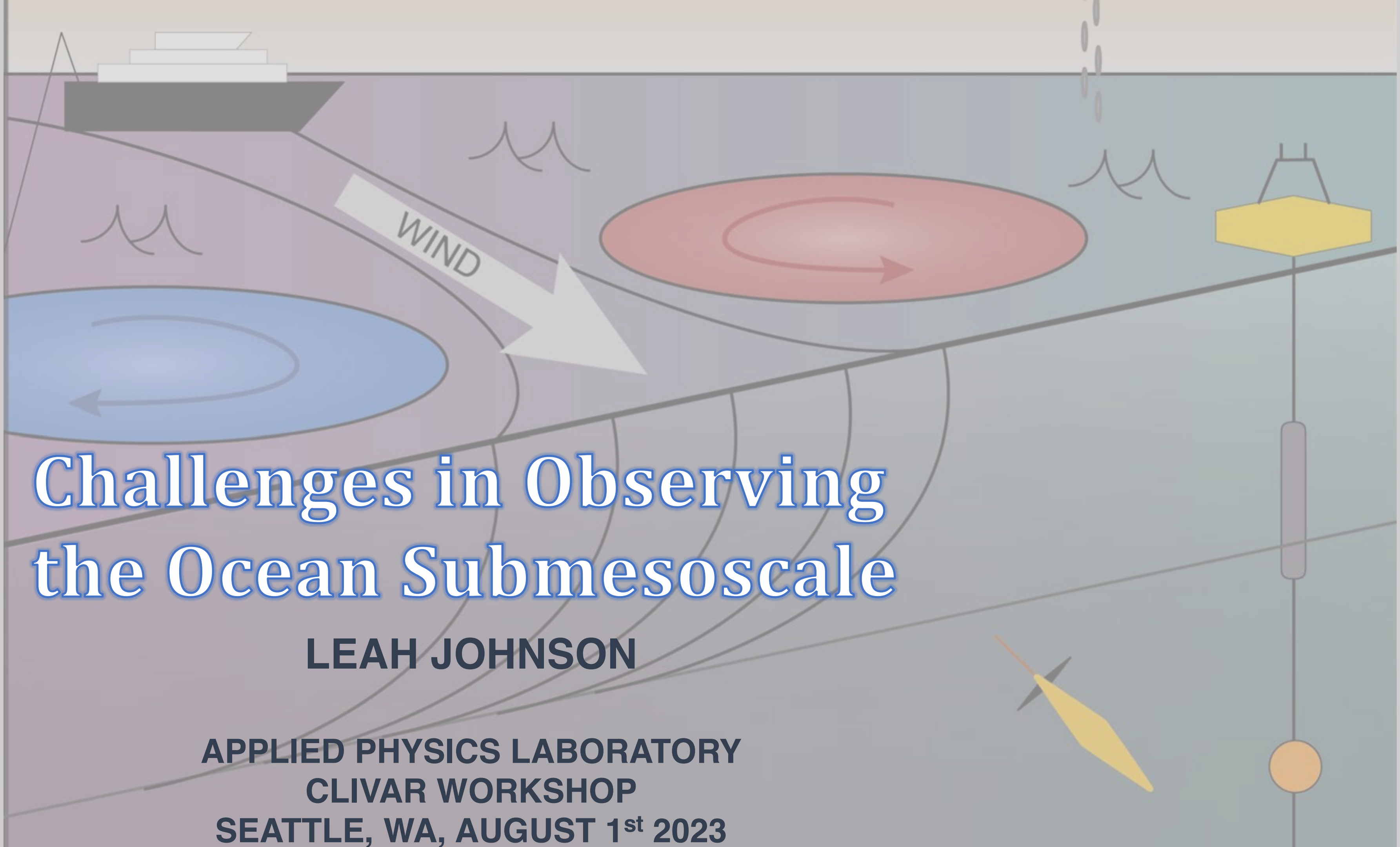


Challenges in Observing the Ocean Submesoscale

LEAH JOHNSON

APPLIED PHYSICS LABORATORY

CLIVAR WORKSHOP

SEATTLE, WA, AUGUST 1st 2023

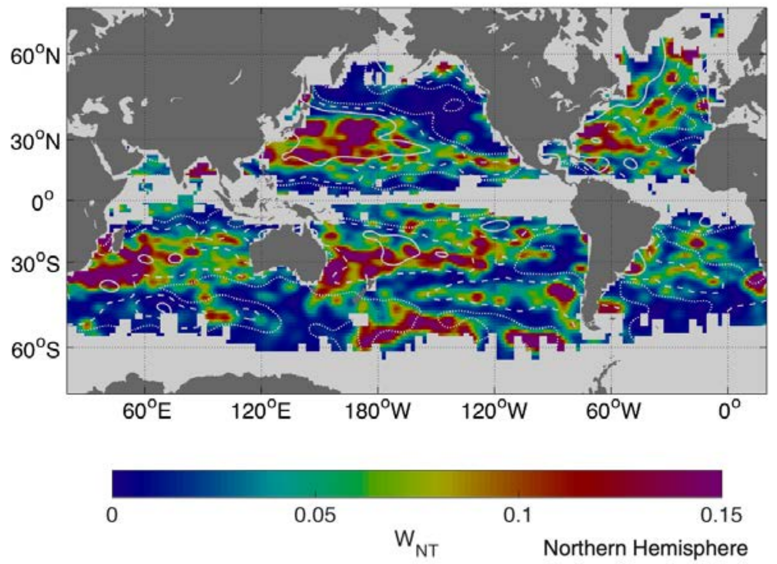
Why observe the Submesoscales?

Buoyancy Budget

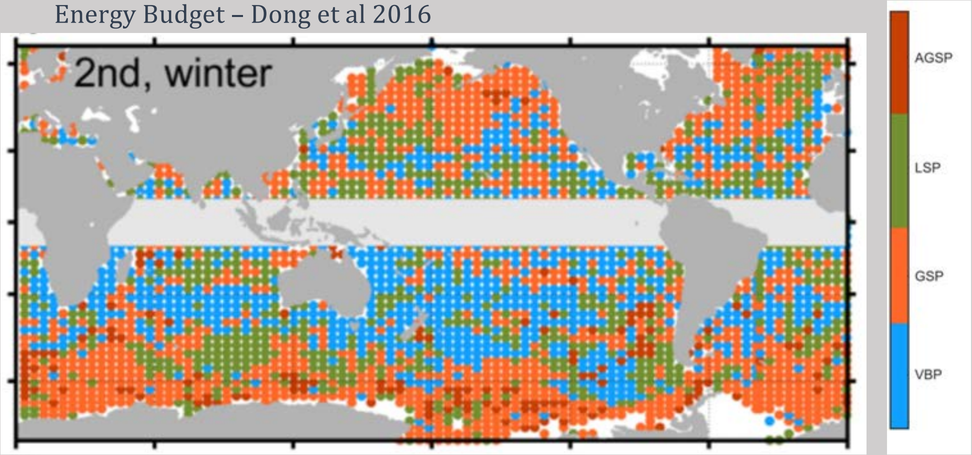
Energetics

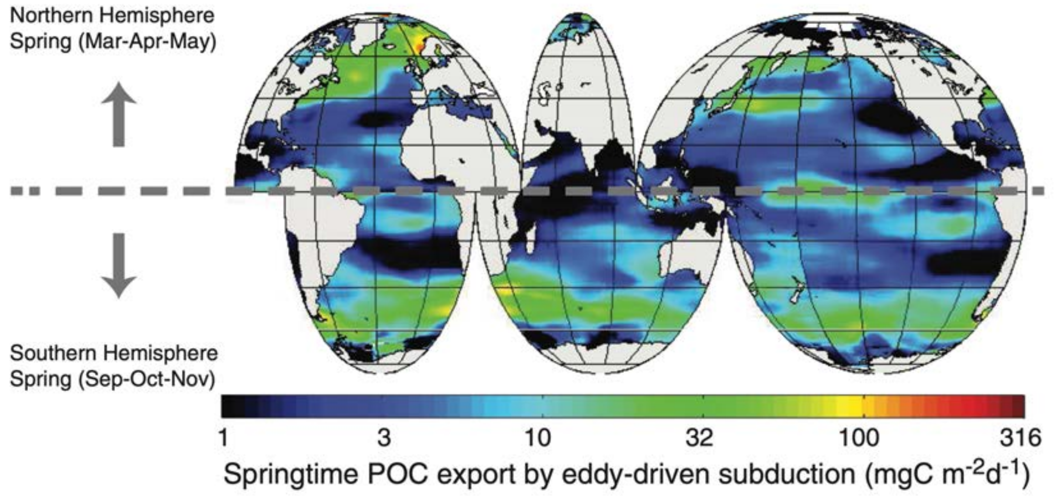
Carbon Cycle

Buoyancy (N^2) Budget – Johnson et al 2016



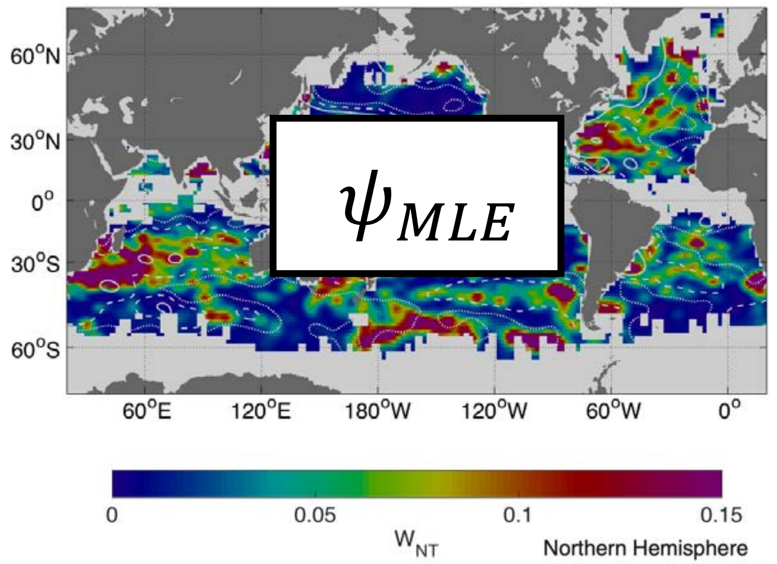
Energy Budget – Dong et al 2016





Carbon Export –
Omand et al, 2015

Buoyancy (N^2) Budget – Johnson et al 2016



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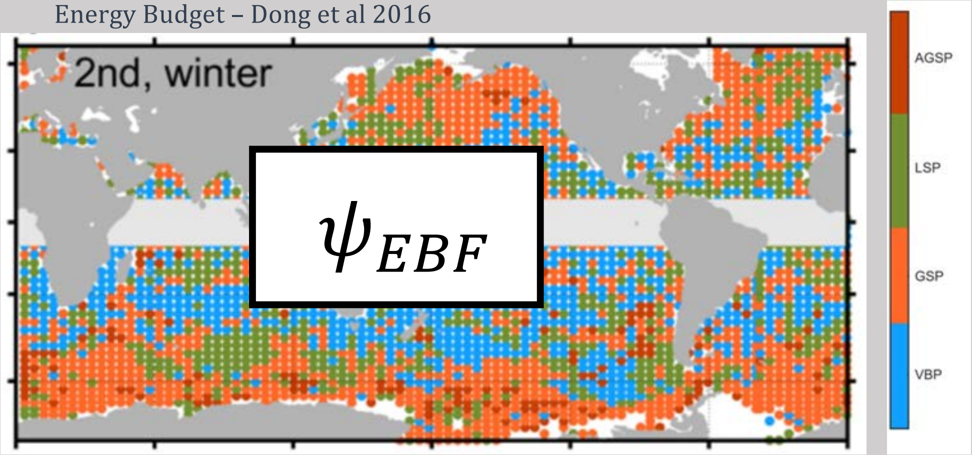

