Using total exchange flow to characterize submesoscale processes in the northern Gulf of Mexico

Dylan Schlichting | OCNG 603

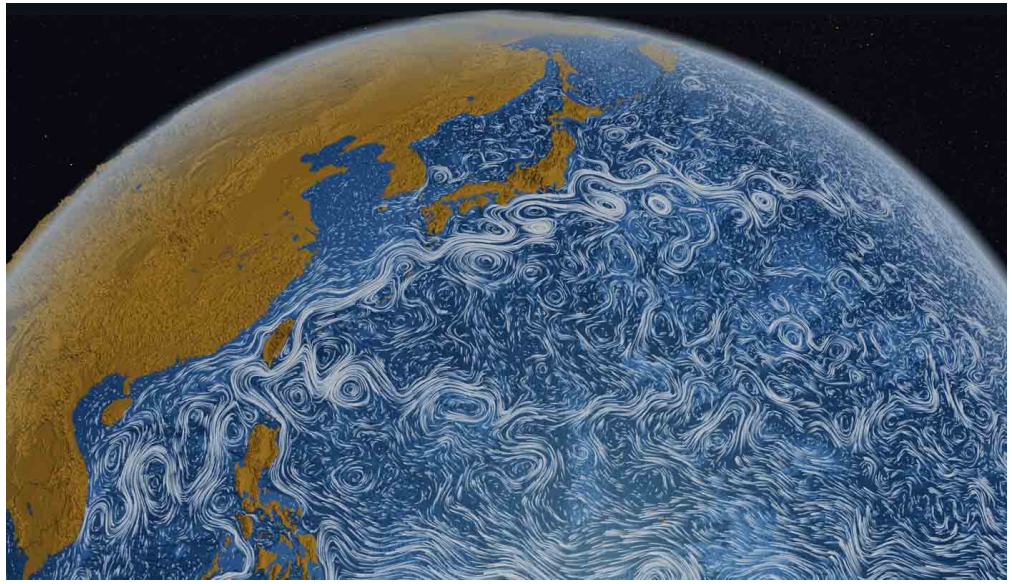
April 28, 2021

sunrise-nsf.org

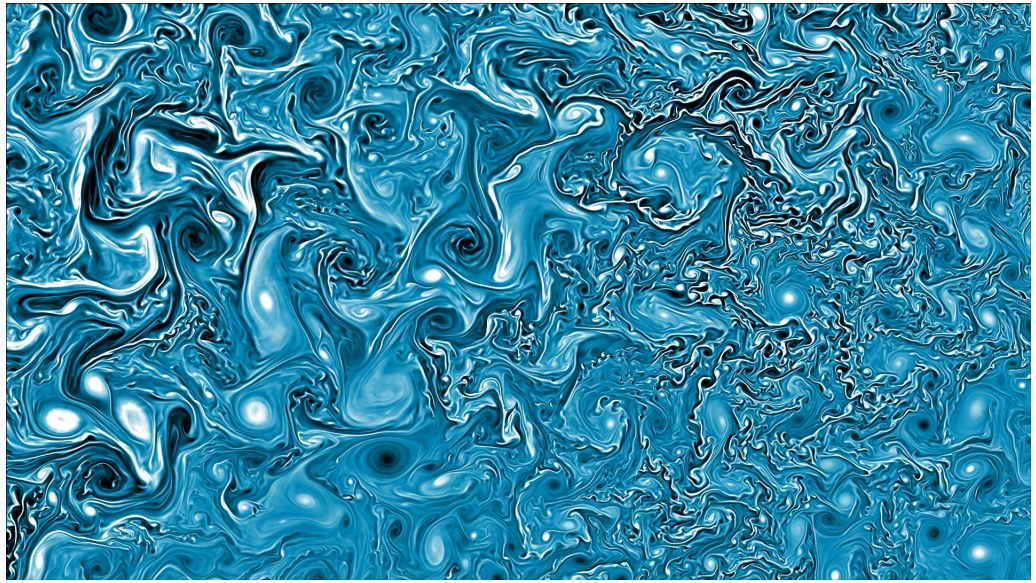
TEXAS A&M UNIVERSITY
