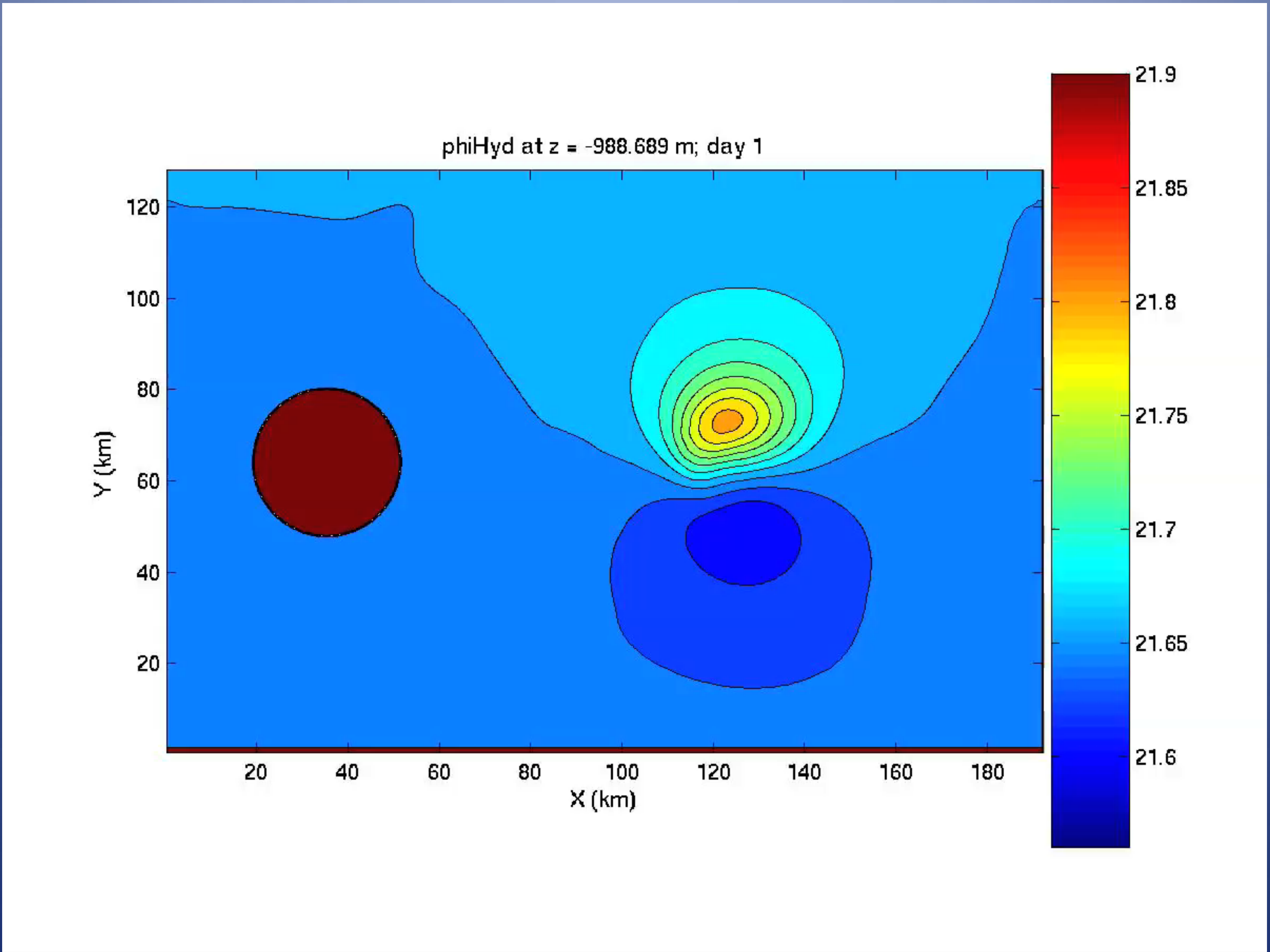
$$v'_t + \left(\frac{v'^2}{2}\right)_y + (v_g v')_y + M'_y = -v_{gt} - v_g v_{gy} - M_{gy}$$

