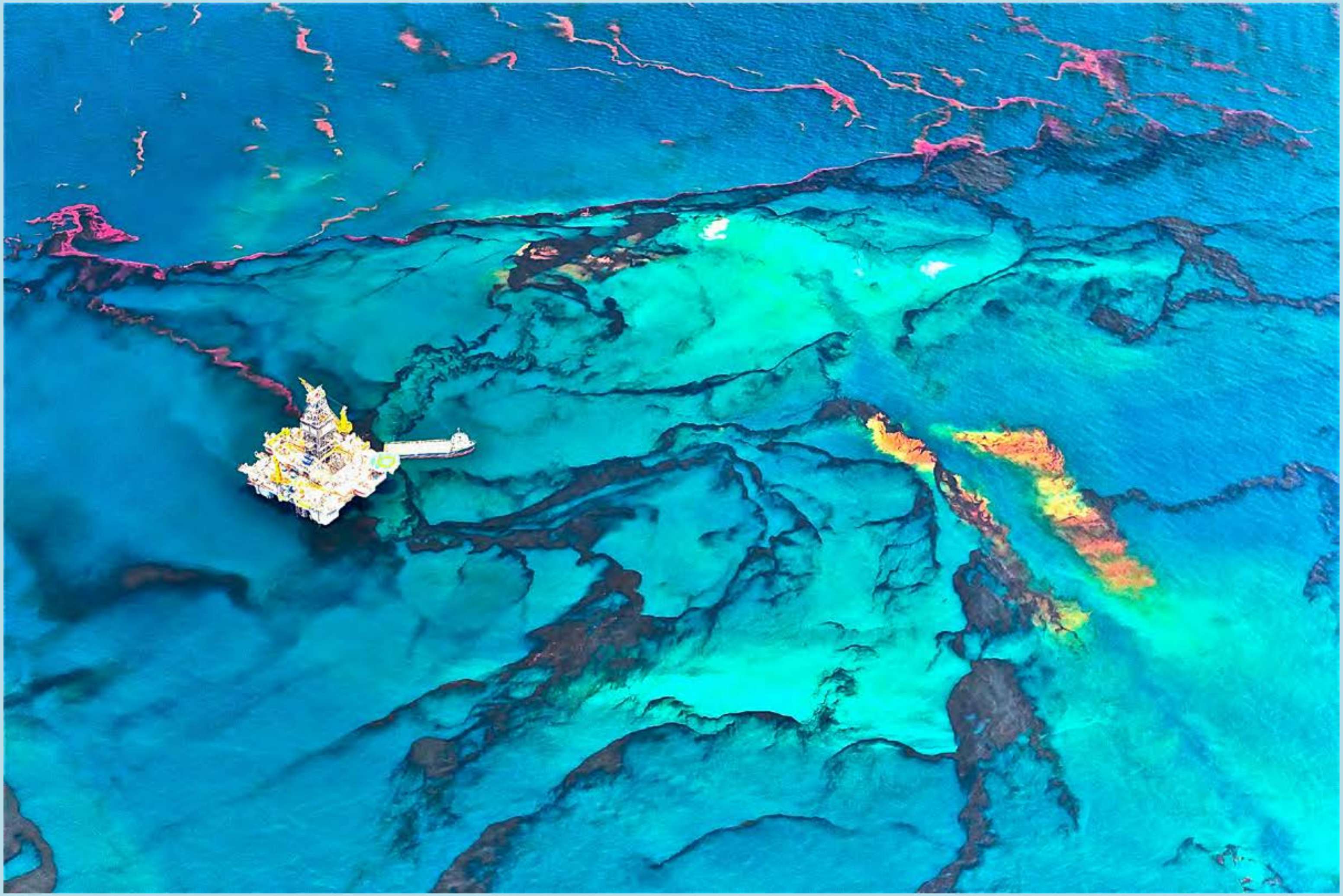
Material Transport by 3D Coherent Structures in the Upper Ocean



Tamay Özgökmen, J. Mensa, A. C. Poje et al., MURI 3D+1***, September 2015***

Outline:

1) In search of applications: 3D FTLE with a visualization code for various modeled flows

2) Summary of recent work:

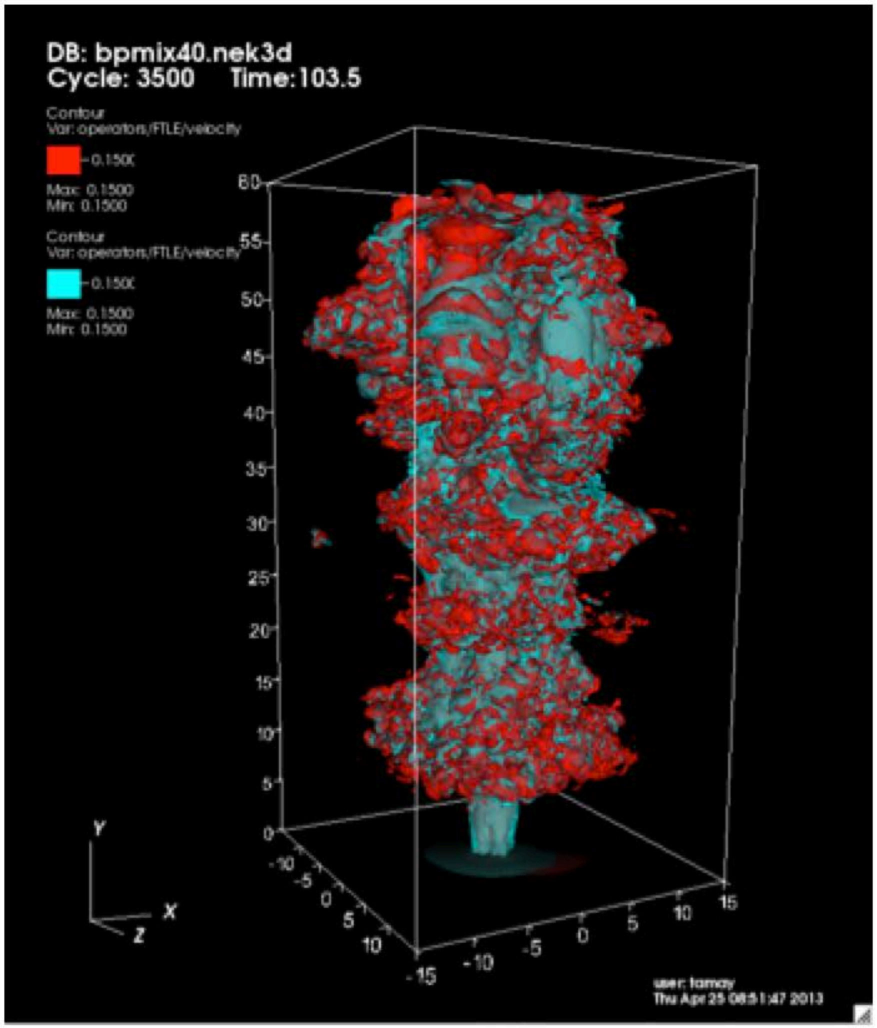
Mensa, Ozgokmen, Poje and Imberger: Material transport in a convective surface mixed layer under weak wind forcing. Ocean Modelling, revised.

3) LASER: a possible experimental program to link with 3D+1 MURI

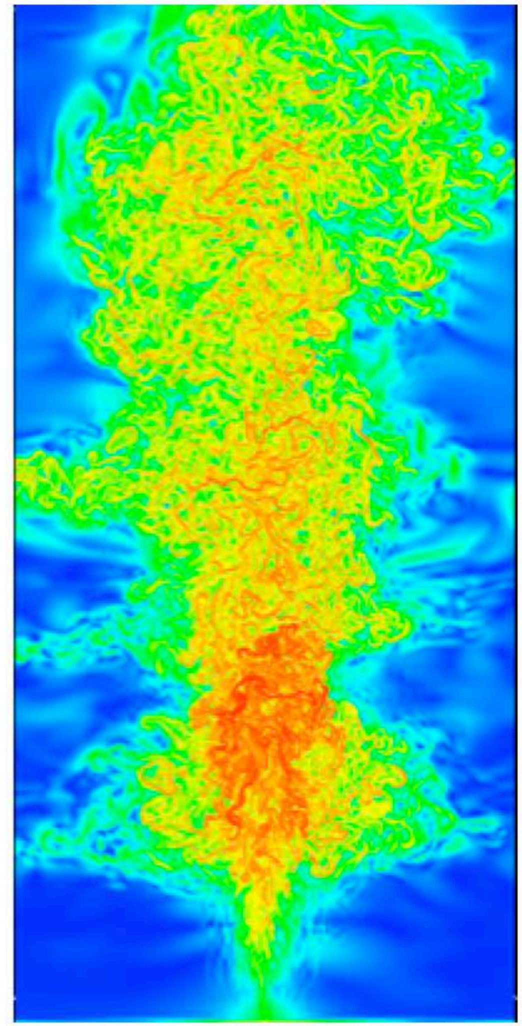
3D FTLEs in 3D turbulence:

3D FTLE Structure in Two-Phase Plumes

Backward (red) & Forward (blue) FTLE

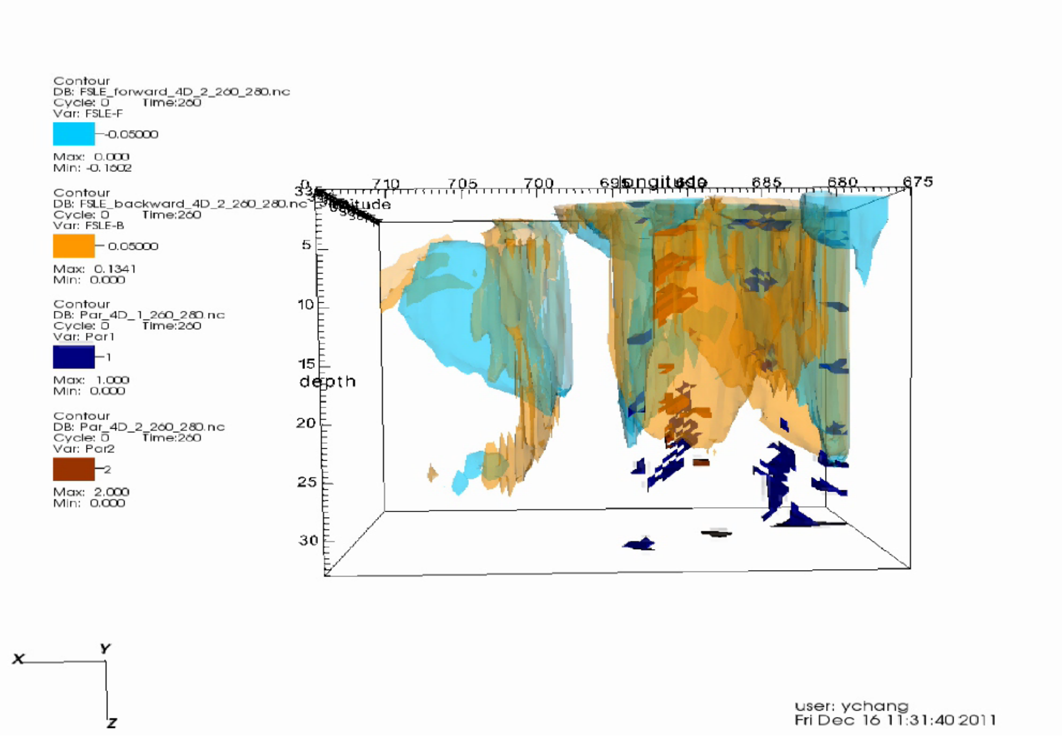


Backward FTLE section



marginally useful…

3D FTLEs in Mesoscale Eddies (HYCOM)



Issues:

- *In the ocean interior, horizontal divergence is small, w ~ 10^{-5} m/s, or 10 years for turn over time in an eddy; 2D LCS is good enough for many applications;*

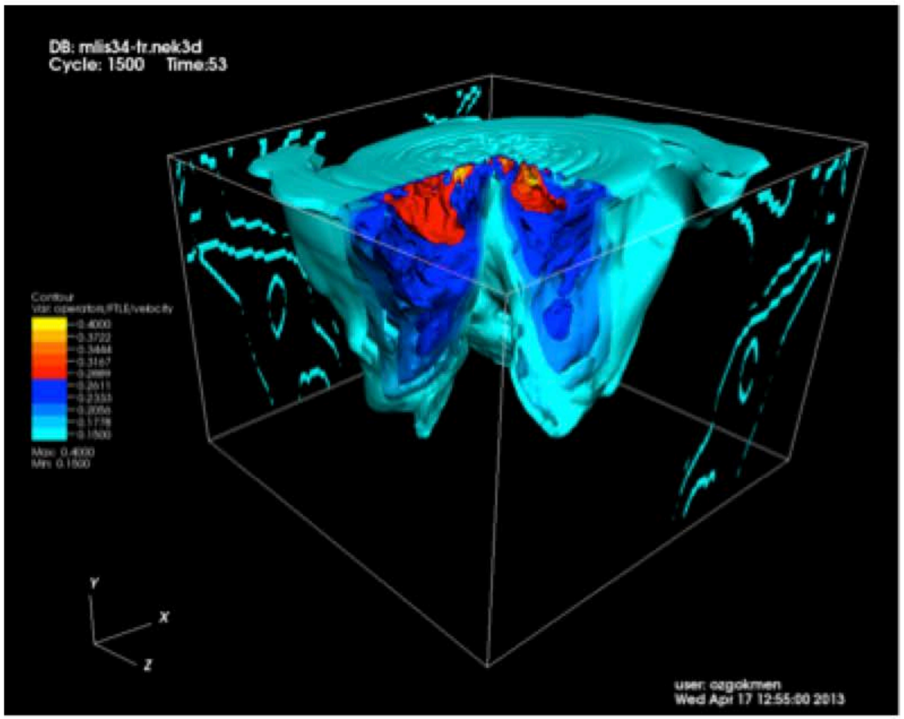
- *HYCOM has isopycnic (naturally Lagrangian) layer; no value added by 3D LCS;*

- *T/S diagrams sufficient to track water masses as mixing is small and along isopycnals*