Oceanography

Overview

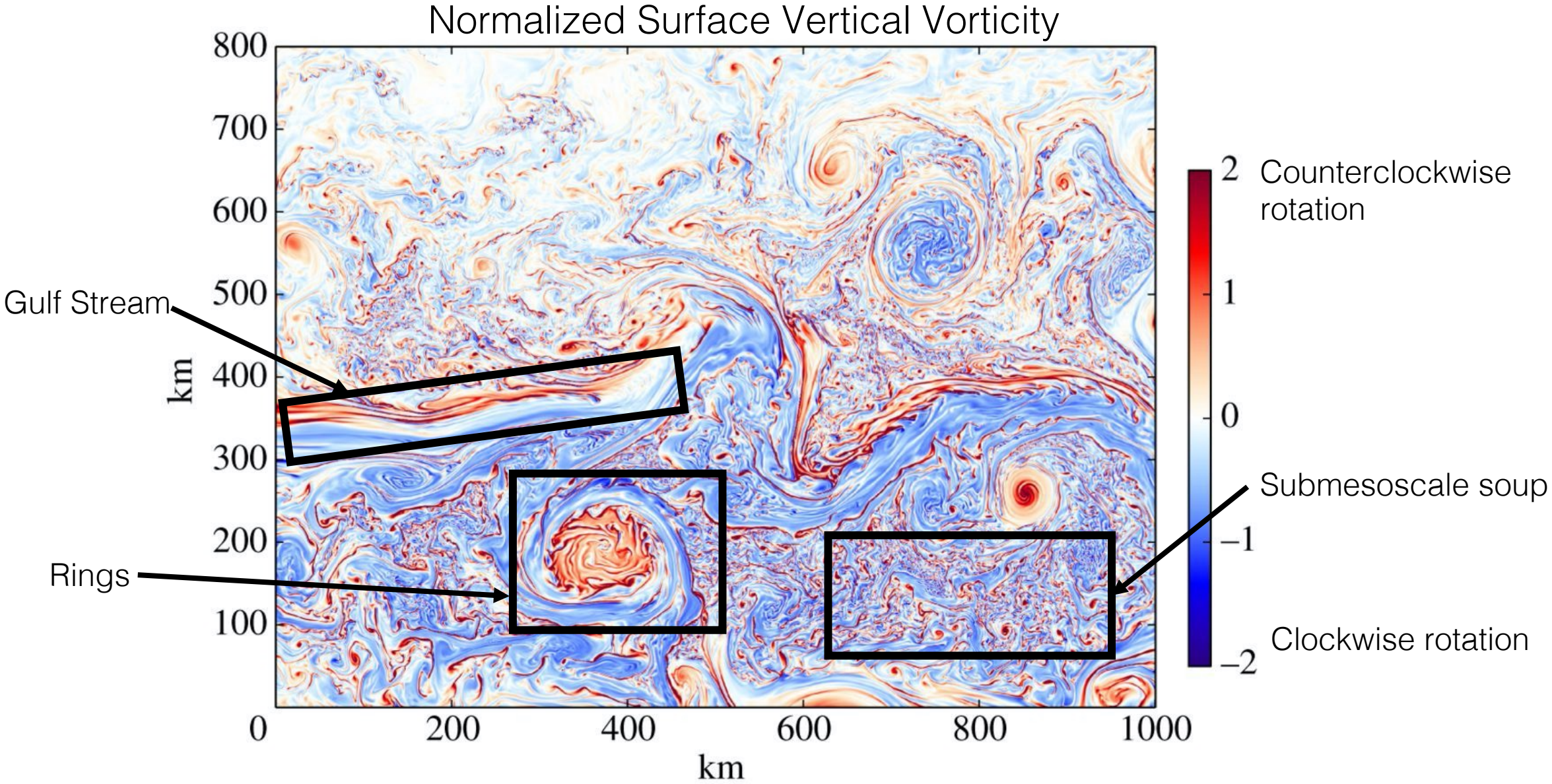
1. The ocean submesoscale
   - Small-scale ocean processes, bigger than microscale, smaller than mesoscale



https://researchfeatures.com/mesoscale-ocean-currents-improved-climate-modelling/



