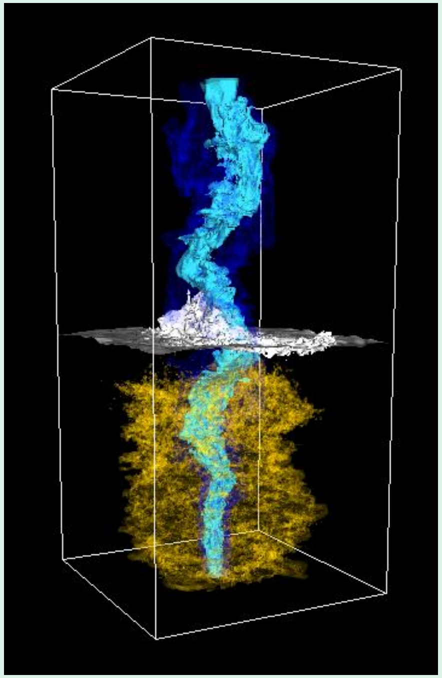
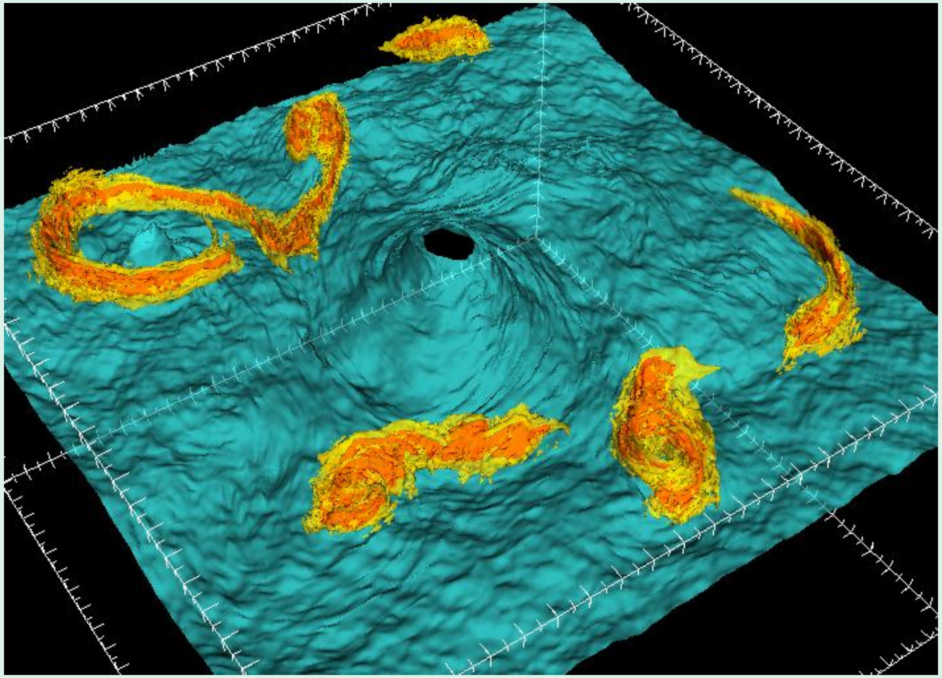
# *Beyond Mesoscale-Driven Transport in the Ocean*

*Tamay Özgökmen, University of Miami*





Ocean 3D+1 MURI Meeting, Chapell Hill NC, February 2013

# *3D+1 Oceanic Processes of Interest:*

***a)*** ***Mixed layer processes*** *pose the first encounter as we go deeper in the water column. In particular:*

*- Do submesoscale processes in the mixed layer affect transport?*

*- How does the mixed layer interact with QG/2D+1-like mesoscale features?*

*{Mixed layer instabilities have been unresolved, until recently, in OGCMs}*

*b)* *Below the mixed layer,* ***internal/inertia gravity waves (IGWs)*** *kick in. Do they contribute to transport?*

*{IGWs are traditionally underresolved in OGCMs; can also be misrepresented}*

***c)*** ***Buoyant multi-phase plumes*** *can be important, such as in deep ocean oil blow outs.*

*{No OGCM has these plumes}*

# Outline:

a) Ocean observations of the effect of mixed layer processes on transport: ***Grand Lagrangian Deployment (GLAD)***

largest synoptic deployment of drifters in oceanography to date

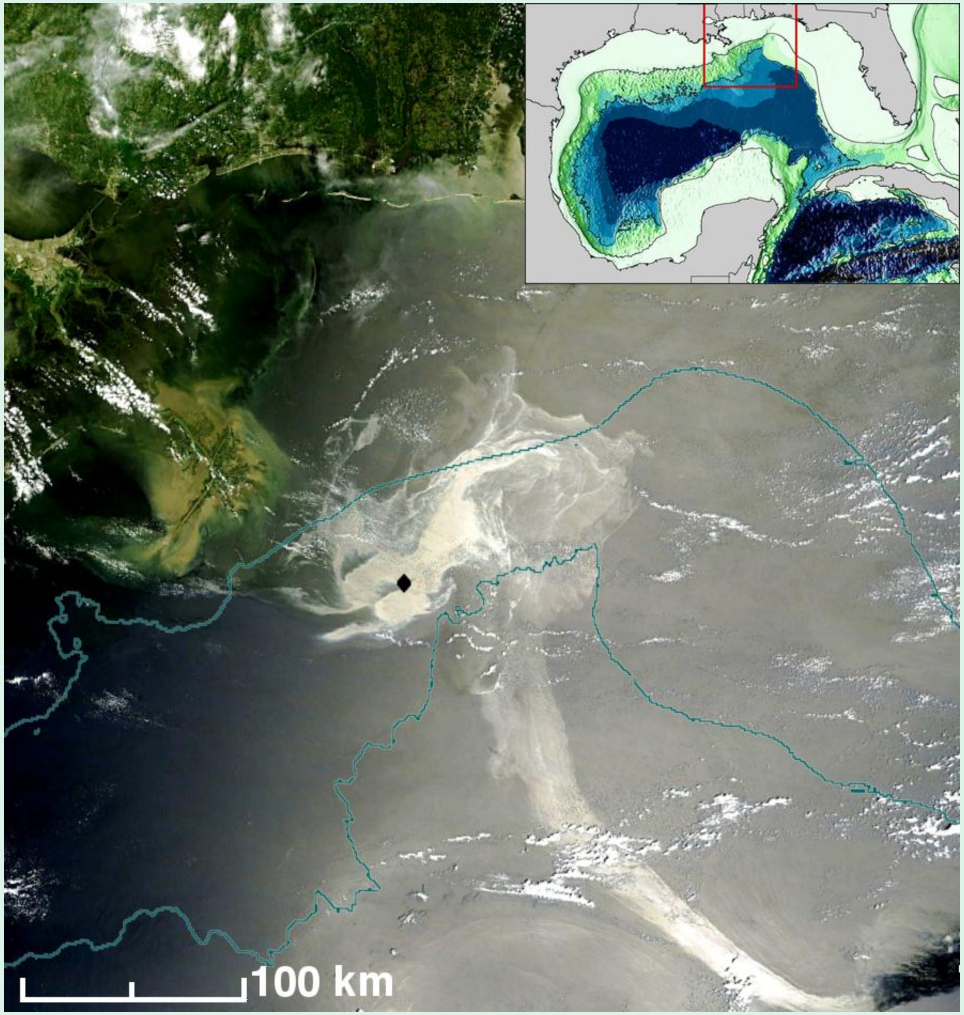
b) 3D dynamics in the upper ocean:

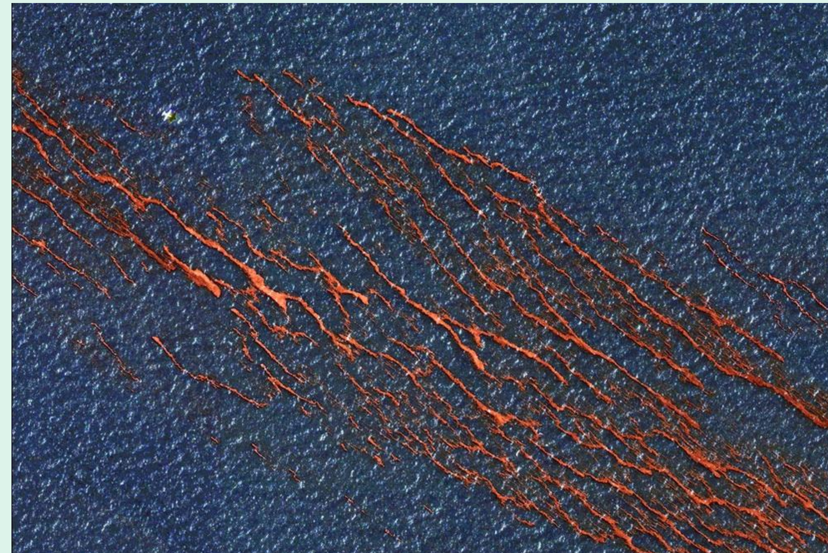
- Formation of “star eddies” by 3D processes (LES)
- Impact of IGWs on transport (LES)
- Mixed layer and eddy interactions (HYCOM)

c) 3D dynamics in the deep ocean:

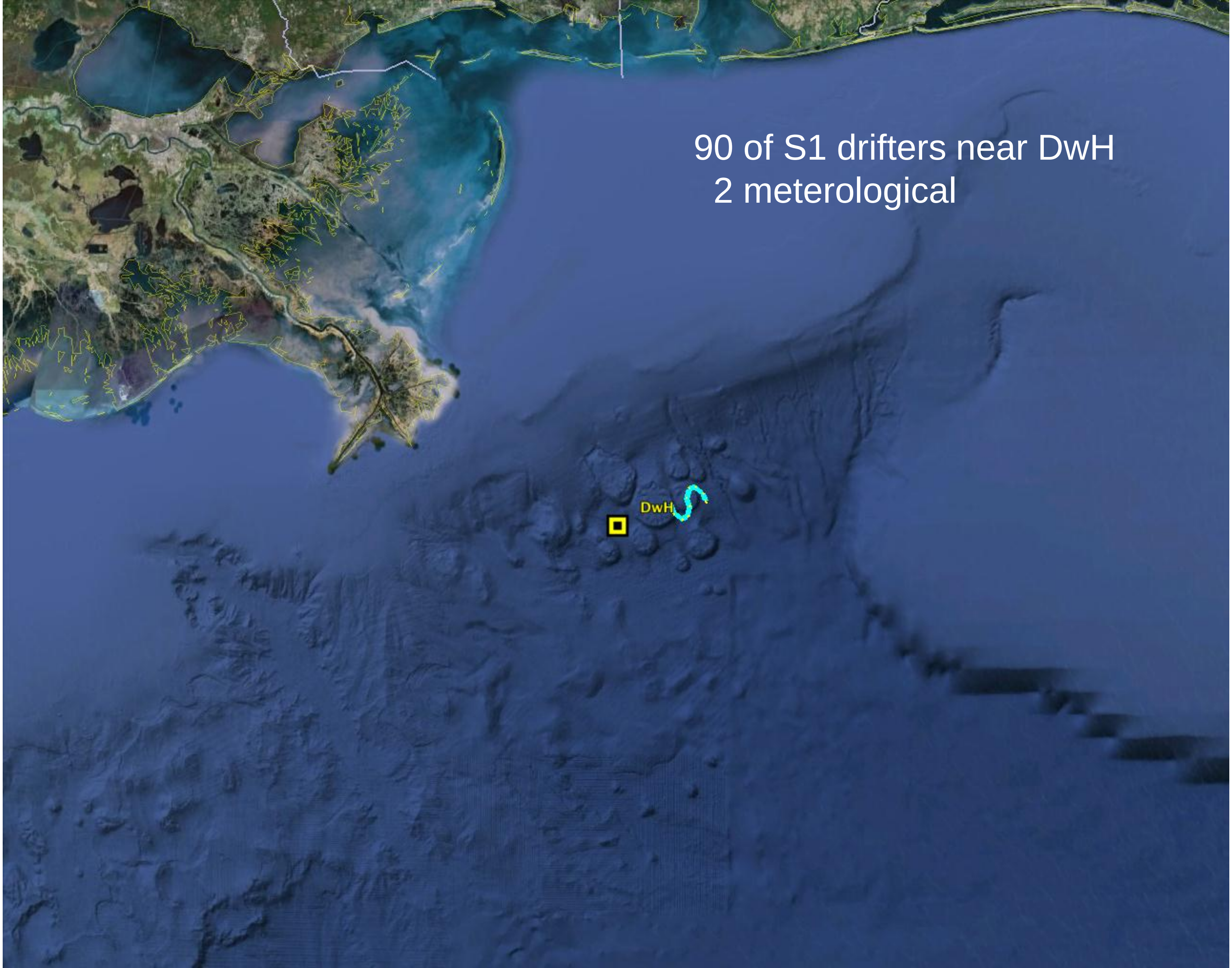
- Mixing in single-phase buoyant plumes (LES)
- Mixing in two-phase buoyant plumes (LES)