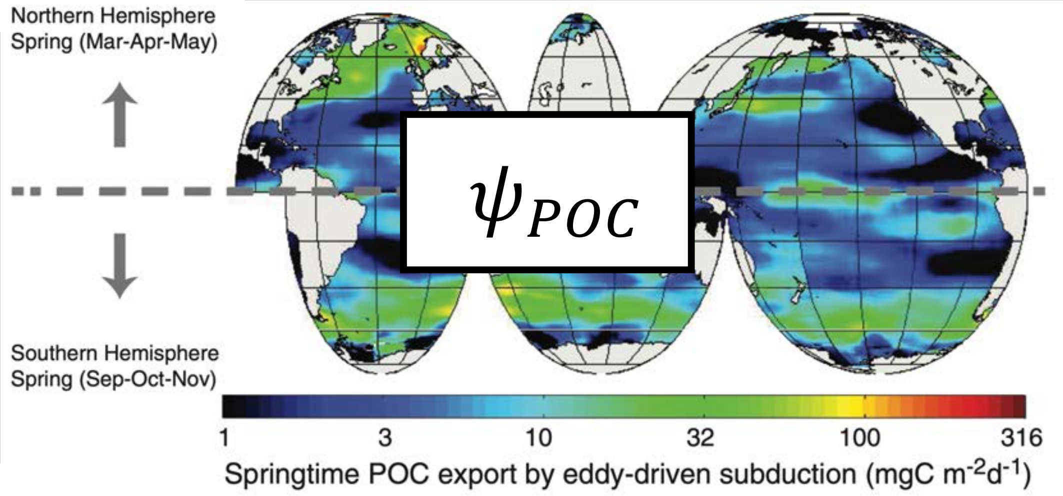

Carbon Export –
Omand et al, 2015

How important are submesoscales?

1 – Understand **dynamics** at submesoscale fronts

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2 – What is the **impact** of those processes

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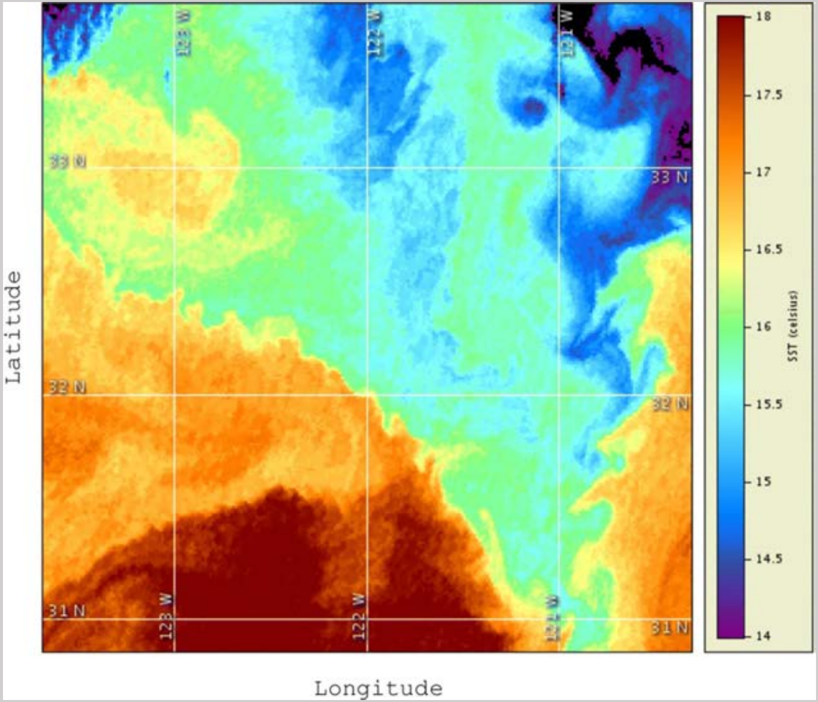
1 – Understand **dynamics** at submesoscale fronts

2 – What is the **impact** of those processes

3 – What is the **global significance** of that impact

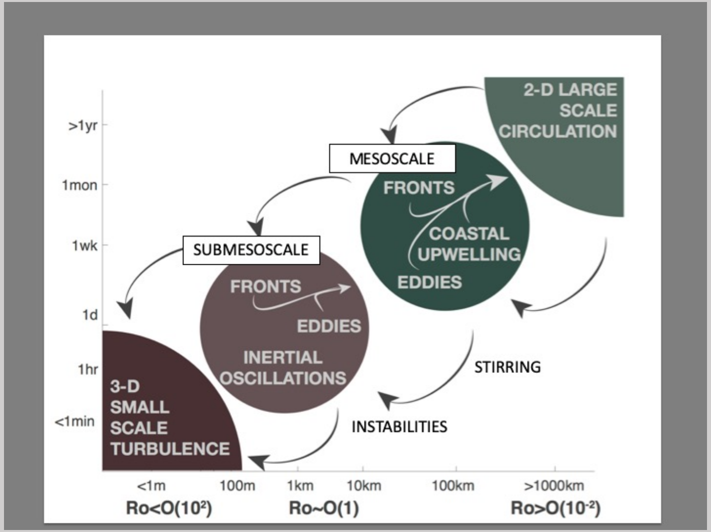
1 – Understand **dynamics** at submesoscale fronts

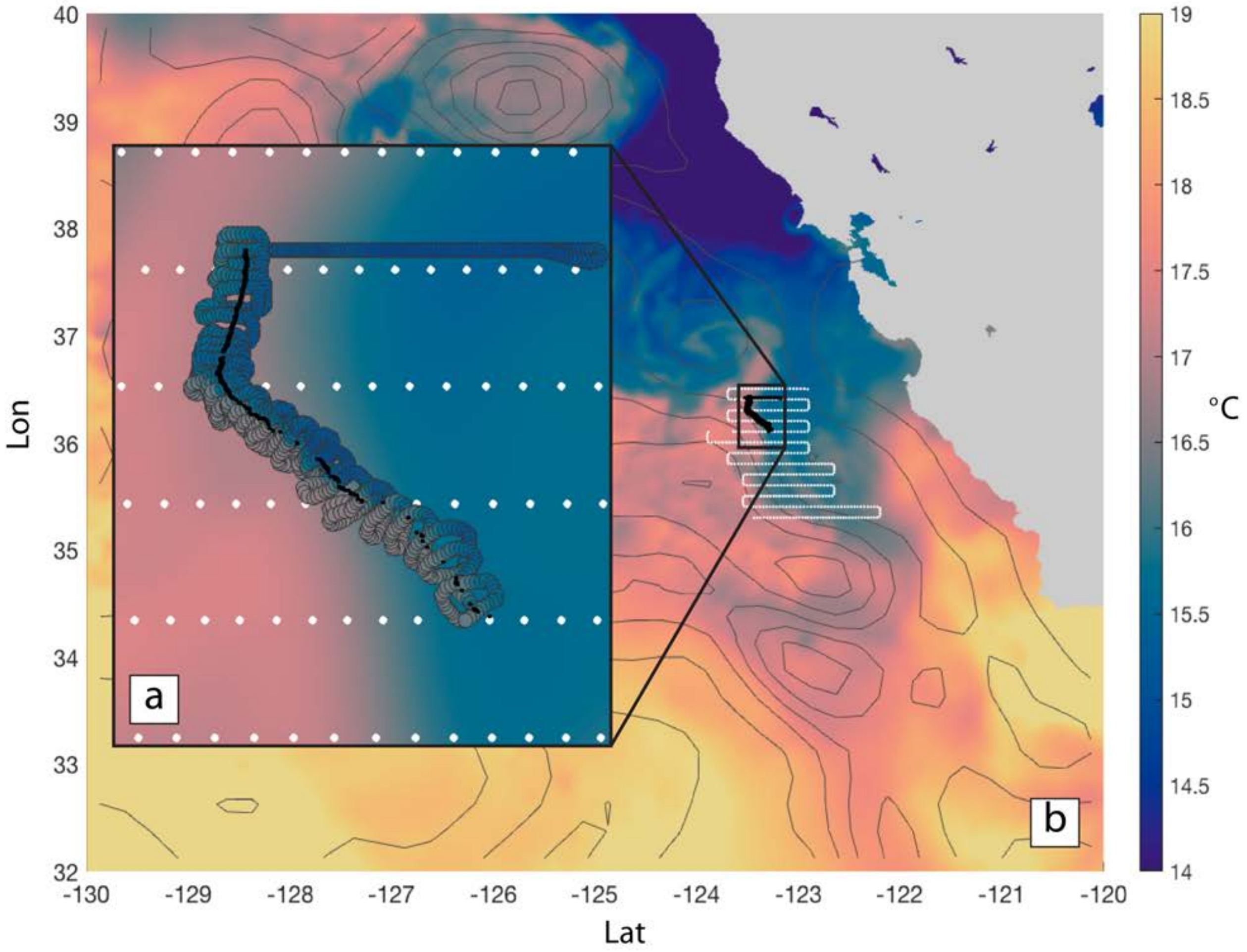


--McWilliams, 2019

For SMCs, their awkward size presents an observational barrier that delayed an appreciation of their abundance: they are large for shipboard instrument detection, small and rapidly evolving for typical ship surveys, small for many satellite remote sensing footprints, and often difficult to distinguish from inertia-gravity waves (IGWs) in single-point time series or individual vertical profiles

