A Progress Report on First Year Research Activities

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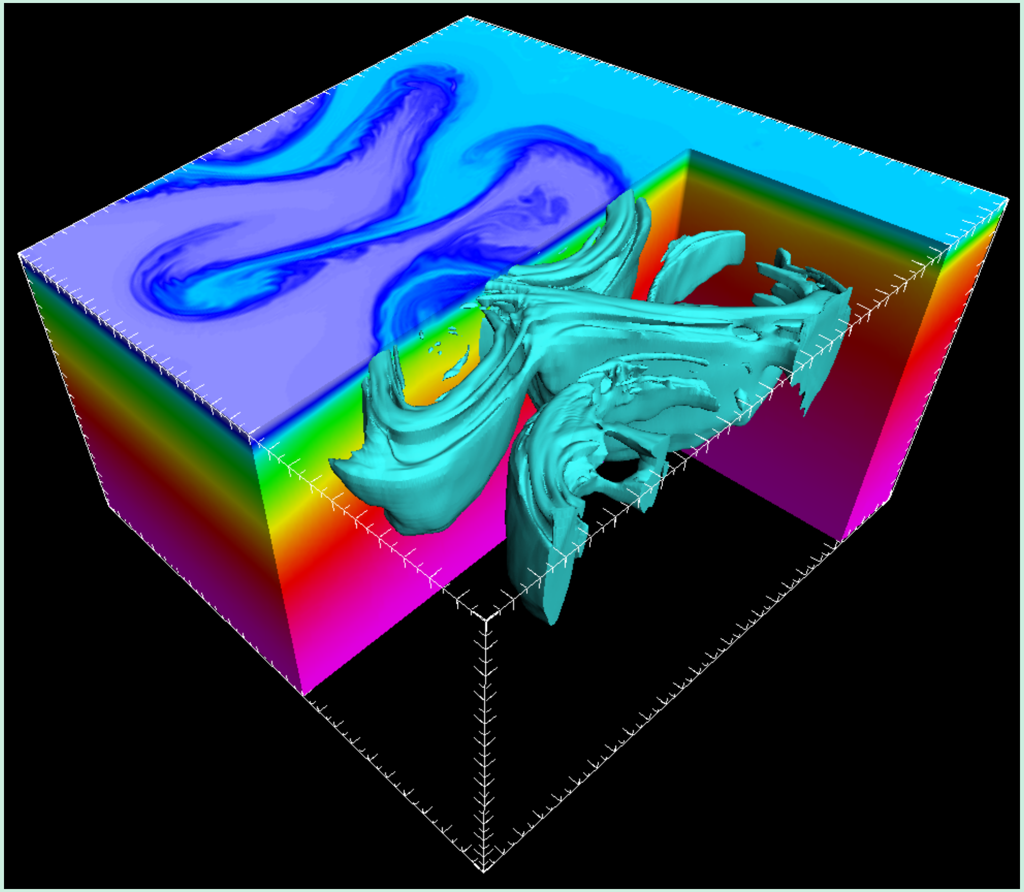


Ocean 3D+1 MURI Meeting, Wilmington/DE, January 2012

Outline:

1) Development of a 3D FTLE code (with Childs, Krishnan, Garth, LLNL)

2) 3D stratified (non-rotating) turbulence problems (with Poje, CUNY, + NSF)

3) Rotating can (not stratified) problem (with Pratt, Rypina, WHOI)

4) Baroclinic instability (rotation+ stratification, with Poje, CUNY, + LATMIX)

5) Realistic HYCOM Gulf Stream eddies (with Chang, Haza, RSMAS)

6) A recent dispersion field experiment (with Griffa + NURC, CNR)

7) Publications in the works, fully and partly funded by 3D+1 MURI

1) Development of a 3D FTLE code (Childs, Krishnan, Garth, LLBL)

(a) Works with CFD (DNS/LES) code Nek5000 and fully integrated with a visualization software (VisIt, https://wci.llnl.gov/codes/visit/)

(b) Parallel version seems to work, as of mid December 2011, but not tested extensively yet. This is needed for large meshes.

Limitations:

(c) The main limitation is that the code is implemented for forward particle advection at this point; backward is a high priority.

(d) Not been applied to any other model output yet; should be possible.

2) 3D stratified turbulence problems (with Poje, CUNY)

(a) FTLE code is tested for two problems first:

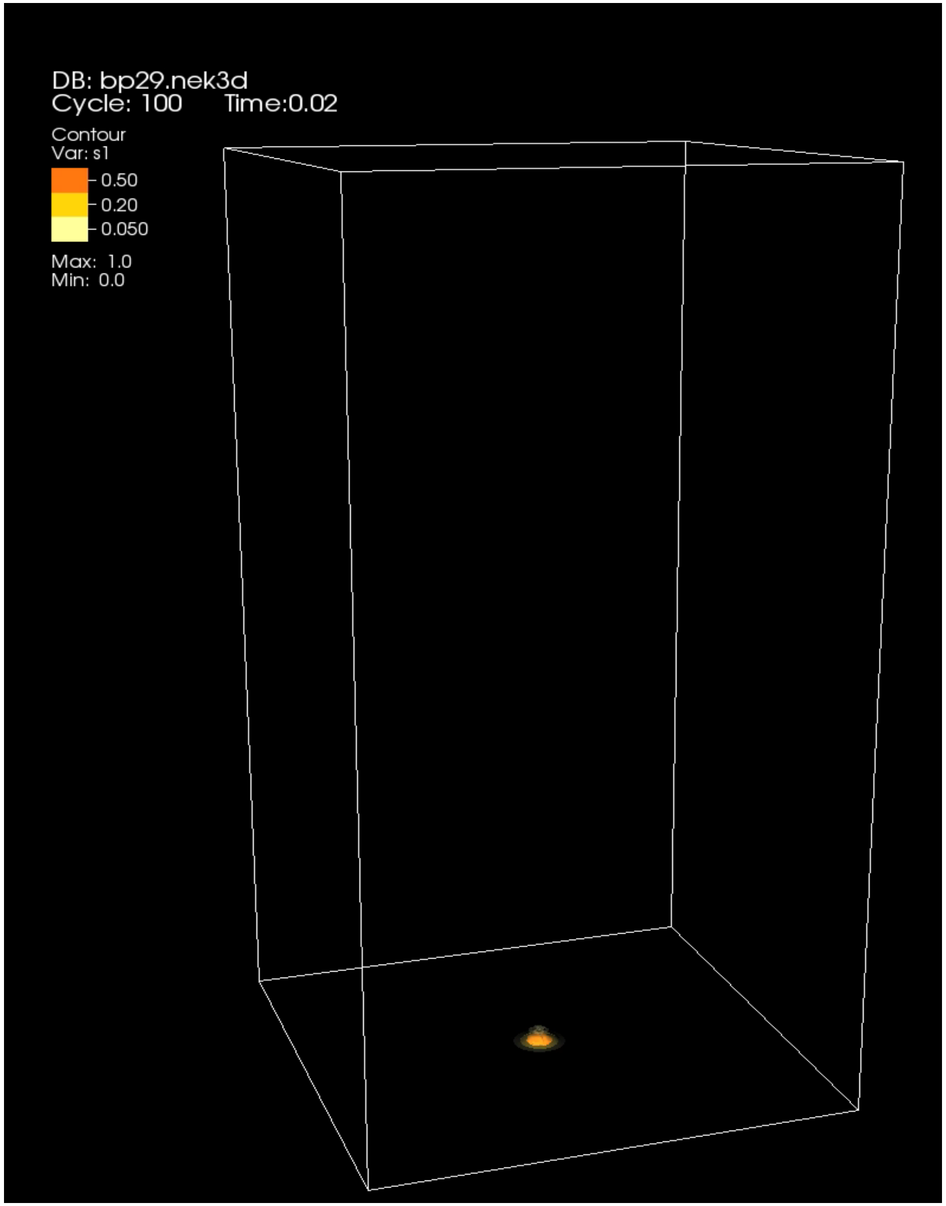
* *buoyant plume and*
* *lock exchange*

(b) Both problems include active and/or passive tracer, which is useful to make some sense of what the FTLE is illustrating.

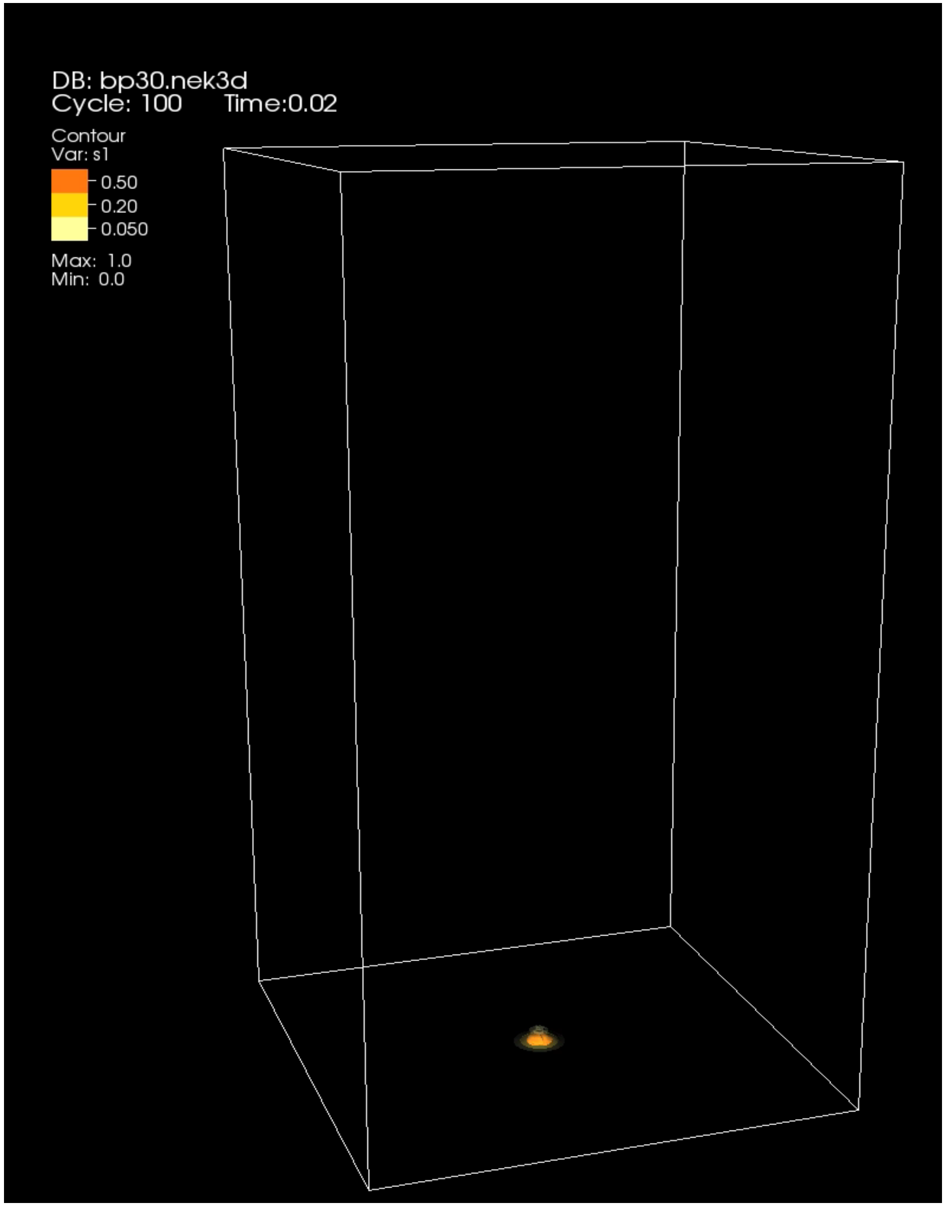
(c) Also to explore the fundamental question whether LCS is a useful diagnostic in 3D turbulence (as opposed to geophysical turbulence in which knowledge about transport barriers is shown to be quite useful in several ways).