Grand LAgrangian Deployment (GLAD): 317 drifters near the DwH region

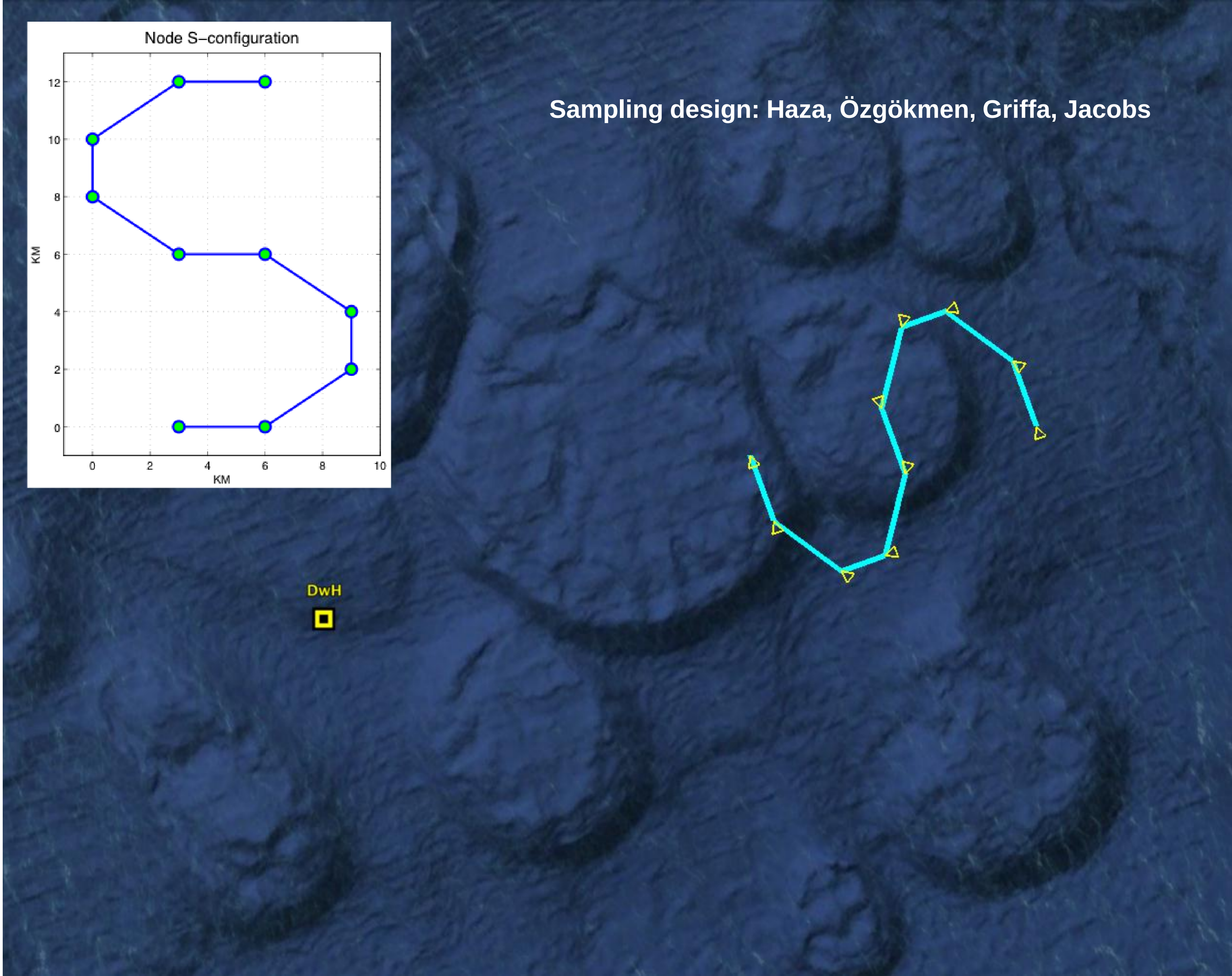


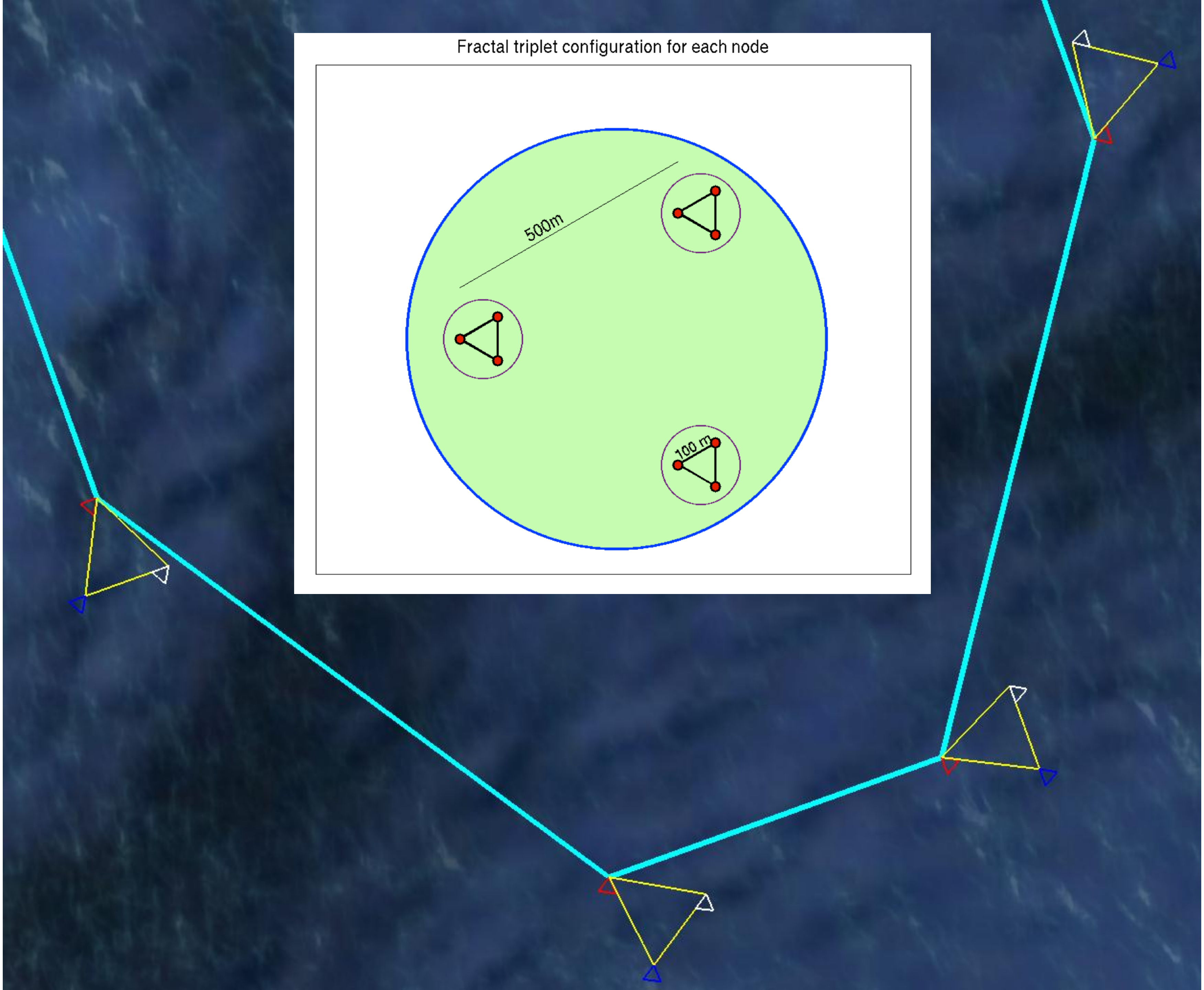



Clear signatures of multi-scale interactions: mesoscale straining, submesoscale fronts and wind/wave-driven Langmuir-like circulations (oil seems to be a very good tracer!)


90 of S1 drifters near DwH
2 meterological
DwH

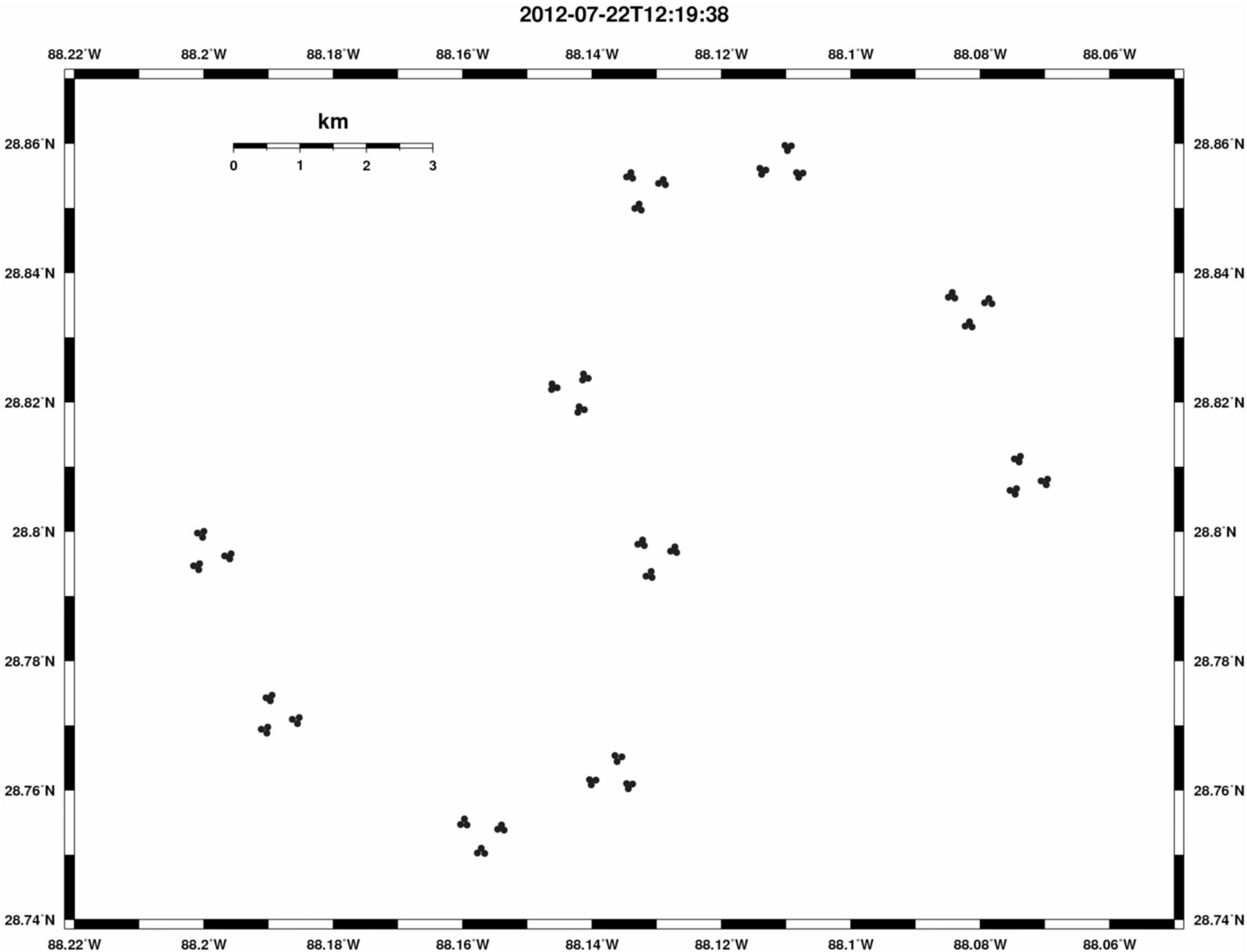
Sampling design: Haza, Özgökmen, Griffa, Jacobs