--McWilliams, 2016





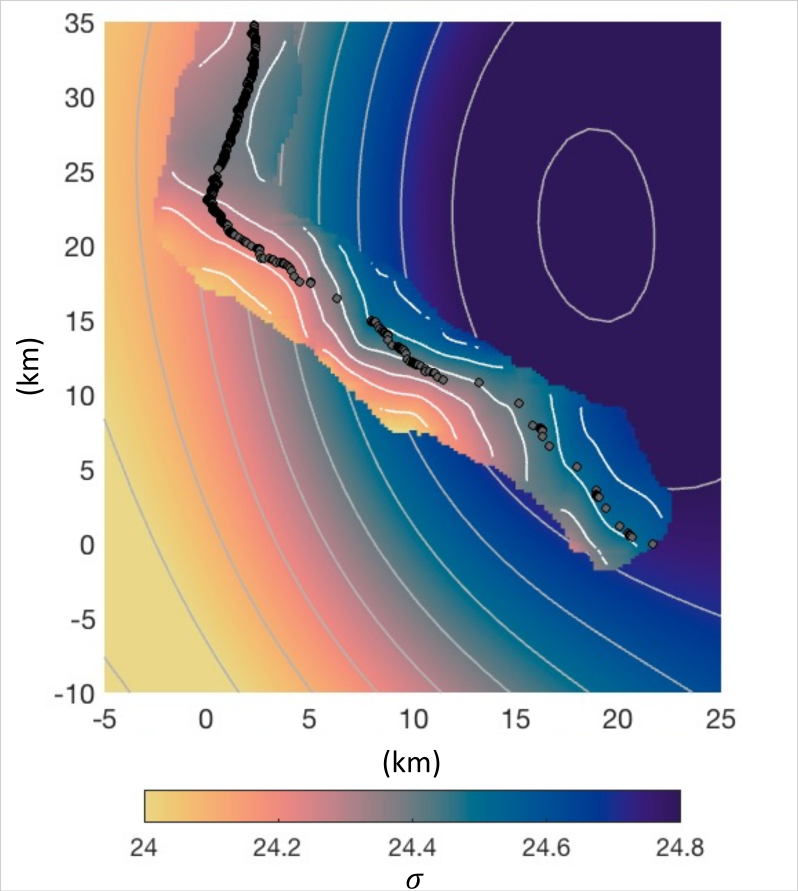
Example from ONR AESOP campaign

California Current System

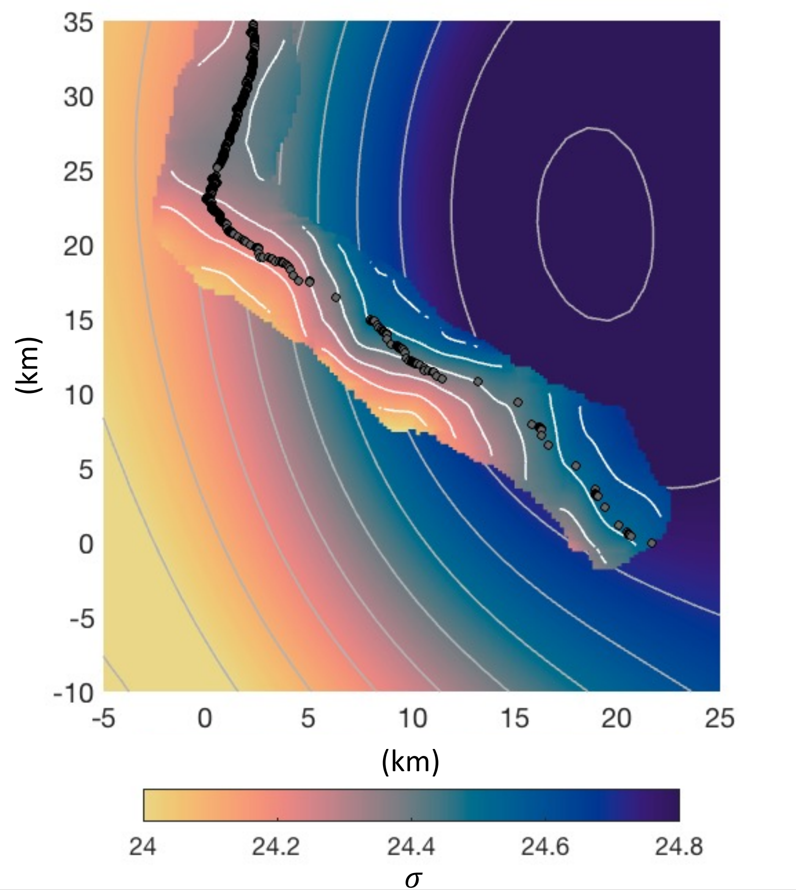
Johnson et al. 2020 - Pt 1 & 2

Pallas Sanz et al. 2010 - Pt 1 & 2

DENSITY STRUCTURE AT DIFFERENT SCALES



DENSITY STRUCTURE AT DIFFERENT SCALES



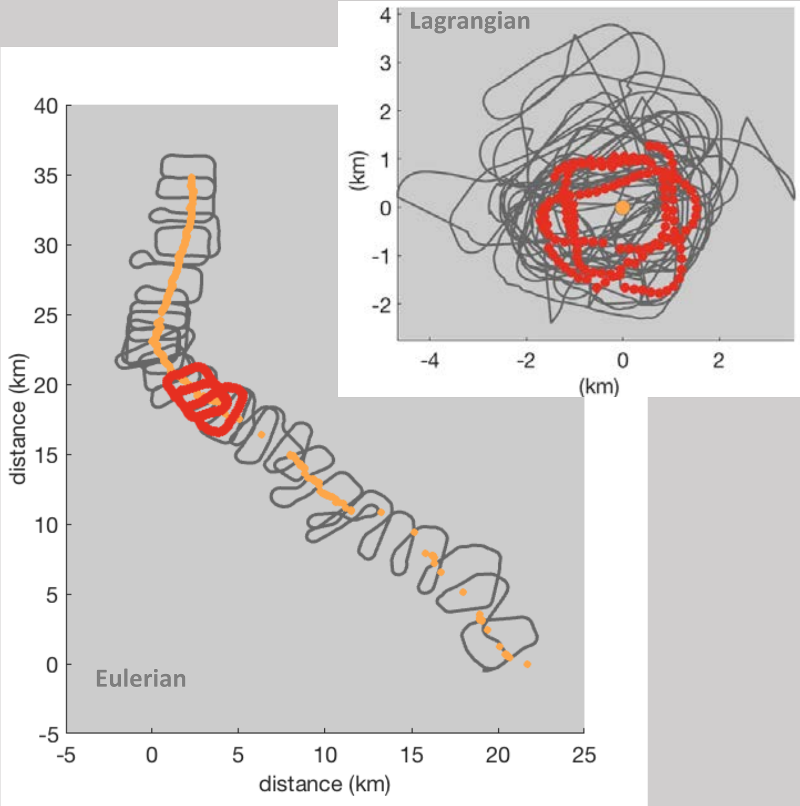
VORTICITY AT DIFFERENT SCALES

AVISO (not shown)
Resolution >100km
$\zeta/f \sim O(0.01)$

SeaSoar*
Lx = 12km, Ly = 45km
$\zeta/f \sim O(0.1)$

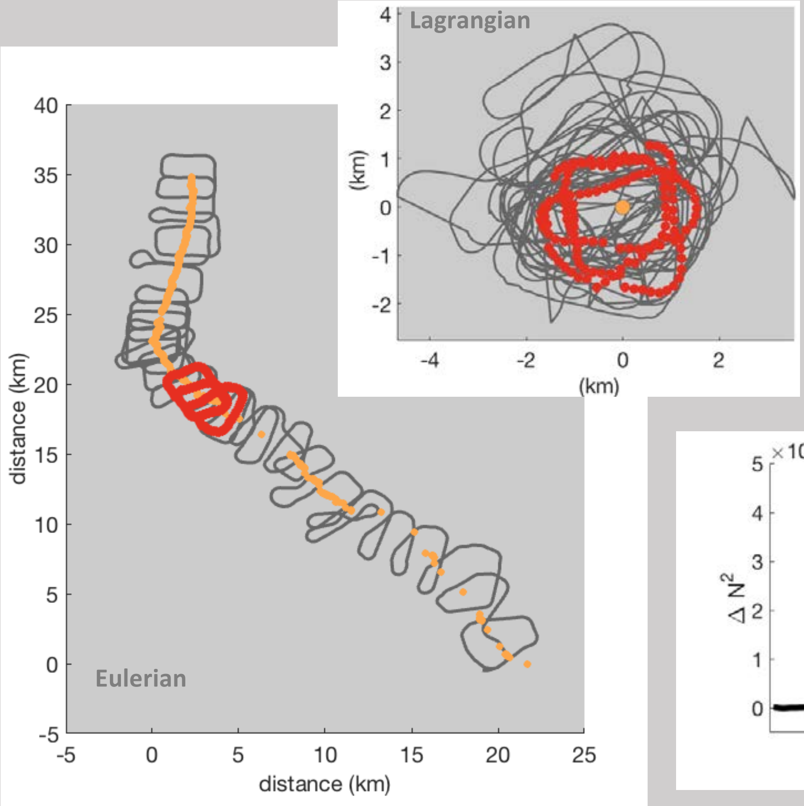
Triaxus
Lx=5km, Ly=5km
$\zeta/f \sim O(1)$

$$N_{INT}^2 = \int u_z b_x + v_z b_y \, dt$$



- **Resolve horizontal and vertical gradients 'simultaneously'**
- **Lagrangian reference frame**
- **Choose and maintain relevant scales to capture target dynamics**

$$N_{INT}^2 = \int u_z b_x + v_z b_y \, dt$$



- Resolve horizontal and vertical gradients ‘simultaneously’
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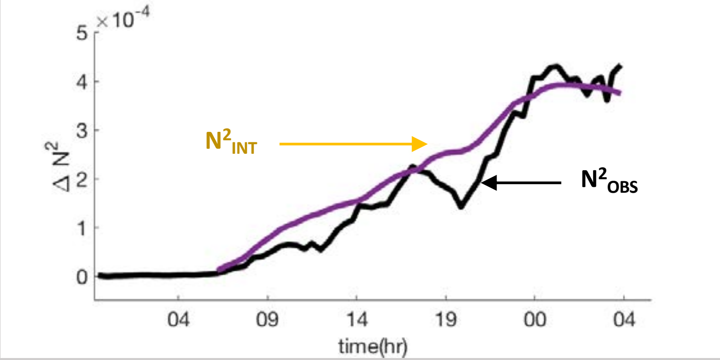
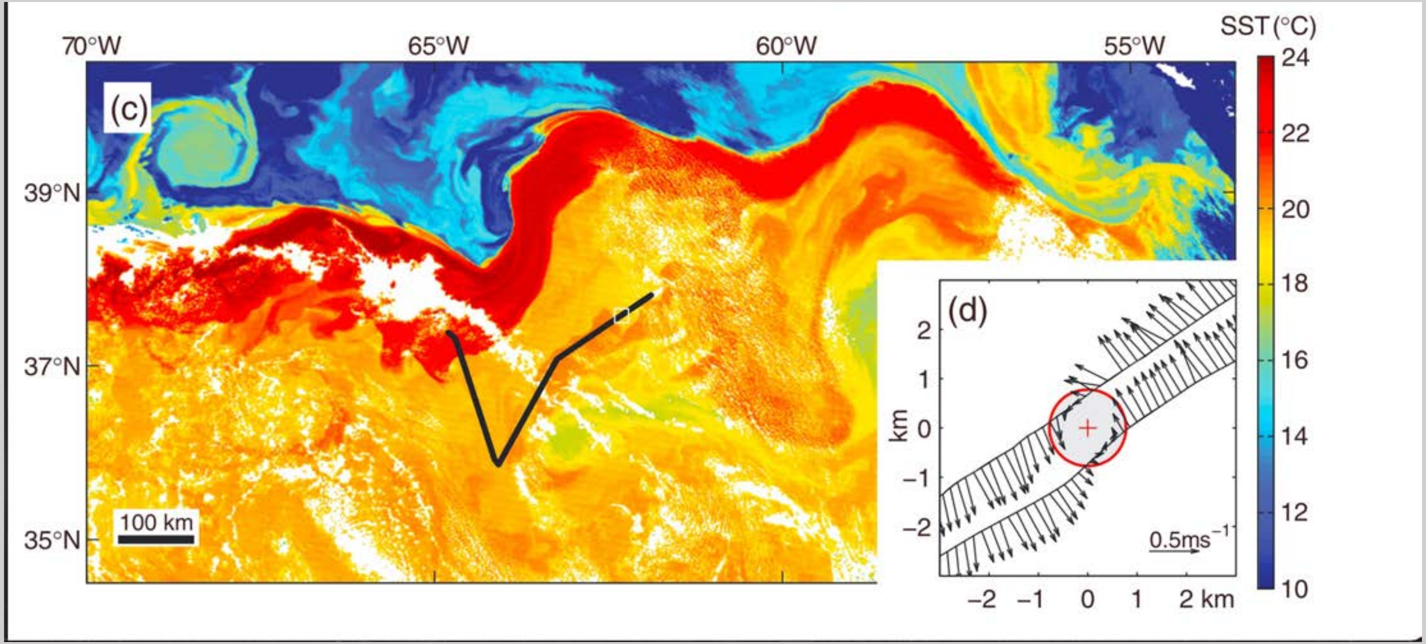