Buoyant Plumes: 22×10^6 mesh points (not small…)

Homogeneous: ρ'=C

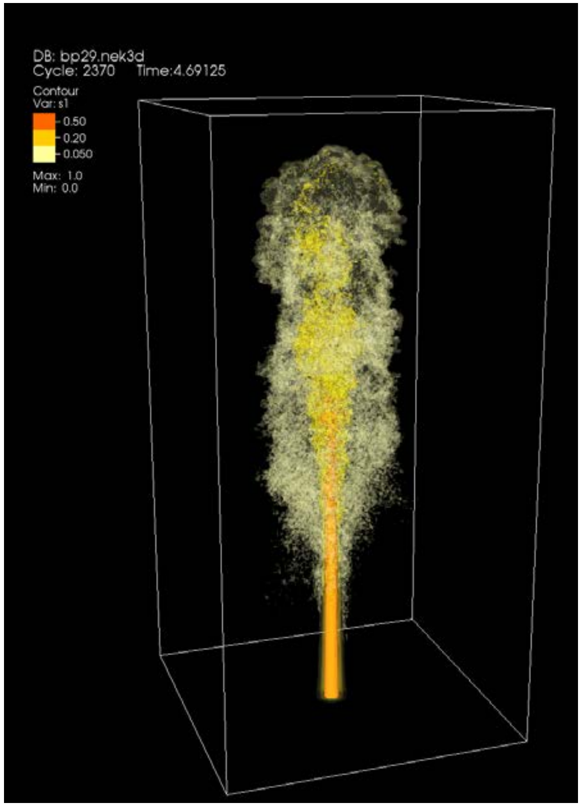


Stratified: ρ'≠C

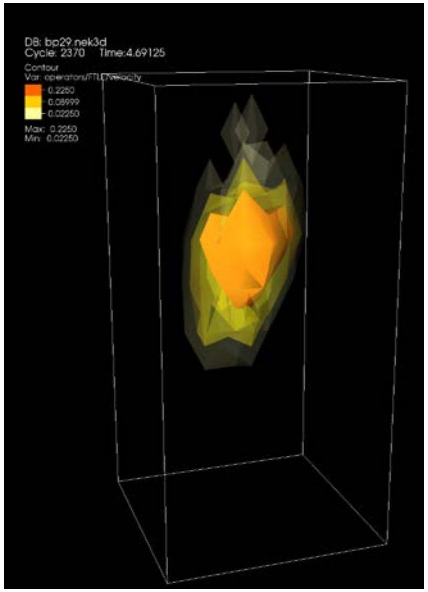


How many particles are needed for the FTLE?

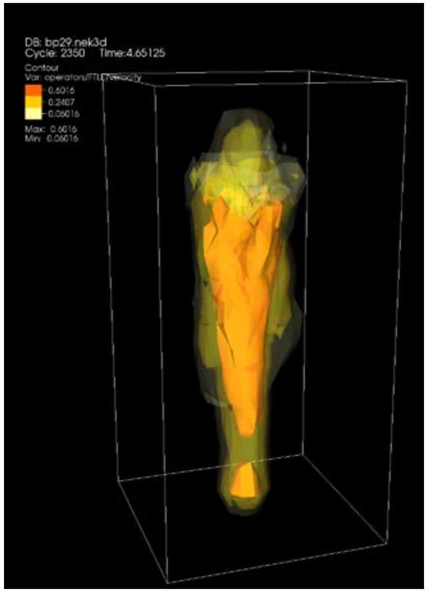
tracer



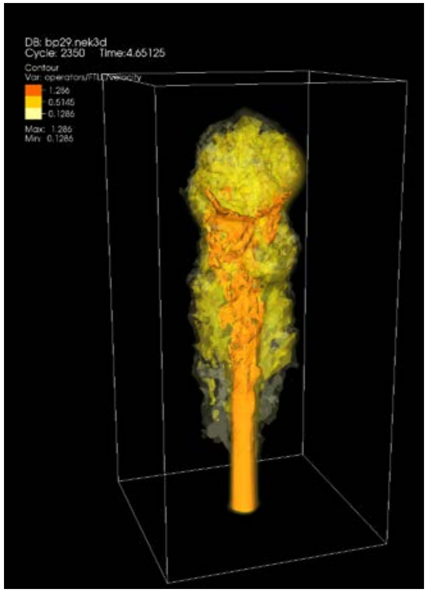
10^3 particles



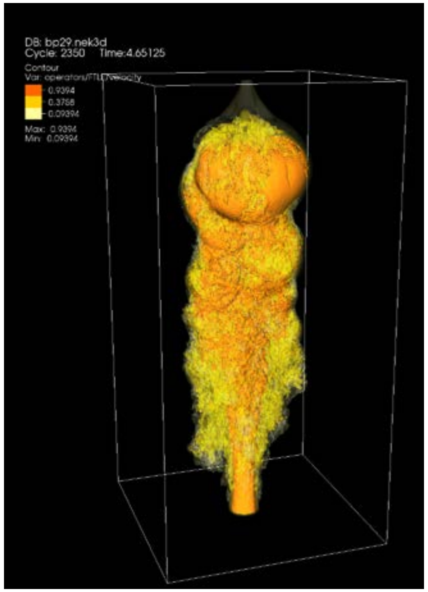
$8x10^3$ particles



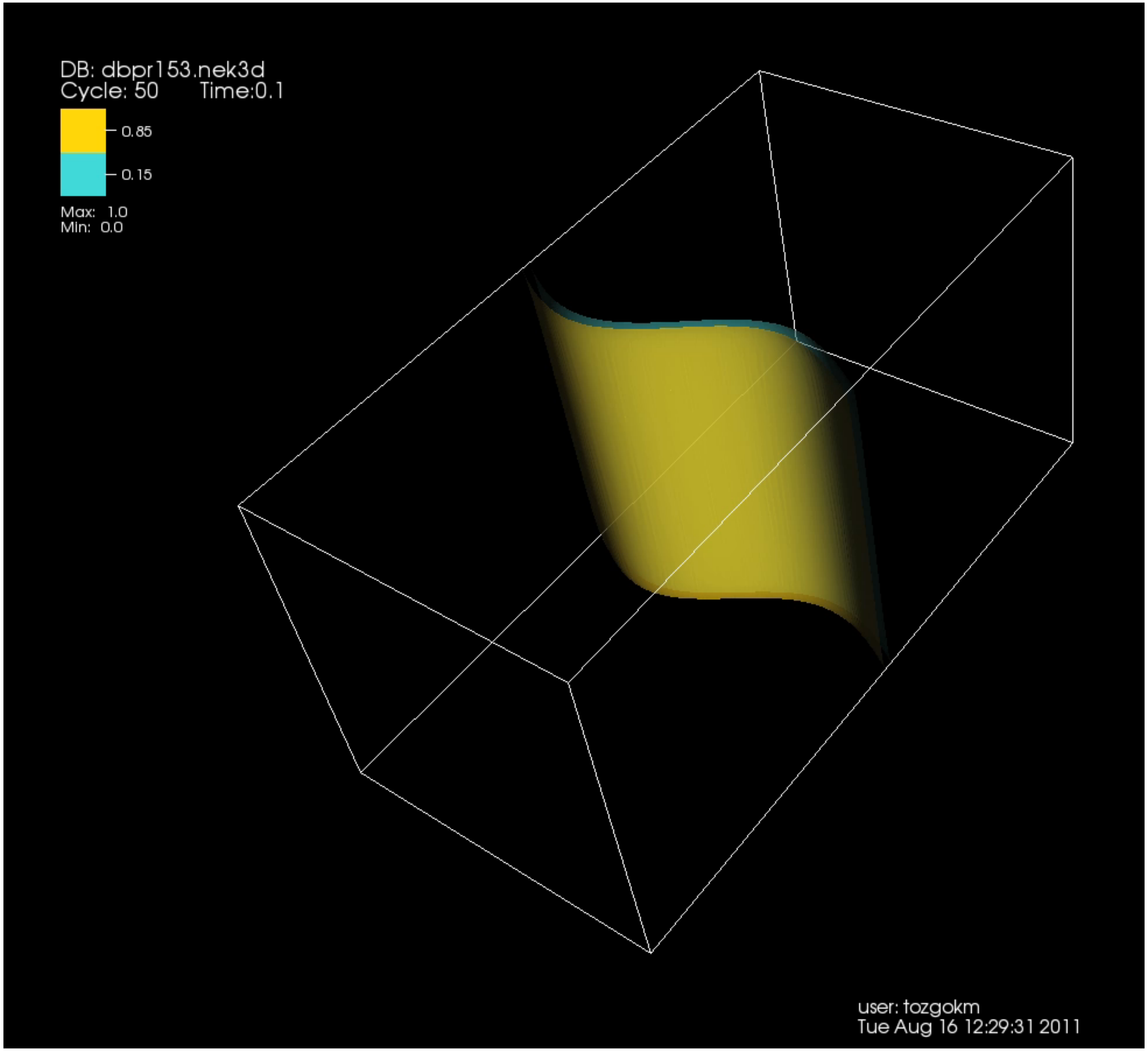
$25x10^4$ particles



$7x10^6$ particles

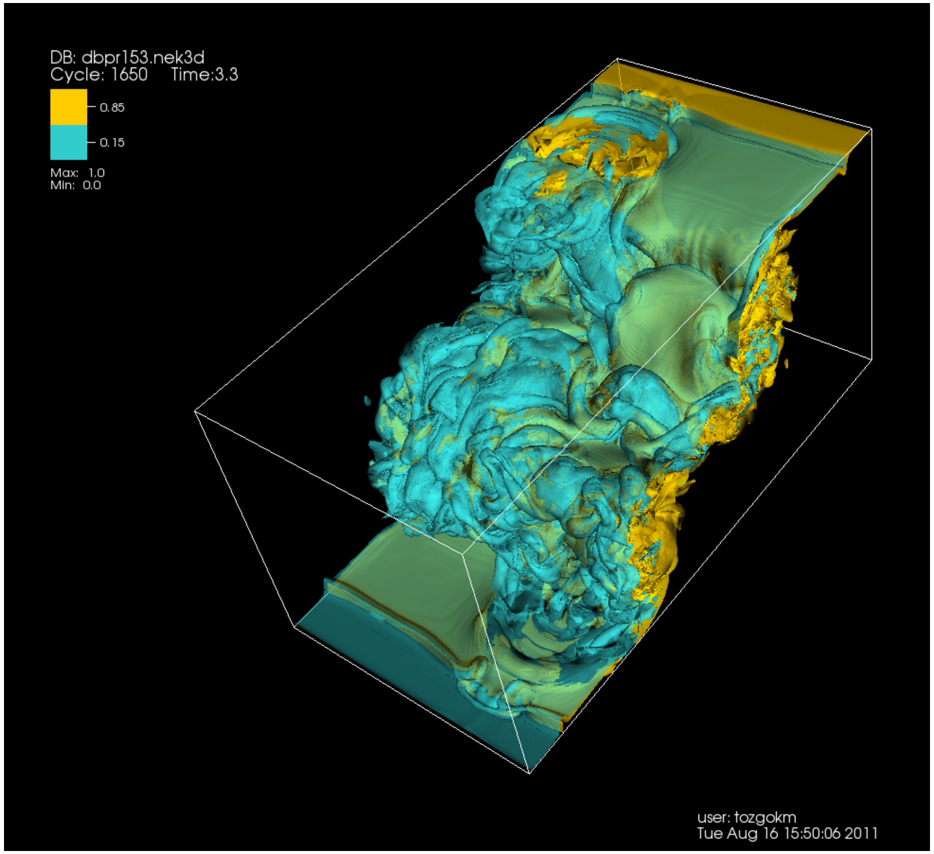


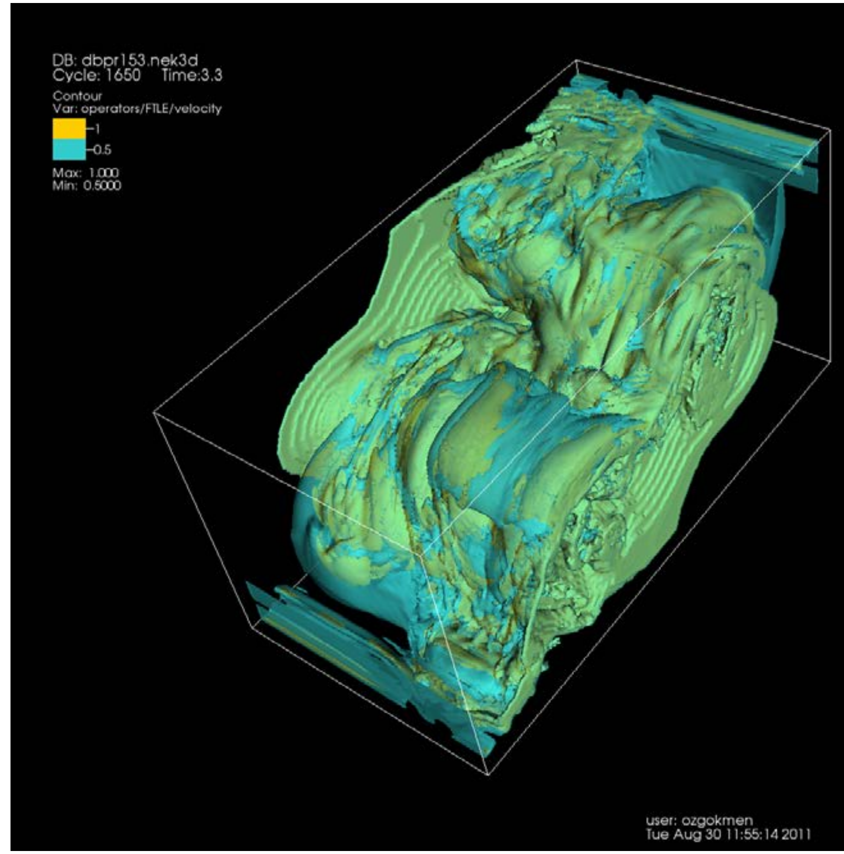
Lock-exchange problem, 50 million mesh points:



Density perturbation field:

FTLE, $2x10^6$ particles:



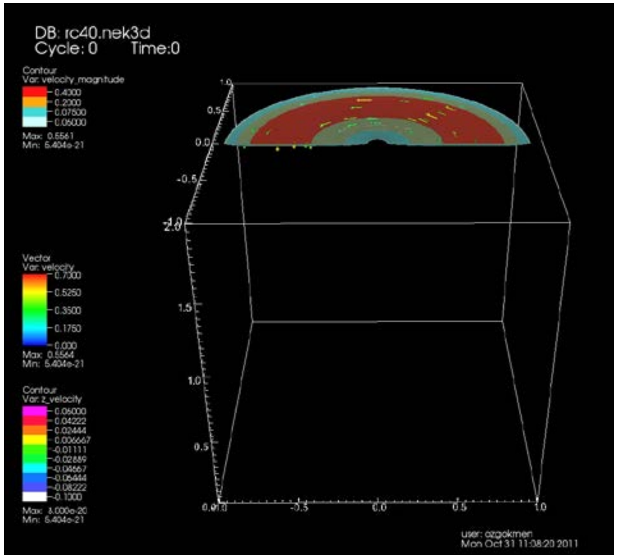


- FTLE seems much smoother than the density perturbation field; large eddies controlling the mixing?

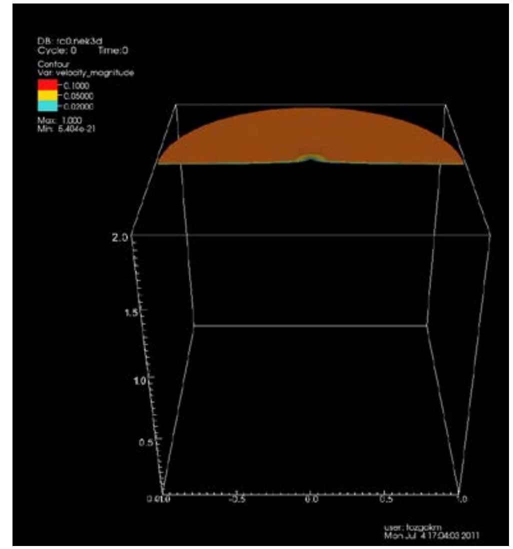
- Periodic bcs are not communicated to the FTLE code. Less of an issue with no-slip, free-slip bcs. Can be overcome by launching particles away from the boundaries, but still an issue at long T.

3) Rotating can problem (with Pratt, Rypina, WHOI):

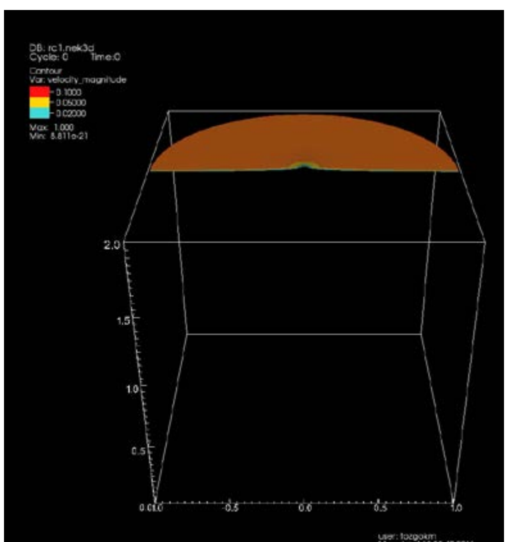
rc40, Re=116, Ro=∞:



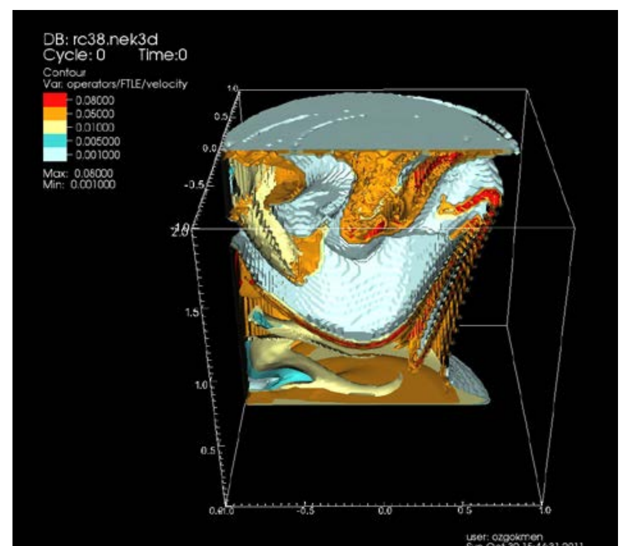
rc0, Re=1852, Ro=∞: vortex breakdown



rc1, Re=3750, Ro=∞:

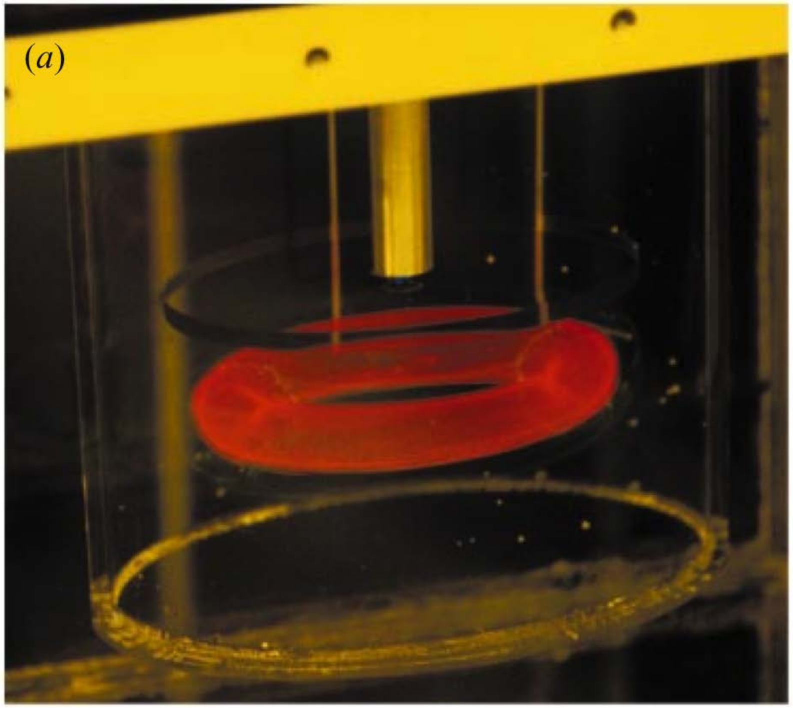


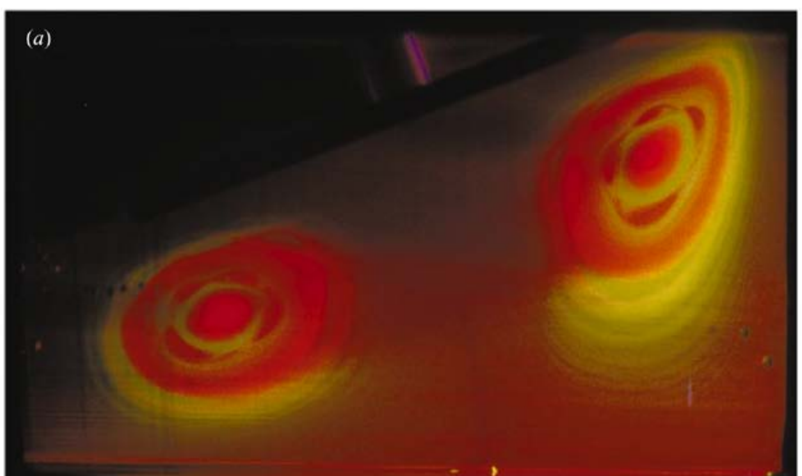
rc38, Re=116, time-dependent lid forcing



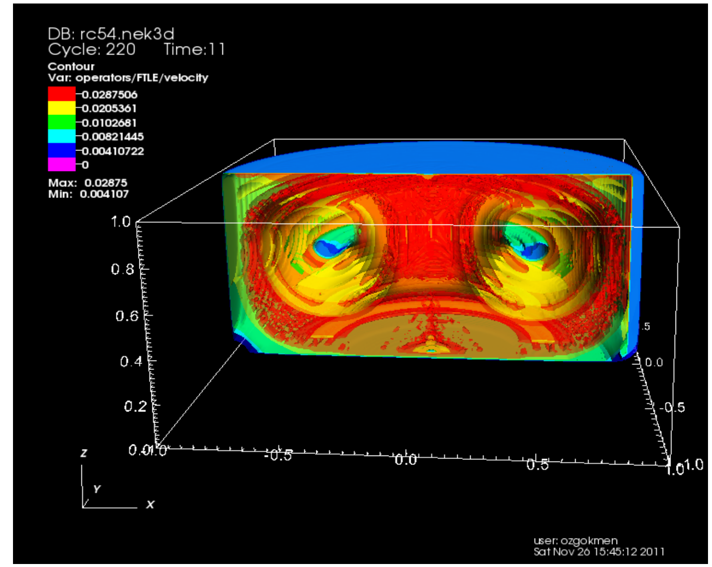
Low Re, steady cases:

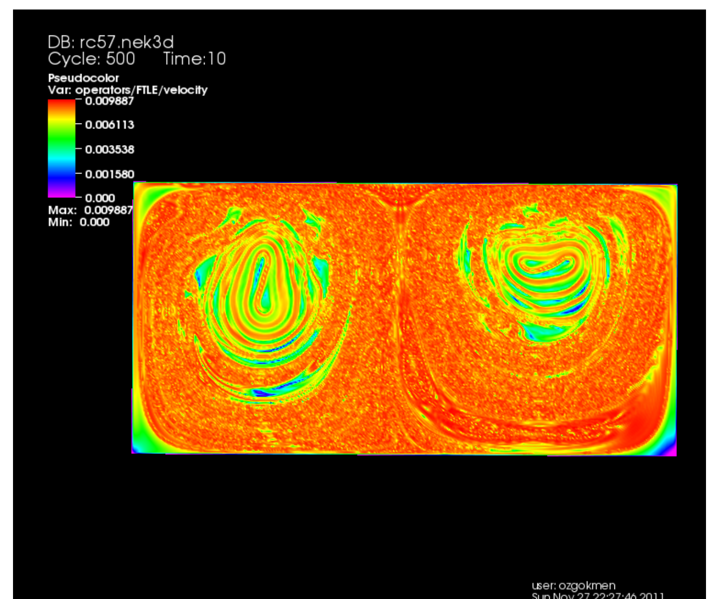
Fountain et al. (2000): (top) period-1 torus, (bottom) higher period tori when perturbed