Fractal triplet configuration for each node
500m
100 m

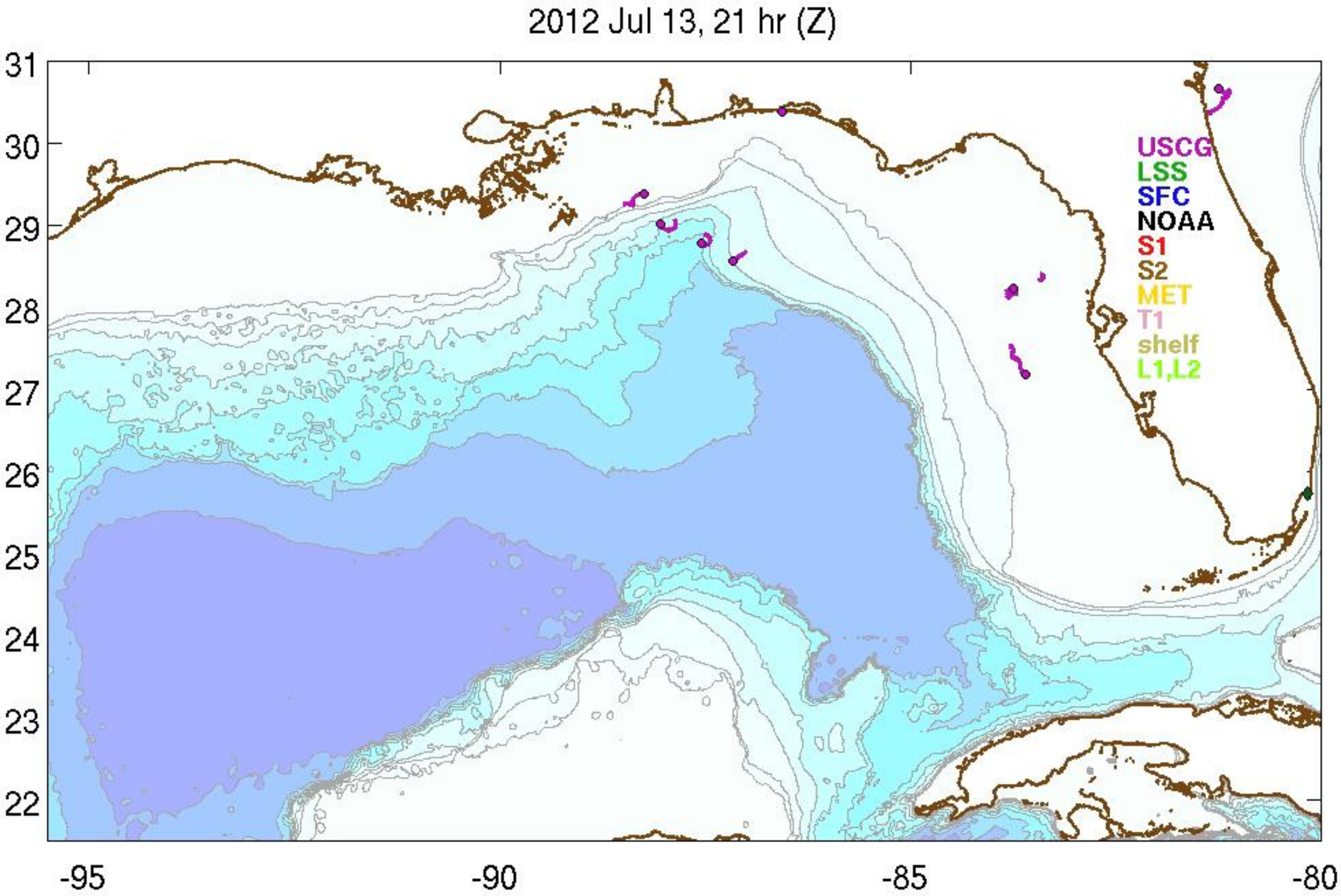
Images: Özgökmen

# *How Accurately Did We Get the Deployment Template?*

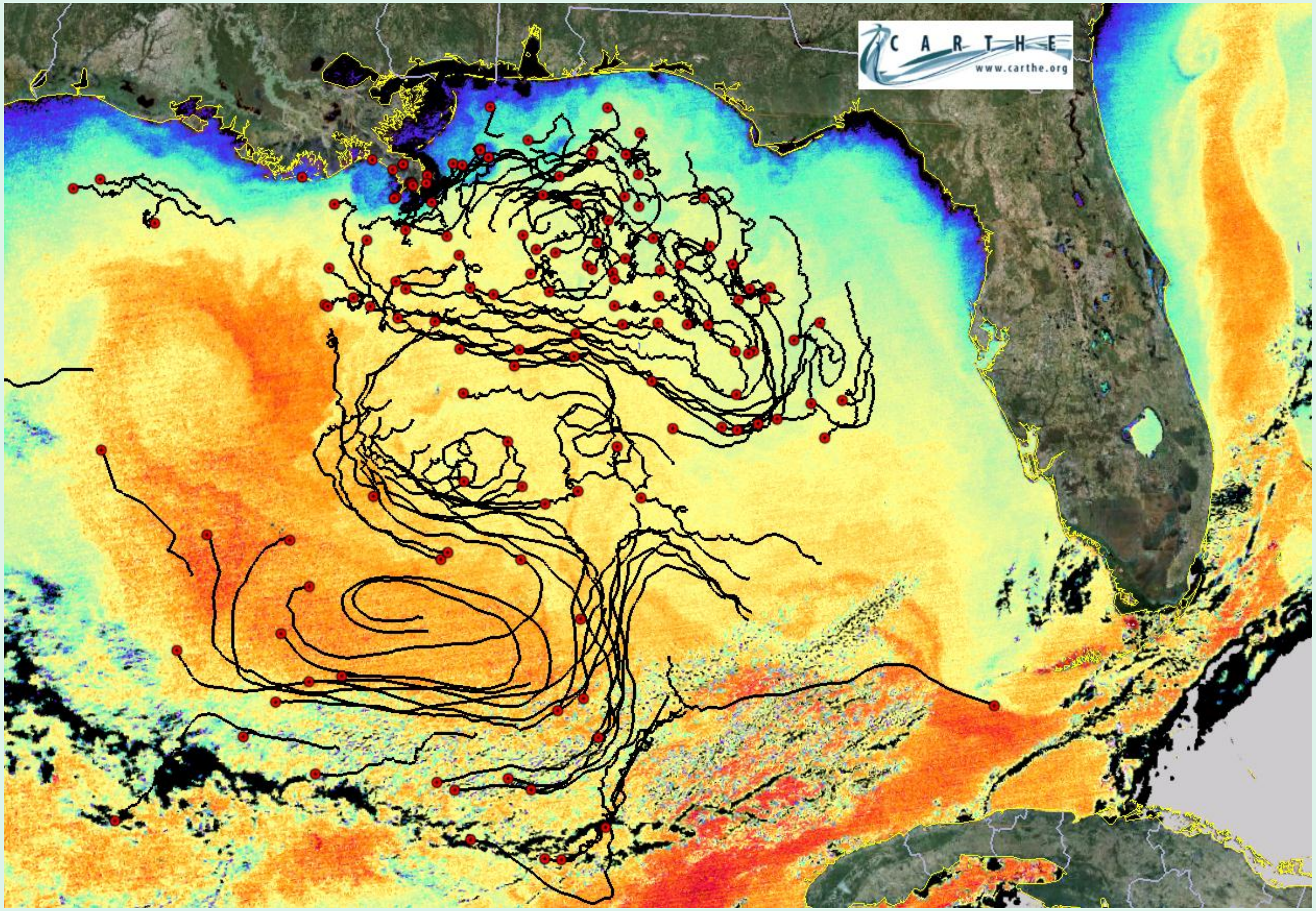


**Entire GLAD Data Set of 317 Drifter Deployments**

**mid July- mid Oct: 3 out of 6 months of data**




***5.5 million data points obtained in total***




GLAD data is being analyzed by many at the present moment…

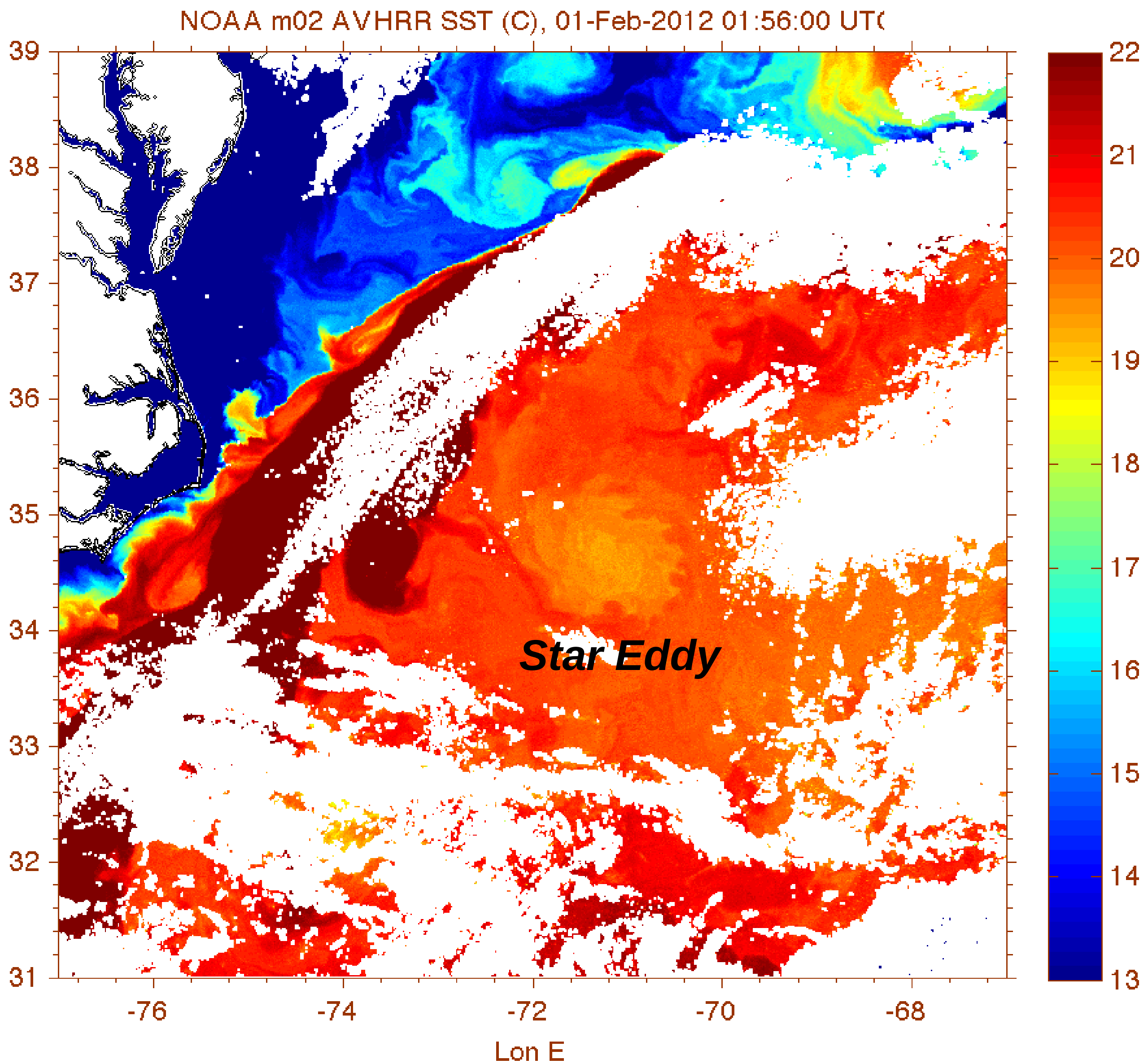
One of the major findings:

***Submesoscale flows impact ocean transport:***

***30x increase in FSLE(delta=100 m) wrt 1 km HYCOM estimates***

***3D+1 type flows are important near the ocean's surface***

# *Cohabitation of Mesoscale and Submesoscale:*

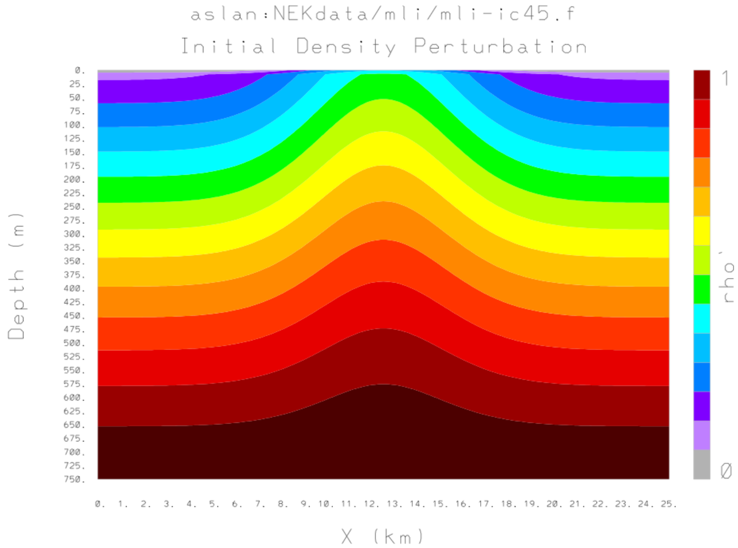



Do MLI play a role in the formation of star eddies?