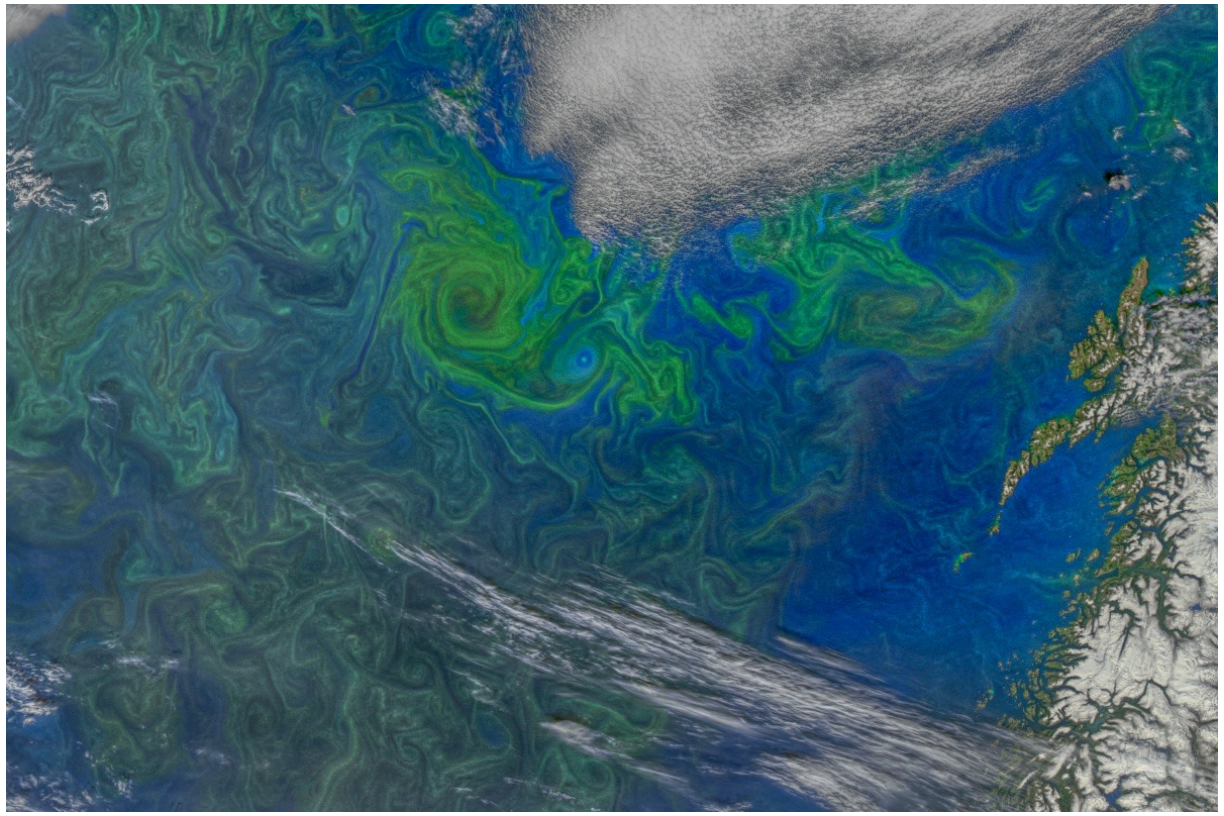
https://ocean-next.github.io/expertise/natl60/