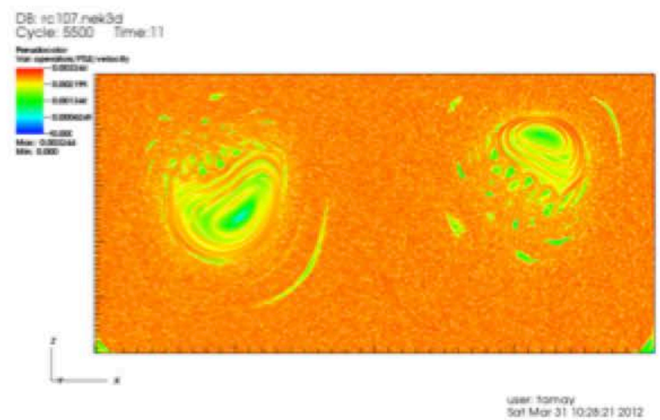
- *Dense observations virtually impossible due to the scale of features*

Search for Pratt-JFM-2013 tori in submesoscale eddies

3D FTLEs From LES of Oceanic Eddies:



Rotating can example:



Do tori exist in more realistic eddies? Look into the influences of
(a) high Re, and (b) high aspect ratio, [(c) stratification, (d) time dependence]

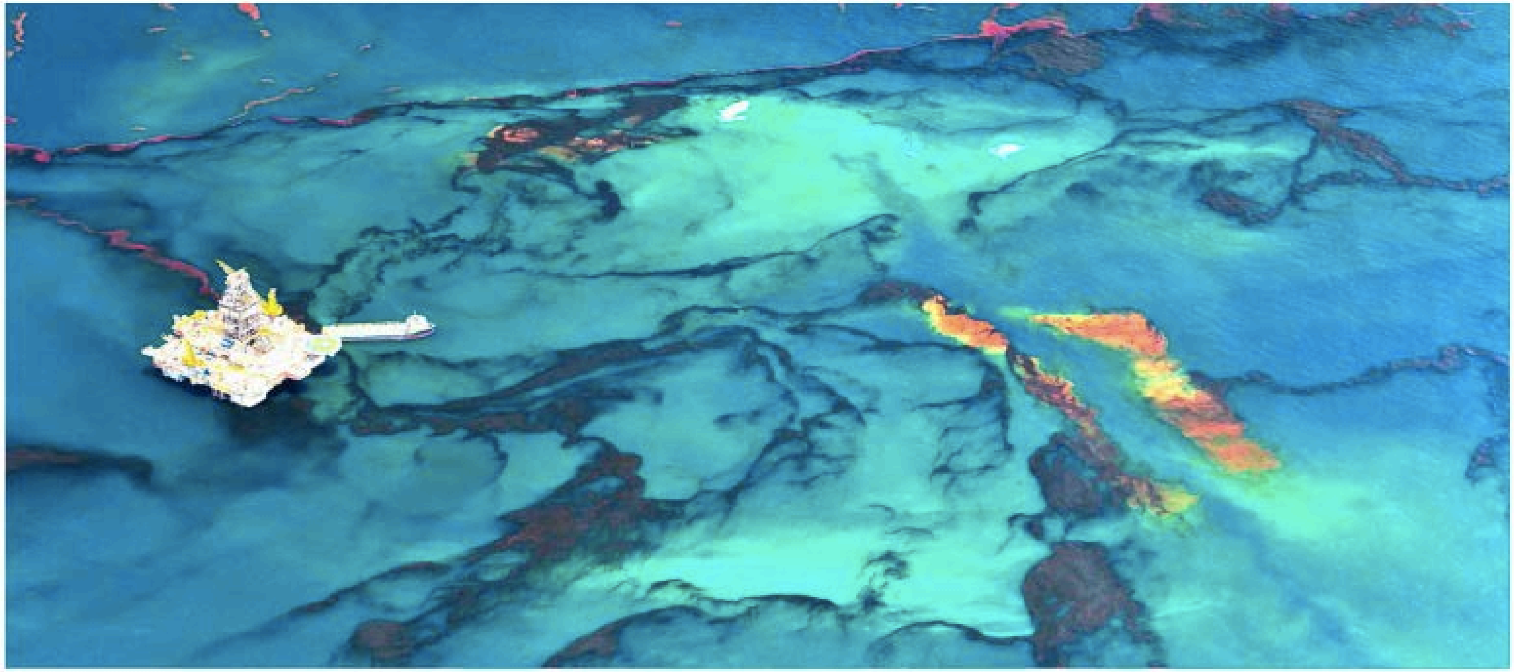
Note:

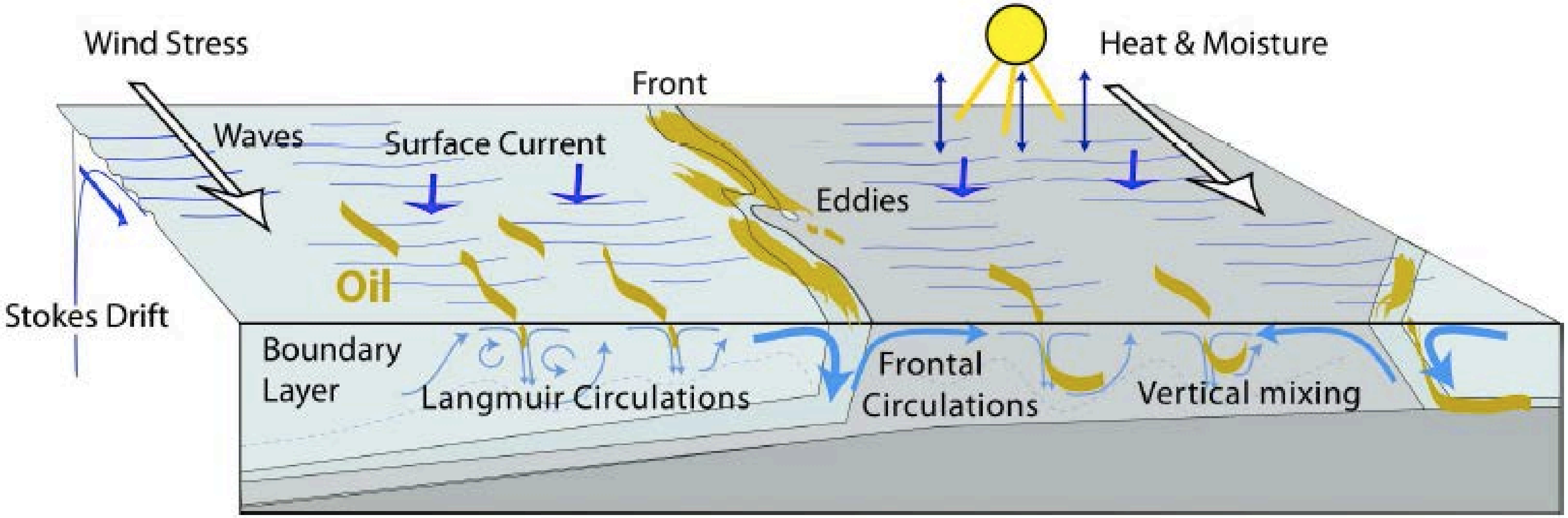
The 3D FTLE code was not a long-term love story (even within our group) since :

- **it requires the launch of O(10 million) particles - not feasible in the ocean;**
- **it is hard to parallelize;**
- **a tremendous debate ensued on whether FTLE is really the LCS with respect to 10 other methods developed over the past few years…**

  An LCS “face off” has not materialized thus far;
- **3D LCS took a back seat to passive tracer releases – which are computationally efficient (parallel) and feasible as an oceanic observation system.**

In contrast, upper ocean processes create 3D coherent structures that are important for material transport and relatively easier to observe…





Objectives:

1) Any interesting coherent structures in the mixed layer even under weak wind forcing? Weak wind of interest since under-investigated yet common in spatio-temporal sense in the world oceans.

2) Is there a particular difference between 2D (drifters) and 3D (floats) sampling, statistically?

3) How does the dispersion compare to canonical scaling laws by Richardson (1926) and Okubo (1971) compilation of measurements?

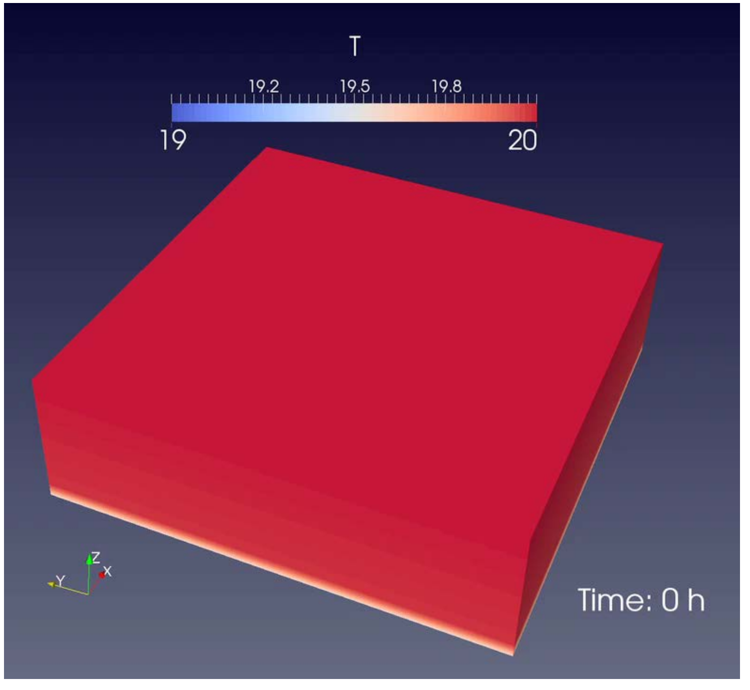
Model Configuration:

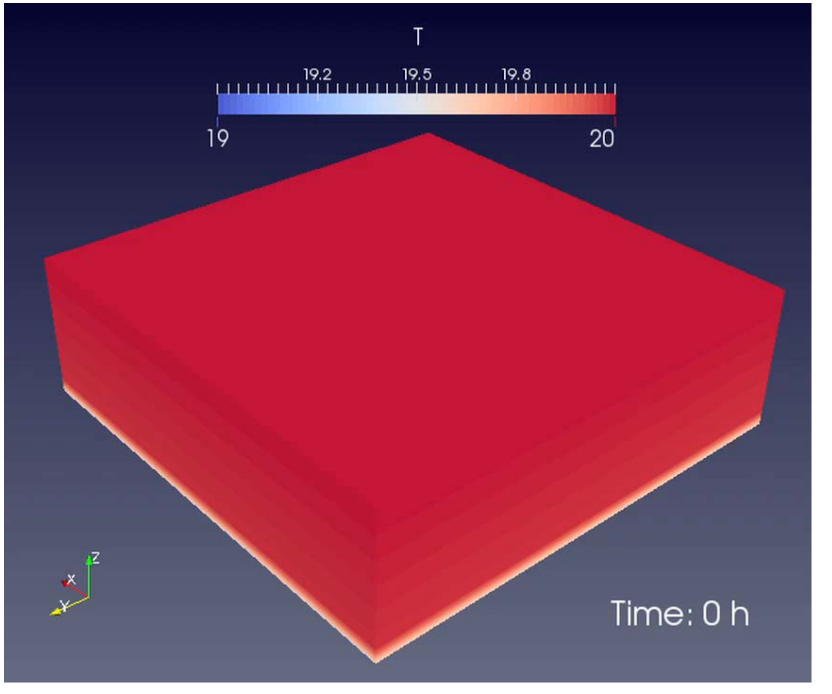
- ICOM: finite element, nonhydrostatic
- Domain: 8 km x 8 km x 50 m (mixed layer only)
- Dx=25m, Dz=1m
- Regular buoyancy forcing (short and long wave radiation) after Price et al. (1986), Brainard and Gregg (1995)
- Constant unidirectional weak wind; U_{10}=5 m/s
- No wave forcing
- Periodic lateral bcs; insulated bottom
- Two simulations:

  Exp. B (buoyancy only), Exp. BW (buoyancy and wind forcing)
- Each run for 10 days for various statistics
- On a recent IBM cluster on 512 cores; only 2x faster than real time

  (but spectral methods should be 10x faster FEM used here)

Evolution of the Temperature Field in Exps. B & BW:





In Exp. B, cell size (250 m > MLD) consistent with rotating convection $(B/f^3)^{1/2}$ (Jones and Marshall, 1993)

Airborne observations of similar features:

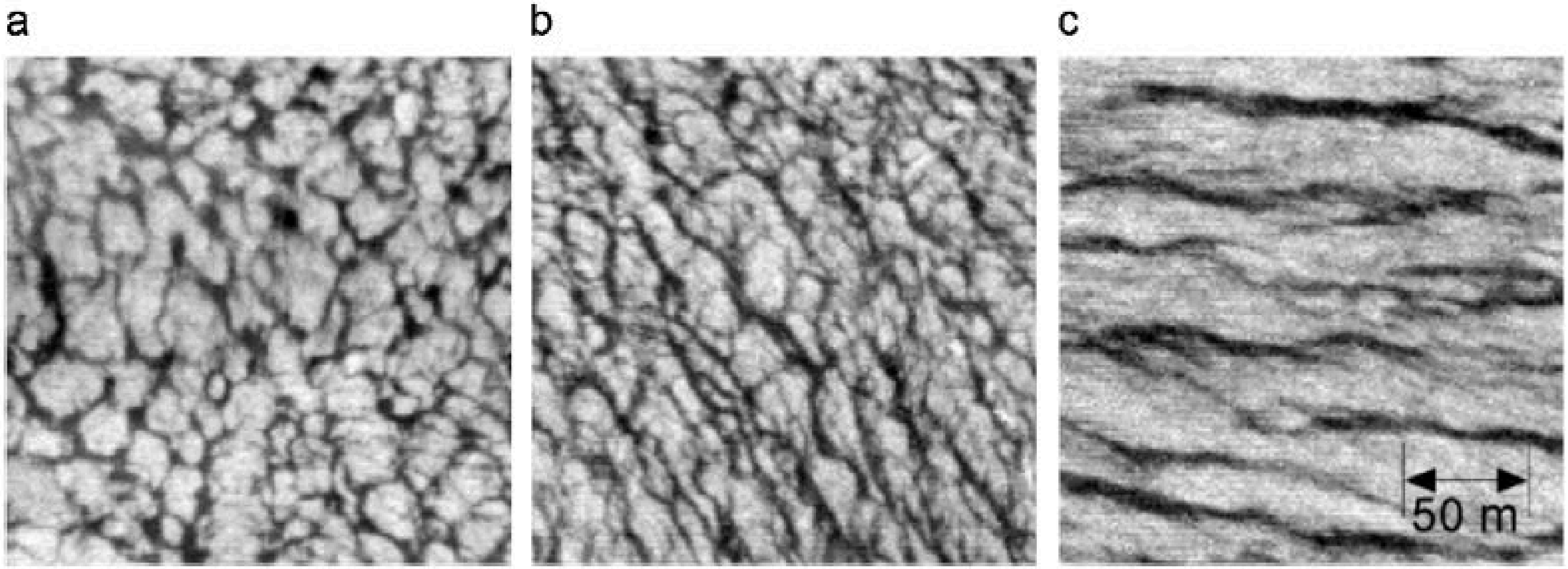
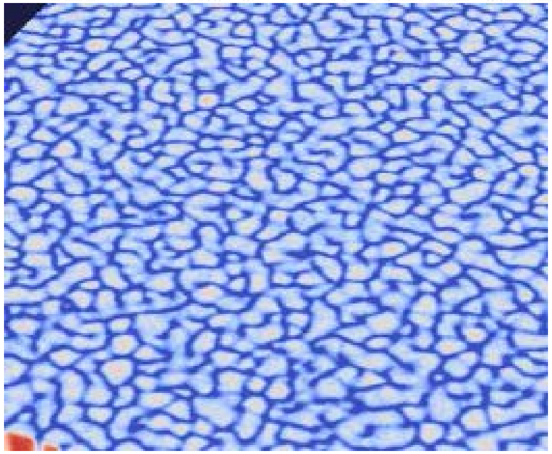
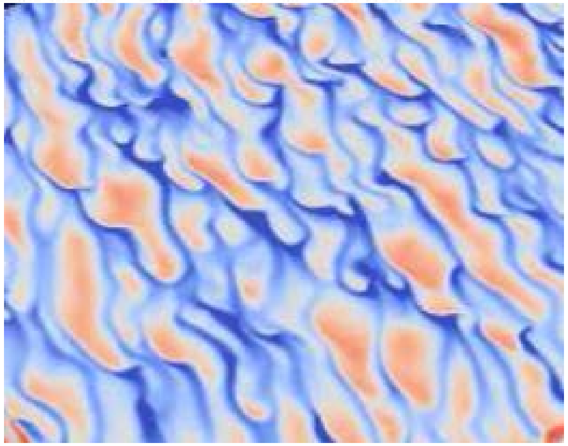
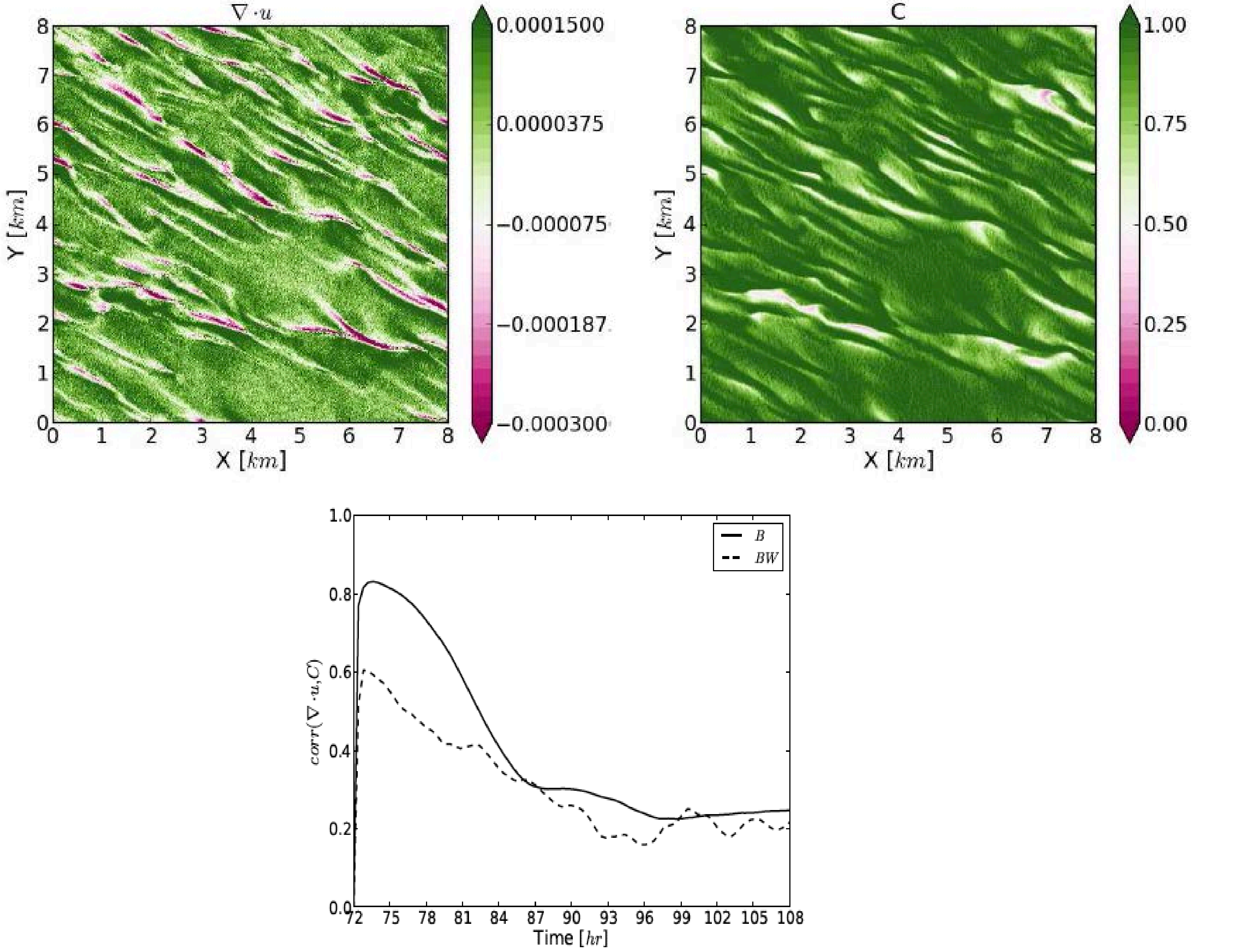


Fig. 4. Subsets of infrared imagery showing details from pass A (a, b) and pass B (c): (a) cellular convection; (b) aligned convection and (c) windrows. North is toward the top of the page, and each image is 200 m on a side. A common reference length of 50 appears in (c). Panels are individually scaled to maximize the contrast, dynamic ranges being 0.90 °C (a), 0.68 °C (b), and 0.47 °C (c).





Correlation between Surface Tracer and Divergence Field:

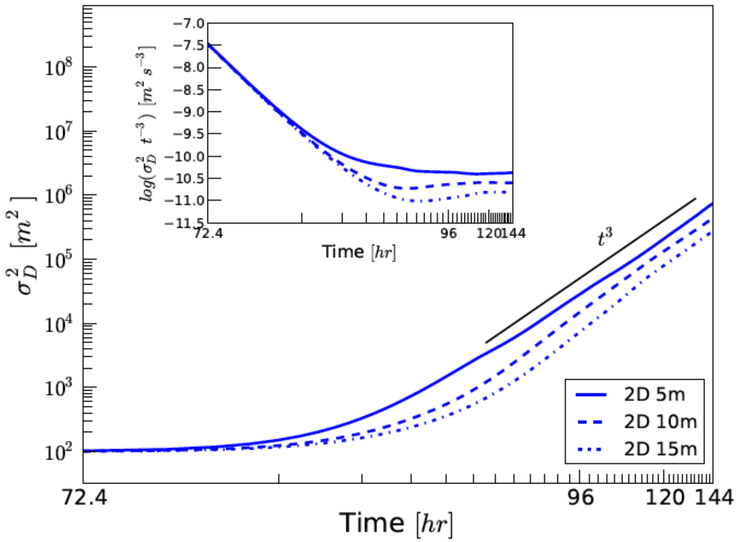


Horizontal Relative Dispersion:

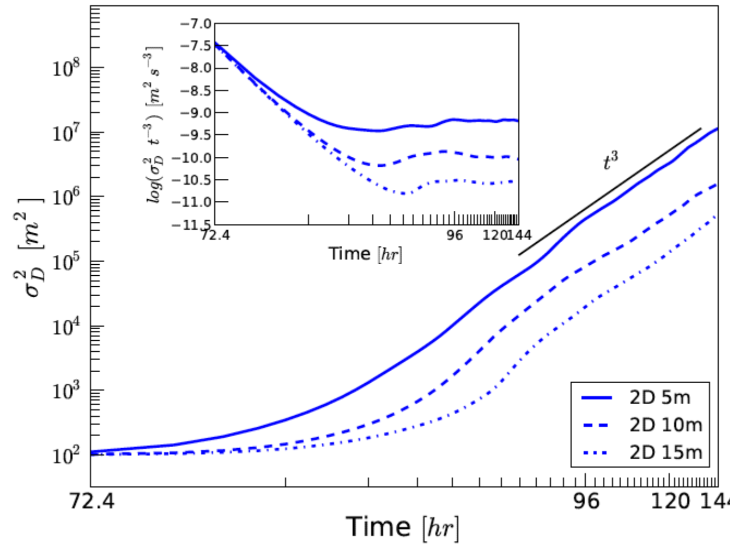
Exp. B

Exp. BW

2D



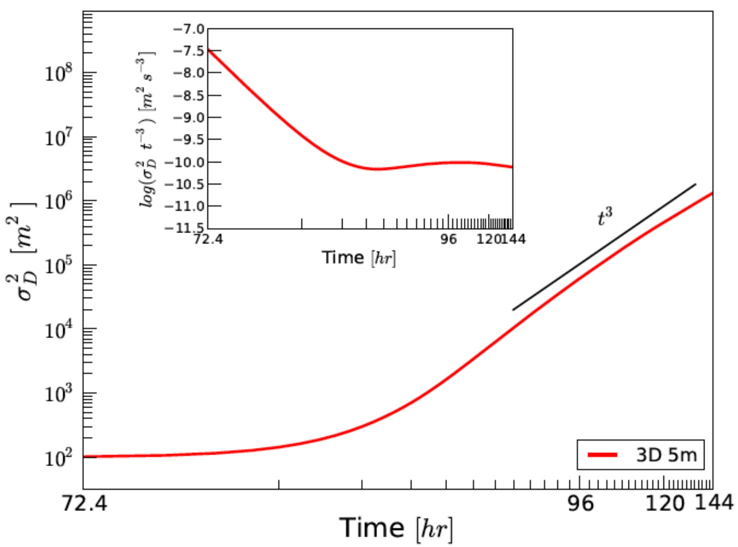
(a)

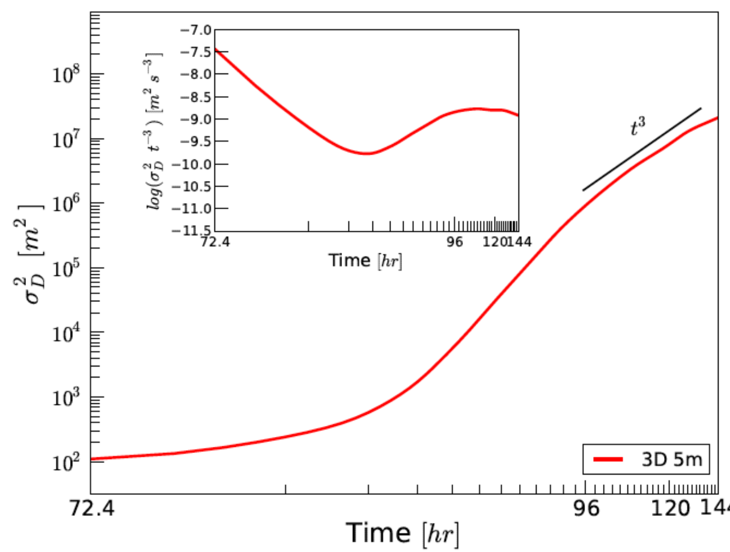


(a)