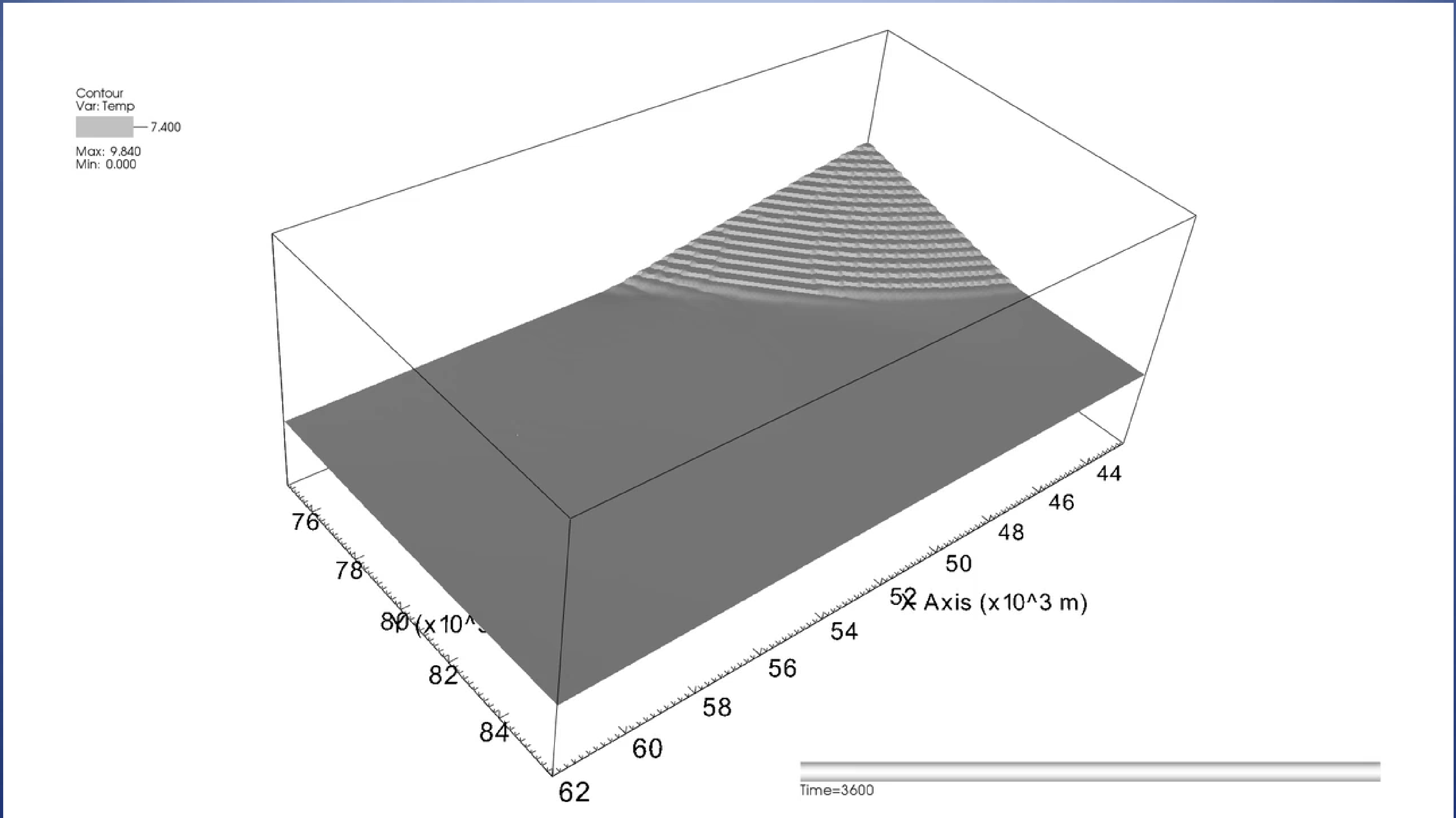
$$M'_{xx} = \frac{f^2}{M_{\rho\rho}} M'_{\rho\rho}$$

Also shows need for non-hydrostatic parameterization



Generalization to ‘realistic’ topography?