Shcherbina et al, 2013

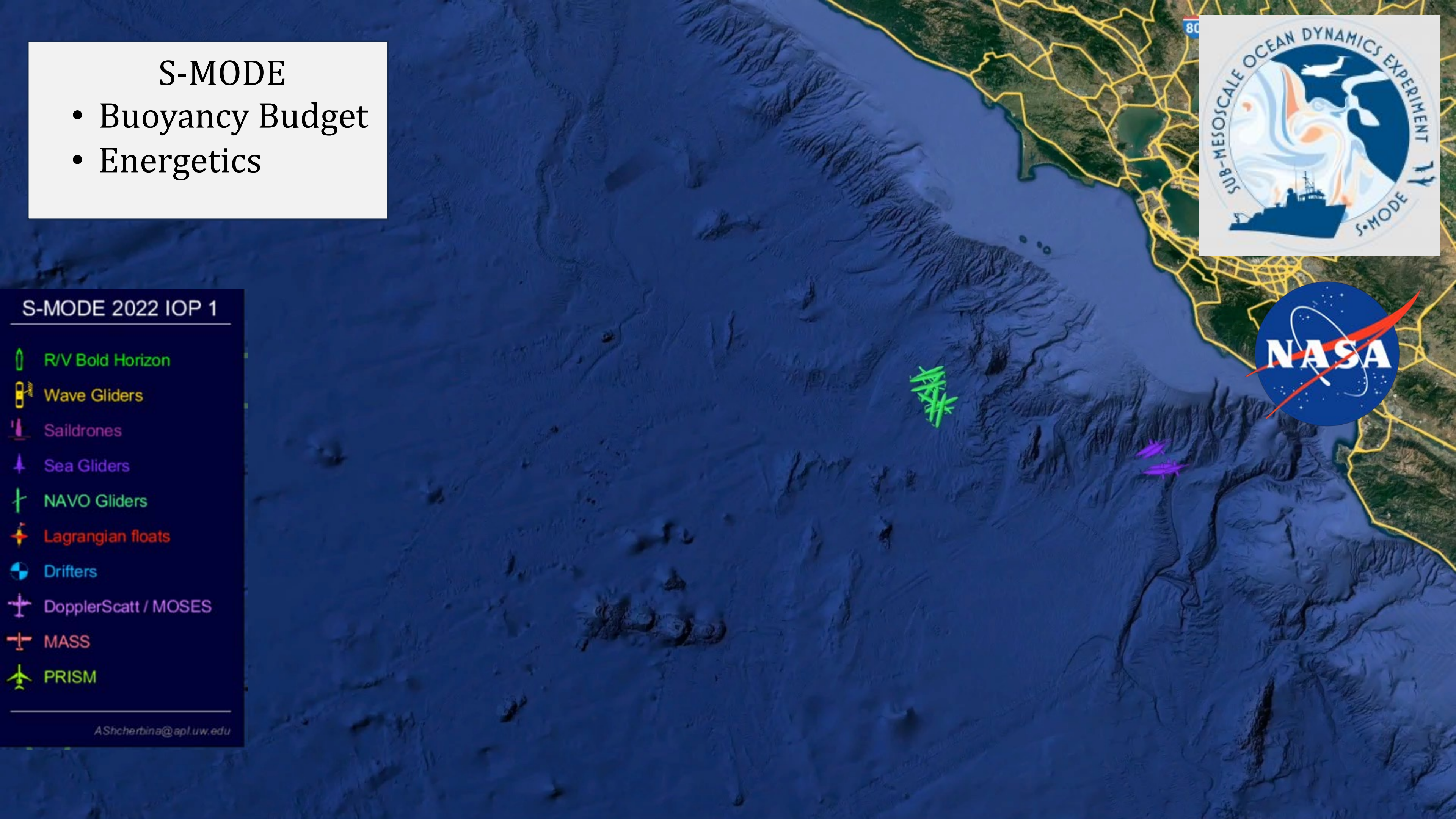
Multiple ships allow estimation of gradients with minimal aliasing

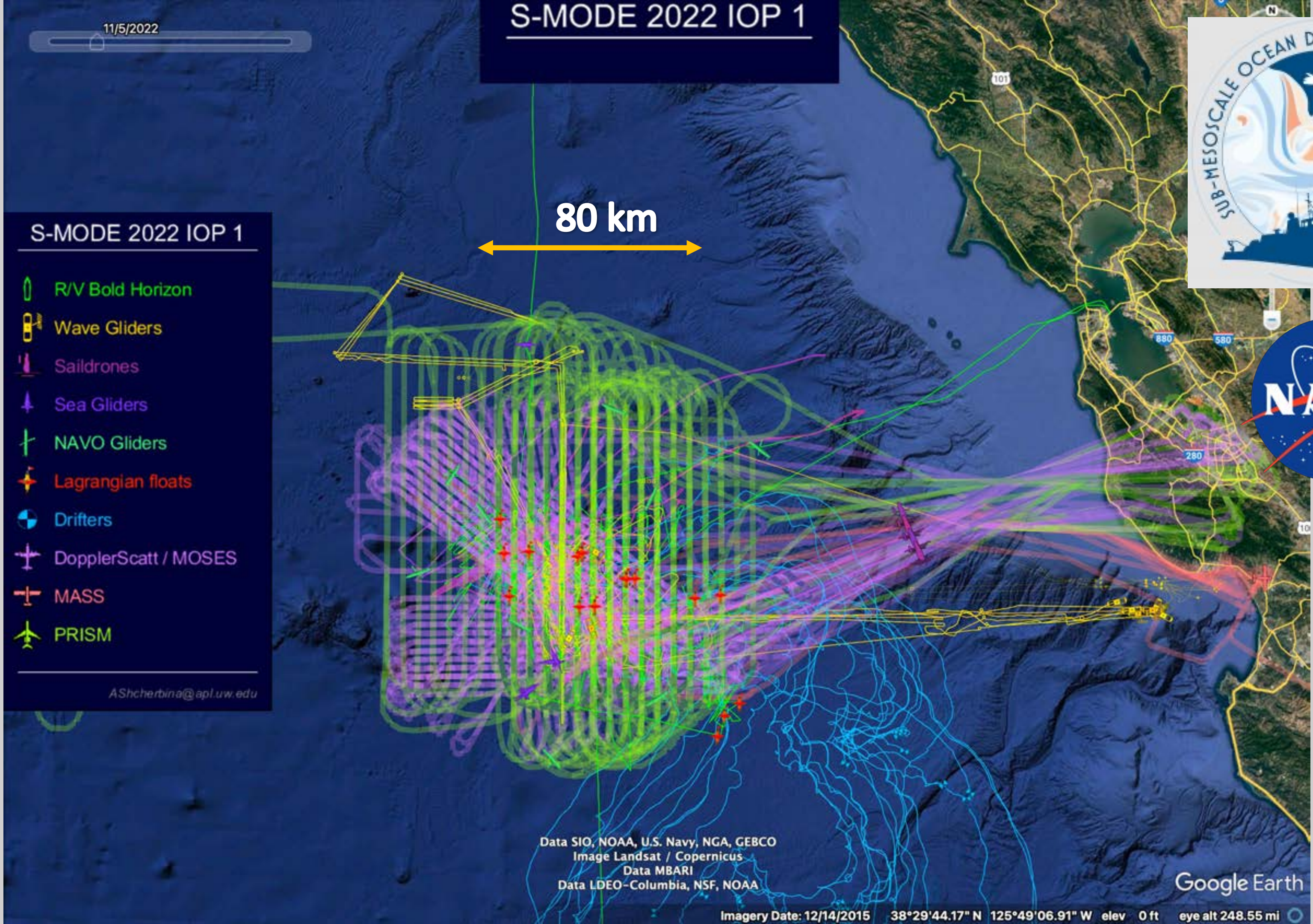
What if there were even **MORE** assets ?

- calculated gradients on a range of scales
- understand evolution in space and time