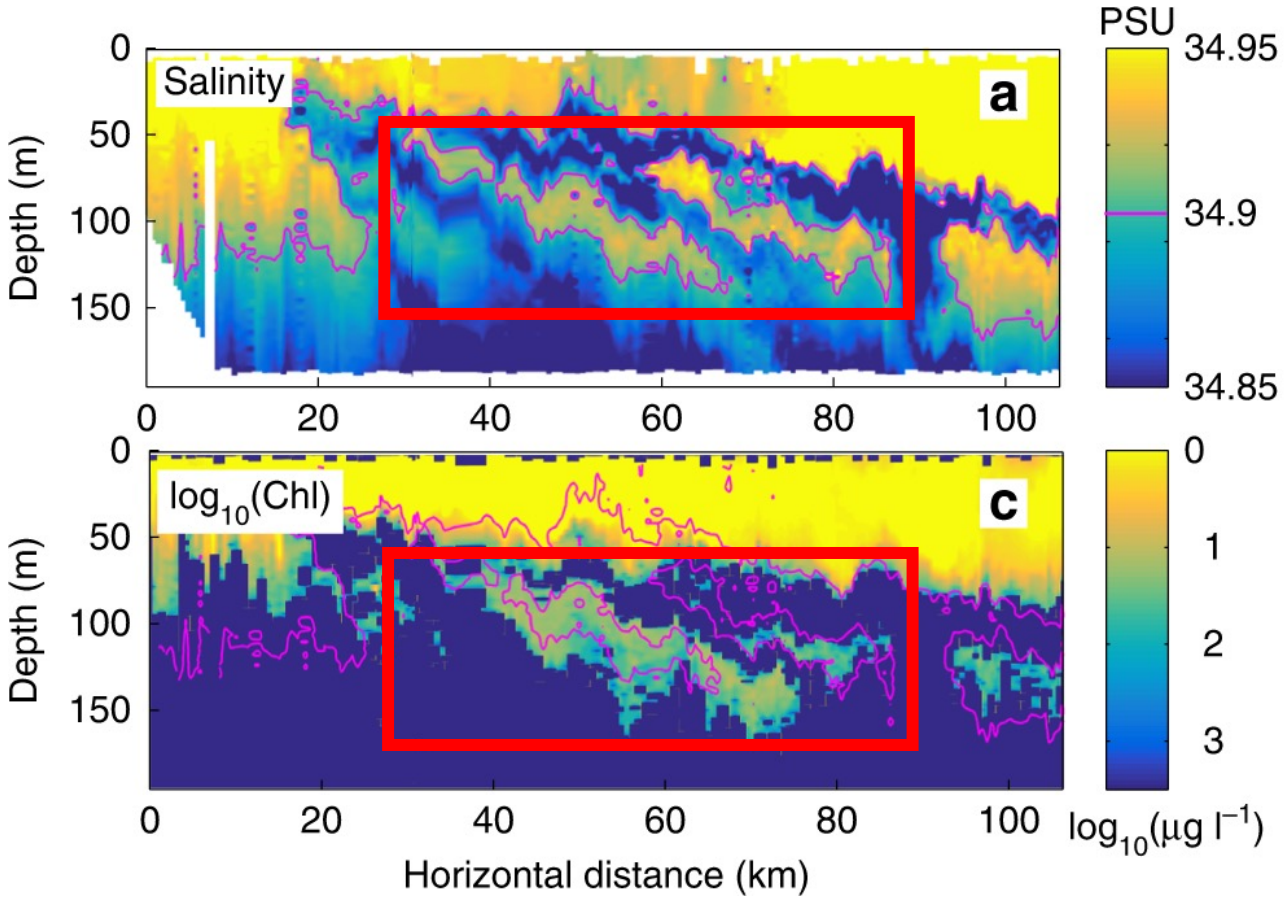
- Spatial scales O(1 km), time scales of O(1 d)
- O(1) Rossby and Richardson Numbers
- Strong relative vorticity
- Large vertical velocities

McWilliams (2016)

Submesoscales modulate surface ocean biogeochemistry!



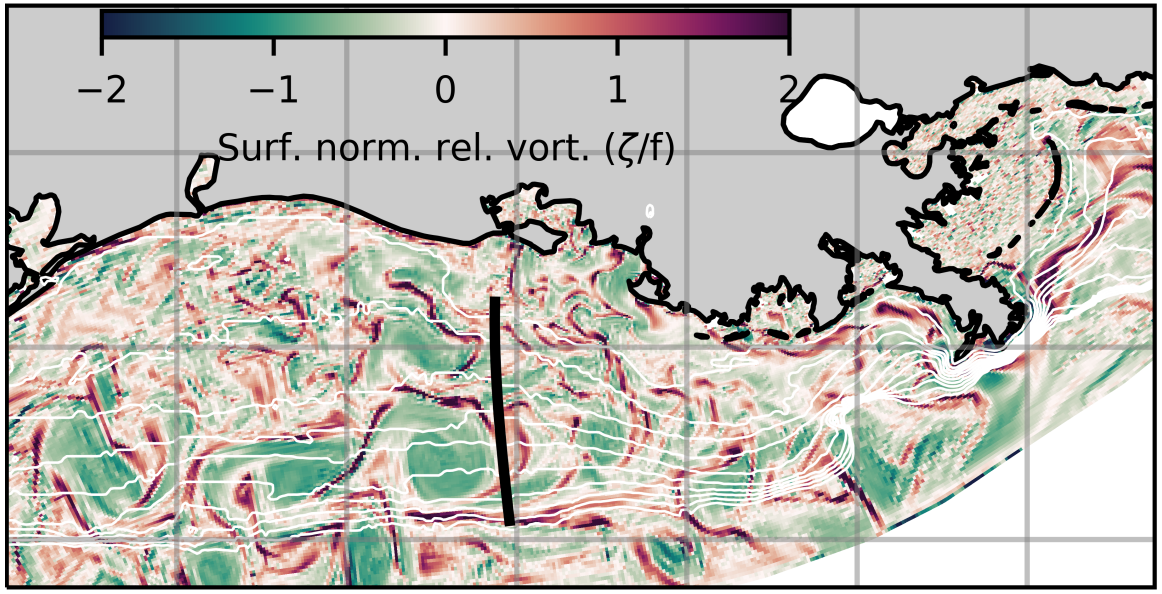
https://oceancolor.gsfc.nasa.gov/gallery/#&gid=1&pid=5