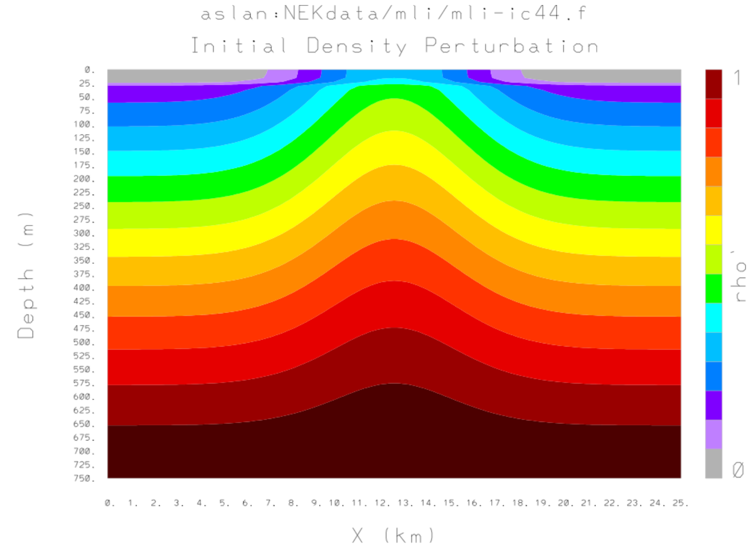
# *A Cyclone Protruding into the Mixed Layer:*

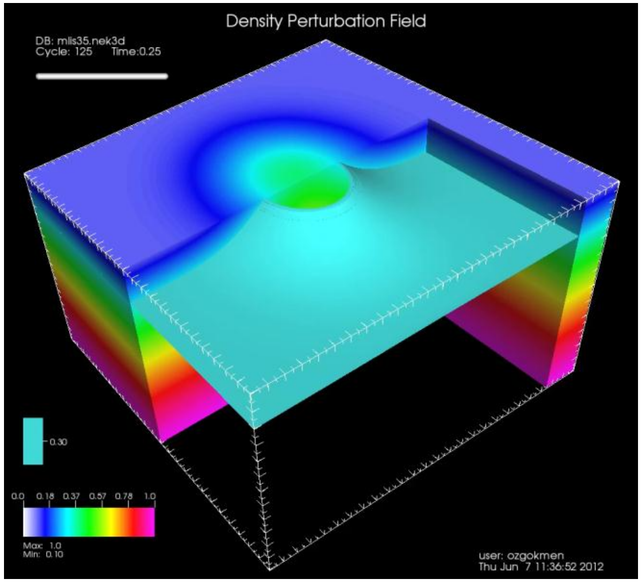
## *Domain: 25 km x 25 km x 750 m*

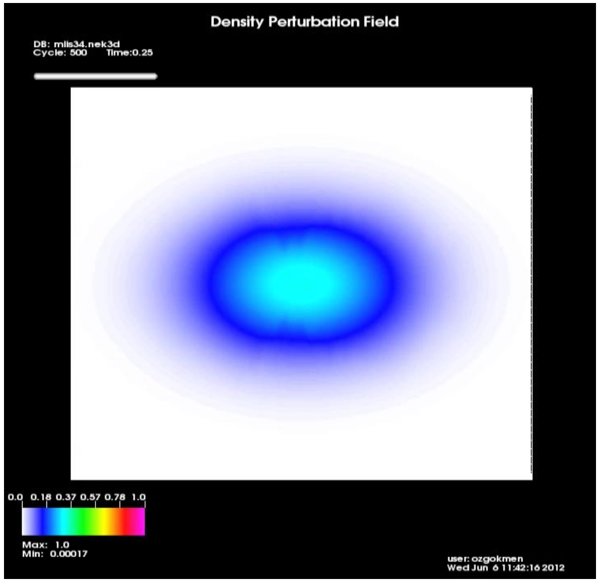
### *MLD=0 m*




### *MLD=25 m*

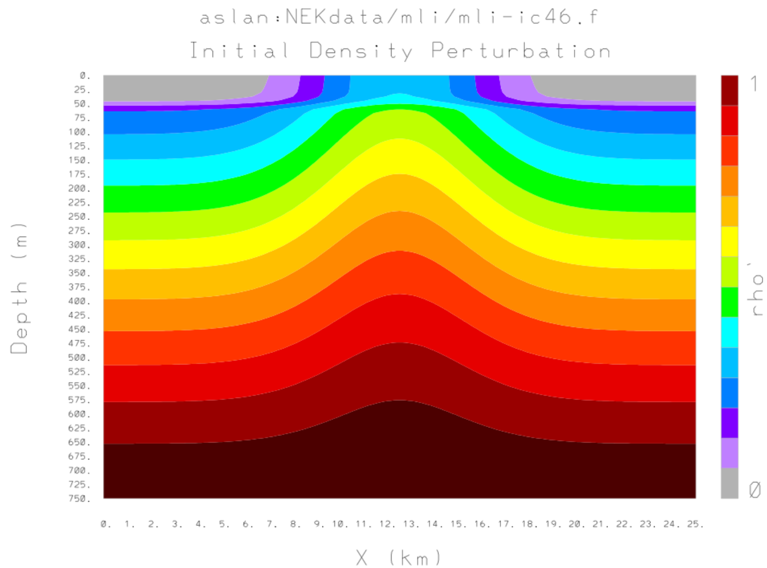


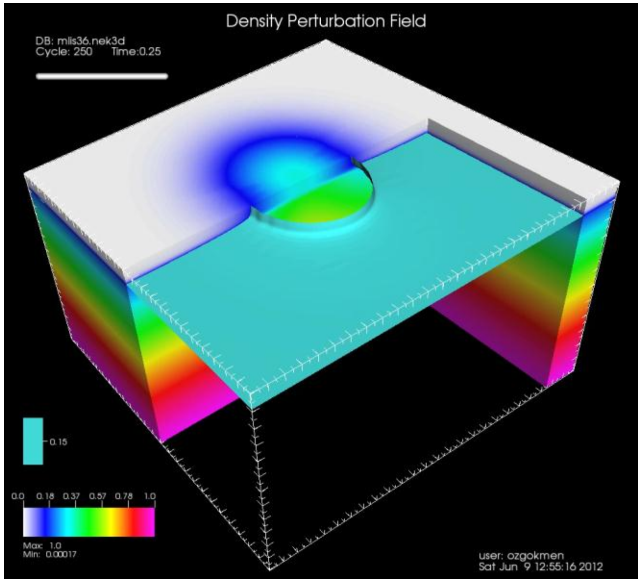



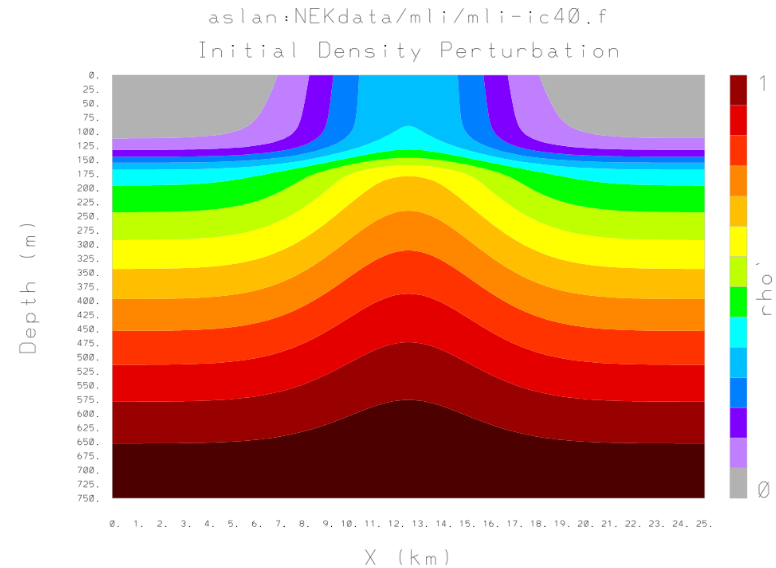
# *A Cyclone Protruding into the Mixed Layer:*