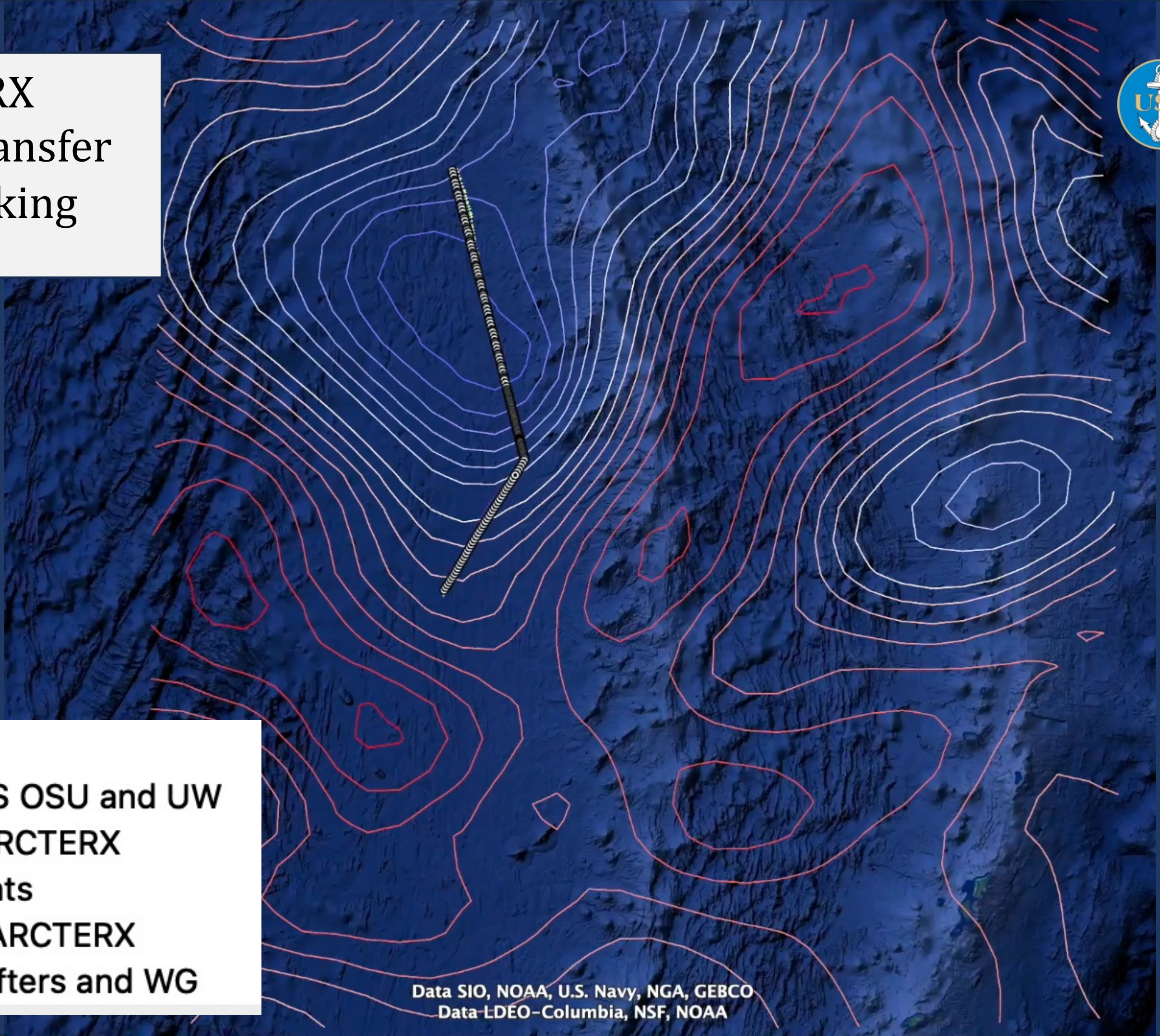
S-MODE

- Buoyancy Budget
- Energetics




11/5/2022
S-MODE 2022 IOP 1
80 km
S-MODE 2022 IOP 1
R/V Bold Horizon
Wave Gliders
Saildrones
Sea Gliders
NAVO Gliders
Lagrangian floats
Drifters
DopplerScatt / MOSES
MASS
PRISM
AShcherbina@apl.uw.edu
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image Landsat / Copernicus
Data MBARI
Data LDEO-Columbia, NSF, NOAA
Google Earth
Imagery Date: 12/14/2015 38°29'44.17" N 125°49'06.91" W elev 0 ft eye alt 248.55 mi

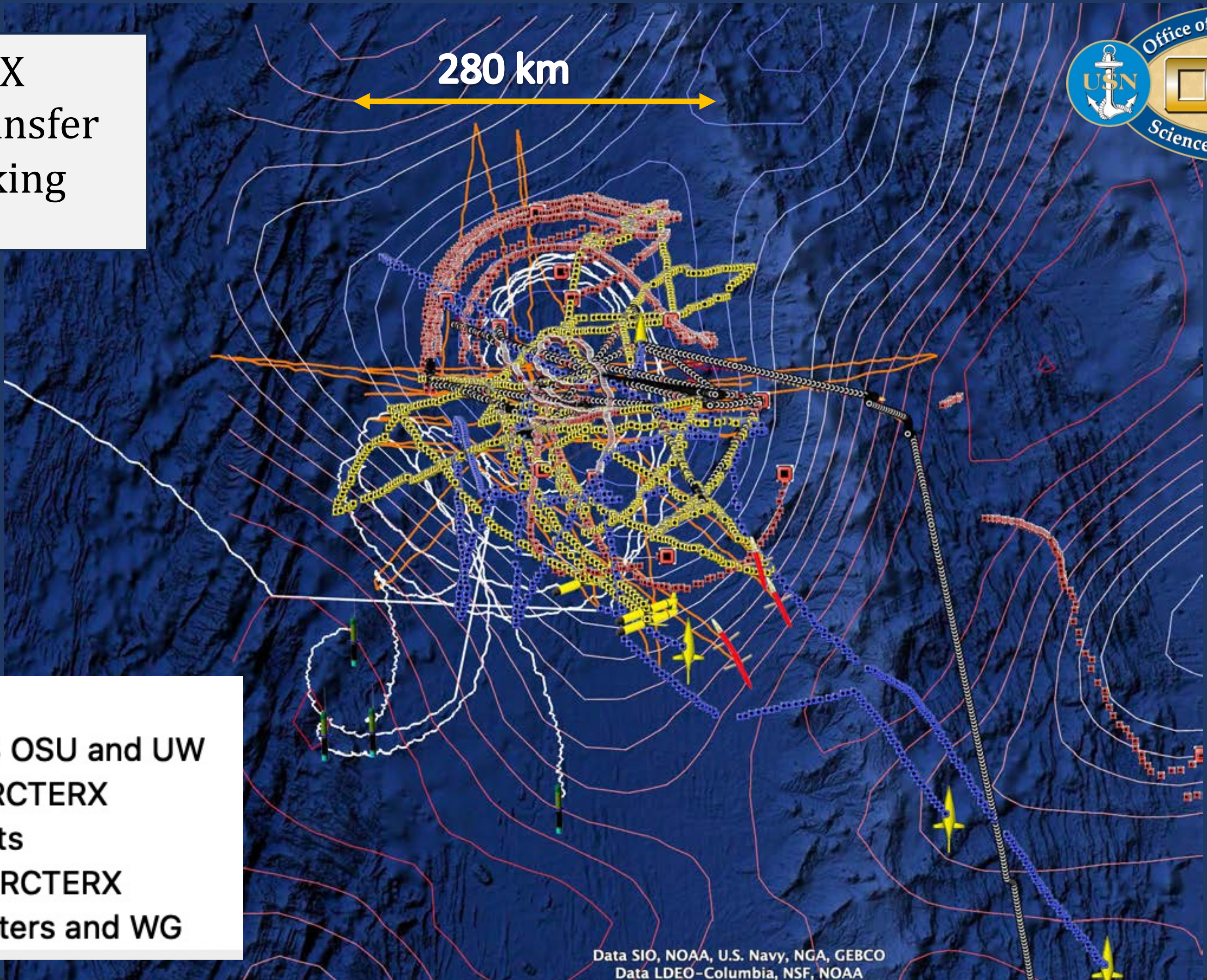
ARCTRX
- Energy Transfer
- Eddy Tracking



- Assets
  - GLIDERS OSU and UW
  - SOLO ARCTERX
  - UW floats
  - SPRAY ARCTERX
  - GDP Drifters and WG

ARCTRX

- Energy Transfer
- Eddy Tracking



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EXPORTS

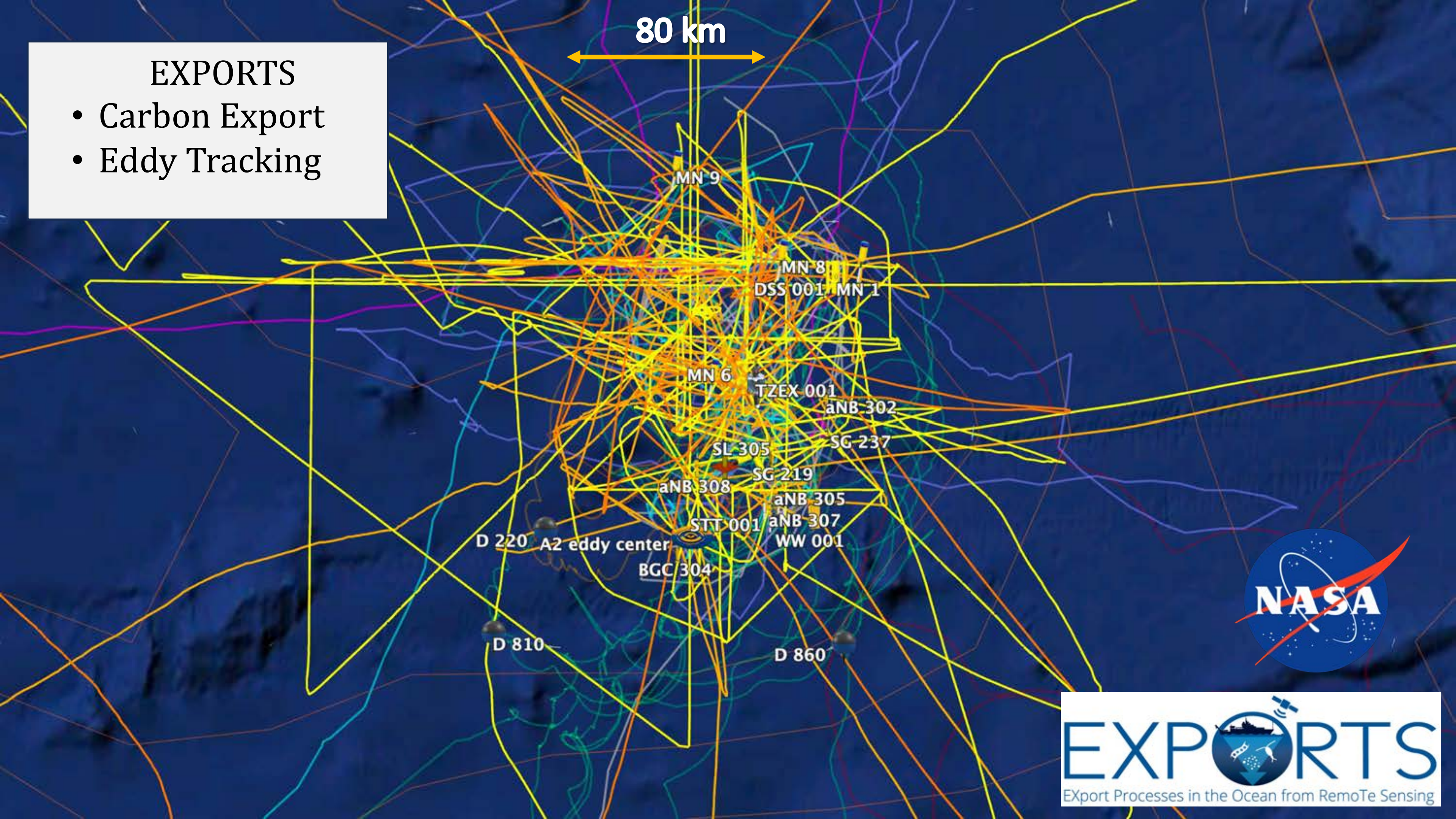
- Carbon Export
- Eddy Tracking

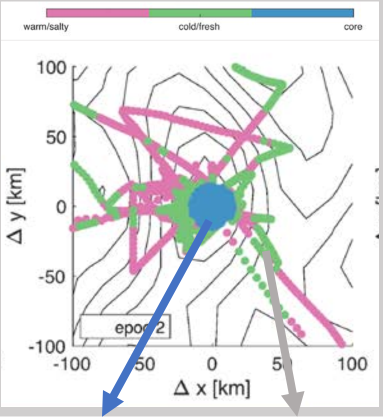
EXPORTS

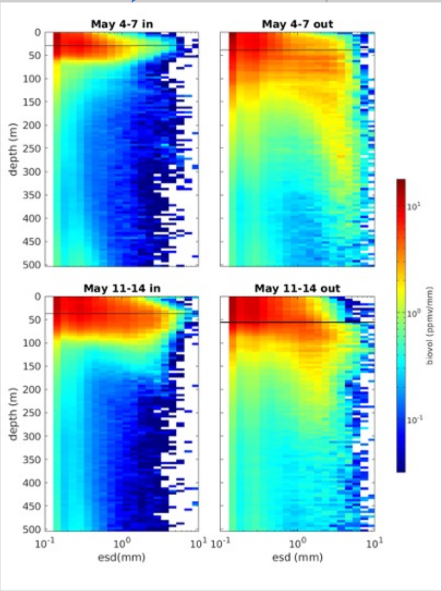
EXport Processes in the Ocean from RemoTe Sensing