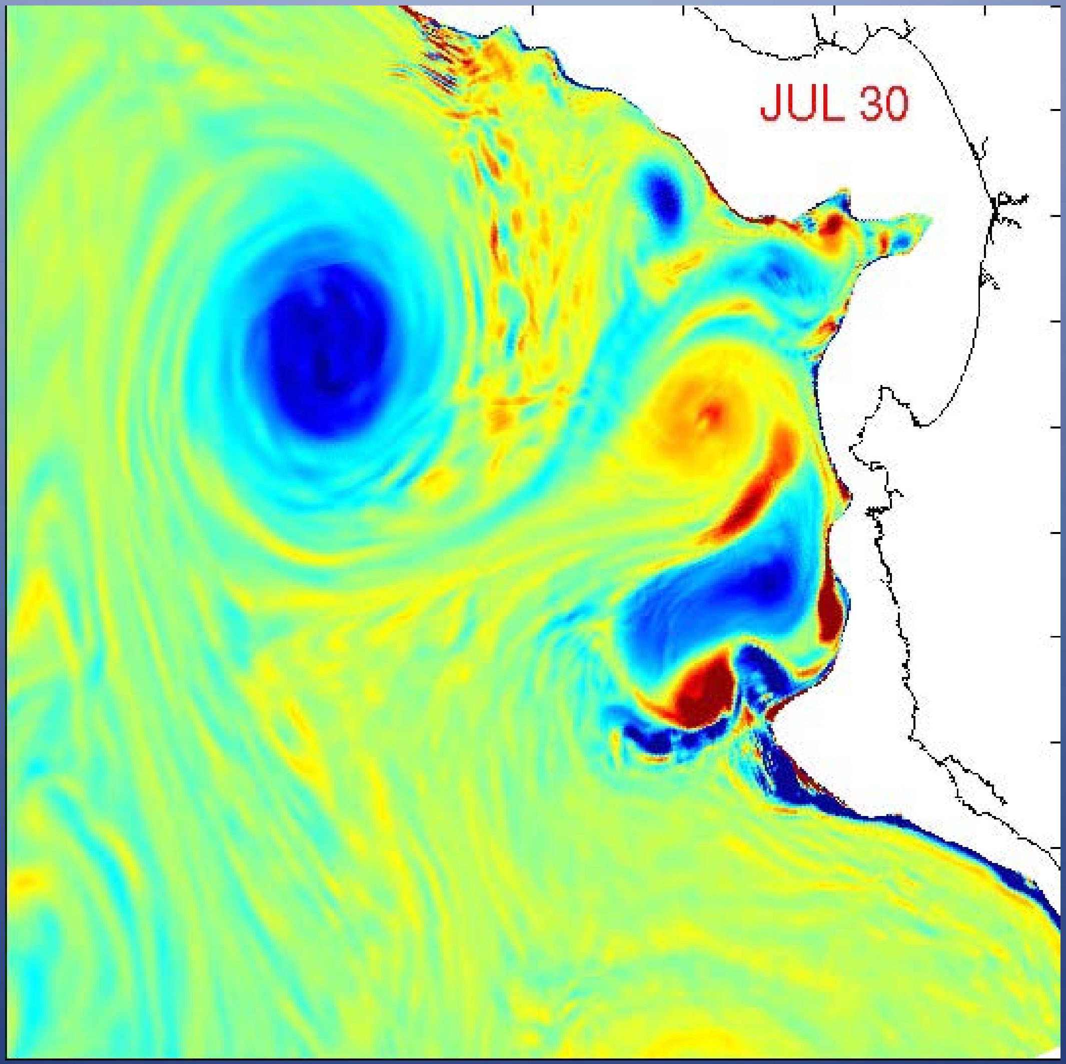




There is no theory for this case.

Connections to models

An ultra-fine embedded solution for Monterey Bay



Summary: The ocean is extremely conservative, but:

- non-conservative processes cannot be ignored for climate modeling purposes
  - set water mass distributions and the energy levels of the balanced flows
- are extremely subtle to capture correctly
- certainly involve processes that are poorly understood AND parameterized in suspect forms in all current climate models

Two examples:

Mixing by clouds of smallish migrators and large unusually shaped organisms

Topography - Candidate equation gives hopes for parameterization of pv fluxes

- Generalization to more complex topographies and turbulent settings?