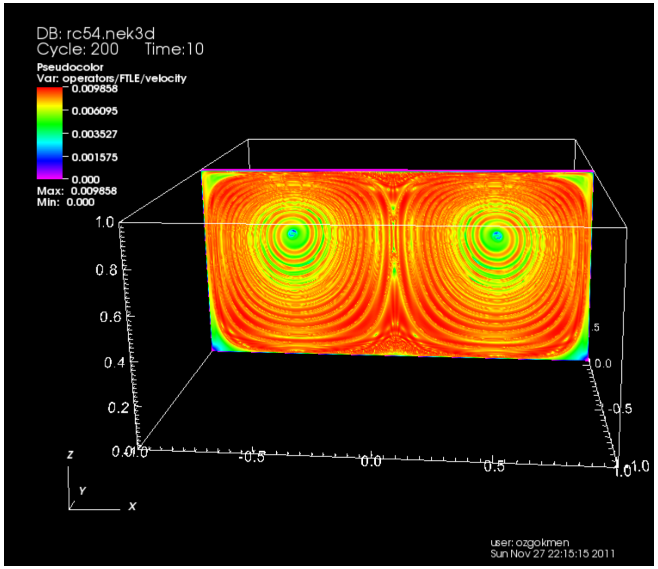
Without (top) and with (bottom) off-axial steady perturbation:



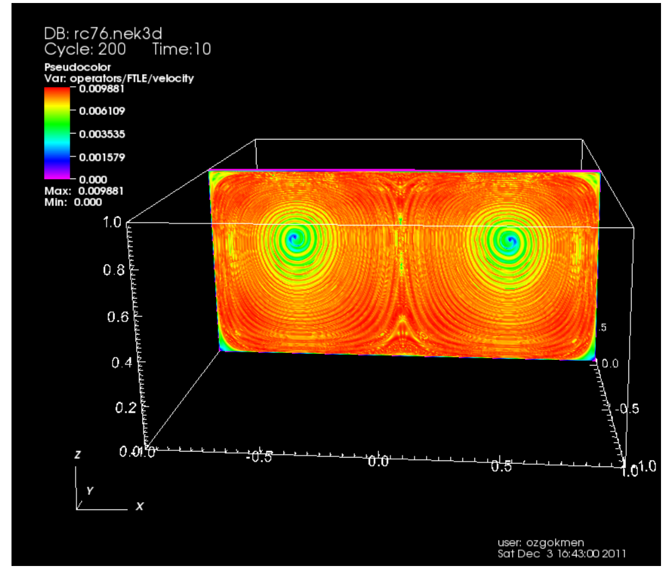


Effect of rotation:

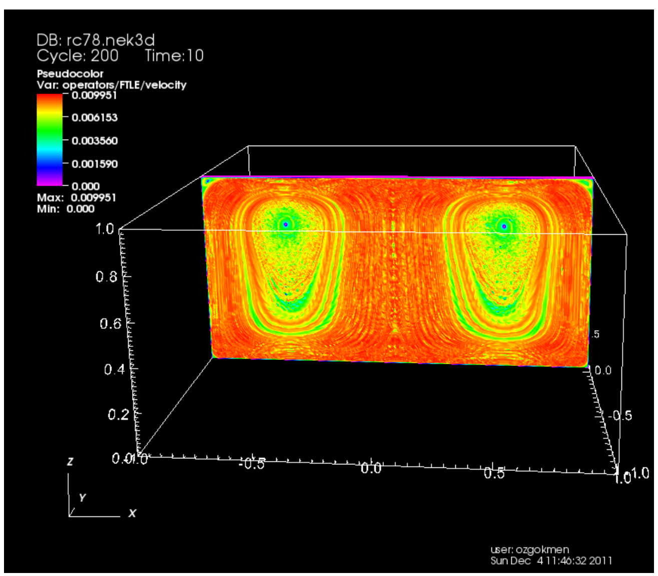
rc54, Re=20, Ro=∞



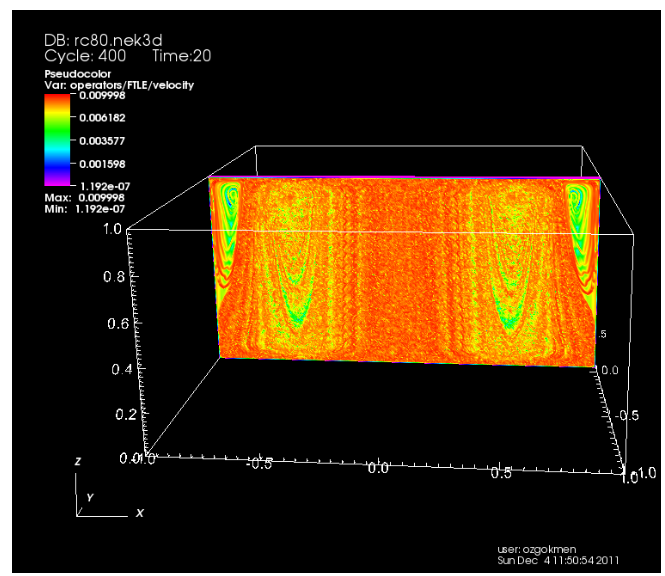
rc76, Re=20, Ro=1



rc78, Re=20, Ro=0.1

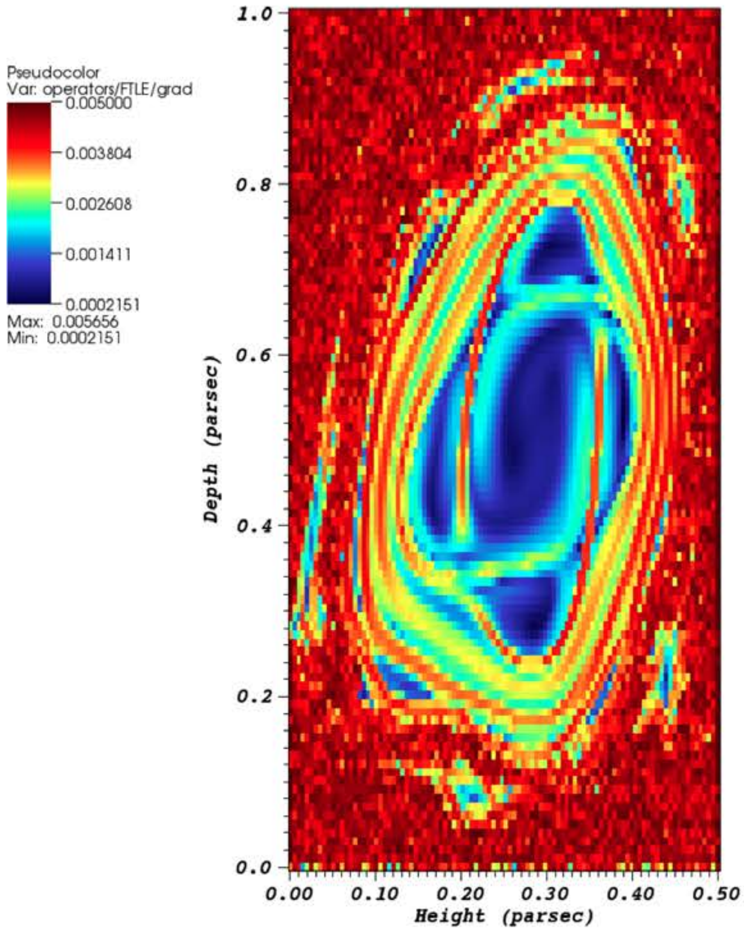


rc80, Re=200, Ro=0.1

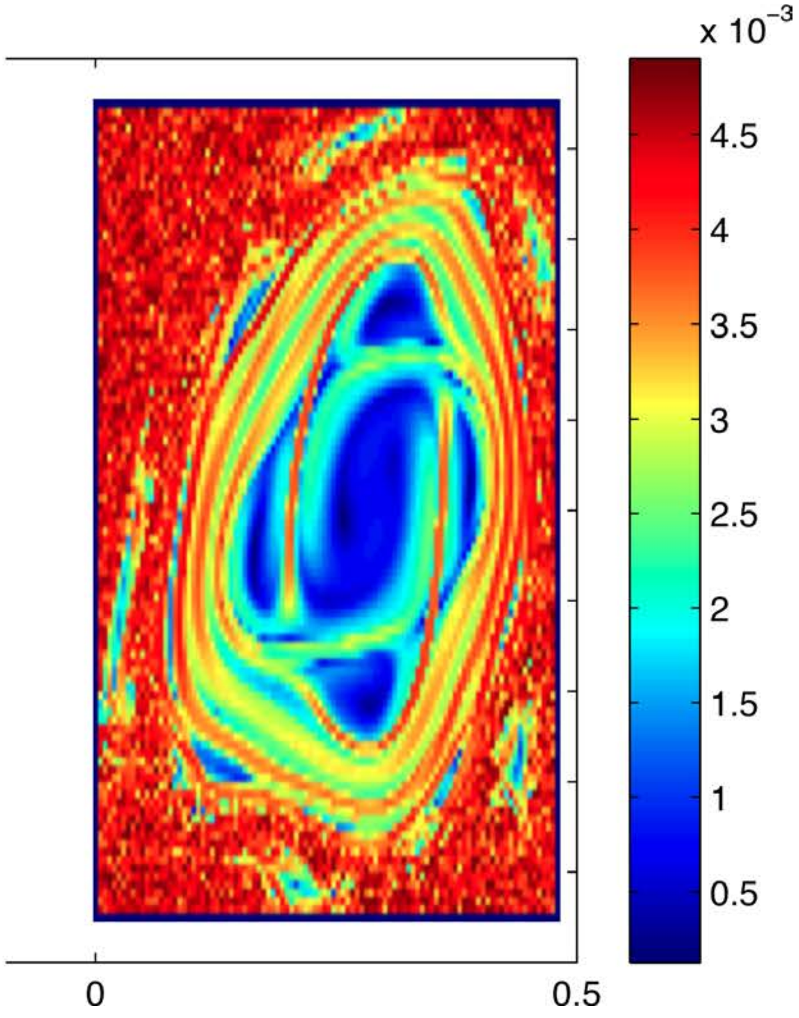


Comparison of FTLEs for Larry/Irina's analytical rotating tank section*:*

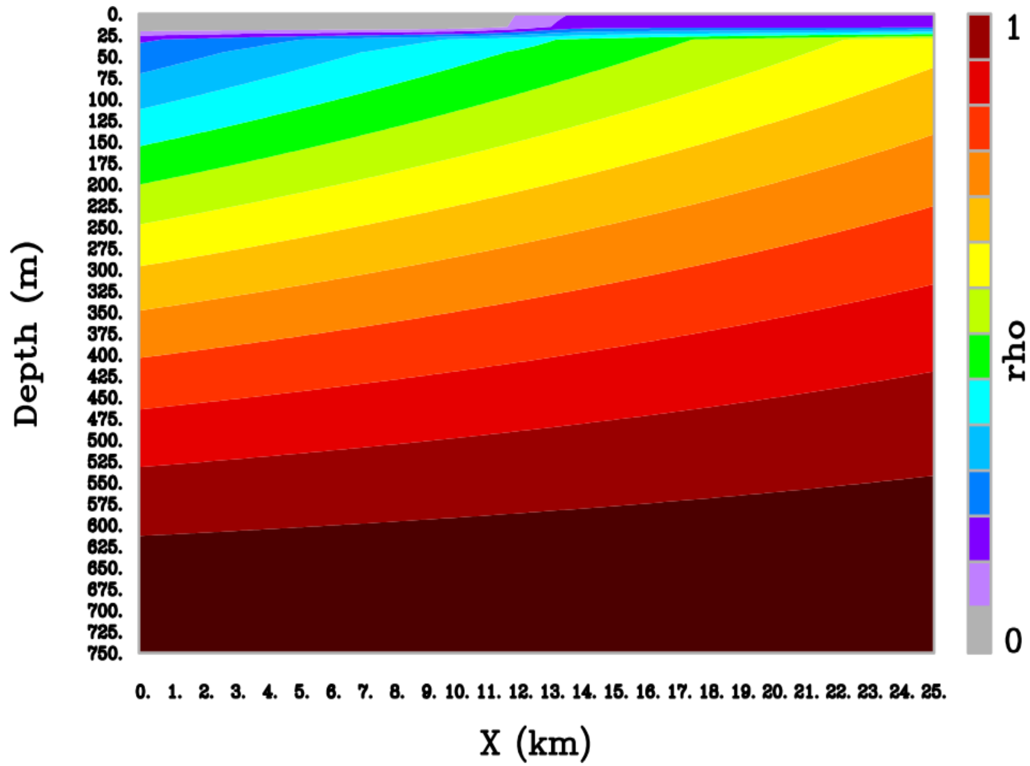
Visit FTLE code*:*



Irina's FTLE code*:*



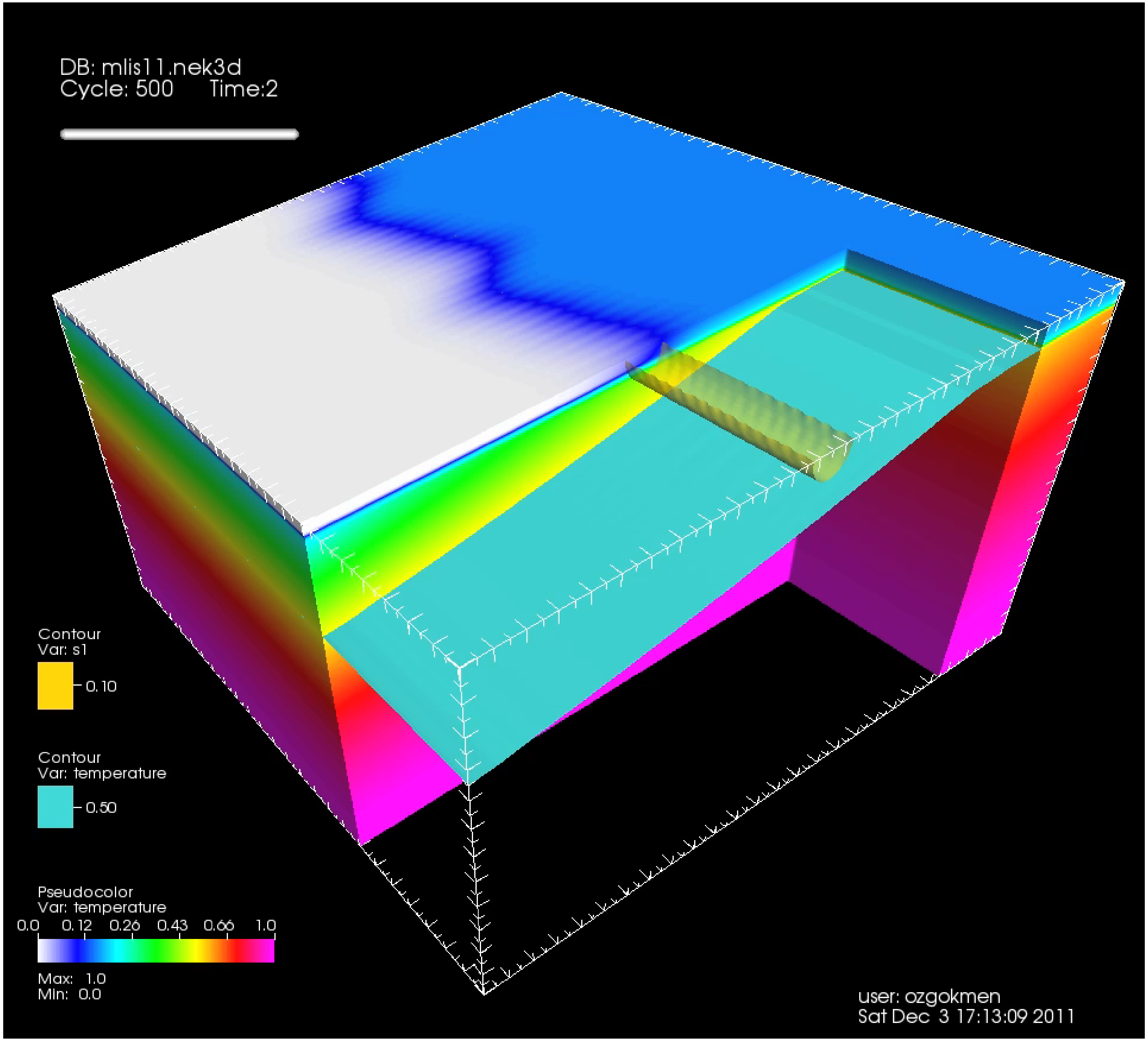
4) Multi-Scale (Submesoscale/Mesoscale) Baroclinic Instability Problem:



* Domain: 25 km x 25 km x 0.75 km

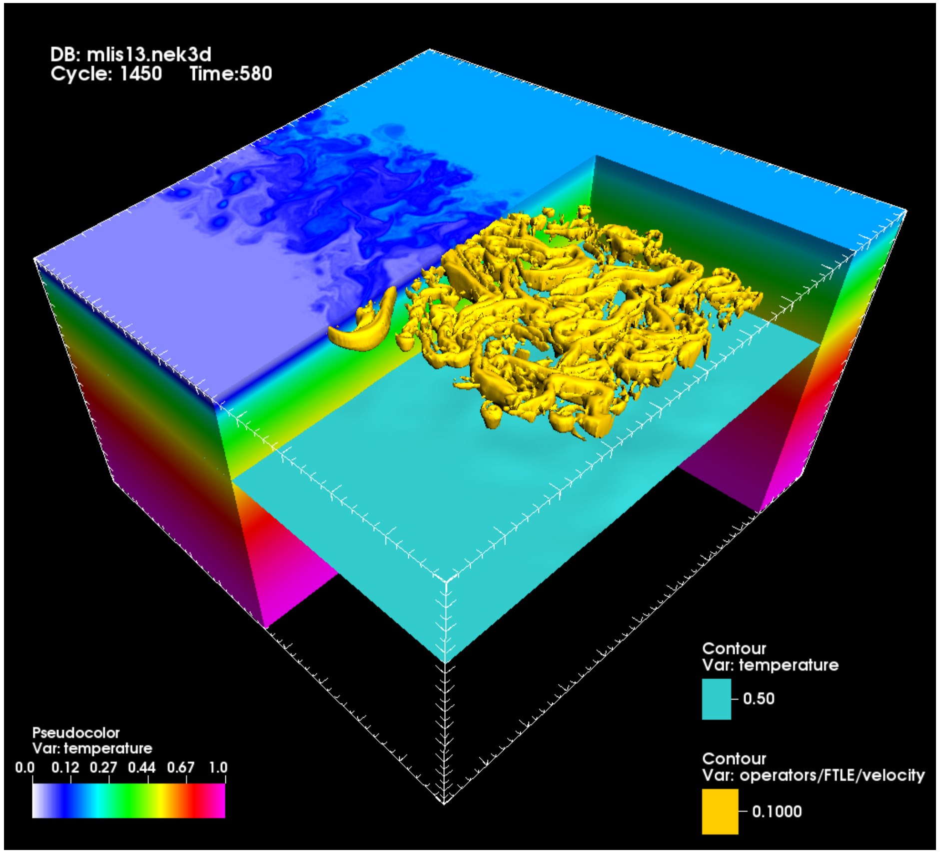
* Shallow (25 m) weak ML front to get 10x scale separation between MLI and deep eddies; no winds or other forcing

* 22×10^6 mesh points (dx=17 m, dz=0.75 m near surface), 2×10^5 time steps
Compute time: 3 days on 256 CPUs (18k CPU hours) of Cray XE6m

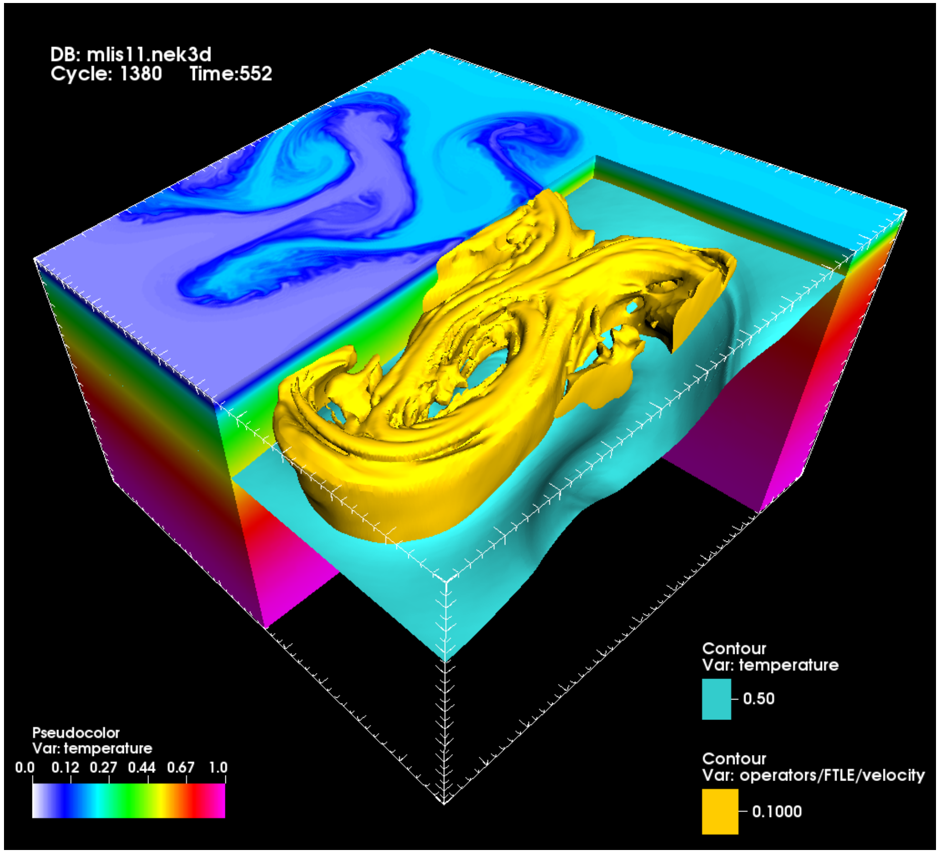

DB: mlis11.nek3d
Cycle: 500 Time:2
Contour
Var: s1
0.10
Contour
Var: temperature
0.50
Pseudocolor
Var: temperature
0.0 0.12 0.26 0.43 0.66 1.0
Max: 1.0
Min: 0.0
user: ozgokmen
Sat Dec 3 17:13:09 2011

3D FTLE:

Submesoscale phase:

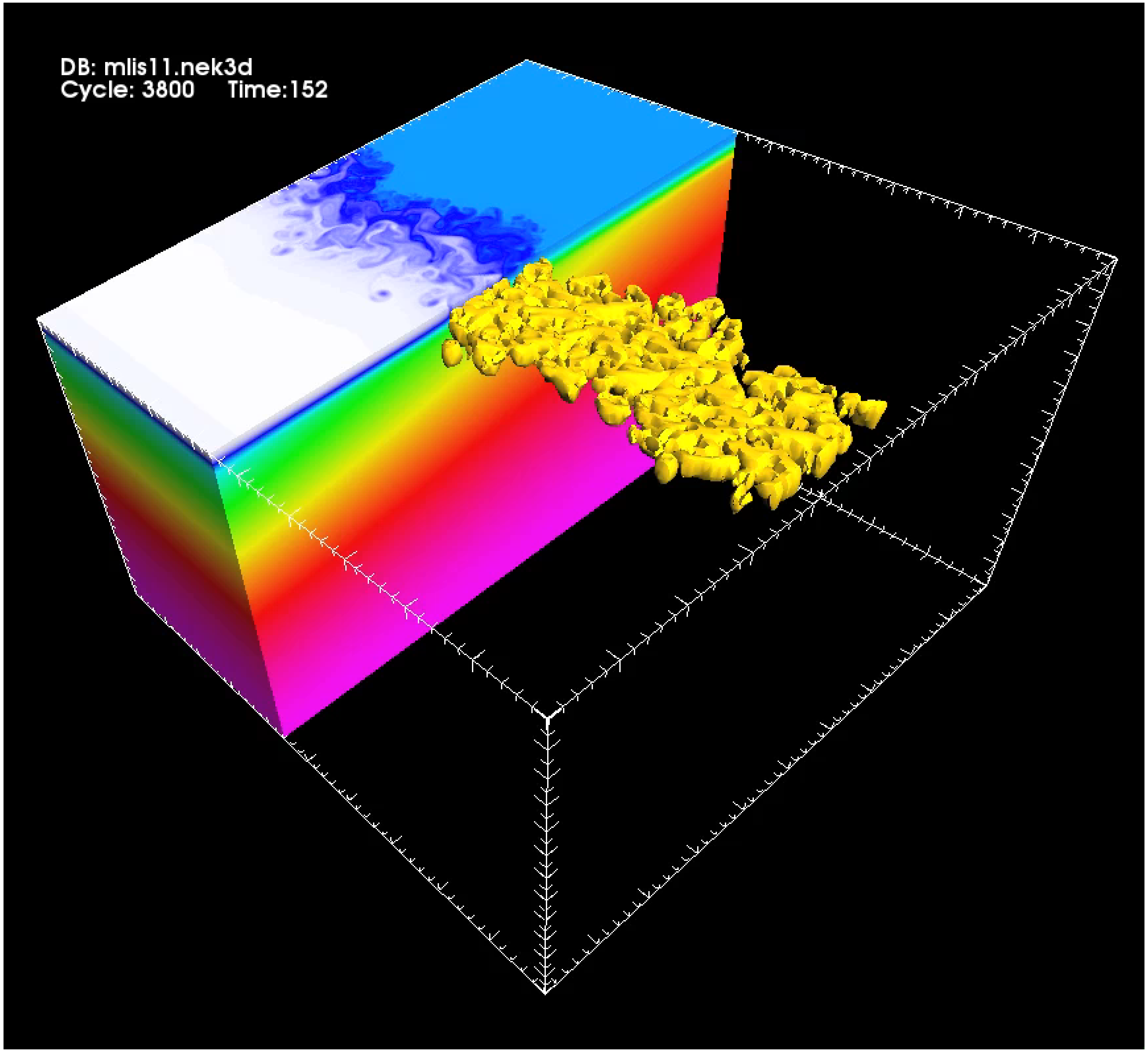


Mesoscale phase:



Clearly different turbulent coherent structures:
shallow submesoscale eddies vs deep mesoscale features…

Transformation in the FTLE over 2 months of flow evolution:



5) HYCOM Gulf Stream eddies (with Chang, Haza, RSMAS)

(a) A separate FSLE routine is used with forward/backward integration.