EXPORTS

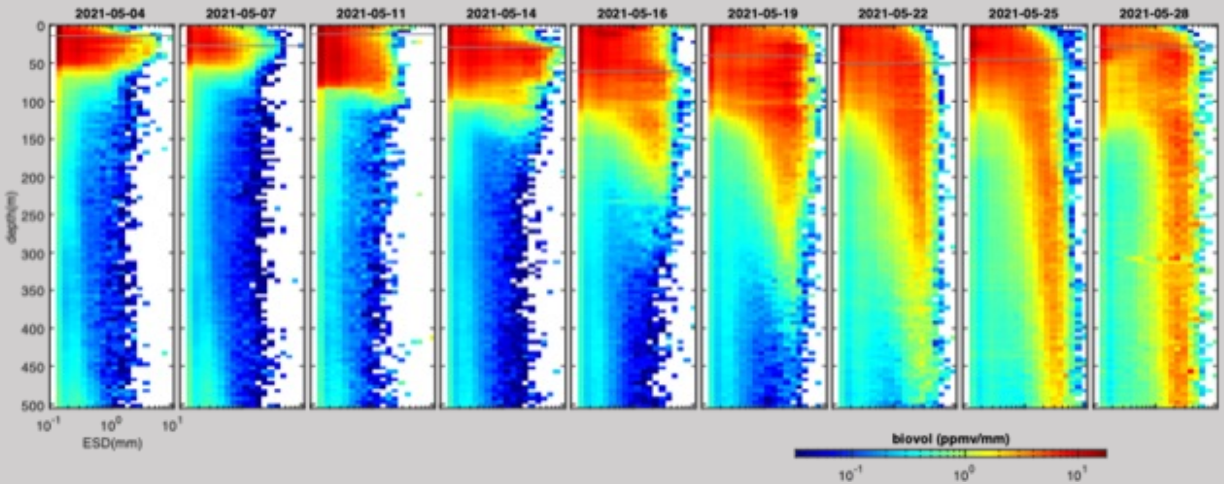
- Carbon Export
- Eddy Tracking







Biovolume in Eddy Center ONLY



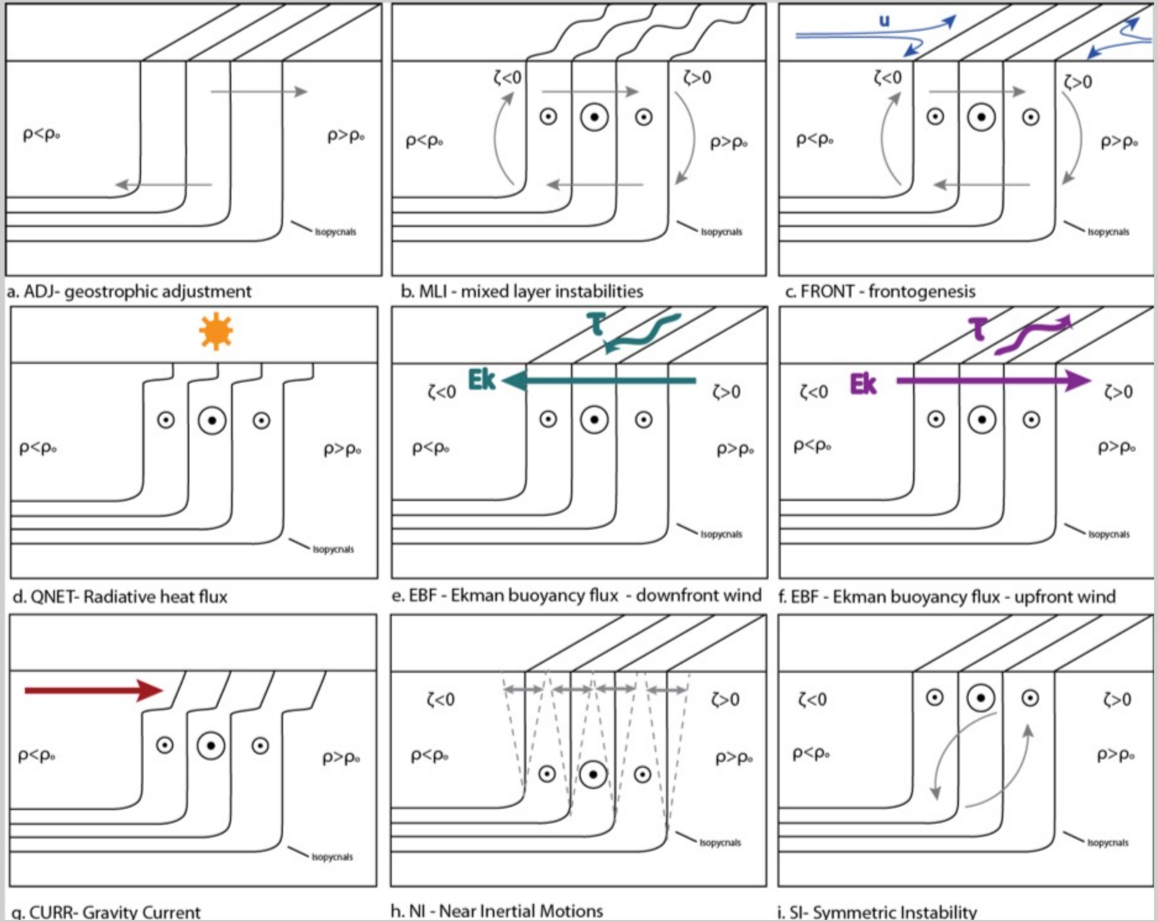
Siegle, Kiko, Fields

Lagrangian sampling isolates Carbon Export

EXPORTS
EXport Processes in the Ocean from RemoTe Sensing

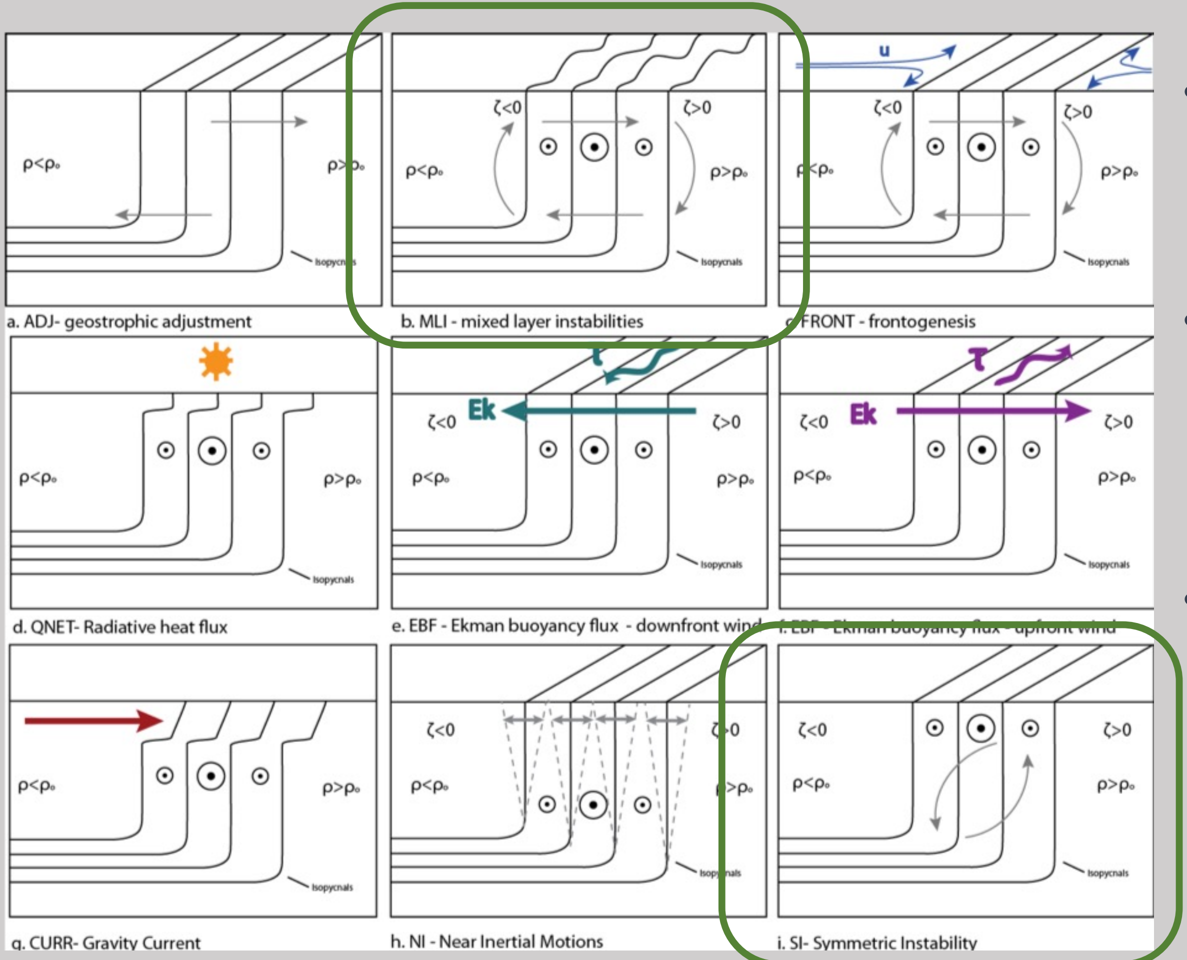
NASA

2 – What is the **impact** of those processes

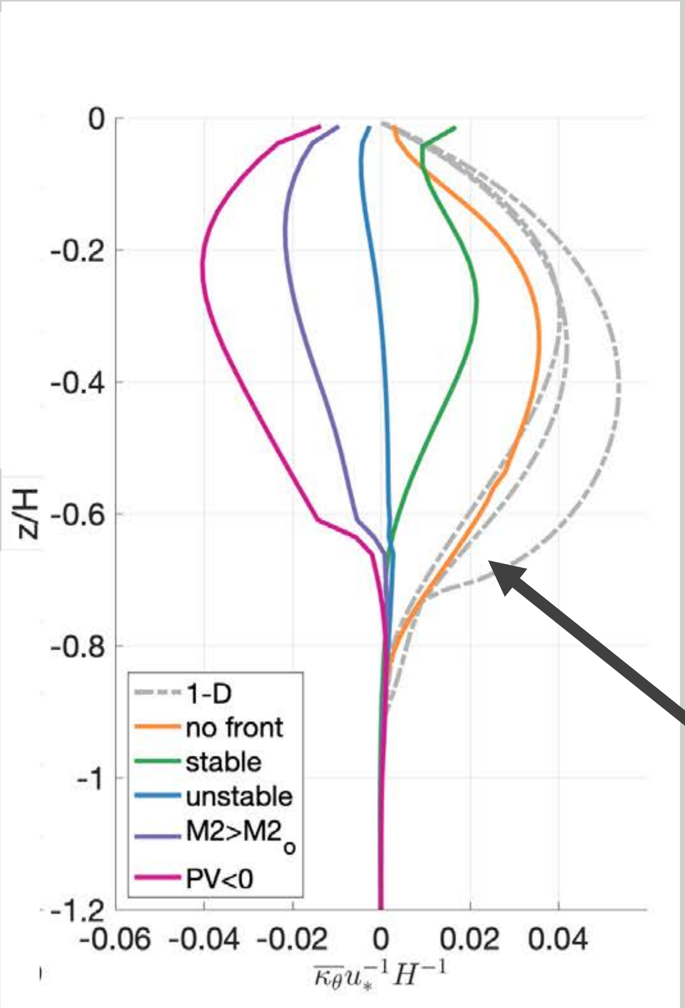


- Parameterize impact of submesoscale processes for models that can't resolve them