Levy et al. (2018)

- Hot spots for flora and fauna
- Nutrient flux pathways out of euphotic zone
- Extraordinarily difficult to observe in the field

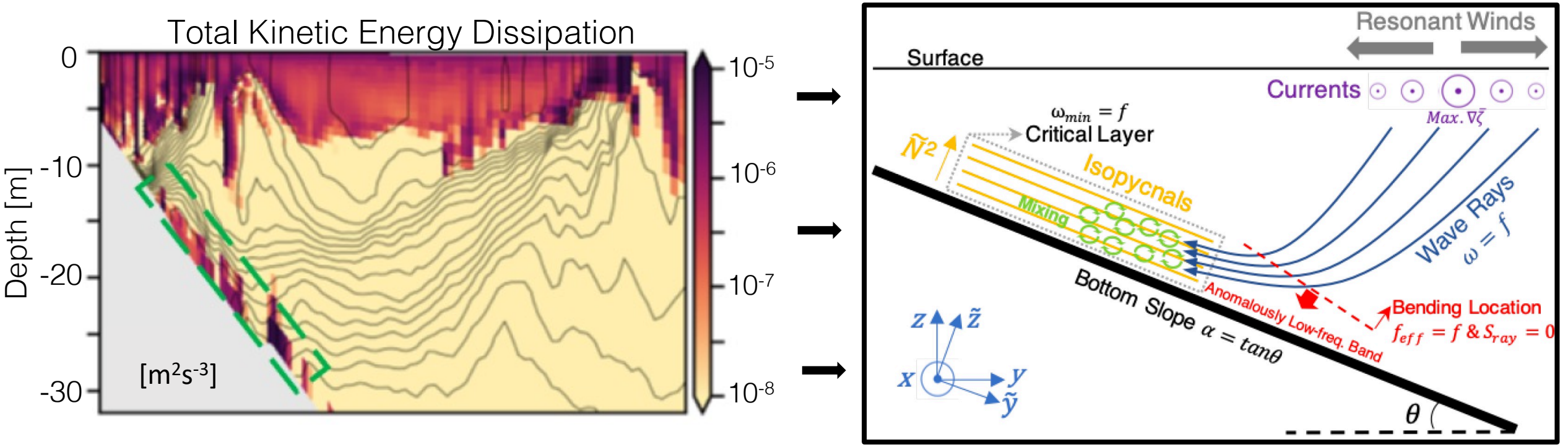
Submesoscales form in the nGoM each summer and enhance mixing



TXLA Model

- Validated, realistic numerical model
- Horizontal resolution of 500 m – 2 km in nGoM
- Vertical resolution of <1 m to 10s of m
- Includes realistic atmosphere and river forcing