Higher with wind forcing

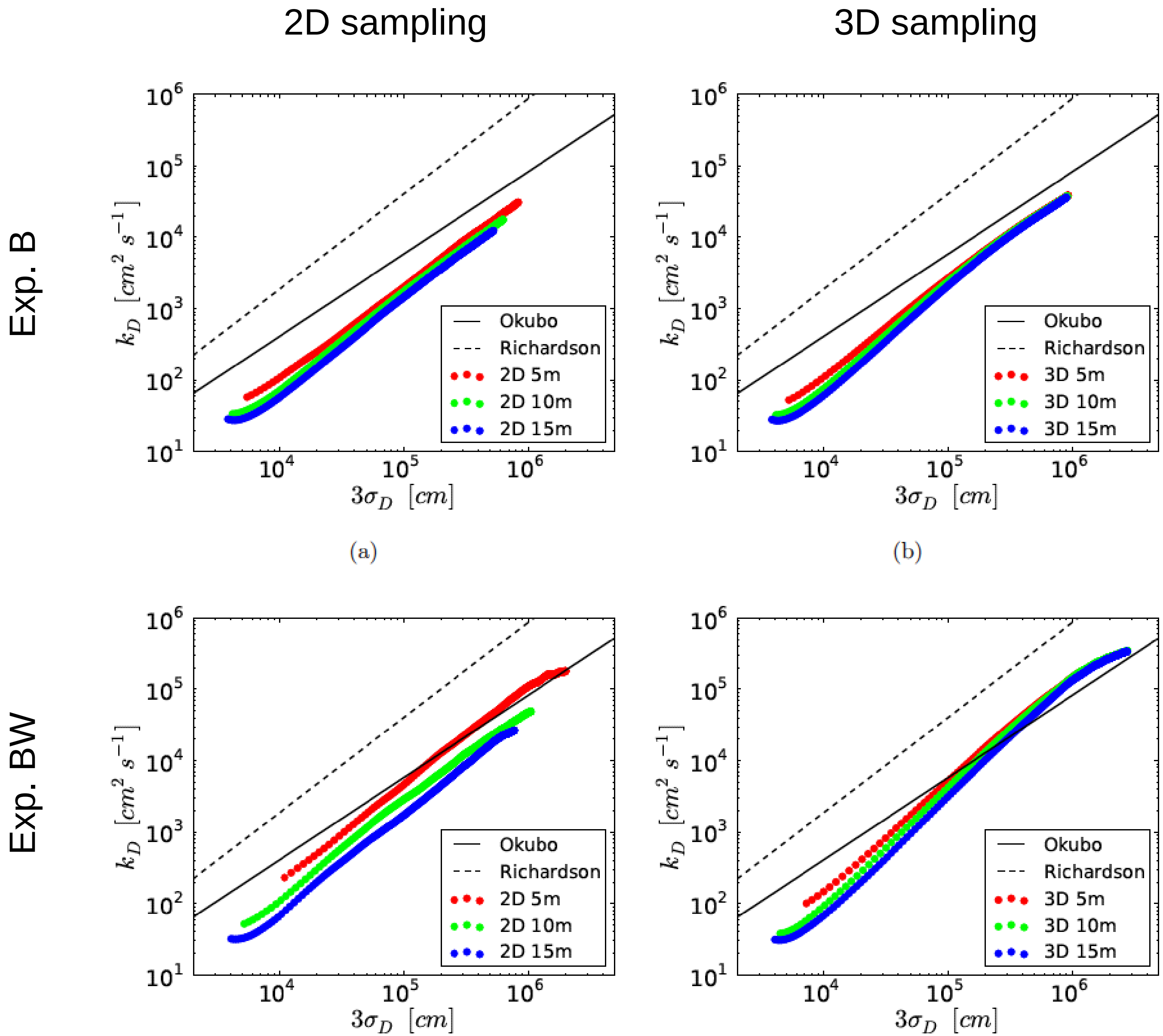
3D





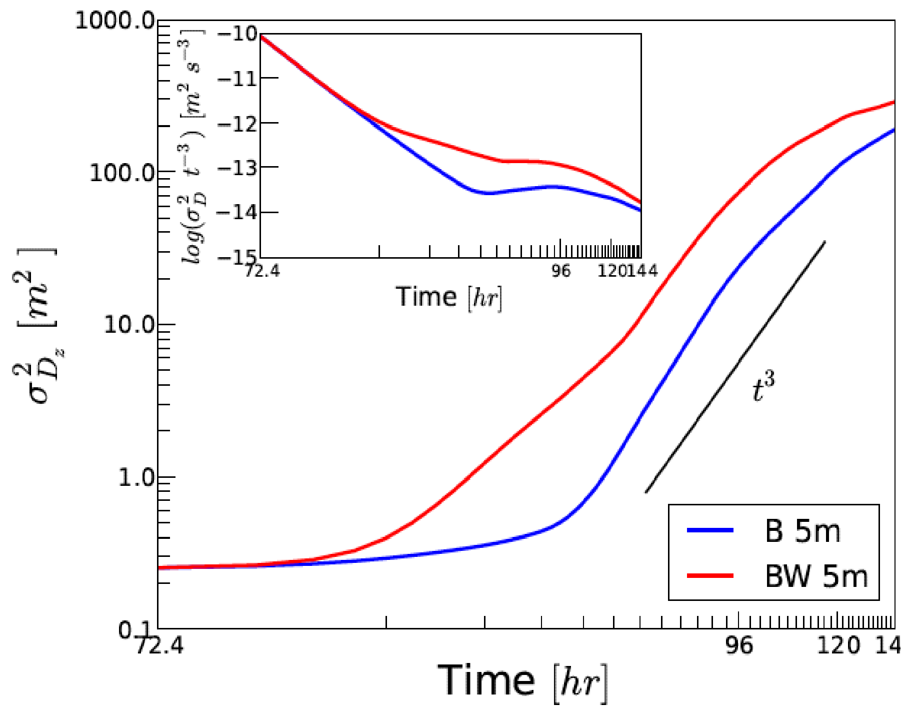
Richardson-Obukhov scaling $D^2(t)=C\ \varepsilon\ t^3$ easier with 2D sampling due to change of ε with depth

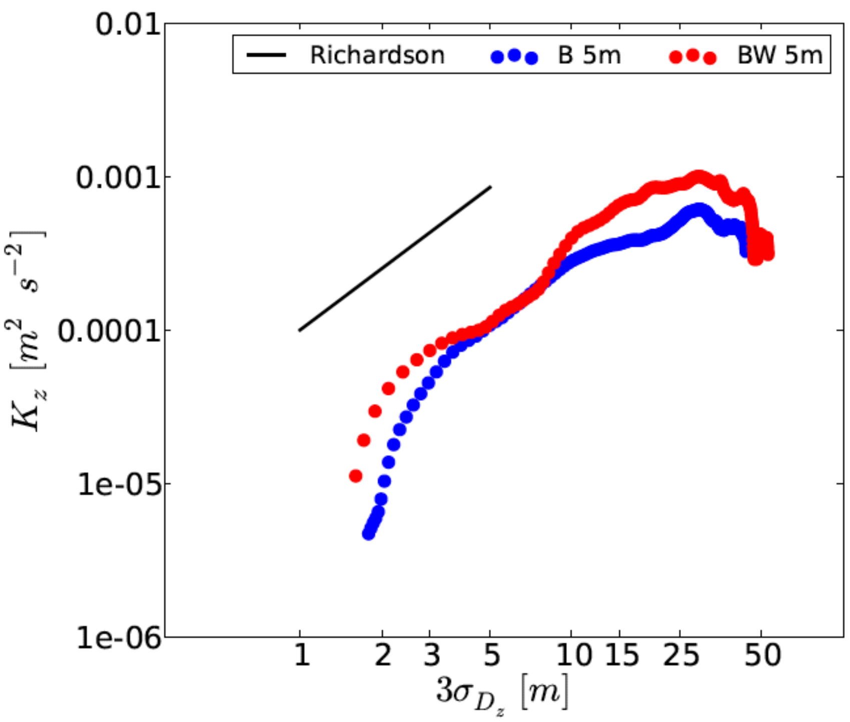
Scale-Dependent Horizontal Diffusivity:



Slopes consistent with Richardson's 4/3rd law; Okubo amplitude attained under wind forcing

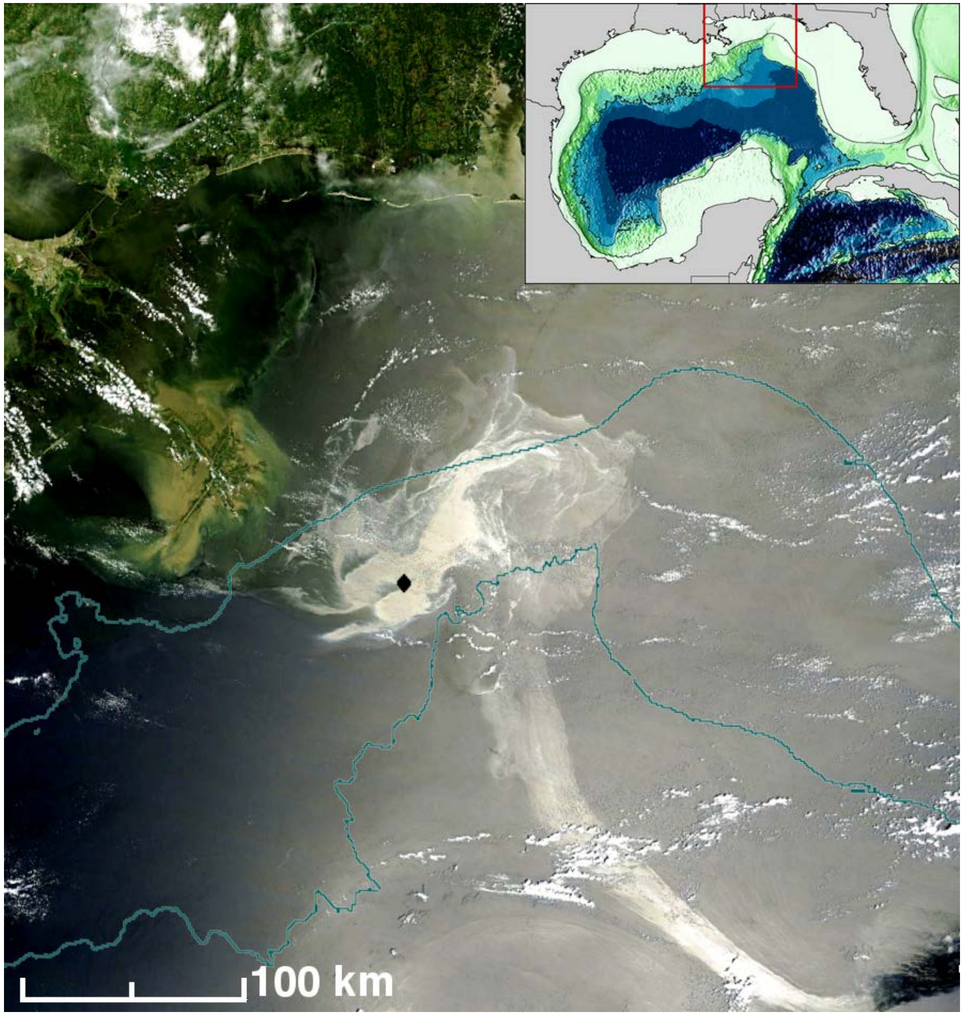
Vertical Relative Dispersion and Vertical Diffusivity:

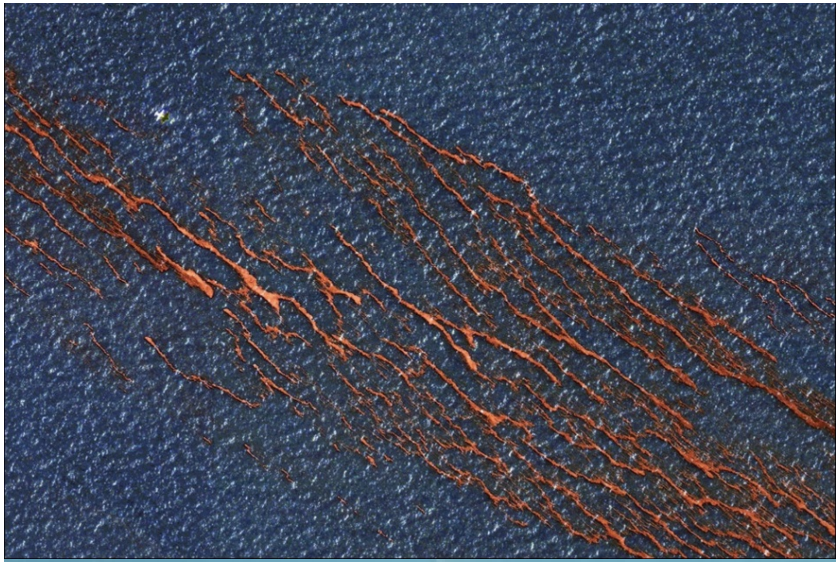




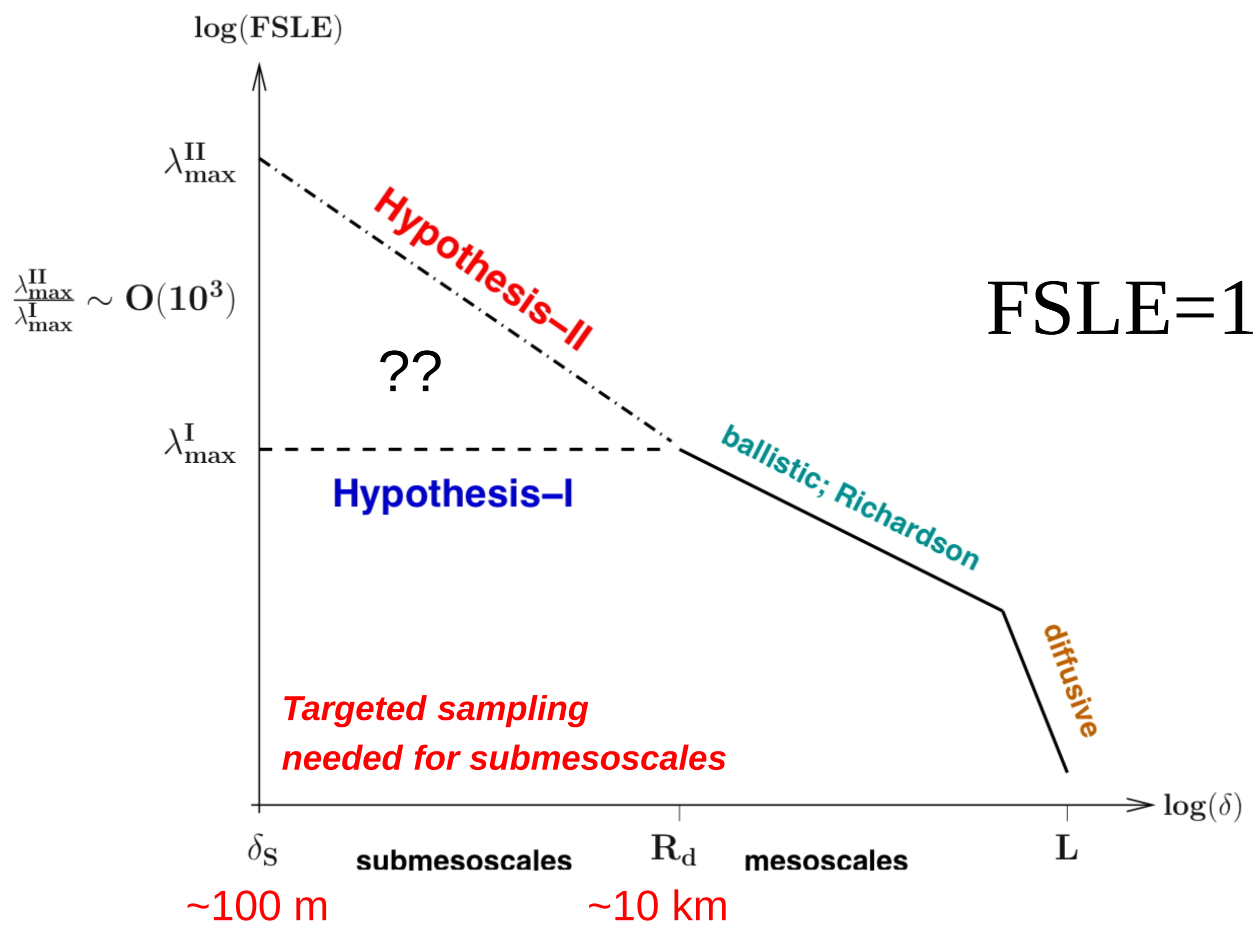
Both consistent Richardson scaling…

CARTHE Observational Programs in the Gulf of Mexico

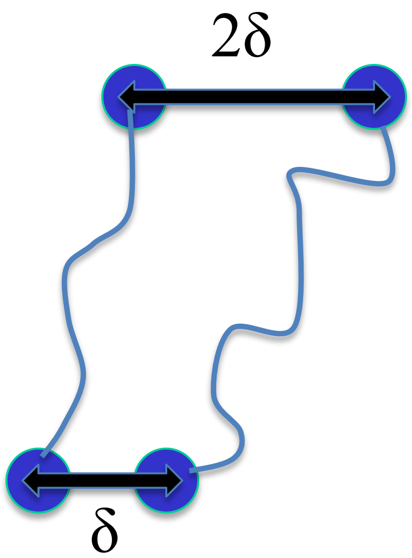




A Scale-Dependent Lagrangian Measure of Ocean Transport



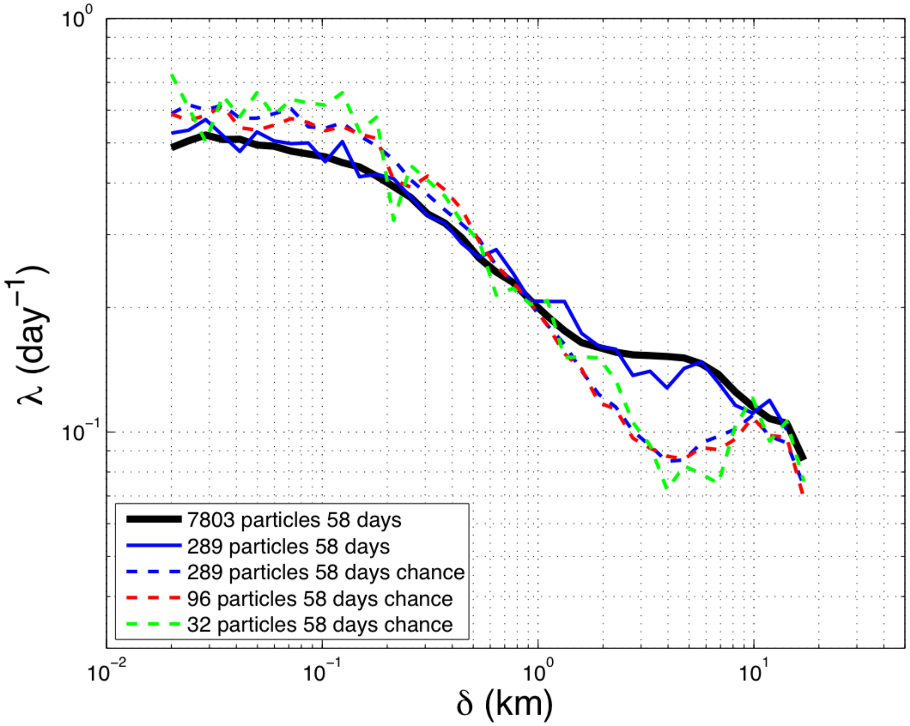
$$FSLE = 1/\tau$$

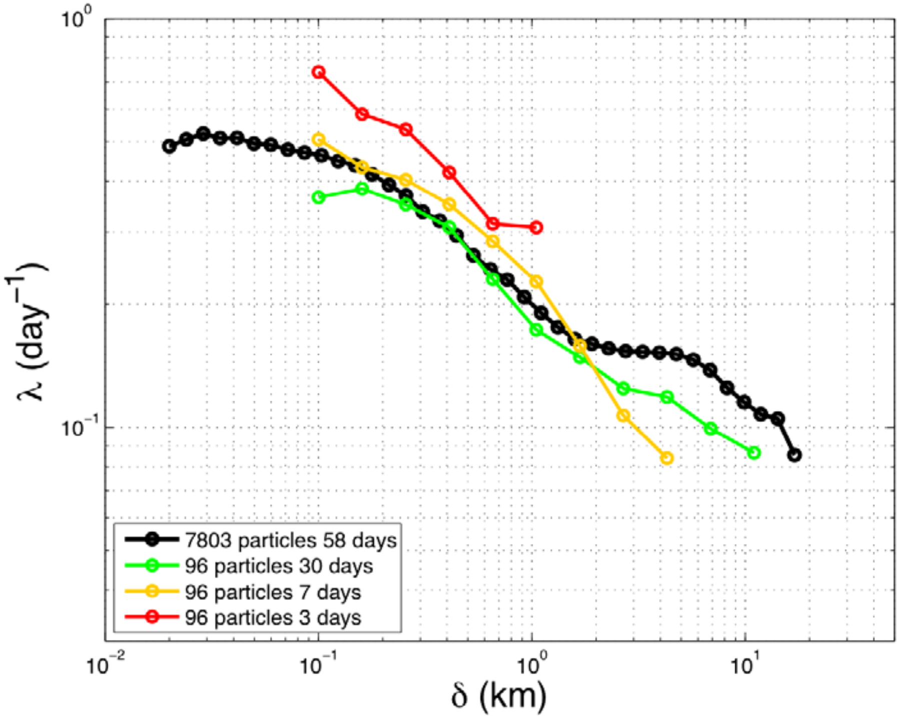


Hypothesis-I : energetic and slowly-evolving turbulent features in control,
data-assimilating OGCMs would be adequate to give good predictions

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

Estimate Resources Needed Based on LES (Ozgokmen et al, 2012): How Many Drifters and How Long Would Be Enough?

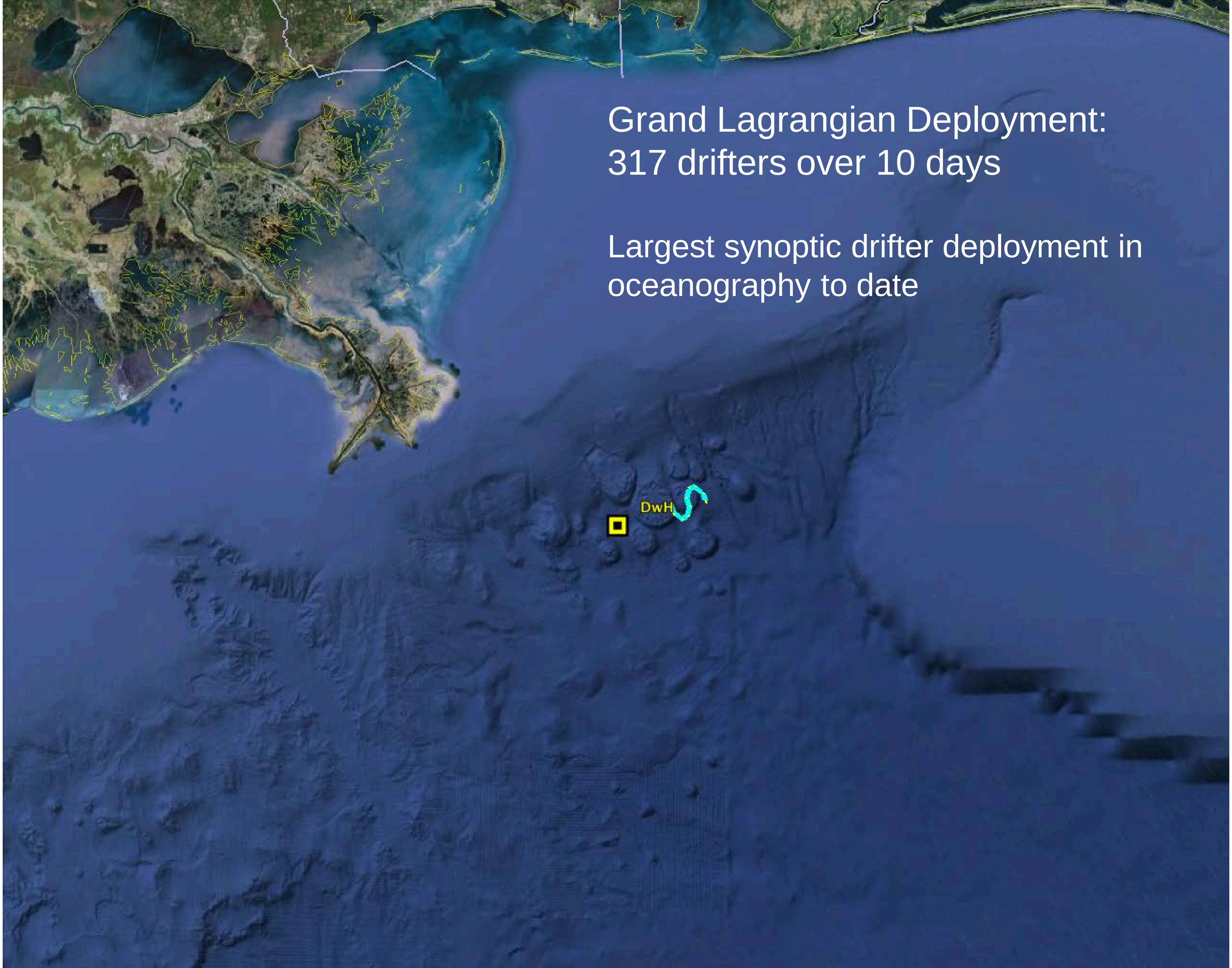




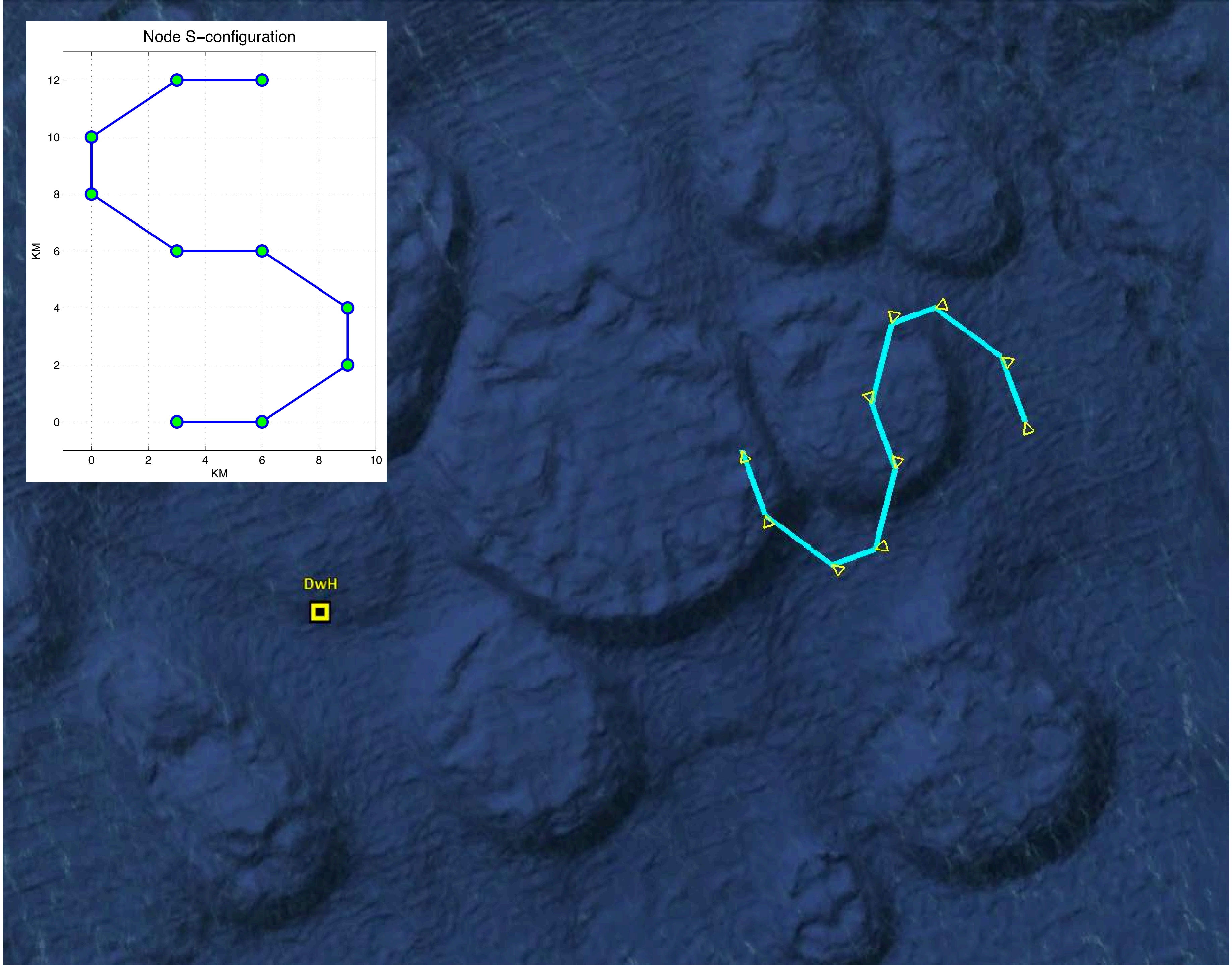
100 to 300 drifters, at least 30 days of data