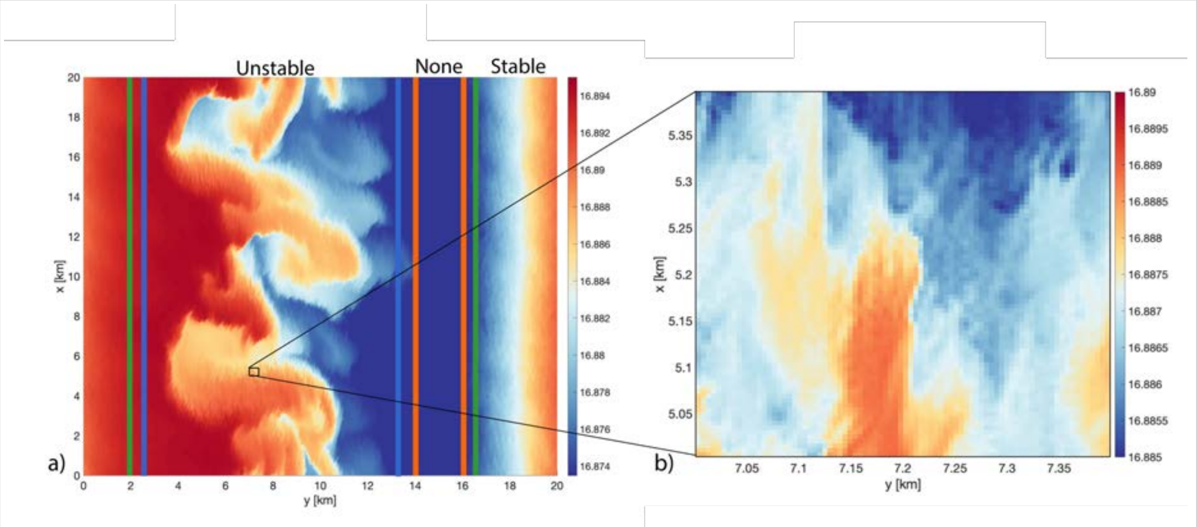
2 – What is the **impact** of those processes



- Parameterize impact of submesoscale processes for models that can't resolve them
- MLI is only parameterization in climate models. SI is parameterized in regional and process models
- **Our understanding of the physics exceeds our ability to account for it in climate models**



Johnson and Fox-Kemper, in prep

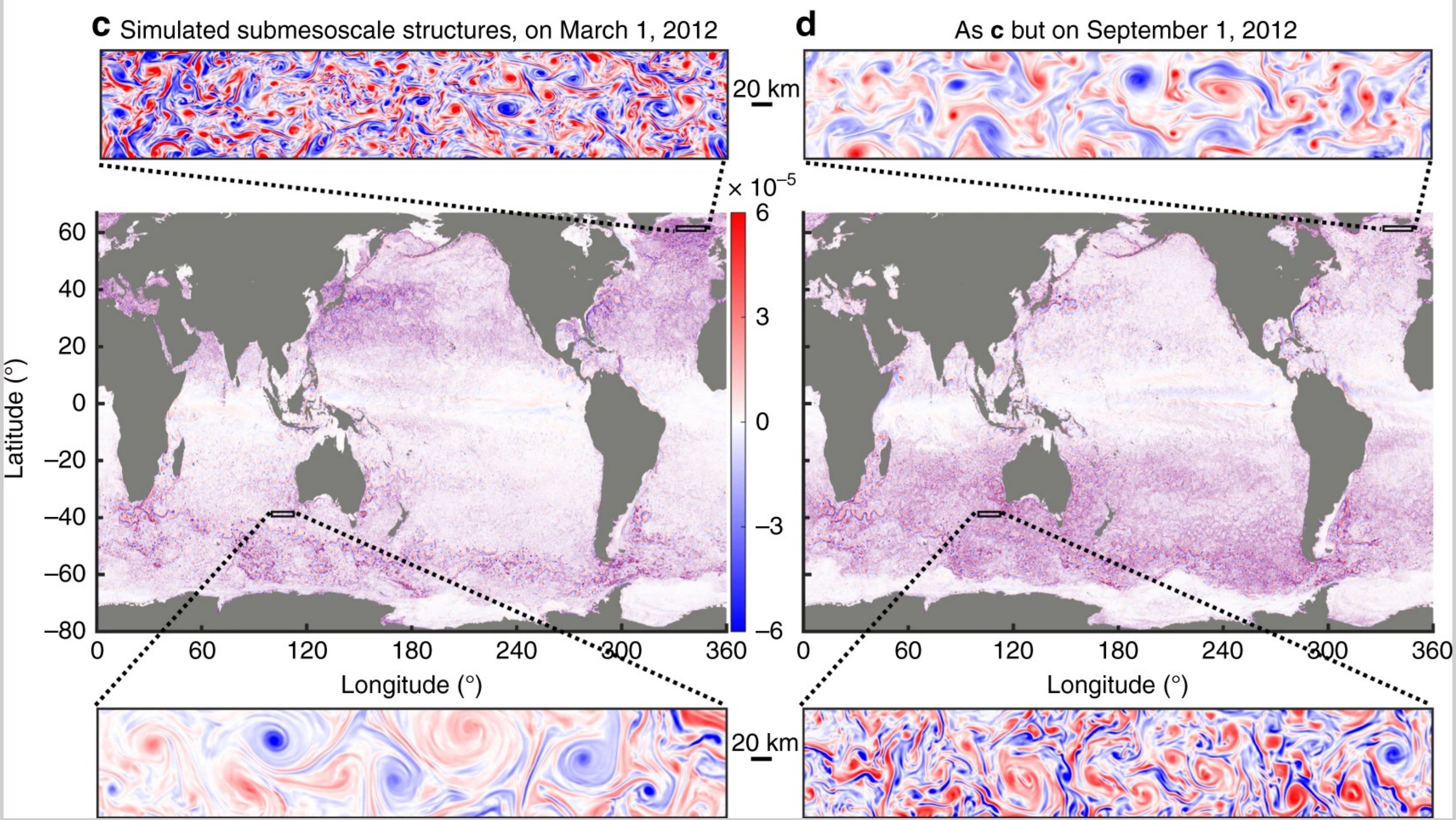


Cross-scale interactions:
Parameterizations change in different regimes

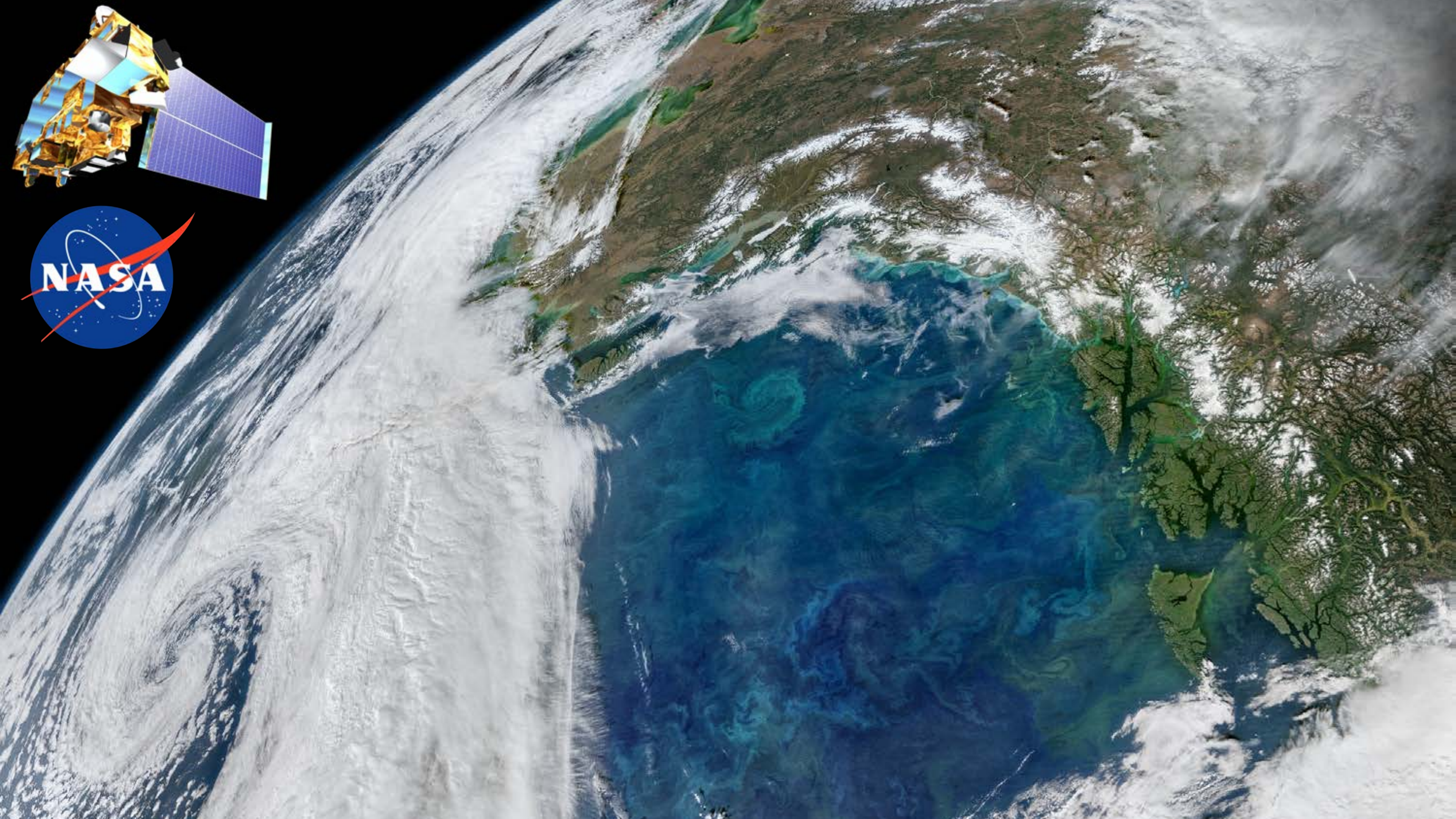
Example – Ocean surface boundary layer parameterizations (i.e. surface forced mixing) break down in presence of submesoscale flows.