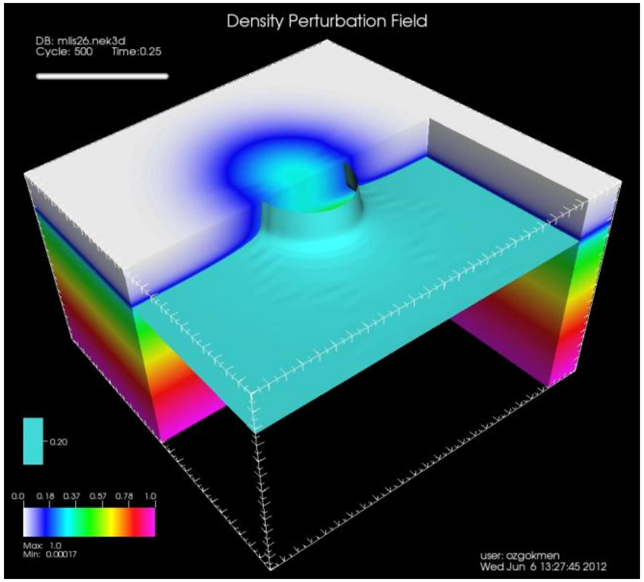
## *MLD=50 m*



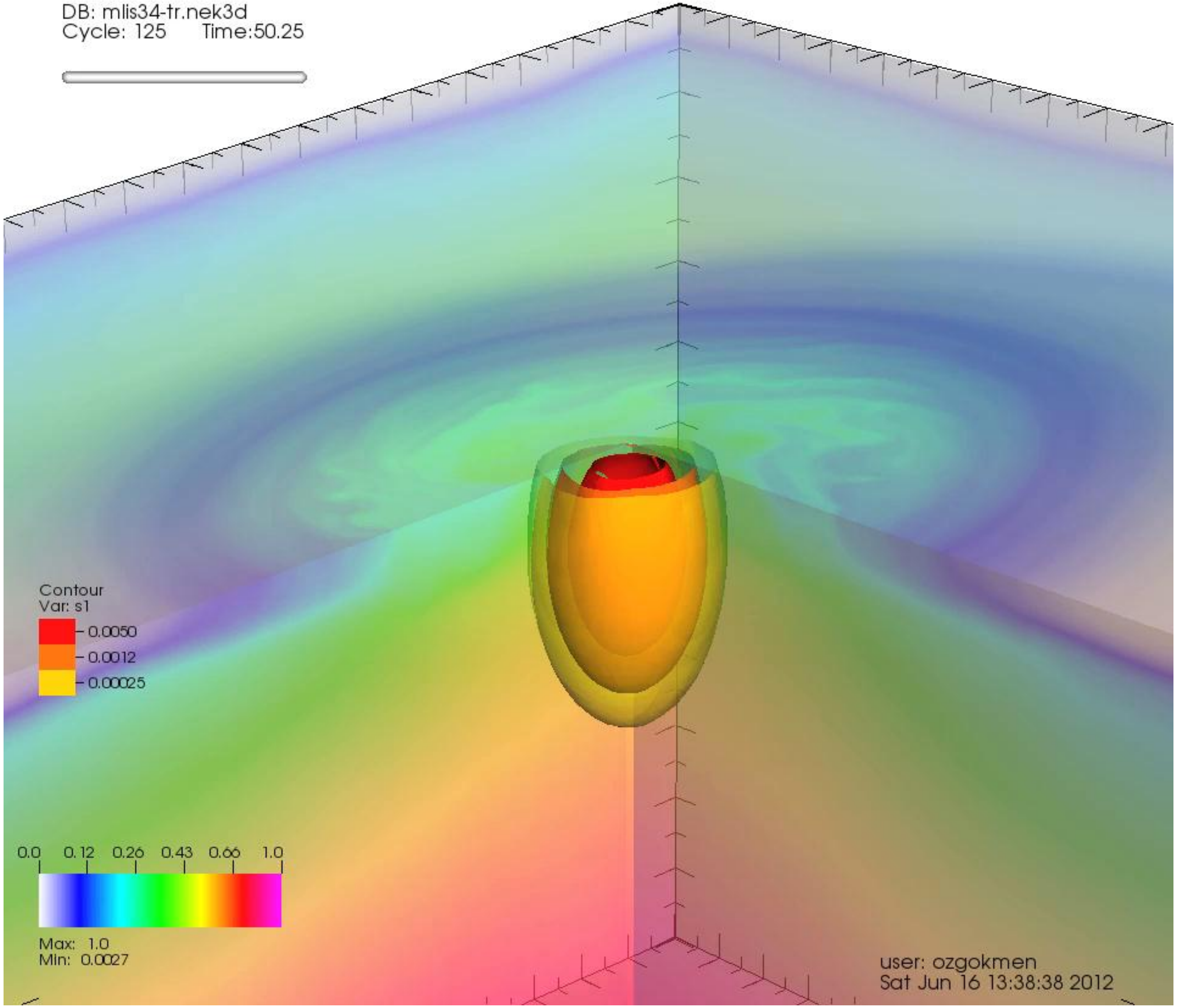

## *MLD=150 m*



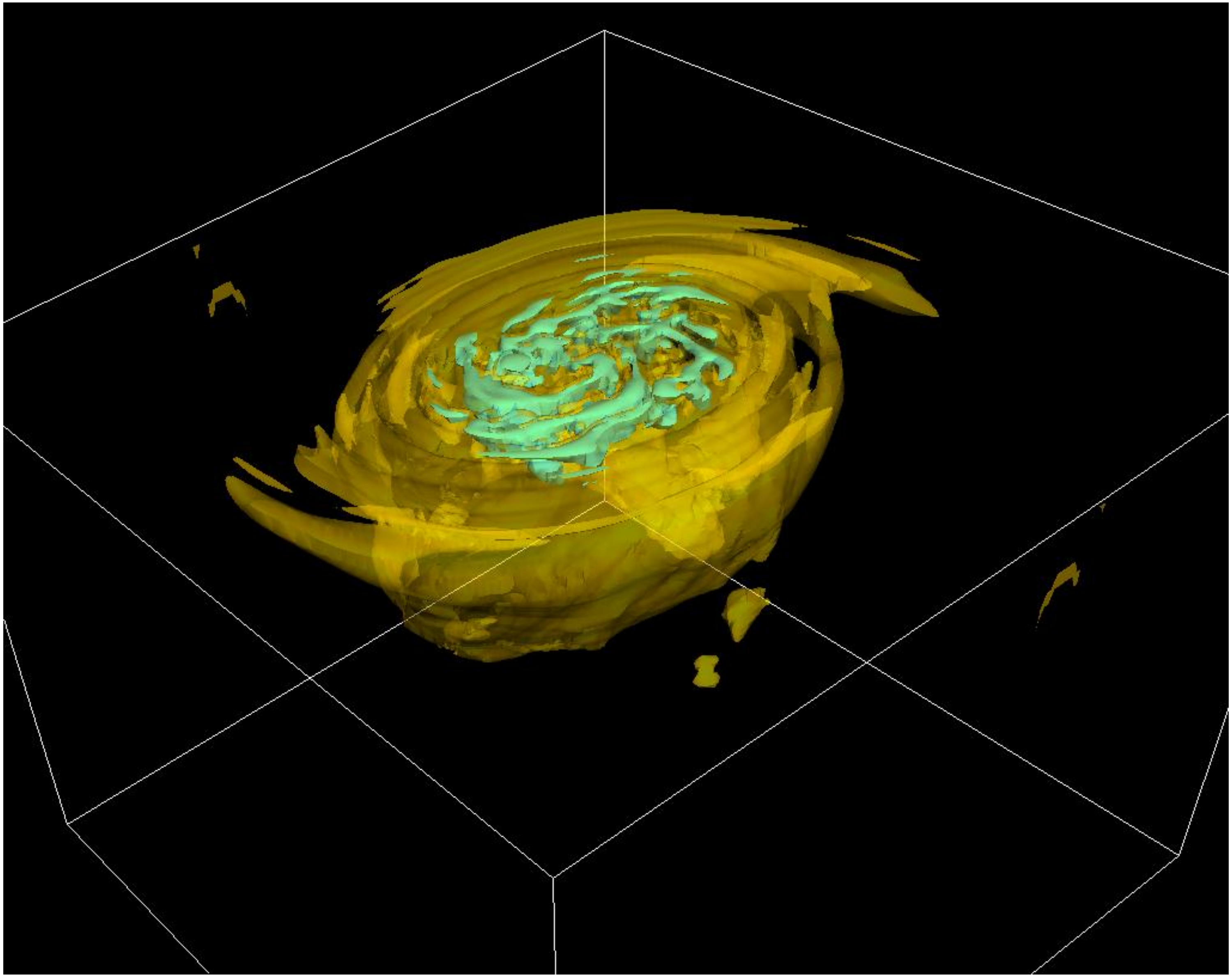



# *Do These Features Influence Transport of Passive Tracer?*

***MLD=25 m***



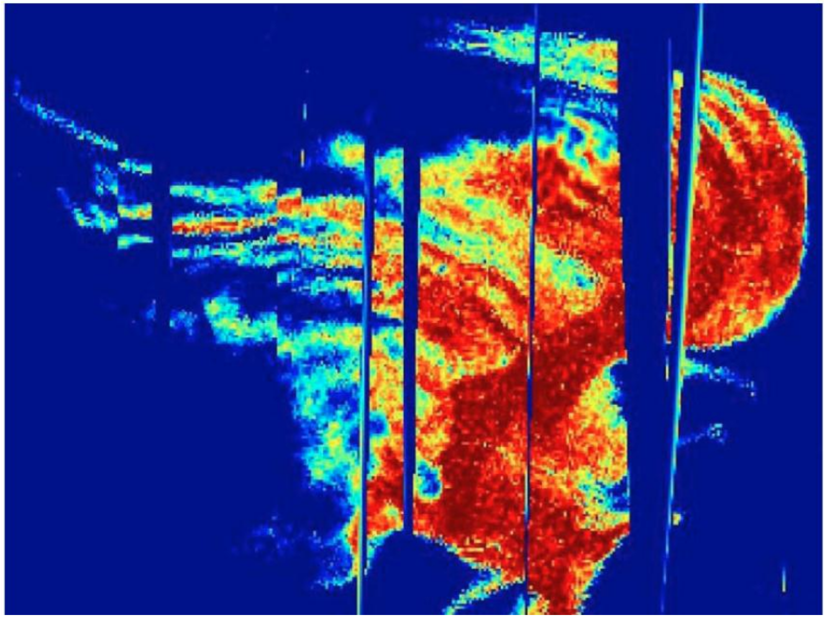
# *3D FTLE From 10 Million Particle Releases:*



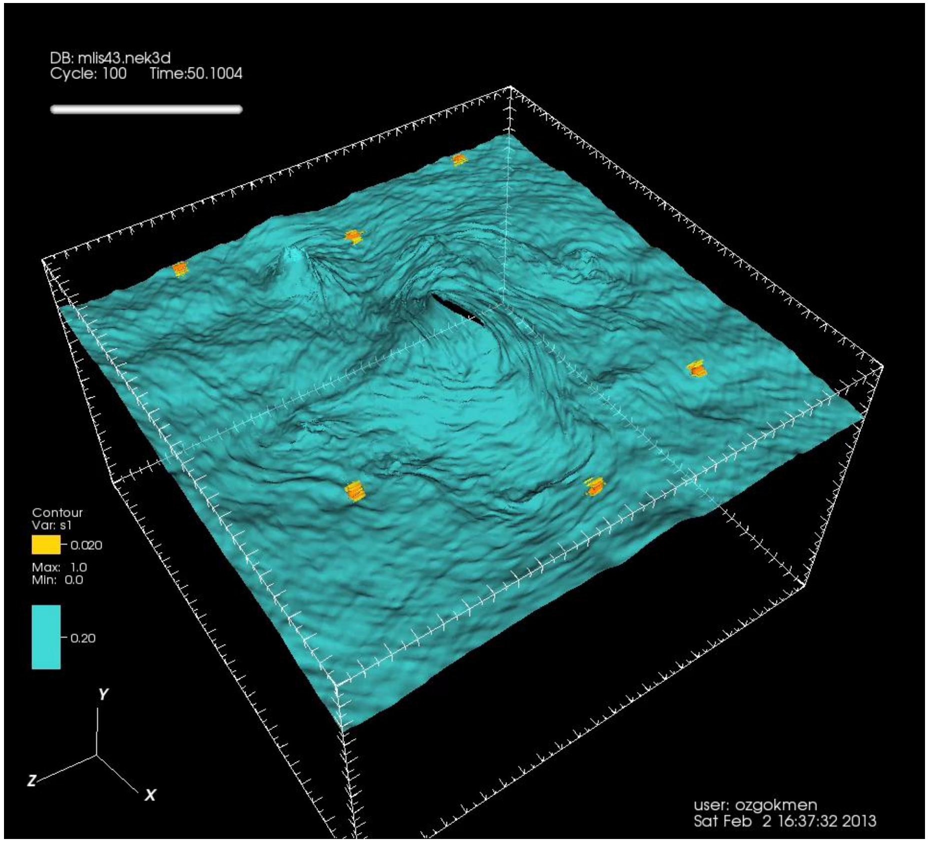
# Inertia Gravity Waves Below the Mixed Layer:

LIDAR Image of Tracer Patch Injected Just Below the Mixed Layer

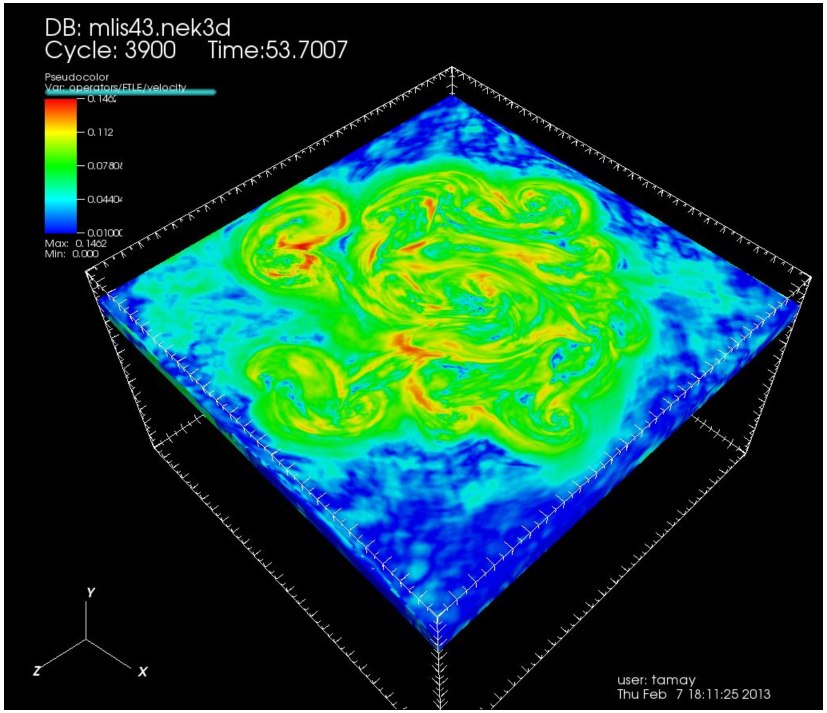
(Ledwell, Sundermeyer, Concannon)

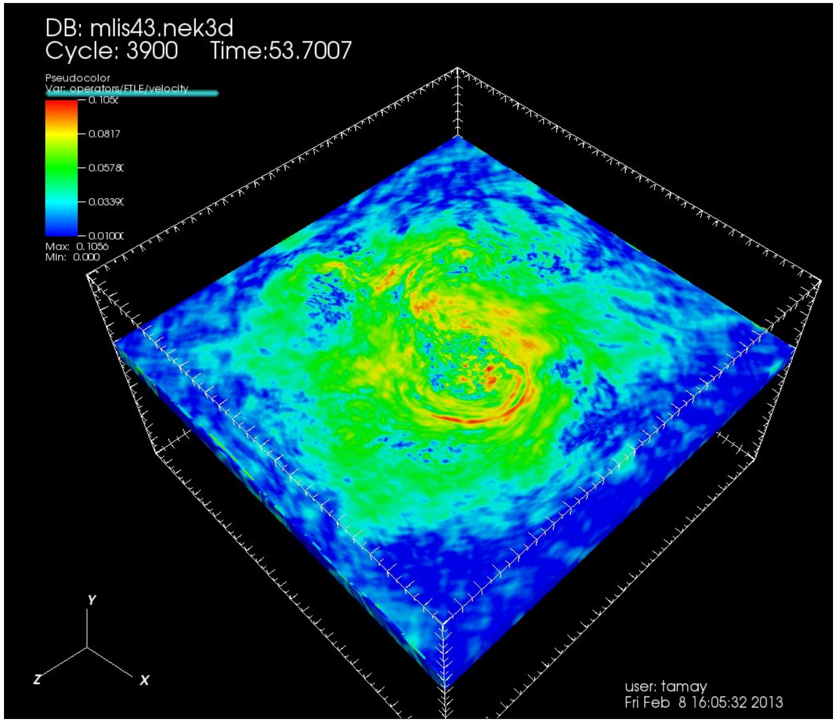


Are these filaments IGW driven?