also 5 min, 5 m accuracy sampling aimed…

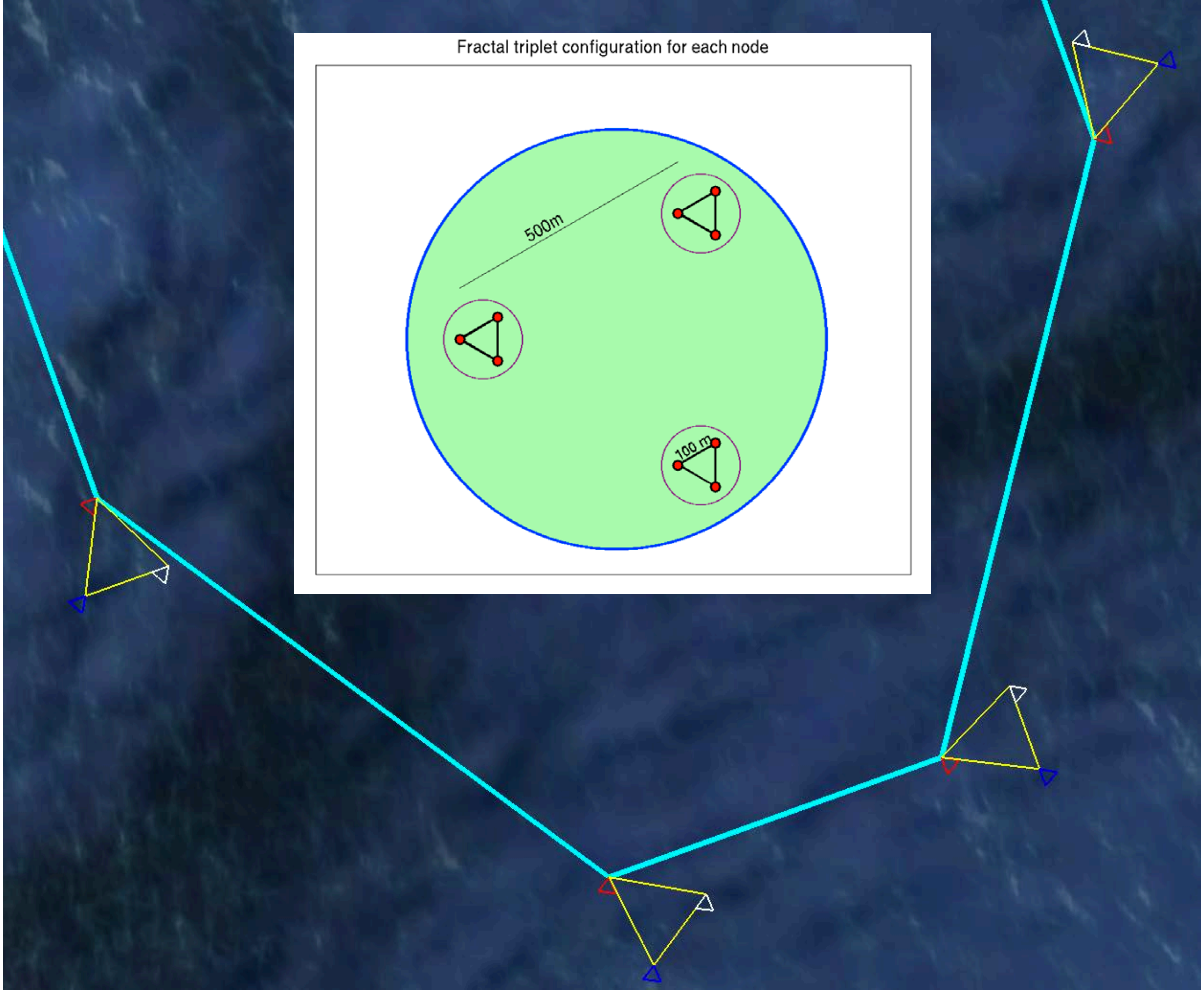
Formed the basis of ocean experiment (GLAD) design…



Grand Lagrangian Deployment:
317 drifters over 10 days
Largest synoptic drifter deployment in oceanography to date
DwH

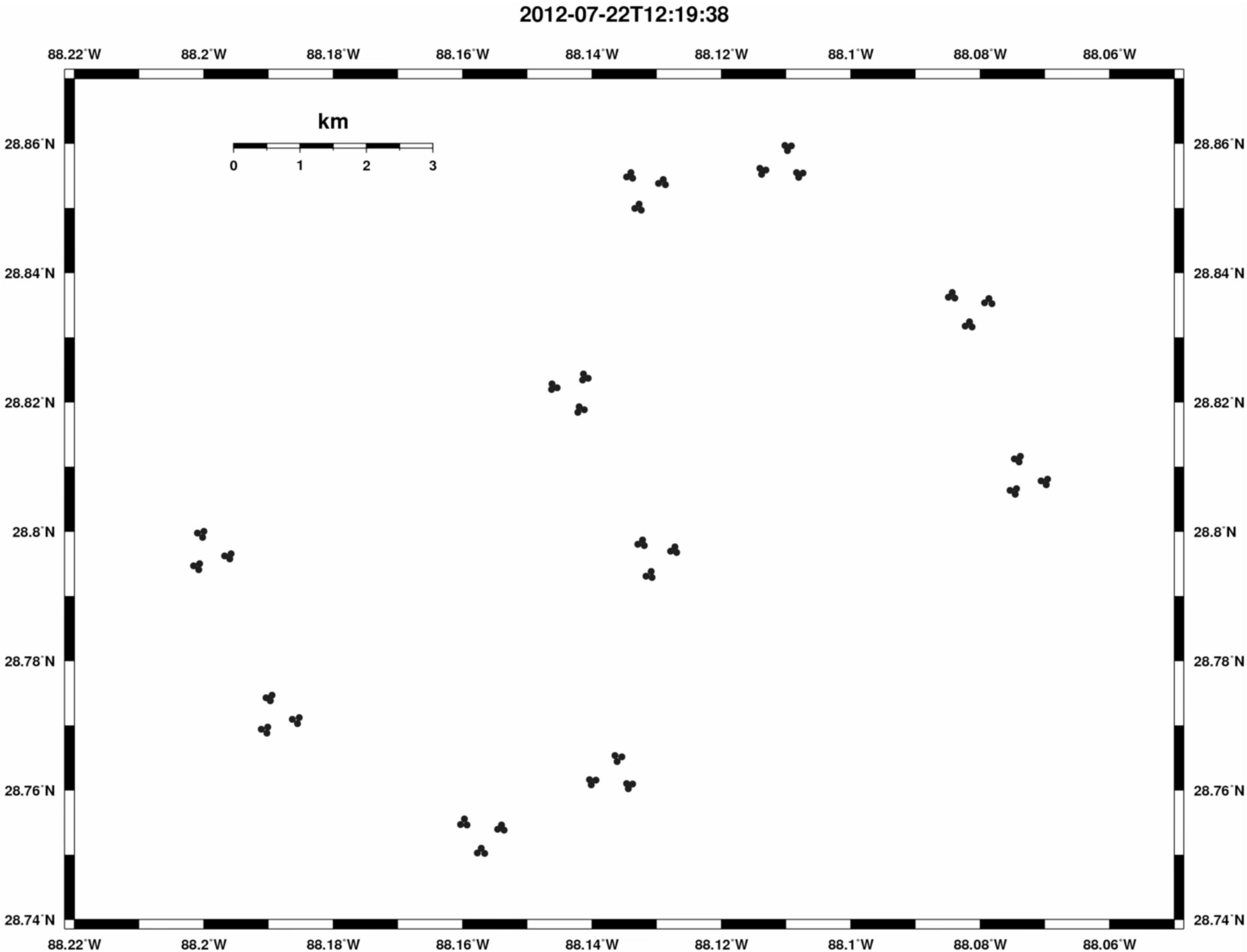


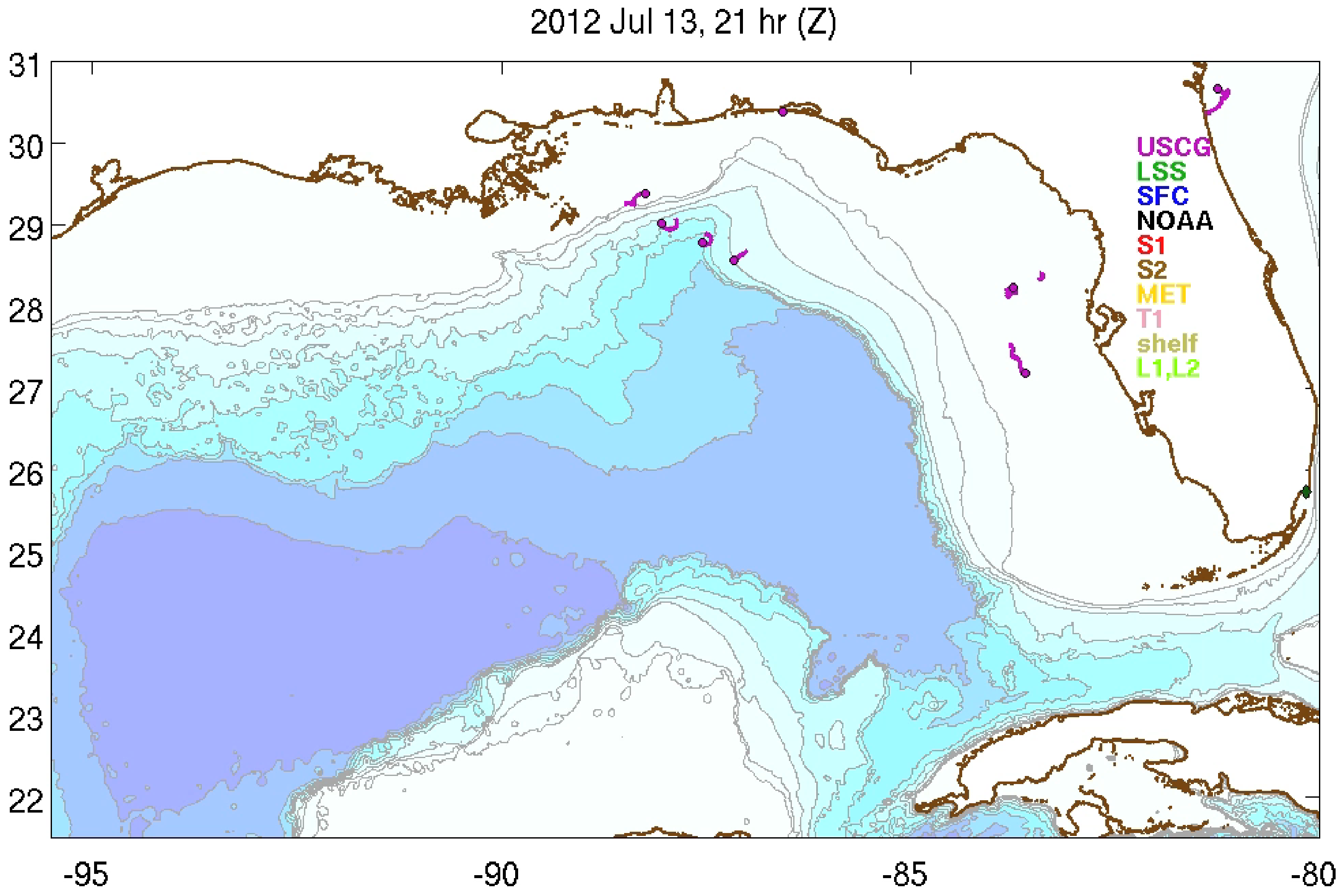
Node S–configuration
KM
KM
0
2
4
6
8
10
12
DwH


Fractal triplet configuration for each node
500m
100 m



How Accurately Did We Get the Deployment Template?




2012 Jul 13, 21 hr (Z)
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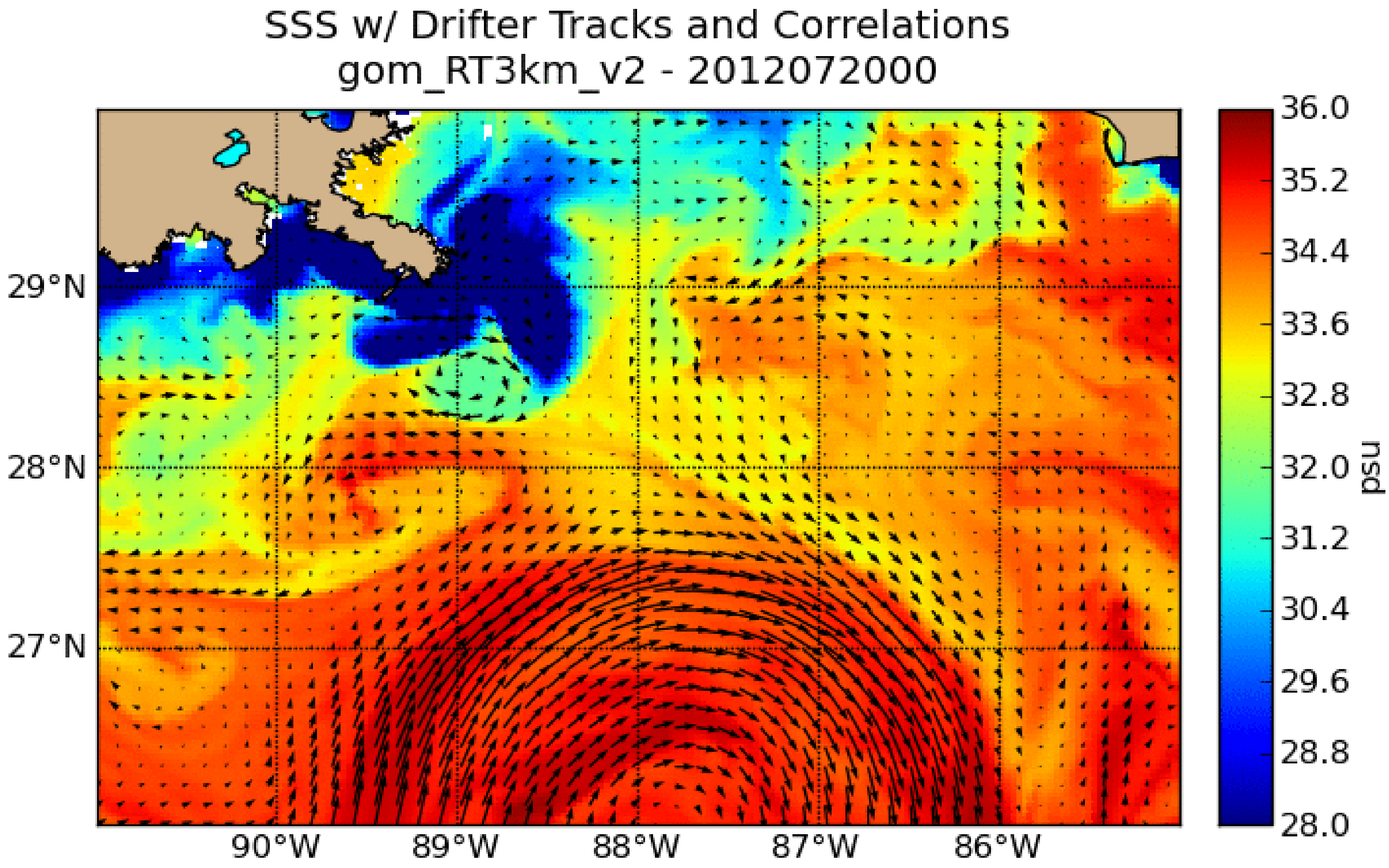
-95
-90
-85
-80
USCG
LSS
SFC
NOAA
S1
S2
MET
T1
shelf
L1,L2