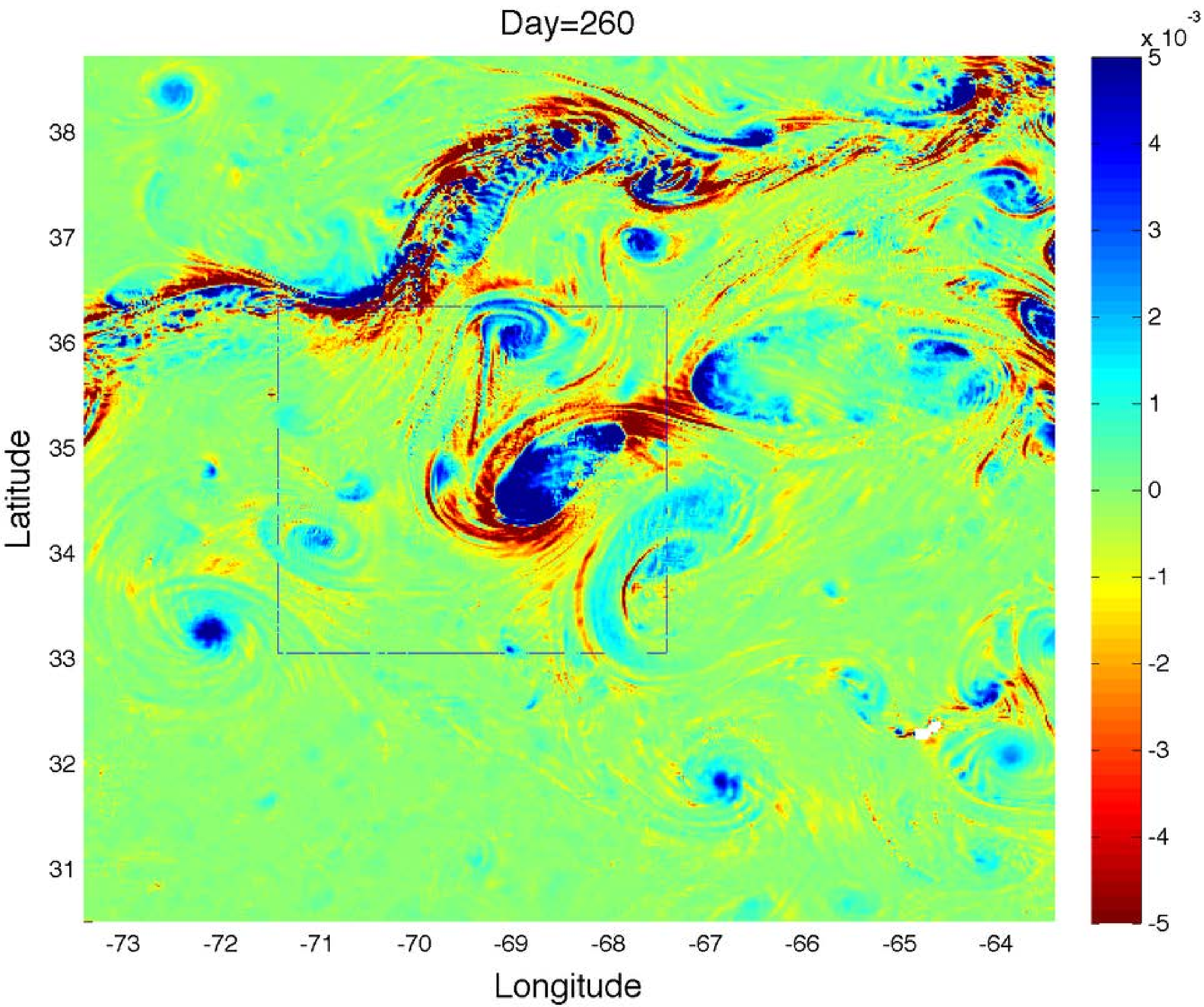
(b) Outputs from 1/48 deg HYCOM are used, below the z-coordinate mixed layer, which has a lot of under-resolved submesoscale features. (These were initially removed using a spatial filter.)

(c) Particles are advected in isopycnic layers and then mapped to z-coordinates.

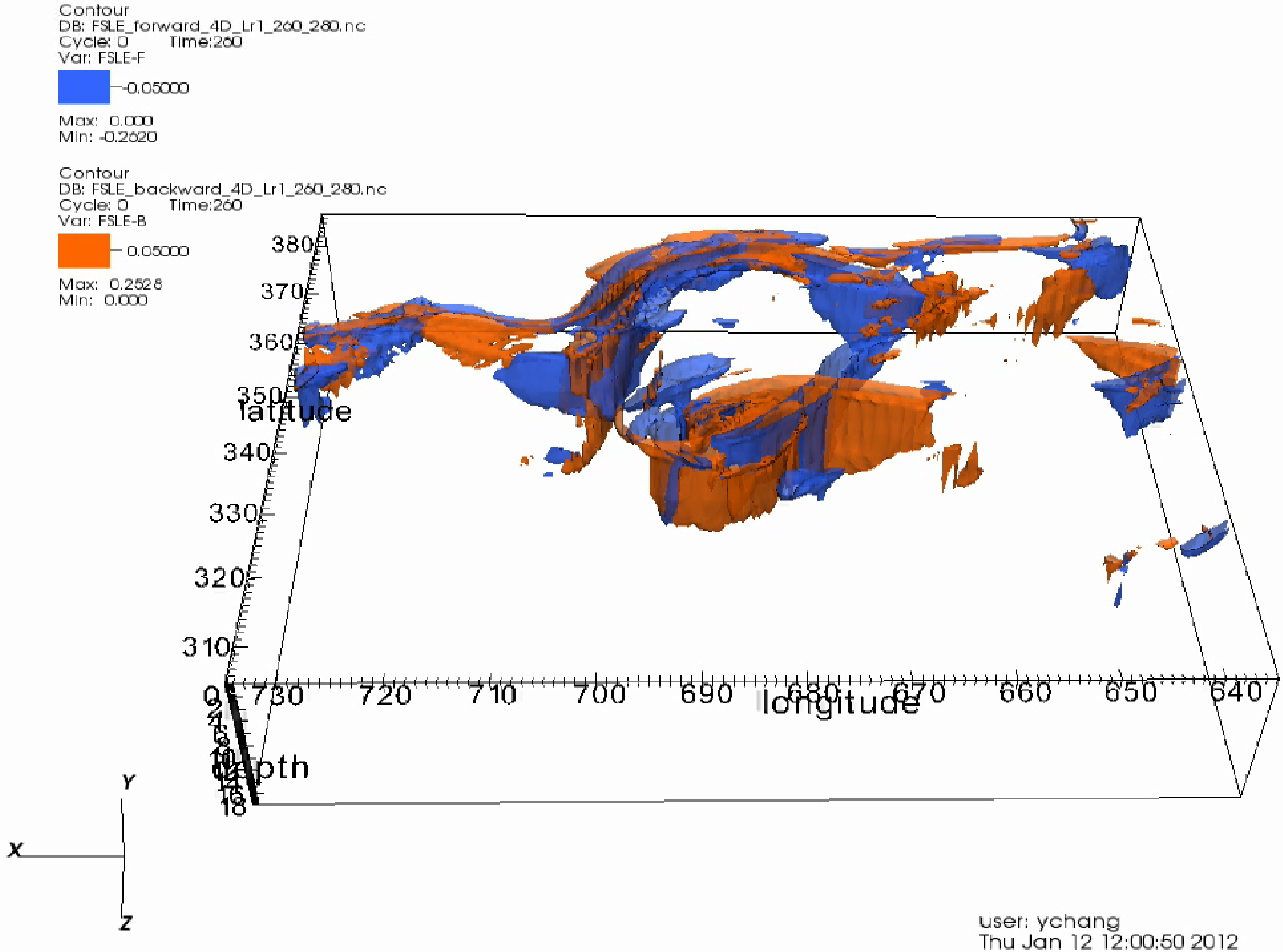
(d) There is unresolved confusion about how to handle isopycnic coordinates that correspond to material surfaces by design…

(as indicated by Denny).

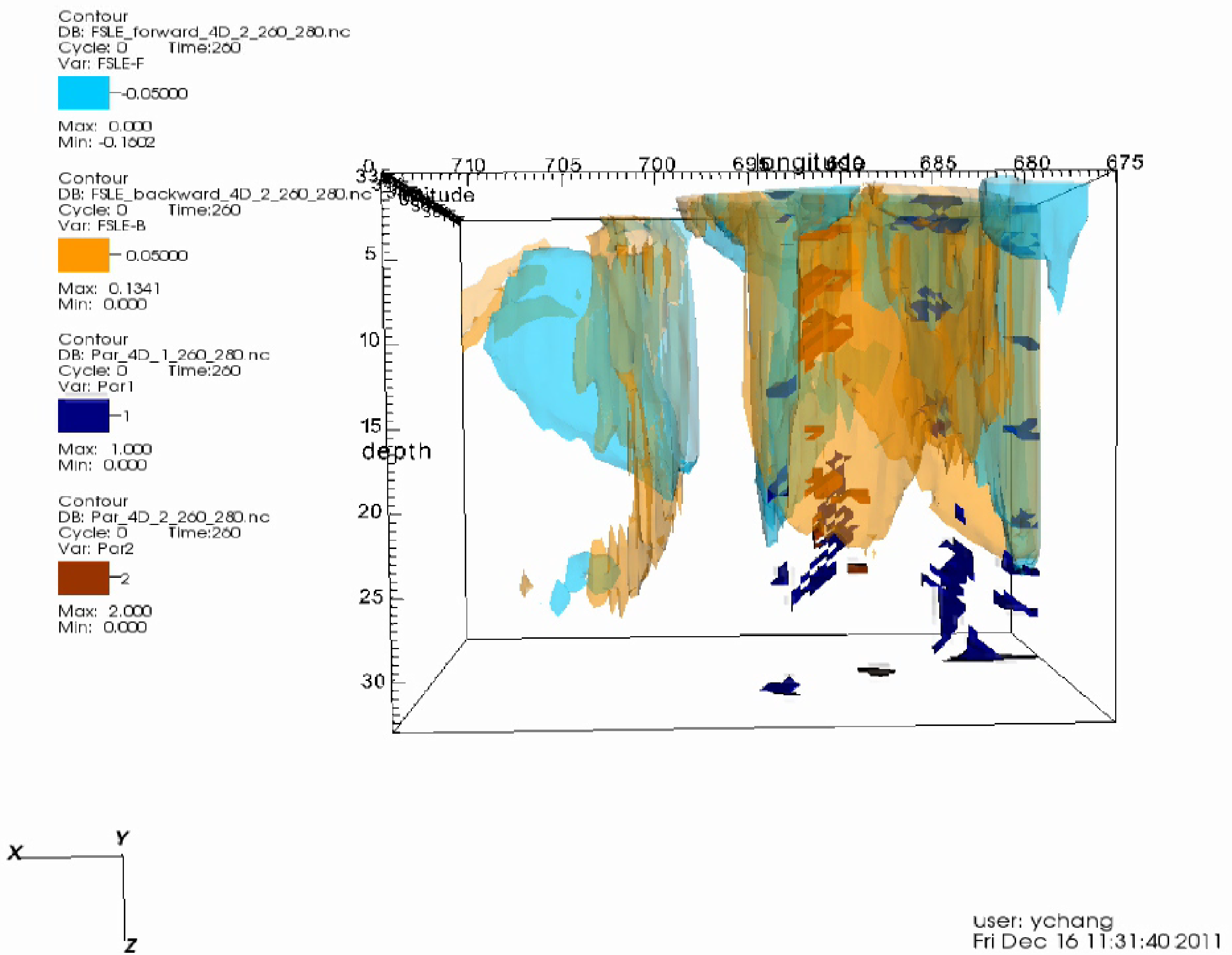
(e) Eddies seem almost never isolated (interact with other eddies and GS) and move around quite a bit (need to be tracked).