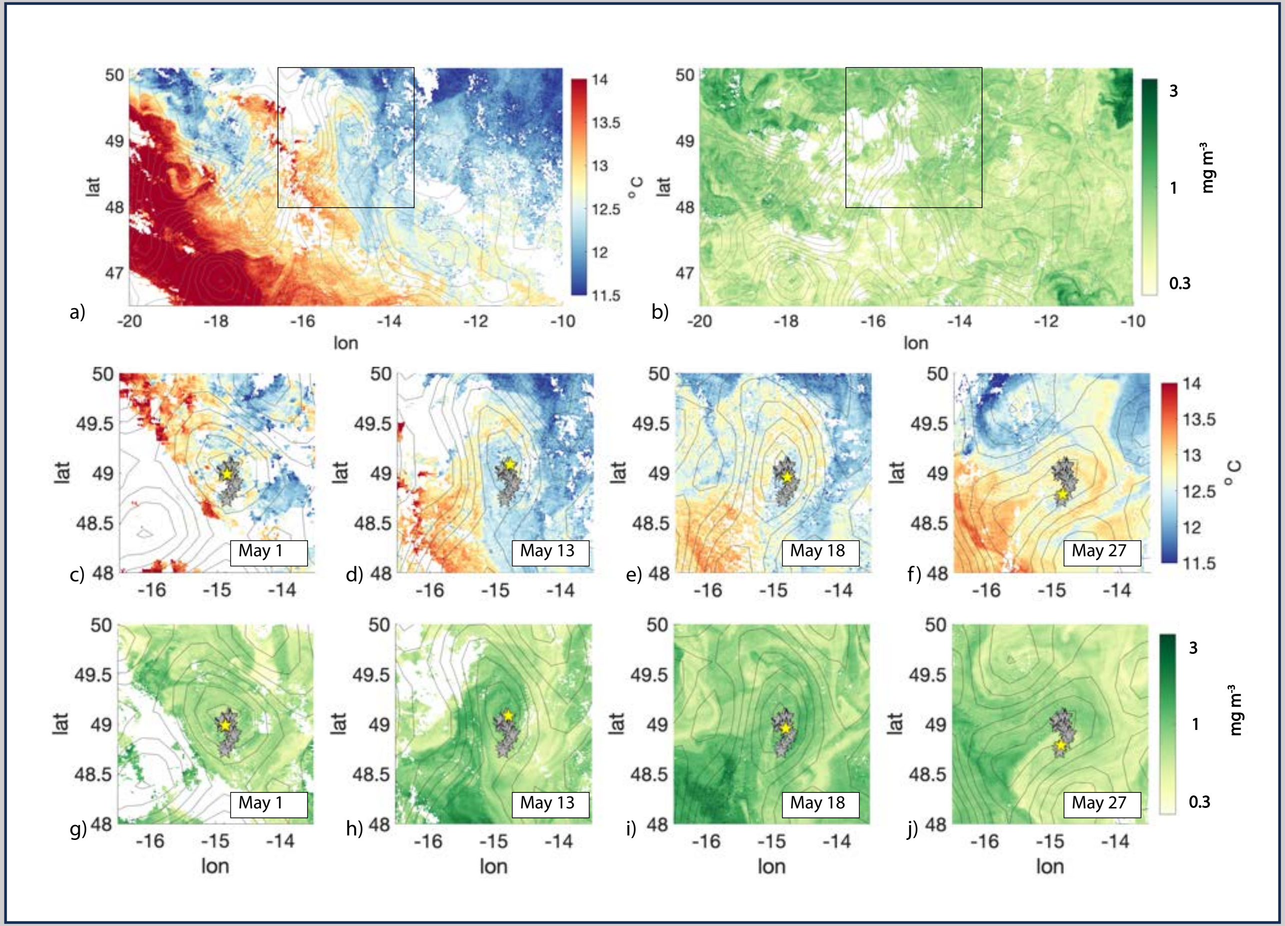
Re-evaluate current parameterizations in submesoscale frontal regions

3 – What is the **global significance** of that impact



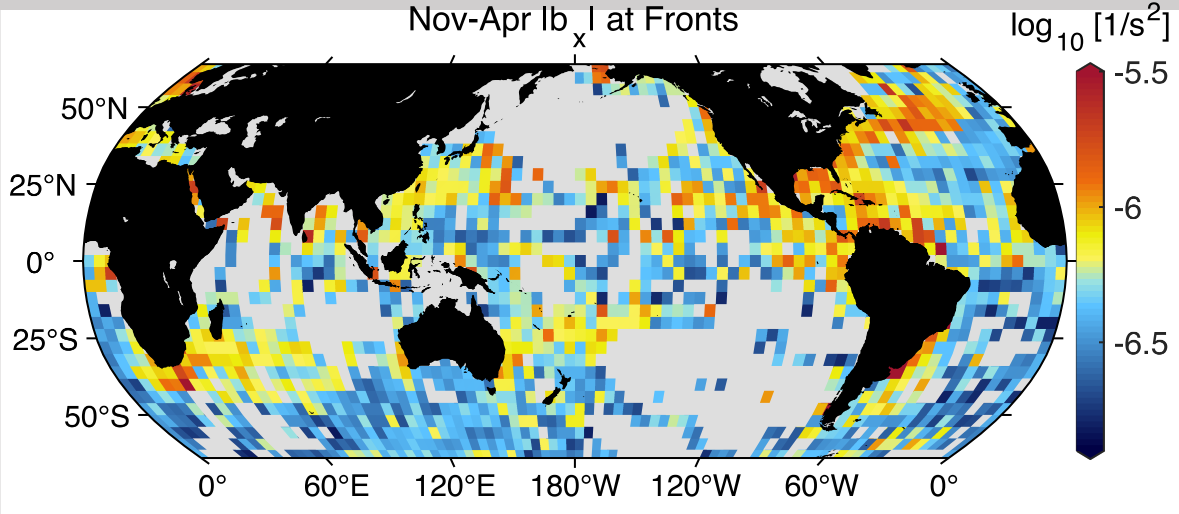
Su et al.2018

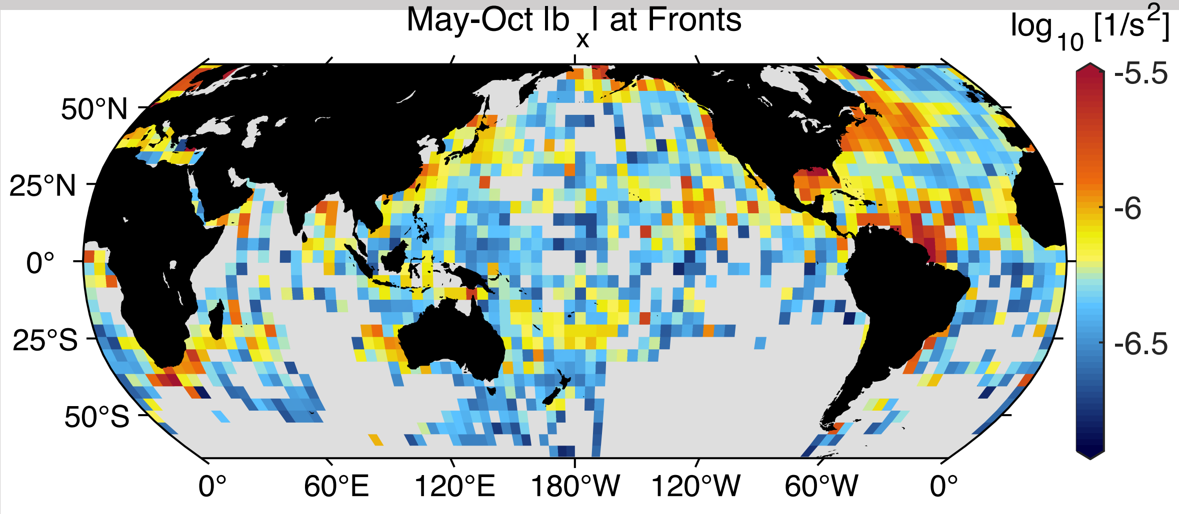

NASA



- Clouds obscure surface signal and complicate statistics and evolution tracking
- SST fronts don't account for density compensation in salinity dominated regions

Johnson et al, submitted

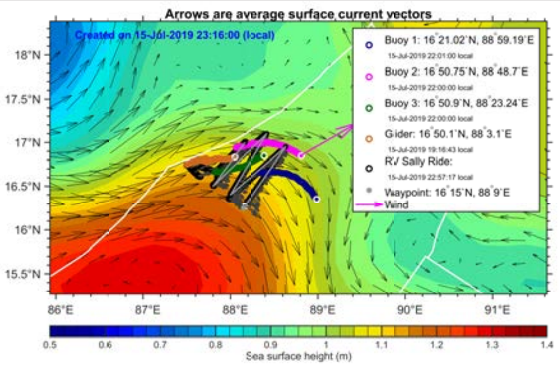




Global distribution of fronts by ships of opportunity

Whalen, in prep

- Seasonal cycle of sharp fronts near the Amazon river
- Sharper fronts near the coastlines
- Winter elevation of frontal gradients in the Gulfstream and Kuroshio extension



Ship based programs tend to bias most **energetic** (i.e. interesting) regions
MISOBOB - 2019

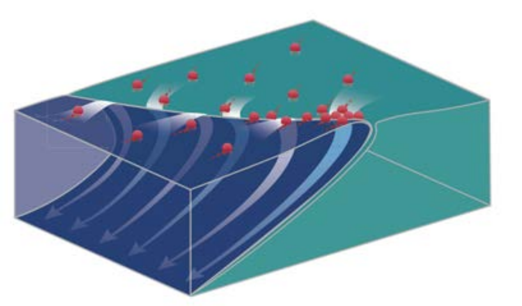


Fig. 2. Ocean surface currents converge and sink at a density front separating light and heavy water, sweeping floating material to the front where it accumulates.

Drifting assets tend to accumulate in **convergence** zones
D'Asaro, 2017

Submesoscale impacts are **highly localized**
Dong at al, submitted

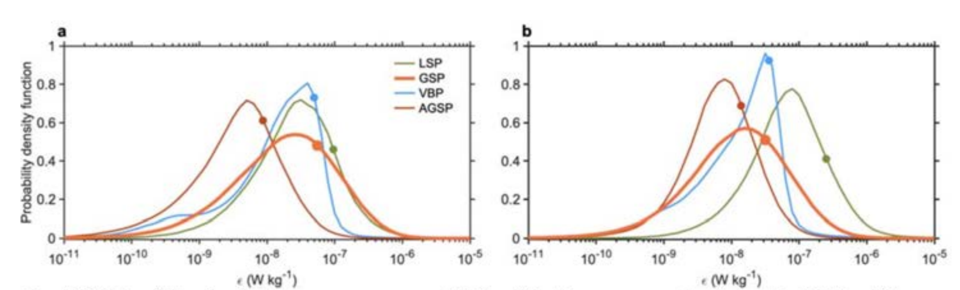


Fig. 3 PDFs of the turbulence sources. a, PDFs of the four sources in winter. **b,** PDFs of the four sources in summer. The dots indicate the corresponding global mean value of each distribution. The log-normal distribution of the PDFs suggests that the mean and integral of OSBL dissipation are determined by intermittent high dissipation rates. The highest intermittency of GSP can also be derived from the distributions.

Statistics of in-situ observational data likely biased

Summary

1 – Understand **dynamics** at submesoscale fronts

Process studies – coordinated multi-asset campaigns are offering broader picture of multiple scales

2 – What is the **impact** of those processes

Understanding impact of submesoscale dynamics and how to implement them as parameterizations in GCMs - the importance of linking observations with numerical simulations

3 – What is the **global significance** of that impact

Global observations of fronts still a challenge, but are needed to scale up process studies and compare with global models