Realistic Modeling by the Naval Research Laboratory Prediction Group:

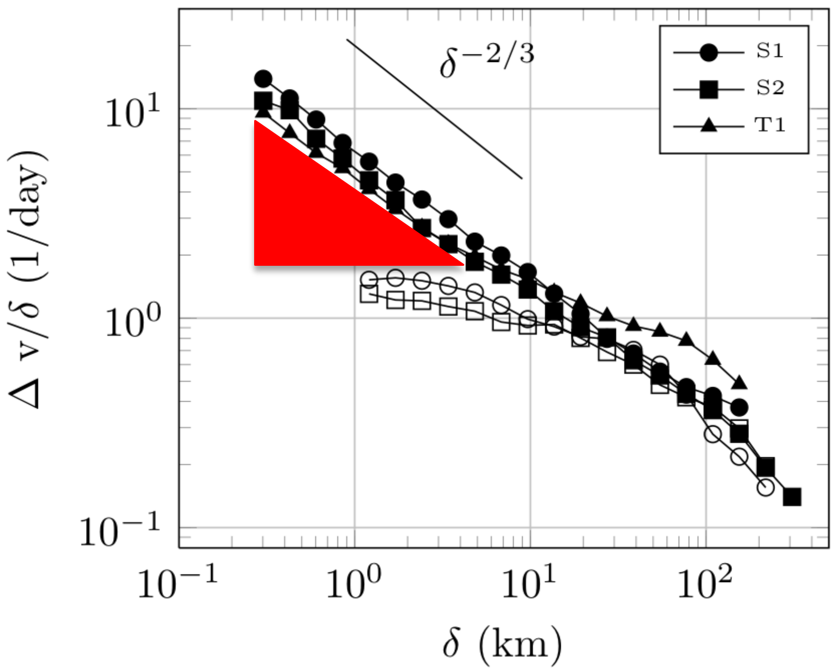


GLAD Results:

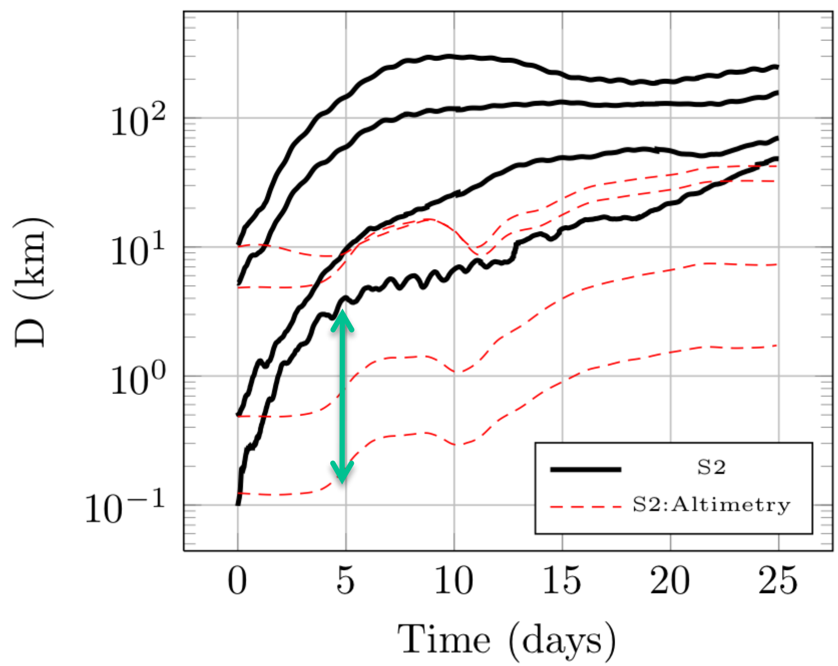
Submesoscales (100 m to 10 km, hours) matter for surface dispersion

(Poje et al, PNAS, 2014)

GLAD vs 3 km NCOM
(Navy Operational Model)

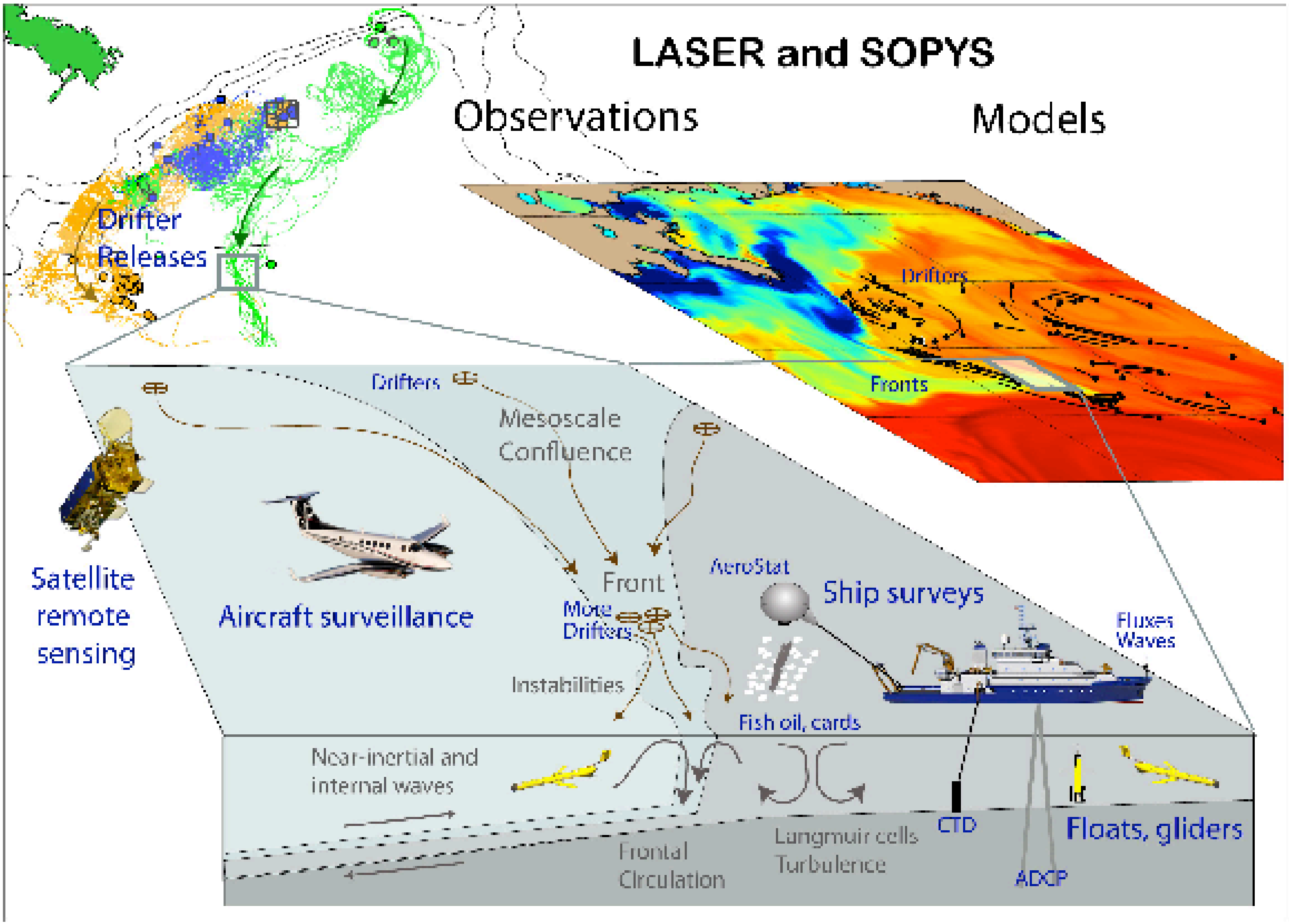


GLAD vs AVISO:
(Satellite Altimeter)



Other GLAD pubs: Olascoaga et al. (GRL, 2013), Jacobs et al. (OM, 2014), Carrier et al. (MWR, 2014), Laxague et al (JGR, 2015), Berta et al. (JTECH, 2015), Musceralla et al. (MWR, 2015), Bogucki et al. (GRL, 2015), Coelho et al. (OM, 2015), Yaremchuk et al. (IEEE JOE, 2015), Curcic et al. (GRL, in revision), Beron-Vera et al. (JPO, submitted), Zhu et al. (JGR, submitted), Berta et al. (JGR, near submission) : ***15 thus far***

LASER: Jan-Feb 2016, Eric D'Asaro chief scientist



General Plan and Goals:

Phase I: seasonal variability in dispersion

through GLAD-like drifter deployments in DeSoto Canyon

Phase II: targeted sampling of surface features & their dispersive effect

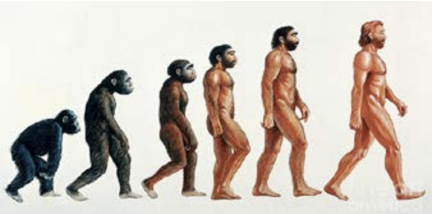
through supplemental drifters with ship surveys at fronts

Phase III: Sub-sub-mesoscale near surface drift

through aerostat/drift card studies

Stokes drift seems to be very important for dispersion
with a very shallow (yet important for oil) depth

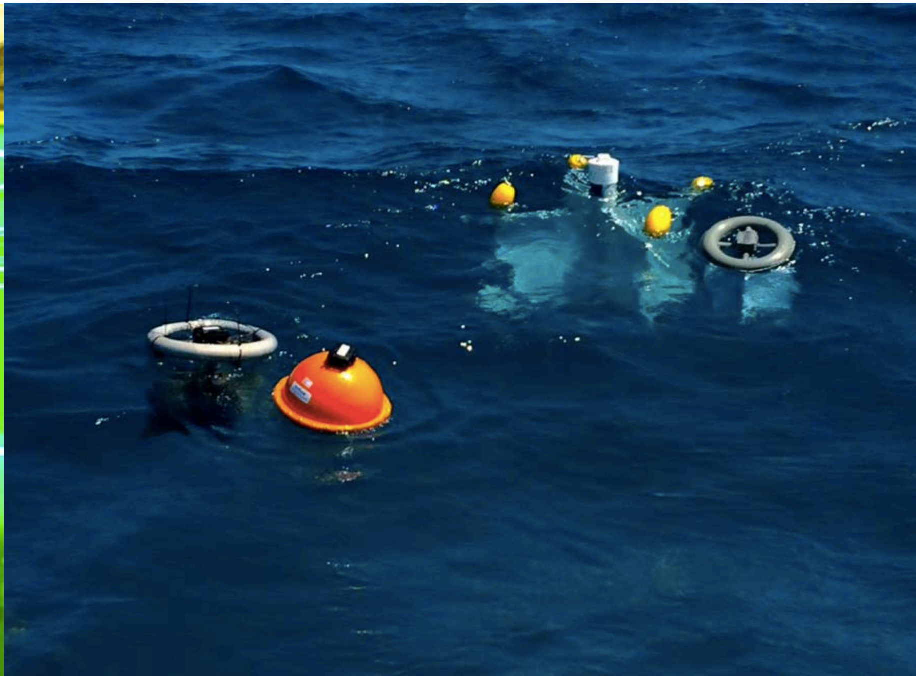
LASER Tools: Drifters (leads: G. Novelli, C. Guigand, C. Cousin)



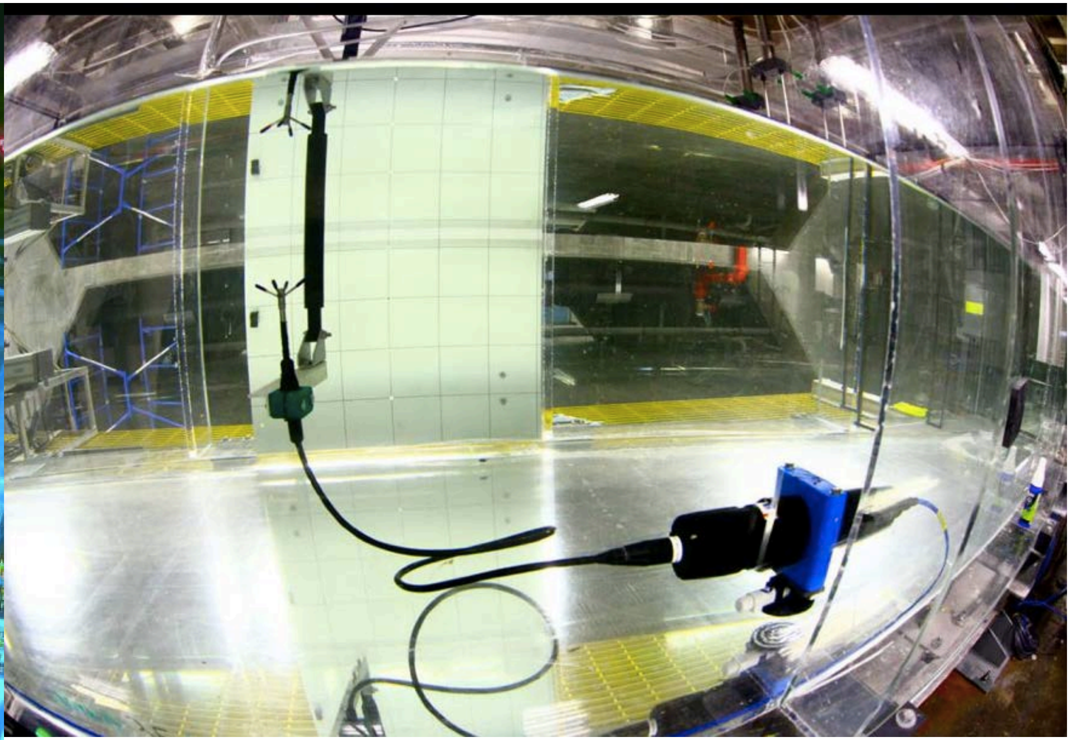
1000 biodegradable, cost-effective, compact, light, easy to transport and assemble drifters

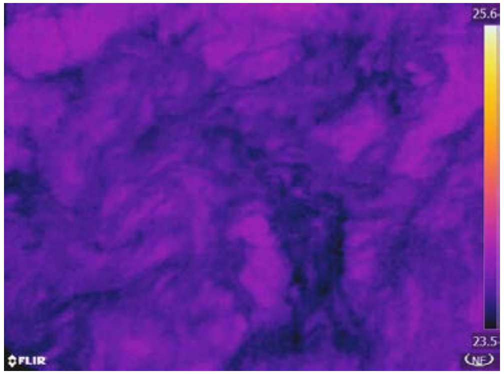
Extensive laboratory and field experiments on wave rectification and drifter characteristics (ongoing)