# Backward FTLE:

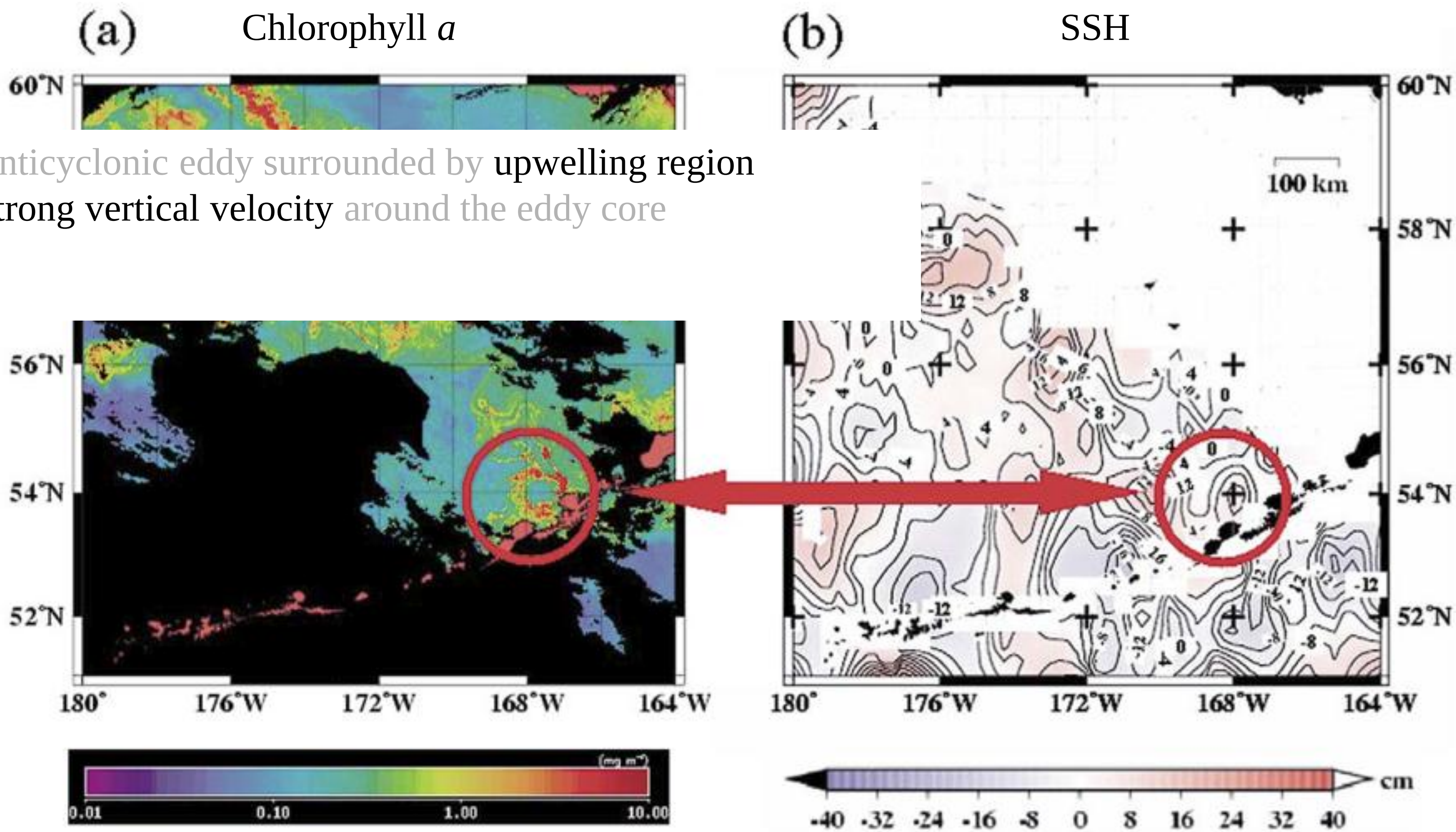



Some structure in the IGW region, but much of the domain is still eddy driven…

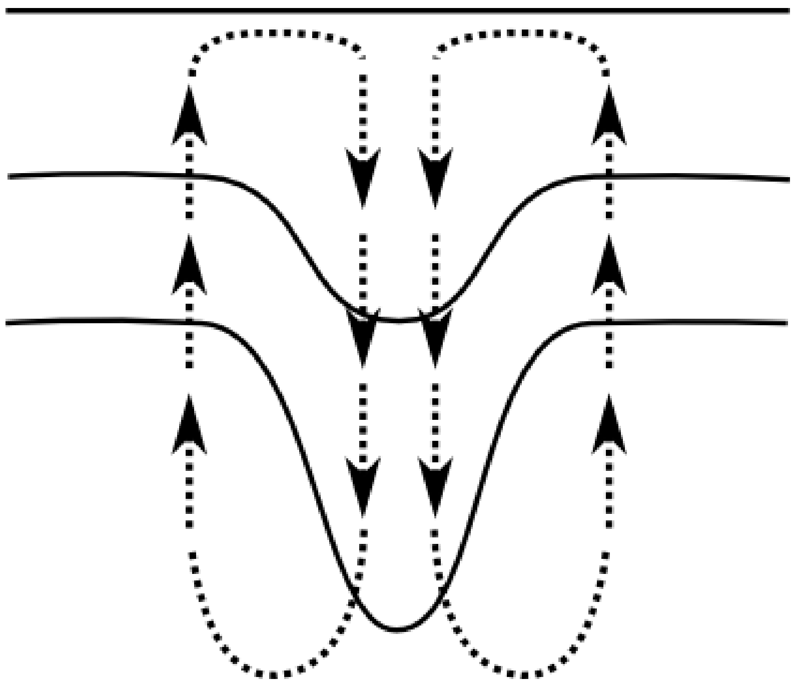
# Upwelling Patterns in Mesoscale Eddies
# (work by PhD student Jean Mensa)

1) Anticyclonic eddy surrounded by upwelling region
2) Strong vertical velocity around the eddy core

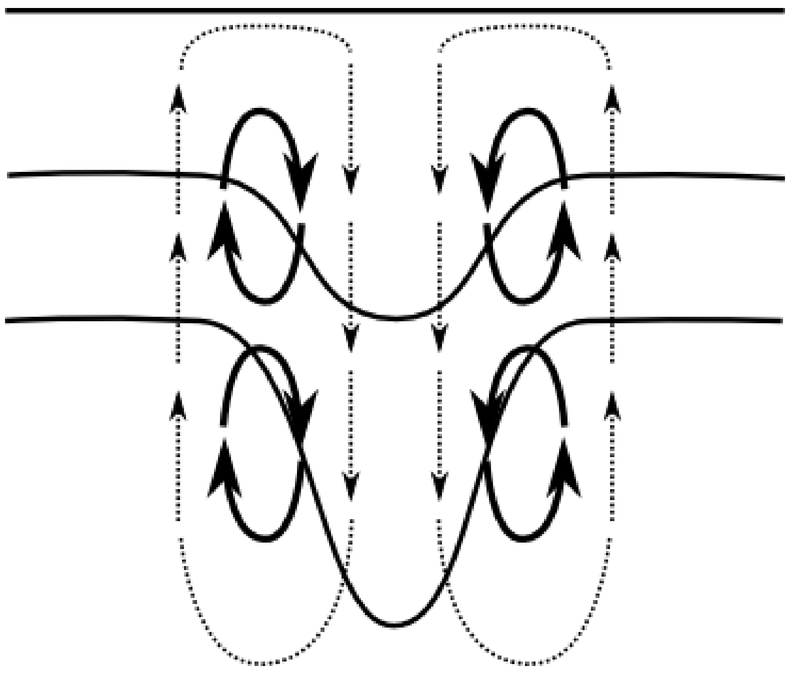



[1] K. Mizobata, S. I. Saitoh, and A. Shiomoto, “Bering Sea cyclonic and anticyclonic eddies observed during summer 2000 and 2001,” Progress in oceanography, vol. 55, no. 1–2, pp. 65–75, Oct. 2002.

- How does the mixed layer (ML) affect vertical transport?

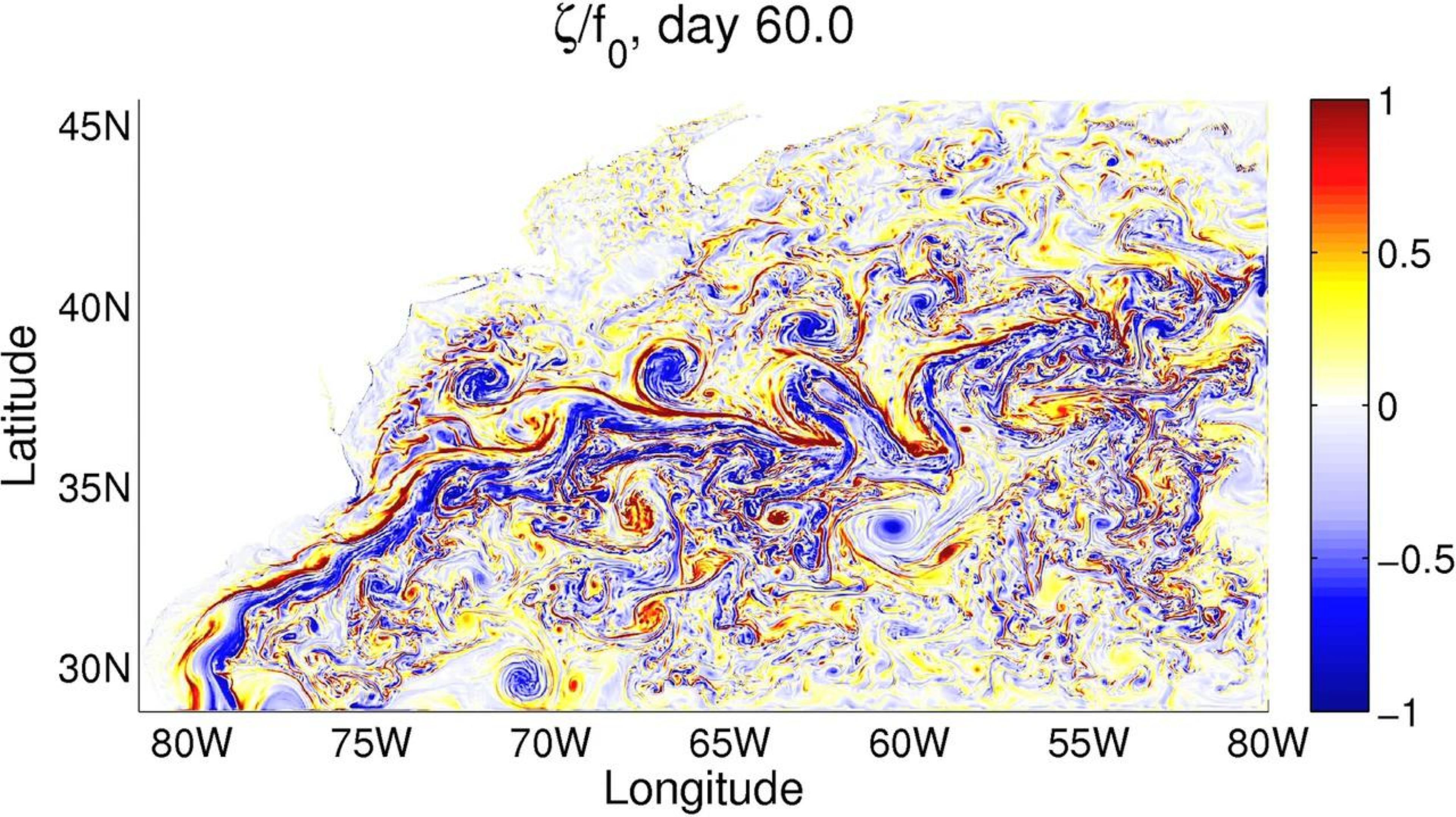


Ekman driven vertical transport



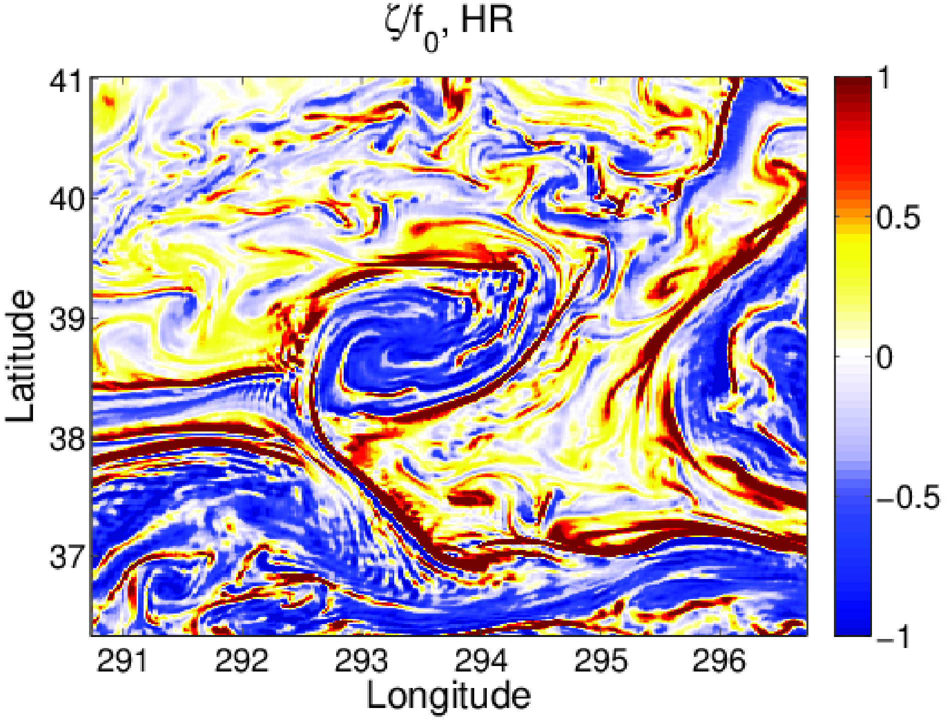
Frontal processes driven vertical transport

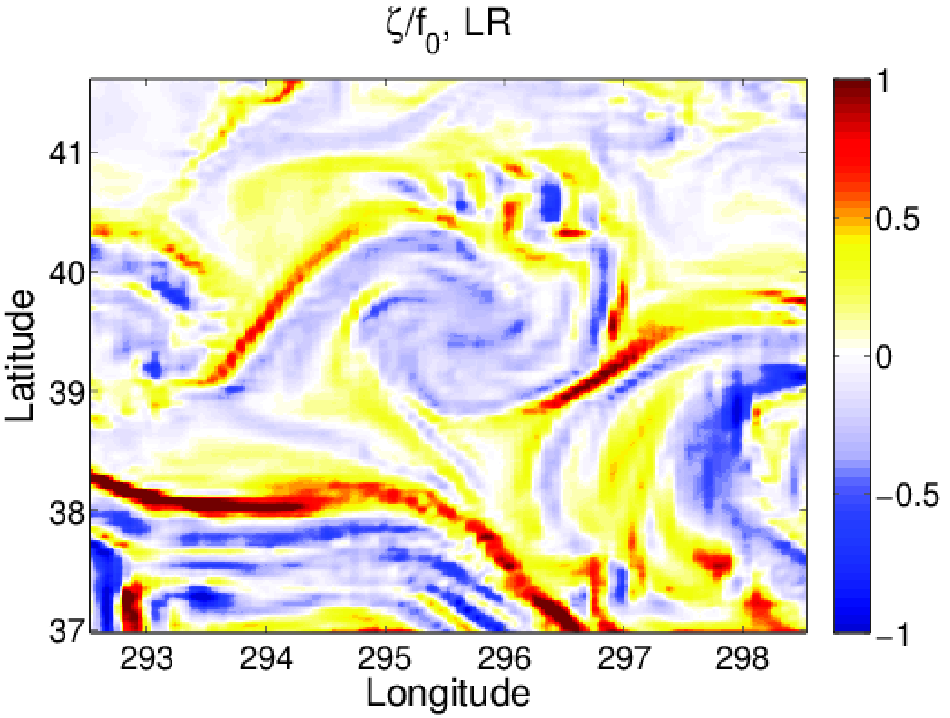
# Method: HYCOM simulation of the Gulf Stream region



# Approach:

- Two seasons: summer and winter
- Two rings: cyclonic and anticyclonic
- Two resolutions: HR and LR