Day=260
x 10^-3
5
4
3
2
1
0
-1
-2
-3
-4
-5
38
37
36
35
34
33
32
31
Latitude
-73
-72
-71
-70
-69
-68
-67
-66
-65
-64
Longitude



Contour
DB: FSLE_forward_4D_Lr1_260_280.nc
Cycle: 0 Time:260
Var: FSLE-F
-0.05000
Max: 0.000
Min: -0.2620
Contour
DB: FSLE_backward_4D_Lr1_260_280.nc
Cycle: 0 Time:260
Var: FSLE-B
0.05000
Max: 0.2528
Min: 0.000
380
370
360
350
latitude
340
330
320
310
730
720
710
700
690
680
670
660
650
640
longitude
depth
Y
X
Z
user: ychang
Thu Jan 12 12:00:50 2012


Contour
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Cycle: 0 Time:260
Var: FSLE-F
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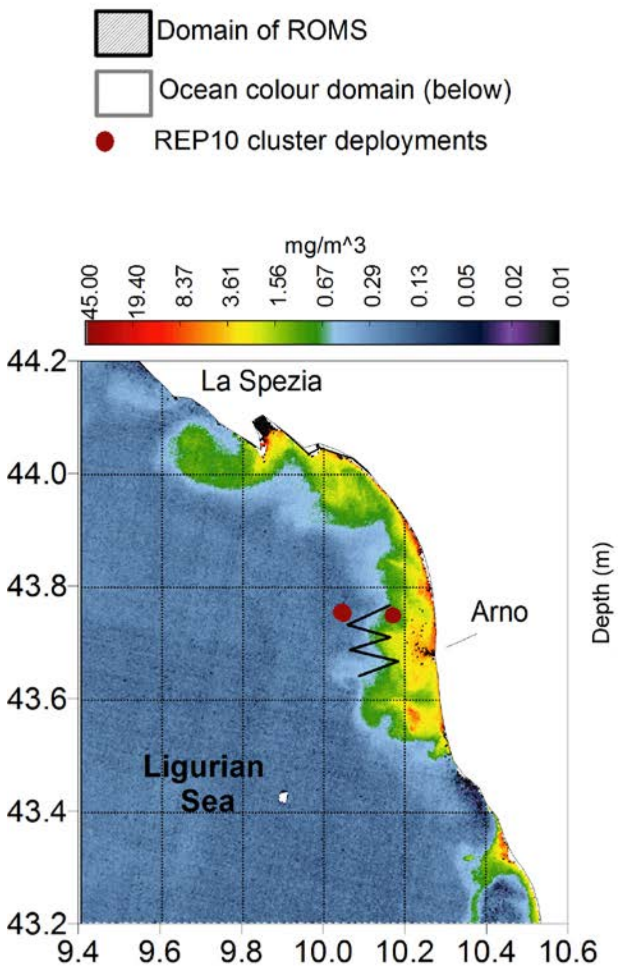
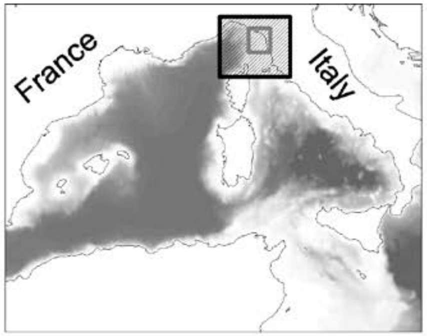
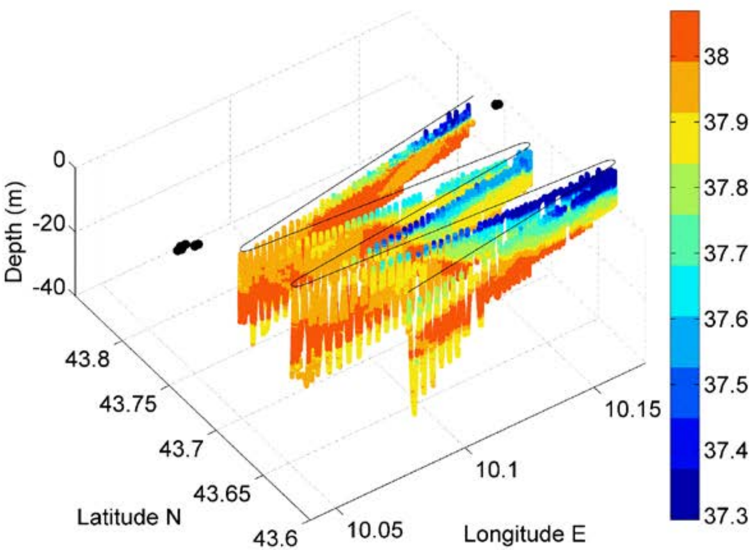
Max: 0.000
Min: -0.1602
Contour
DB: FSLE_backward_4D_2_260_280.nc
Cycle: 0 Time:260
Var: FSLE-B
0.05000
Max: 0.1341
Min: 0.000
Contour
DB: Par_4D_1_260_280.nc
Cycle: 0 Time:260
Var: Par1
1
Max: 1.000
Min: 0.000
Contour
DB: Par_4D_2_260_280.nc
Cycle: 0 Time:260
Var: Par2
2
Max: 2.000
Min: 0.000
longitude
710
705
700
685
680
675
latitude
depth
0
5
10
15
20
25
30
X
Y
Z
user: ychang
Fri Dec 16 11:31:40 2011

6) A recent dispersion field experiment (with Griffa + NURC, CNR)

- Two experiments, one month apart, have been performed during summer 2010 targeting a coastal area characterized by shallow salinity fronts due to river discharge.

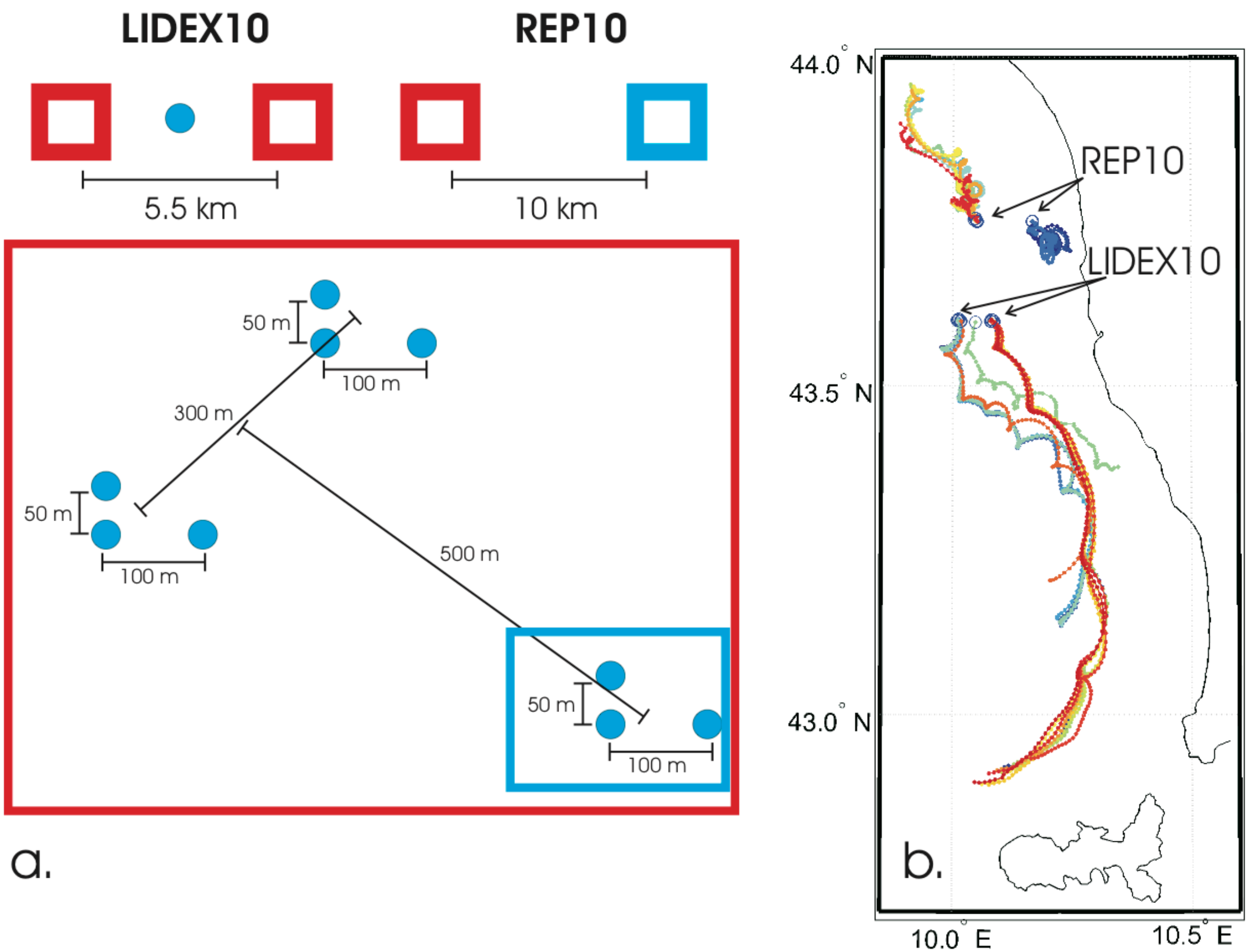




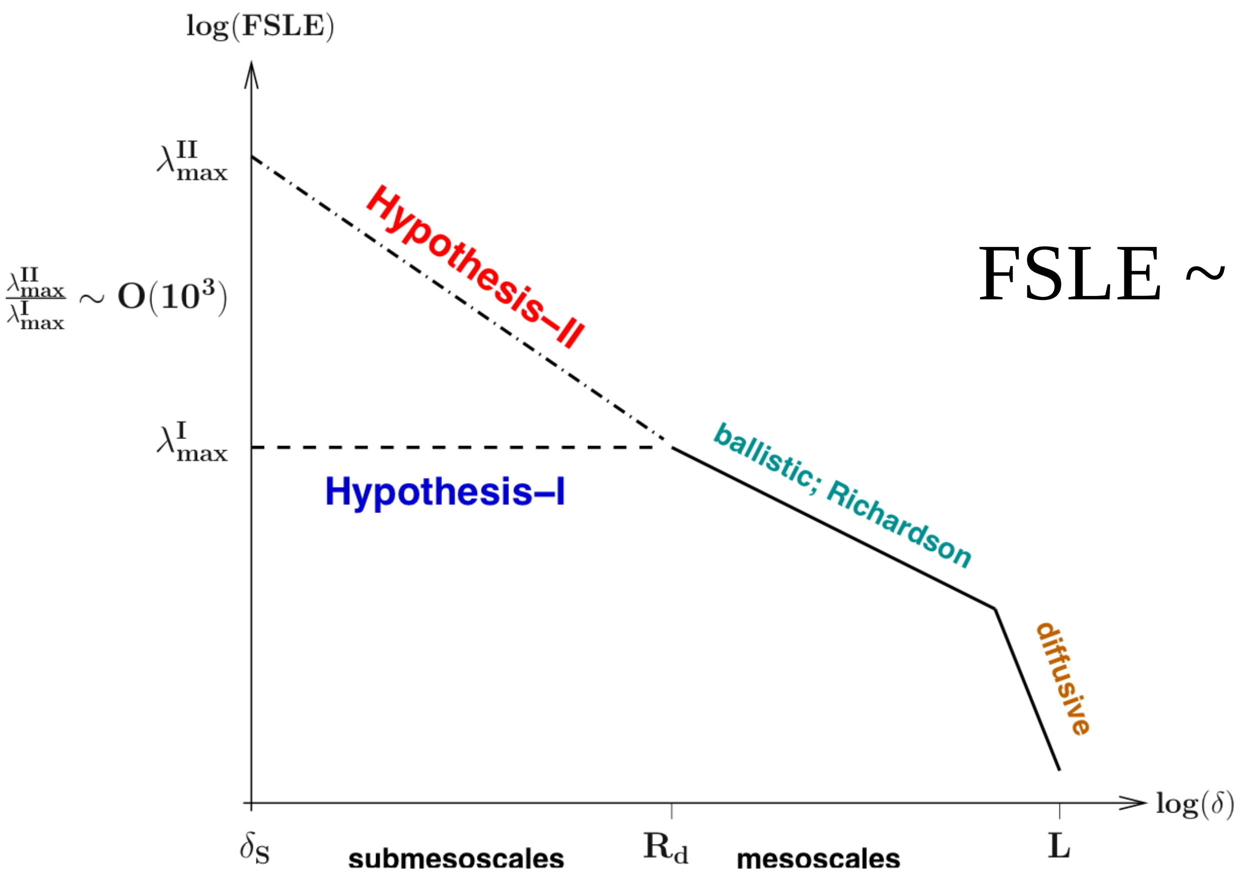


Multi-Scale Sampling Strategy:

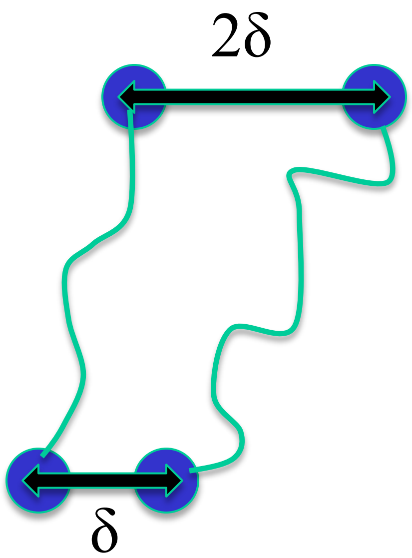
- Drifters were launched in clusters, using a design targeted to facilitate the simultaneous sampling at multiple separation scales



What are we after?



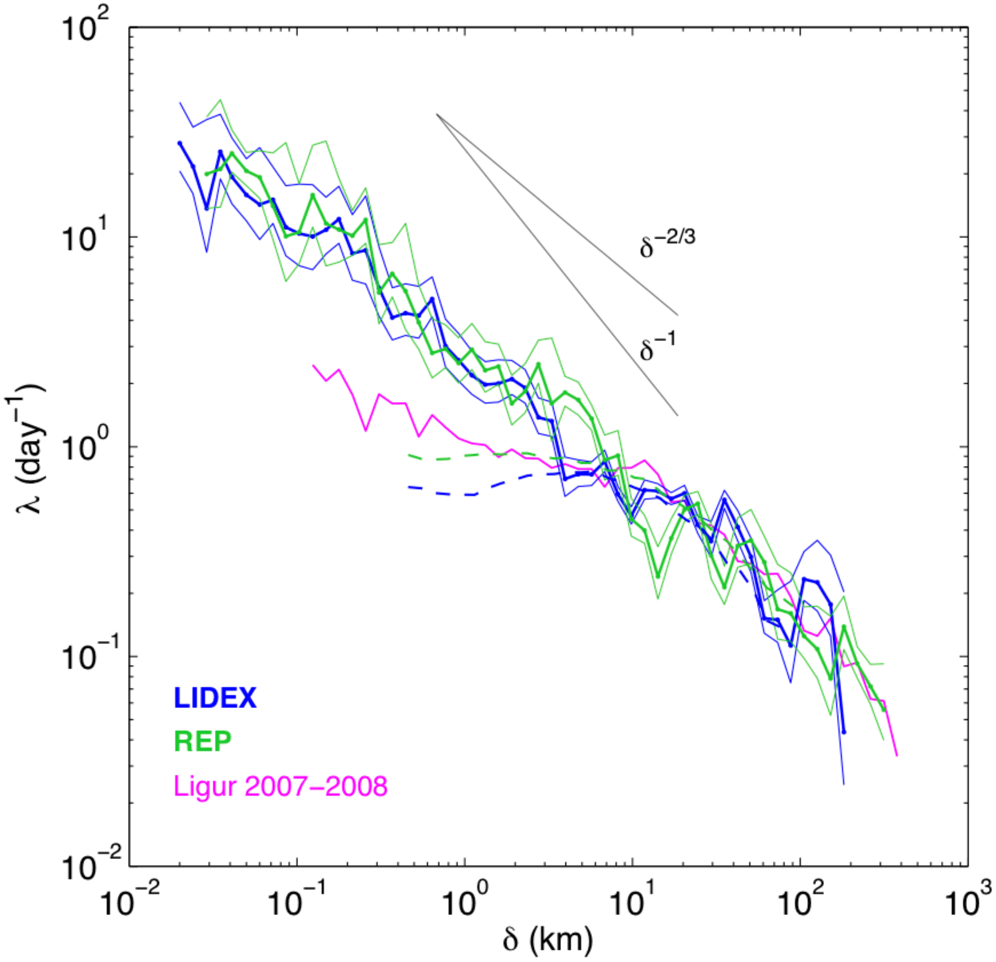
$$\text{FSLE} \sim 1/\tau$$



Hypothesis-I : energetic and slowly-evolving turbulent features in control,
data-assimilating OGCMs would be adequate to give good predictions

Hypothesis-II : rapidly-evolving small scales dictate relative dispersion at submesoscales,
parameterizations for submesoscale processes would be needed in OGCMs

Results:



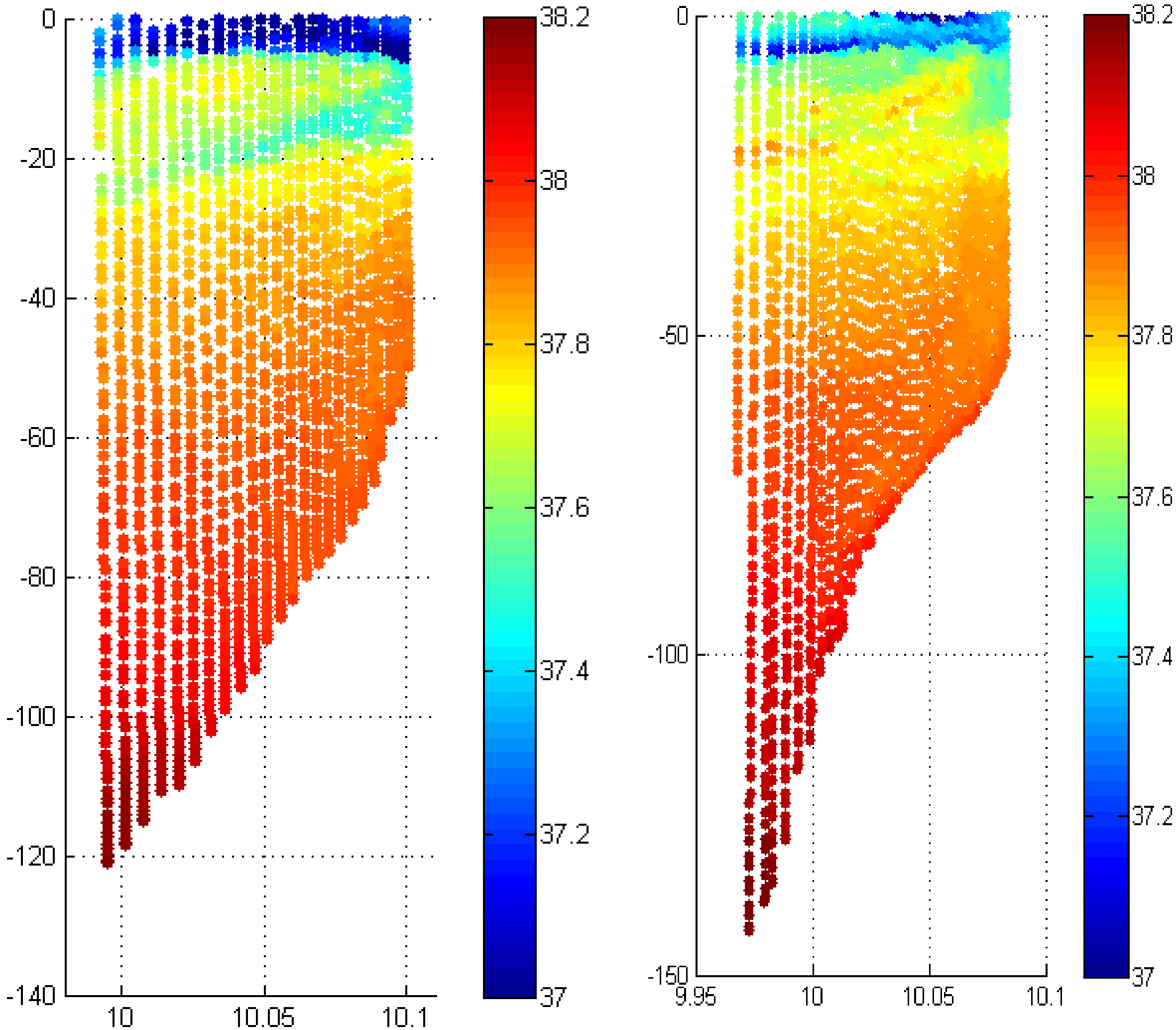
(a) results from LIDEX and REP are similar

(b) values of λ_{max} reach 10 1/day at separation scales of of 100 m.

(c) observed values are almost one order of magnitude higher than the ROMS model result and the results of a previous experiment in the center of the main Ligurian currents.

(d) relative dispersion at scales 100 m to 1000 m appears local (Hypothesis-II); perhaps due to active submesoscale motions.

Glider Data:



- The two panels show salinity evolution during the first 1.5 day of the LIDEX experiment
- Striations underneath the front are suggestive of inertial waves, consistent also with drifter patterns
- The data will be analyzed in collaboration with L. Piterbarg and A. Molcard using fusion techniques. Mesoscale and submesoscale features will be isolated and used in conjunction with model results

Next Few Steps:

1) Continued FTLE code development: complete parallel version, backward in time, perhaps adaptive particle seeding, interface to be used by other models (essentially to work with netCDF).

2) Rotating can problem has been very interesting; will work on papers with Larry and Irina.

3) HYCOM realistic case needs work & guidance; need some help/collaborations/direction for that problem (Drew, Bruce?).

4) Targeted tracer release in HYCOM using Drew's new code.

5) Is comparison of FTLE and FSLE of interest? They seem to give somewhat different results from very preliminary testing.

Publications Fully or Partially Supported by 3D+1 MURI:

- Haza, A.C., Özgökmen, T.M., A. Griffa, Z. D. Garraffo and L. Piterbarg, 2012: Parameterization of particle transport at submesoscales in the Gulf Stream region using Lagrangian subgridscale models. Ocean Modelling, 42, 31-49. Ocean Modelling, 42, 31-49.
- Griffa, A., Haza A.C., Özgökmen, T.M., A. Molcard, V. Taillandier, K. Schroeder, Y. Chang and P.M. Poulain: Investigating transport pathways in the ocean. Deep Sea Research II, in press (8 December 2011).
- Özgökmen, T.M., A.C. Poje, P.F. Fischer, H. Childs and A. Haza: On multi-scale dispersion under the influence of surface mixed layer instabilities and deep flows. Almost ready.
- Haza, A.C., Özgökmen, T.M. and A. Griffa: Impact of noise and sampling on relative dispersion estimates at oceanic submesoscales. Almost ready.
- Griffa, A., K. Schroeder, Jacopo, Haza, A.C., and Özgökmen, T.M.: Targeted Lagrangian sampling for dispersion under coastal submesoscale motions. In preparation, January 2012.

Soon (highest priorities):

With Pratt and Rypina: the rotating can problem.

With Poje: buoyant plume problem.