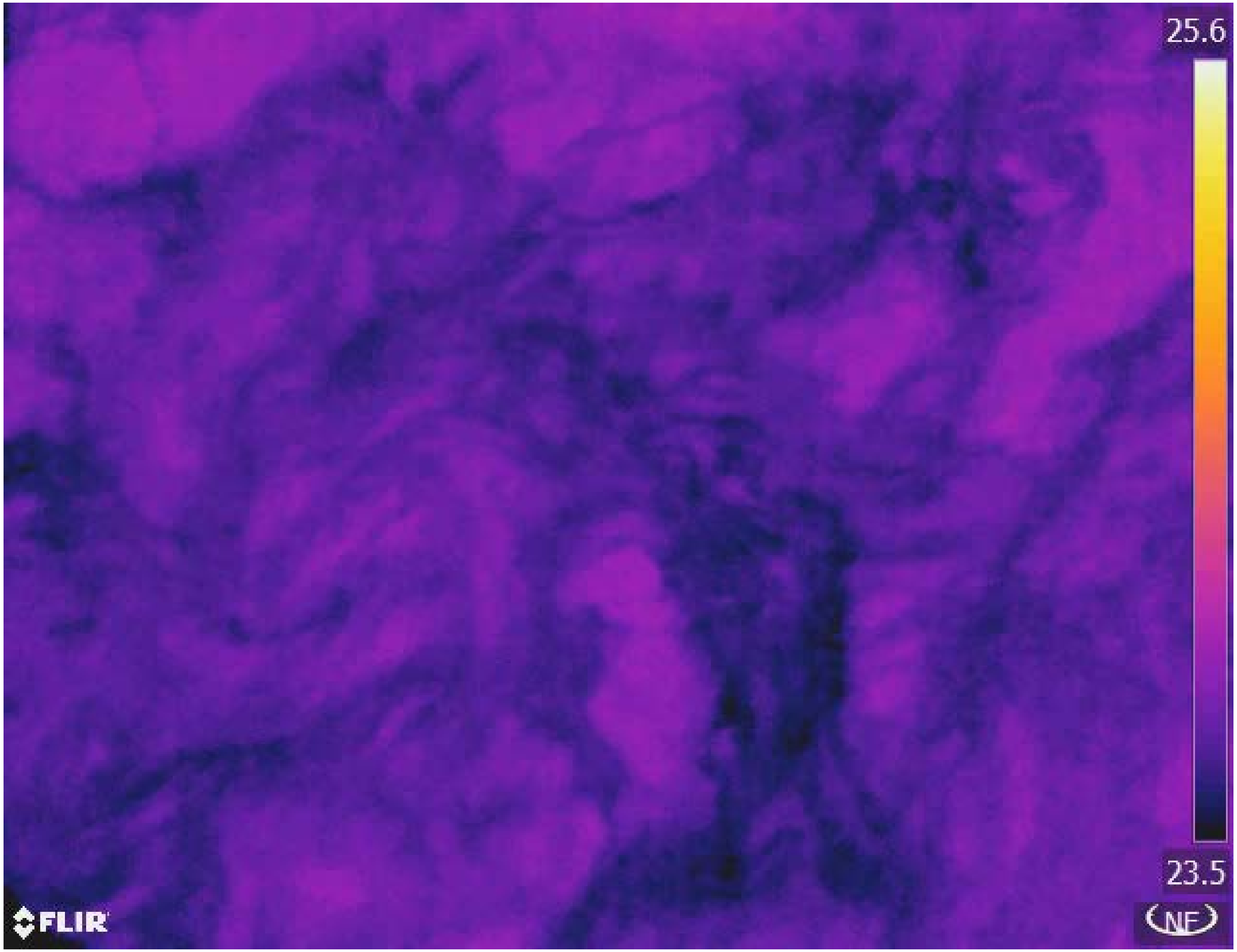
Eliminating wave rectification turned out to be a major issue in the design



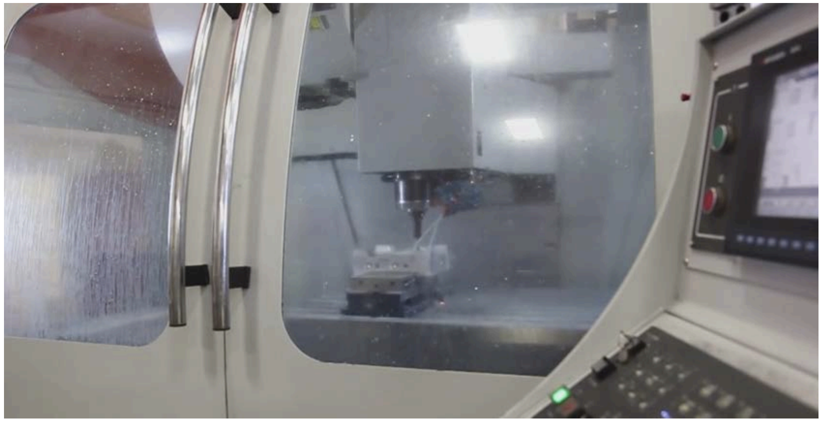
Laboratory Measurements in RSMAS Wave Tanks (Novelli, Guigand, Haus)





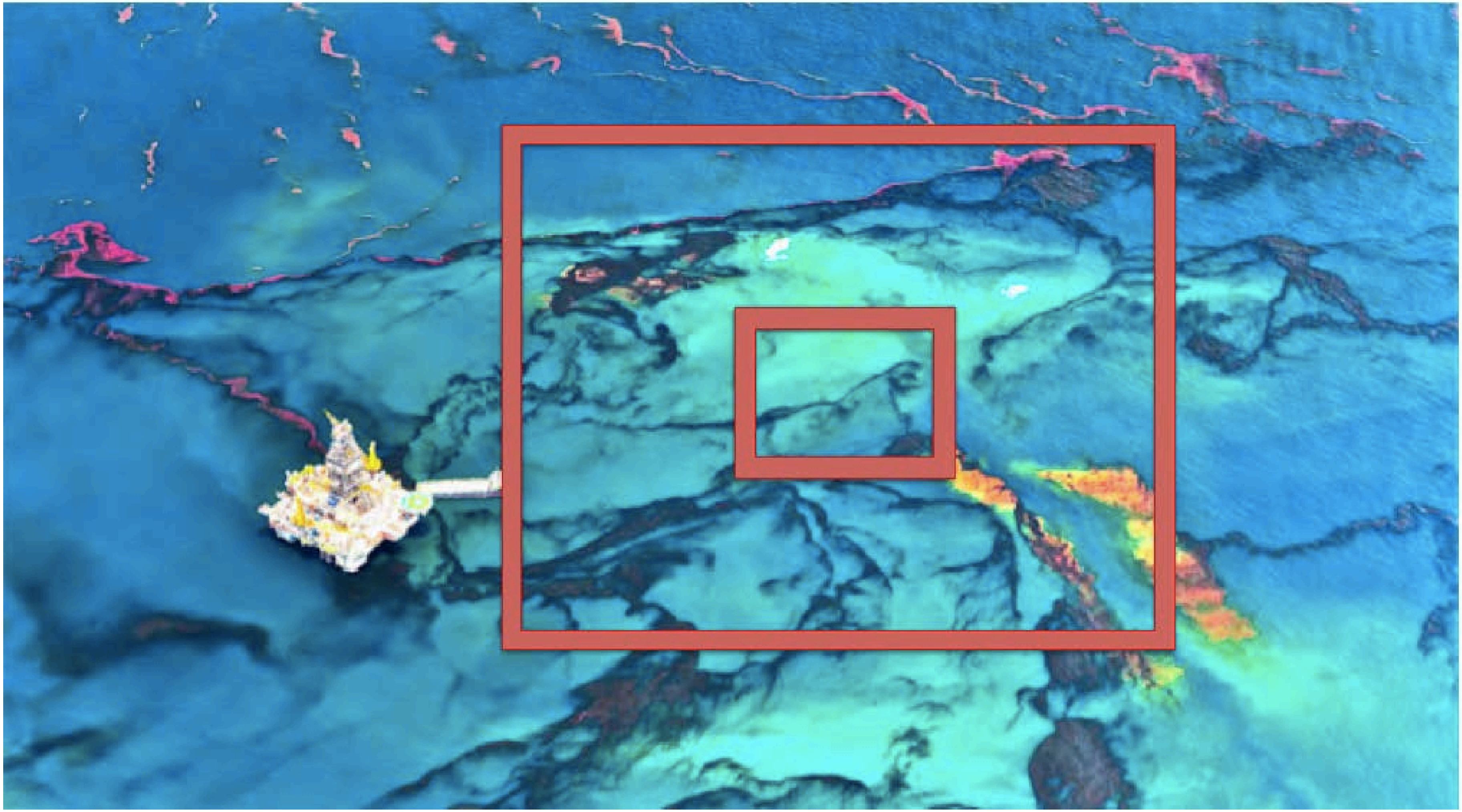

25.6
23.5
FLIR
NF

Mass Production & Ocean testing (C. Cousin, G. Novelli, C. Guigand)



But drifters cannot capture the very near surface (centimeters) …

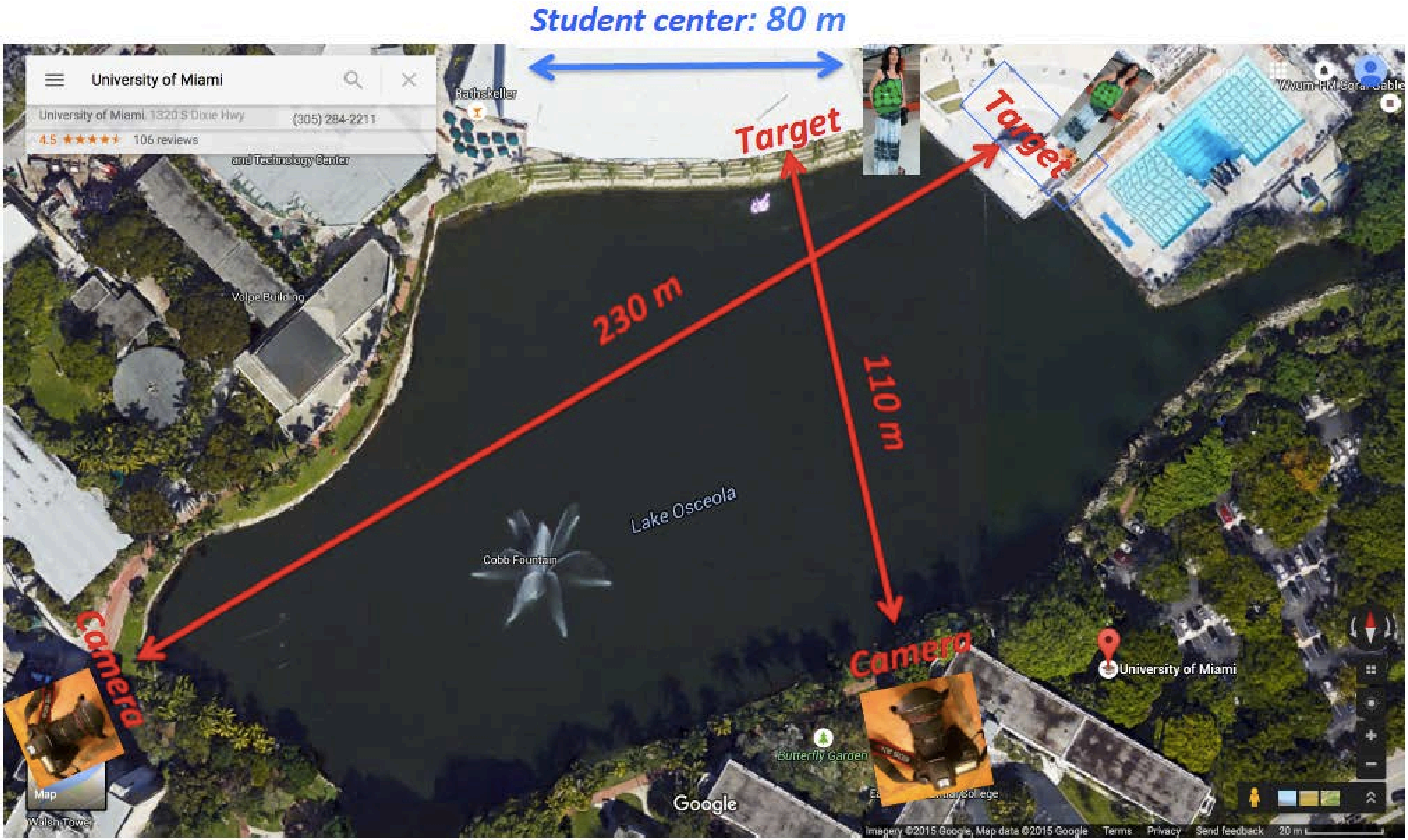
Approximate size of aerial coverage of 300 m x 200 m and 900 m x 600 m with respect to dynamical features of interest near the DwH region:



LASER Tools: Aerostat (lead: Dan Carlson)

Equipped with a high-resolution camera, PIV of the surface flow field will be attempted using thousands of "drift cards".

Necessary to cover 500 m domain using centimeter-scale resolution:



50 MP image postprocessed to super-resolution (200 MP) using multiple shots:

Leveraged Participation (in the Progress):

SVP drifters*: courtesy of Rick Lumpkin & Shaun Dolk (NOAA/AOML)*

AirSWOT + AirSAR: *Ernesto Rodrigues (JPL, contingent on NASA budget)*

Wavegliders + aerial obs: *Ken Melville and/or his team (Scripps)*

Remote sensing: *Bertrand Chapron (Ifremer)*

Industrial in-situ observations: *Chevron (?)*

3D+1 MURI: ?

Summary:

Ocean's surface contains turbulent coherent structures in the submesoscale range (10 m to 10 km, hours to days) that have much more direct socioeconomic relevance and that are ripe for rapid development of

high-density observational capability, and original modeling than deeper, slower, larger mesoscales.

3D Lagrangian dynamical systems methods should target near-surface submesoscale (10 m to 10 km) rapidly-evolving (hours to days) flows.

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