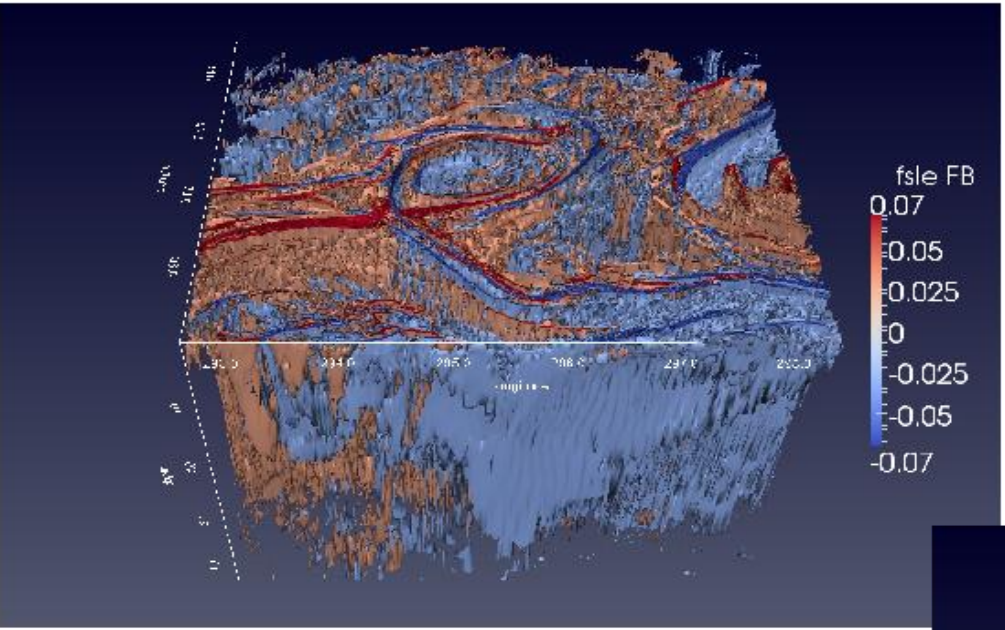


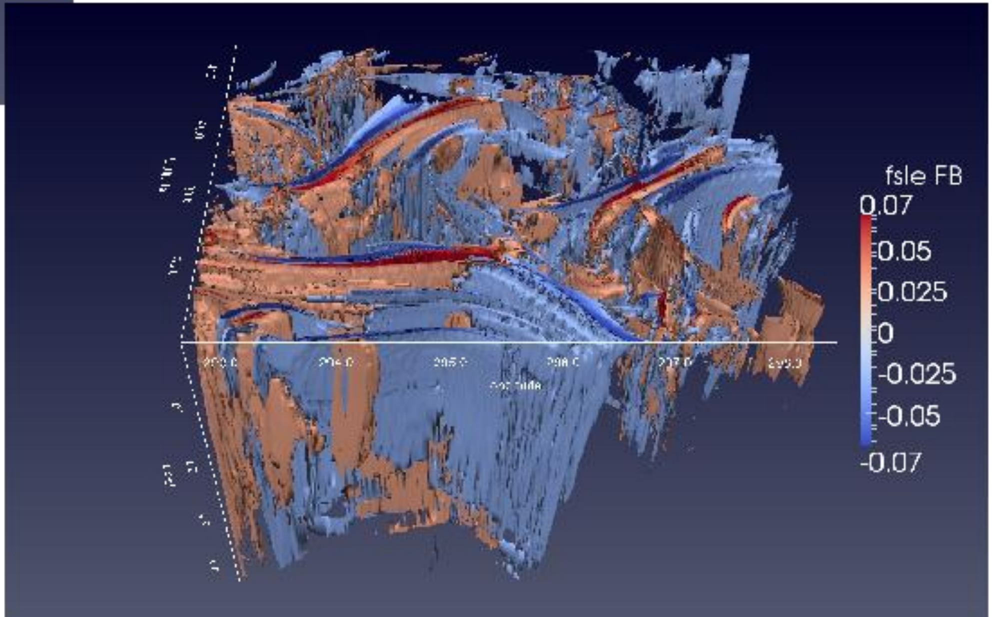
# Results

- Forward (+) and backward (-) FSLE

HR, winter, anticyclonic

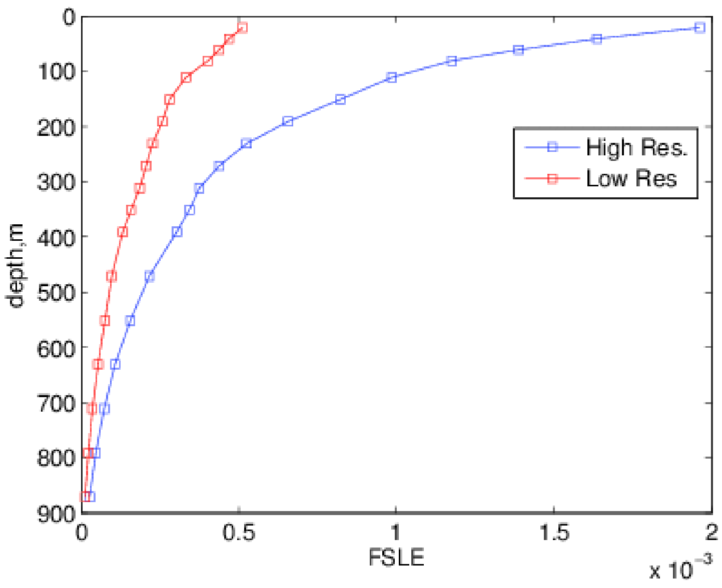


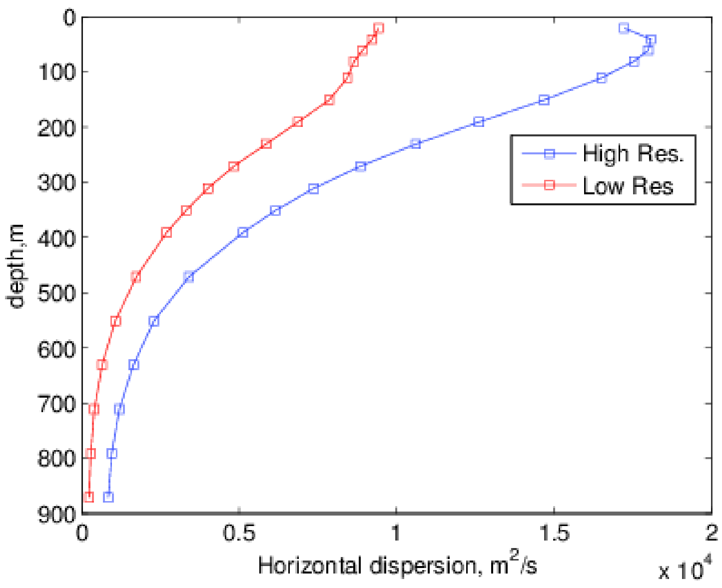

LR, winter, anticyclonic



- Vertical profiles of FSLE and lateral mixing

$$\int \lambda(\delta) d\,A = \int log(\alpha)/\langle\tau(\delta)\rangle\, d\,A \qquad \int K_h(t)\, dA = \int \frac{1}{2}\frac{d}{dt}\langle|x_i(t) - \langle x_i(t)\rangle|^2\rangle\, dA$$



## Lingering Numerical Issues In OGCMs:

1) Mixed layers are heavily parameterized with respect to the rest of the modeled ocean flows.

2) Vertical velocity is not prognostic; the accuracy of diagnostic W overall is in question.

3) Significant vertical velocities arise from frontal mixed layer instabilities at OGCM spatial resolutions where hydrostatic approximation breaks down; computed mixed layer vertical velocities are highly questionable…

4) Mixture of vertical coordinate systems (z, sigma, isopycnic) in the same model; are the errors due to coordinate transformation smaller than W ($10^{-7}$ to $10^{-2}$ m/s)?

5) Isopycnic coordinate already represents the material surface; do we take advantage of this?

## Lingering Mixed Layer (Physical) Issues :

1) What are the vertical velocities and horizontal convergence at the mixed layer and near the ocean’s surface?

   W~O(few mm/s): hard measurement!

2) How strong is the vertical shear (as Bruce indicated)?

   The questions – very important for high impact pollutant transport problems - demand accurate oceanic data;
   can’t be done on the basis of OGCMs and LES…

# Deep Plumes:

## Mixing of dispersants with the plume

Small source, released in the jet region…

• How effective is the mixing?

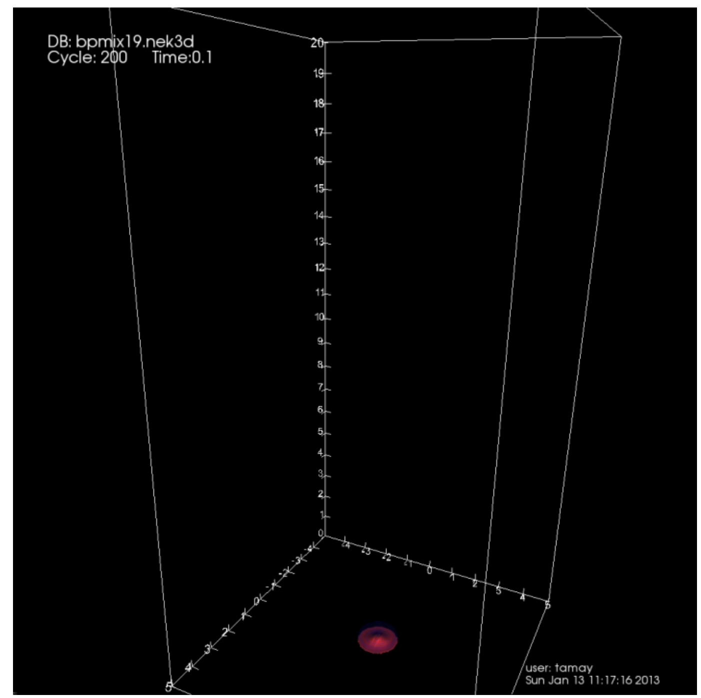
• How far from the source for complete mixing?

***Computational challenges:***

• Very turbulent plume

• Outflow for long integrations

• 75M points, 129k CPU hours
(13 years on a laptop)




**Computation: Özgökmen, Poje**

Two-Phase (Bubble) Plumes - Schematics of Experimental Results:

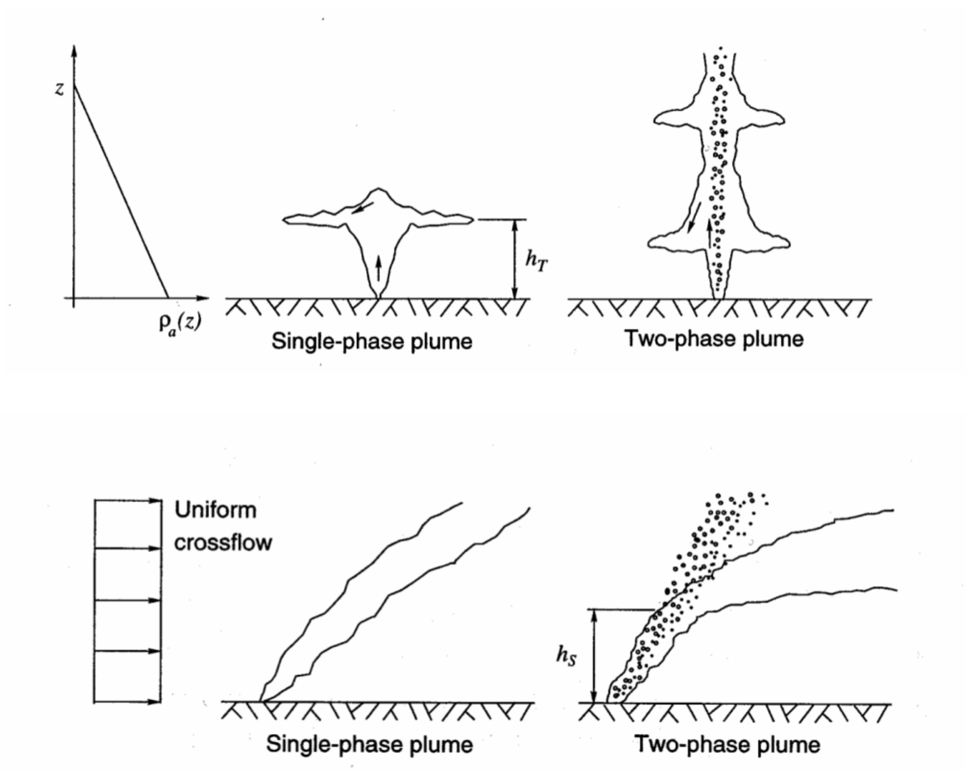



**Fig. 6** Separation of plume phases due to ambient stratification (top) and current (bottom).

From Adams and Socolofsky, 2004, MMS report

From Socolofsky and Adams, 2005, J. Hyd. Engg.

# Two-Phase Representation Within LES:

Poje and Özgökmen

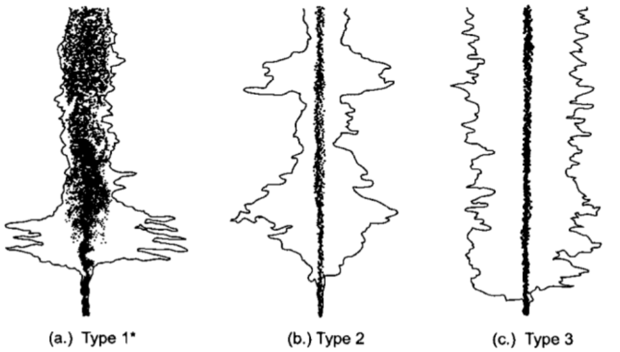
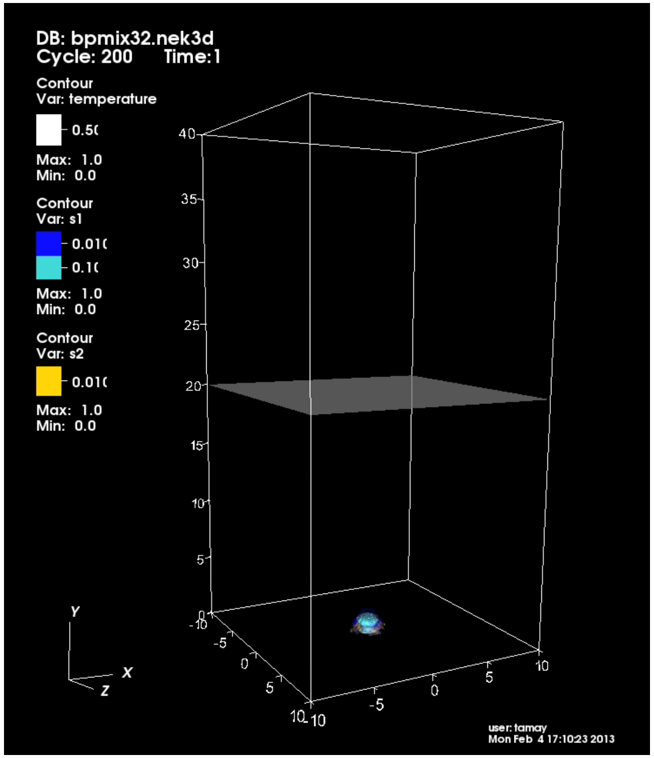
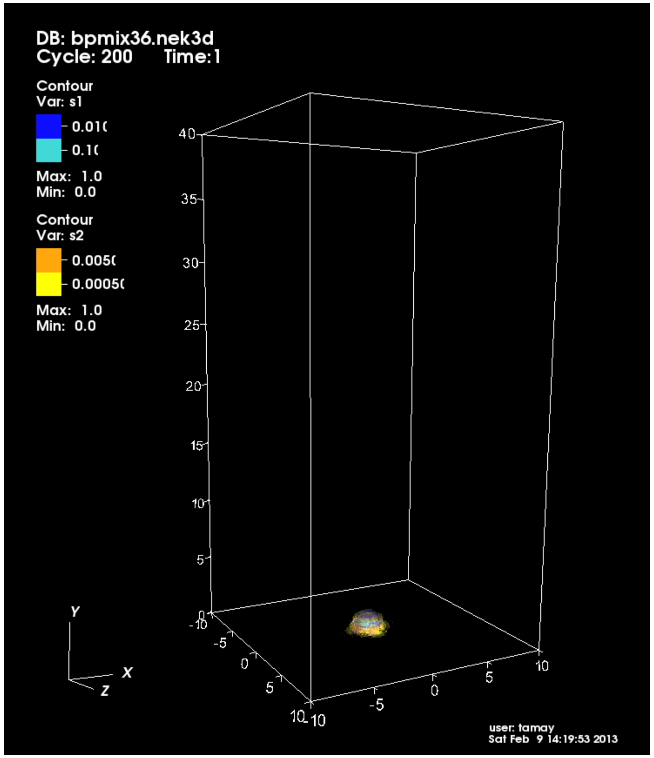



**Fig. 3.** Sketches of three plume types takes from photographs of actual experiments. Buoyancy flux and stratification are same for all three plumes; only slip velocity changes.

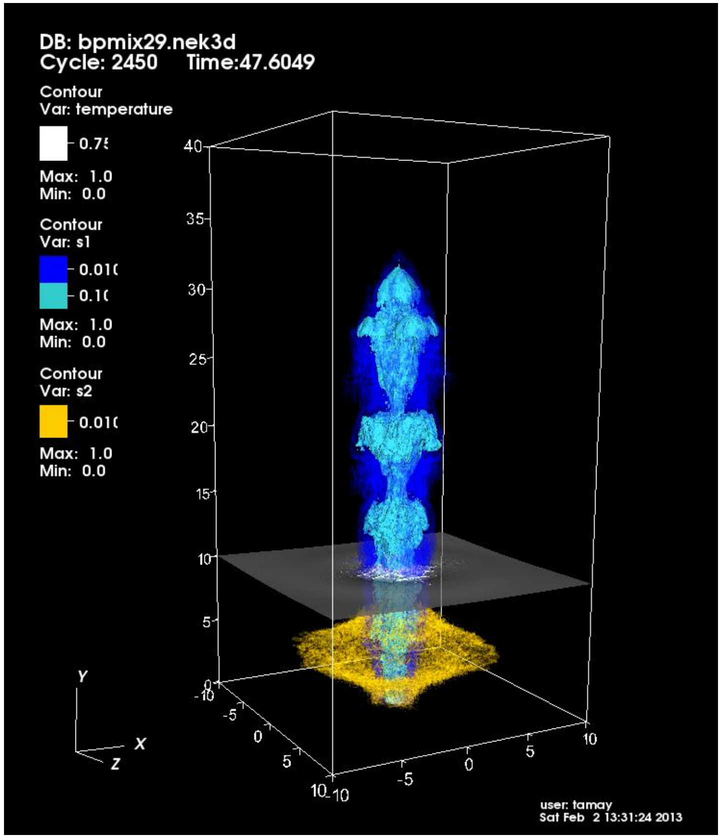
Type-I Plume:



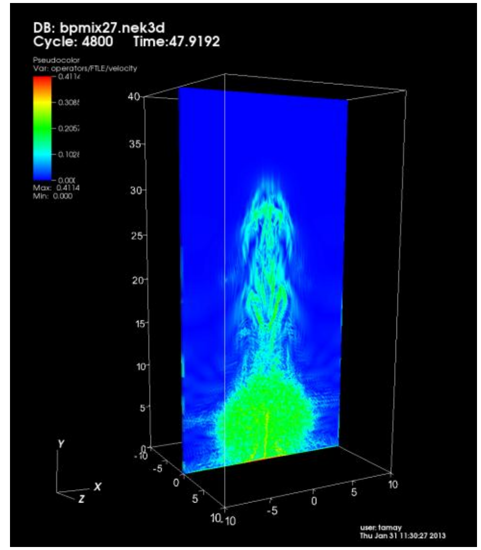

Type-II Plume:



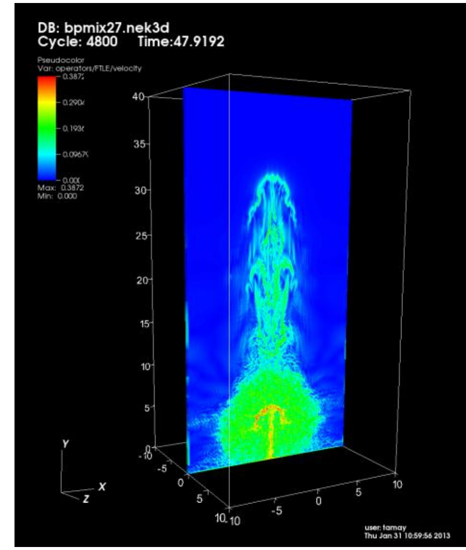
# Bubble (blue), tracer (yellow) and density (gray) fields



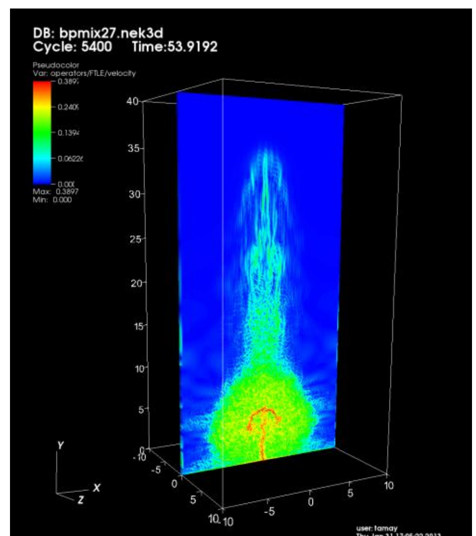

FTLE, forward, steady state, 10 iterations
201x401x3 particles



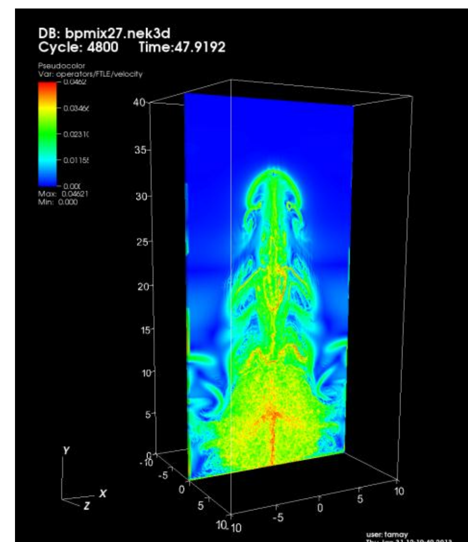

FTLE, backward, steady state, 10 iterations
201x401x3 particles




FTLE, backward,un steady state, 10 iterations
201x401x3 particles




FTLE, backward, steady state, 100 iterations
201x401x3 particles



# Summary:

1) Presented ongoing studies on a number of ***oceanographically relevant problems*** for which 3D+1 transport and mixing methods are useful.

2) Significant effort was spent to test and develop 3D parallel FTLE (backward and forward) software within a visualization package with their developers. Numerical chaos arising from off-line integration non-native mesh make it very difficult to use for very long integrations needed in rotating-can study, but OK for short term integrations.

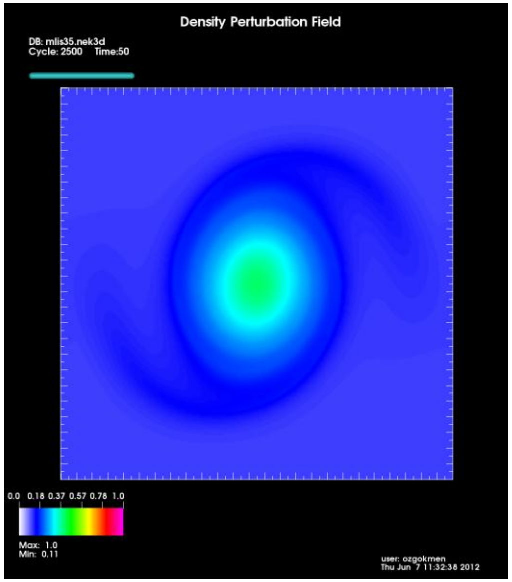
3) Passive tracer release (nicely online and parallel in LES) seems to be also a very useful and practical tool.

   The non-conservative nature (even at very high Pe) of tracer advection with respect to particles seem to be an academic issue, in many cases I have been dealing with…
   (what are the important problems that one can attack only with particles (3D LCS)…??)

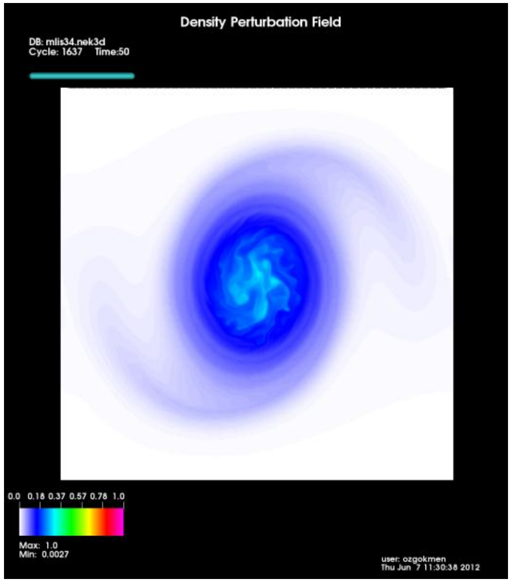
***Comment:*** “Face-off” (FTLE… geodesic, half dozen metrics and growing) is not yet done…

# *Surface Density After 25 days of Integration:*

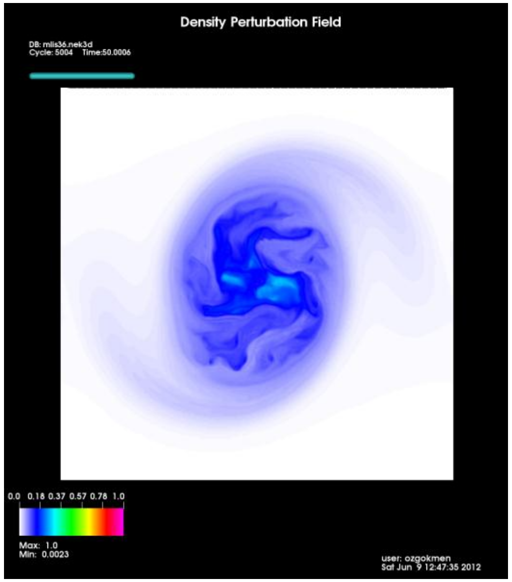
***MLD=0 m***




***MLD=25 m***




***MLD=50 m***




***MLD=150 m***