Local mixing processes are complex – not what I'm interested in



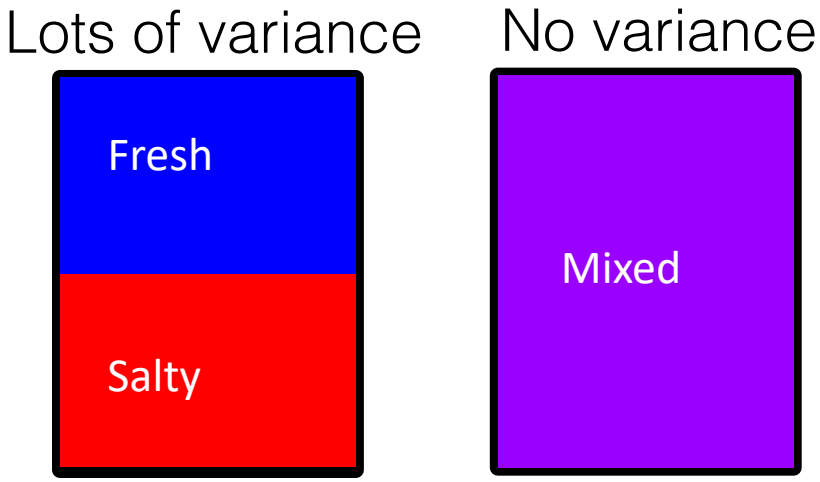
Qu et al. (2021) JPO

Research Questions:

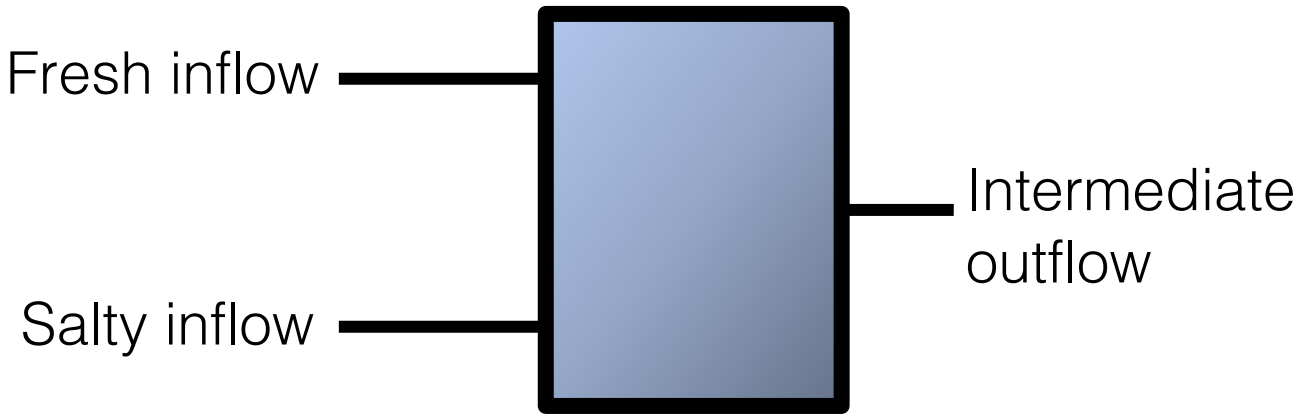
1. How does net mixing vary over different scales?
2. What processes drive mixing over different scales?
3. What is the net effect of that mixing?

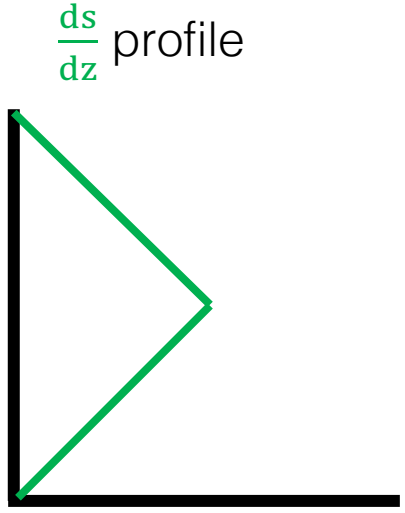
What definition of mixing should we use? Salinity variance dissipation!

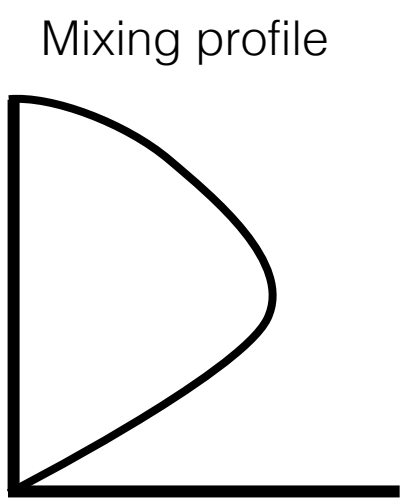
- $s' = (s - \bar{s})$
- $M = \iiint_V 2K_s(\nabla s')^2 \, dV,$
- M = (Salt diffusivity) (variance gradients)^2



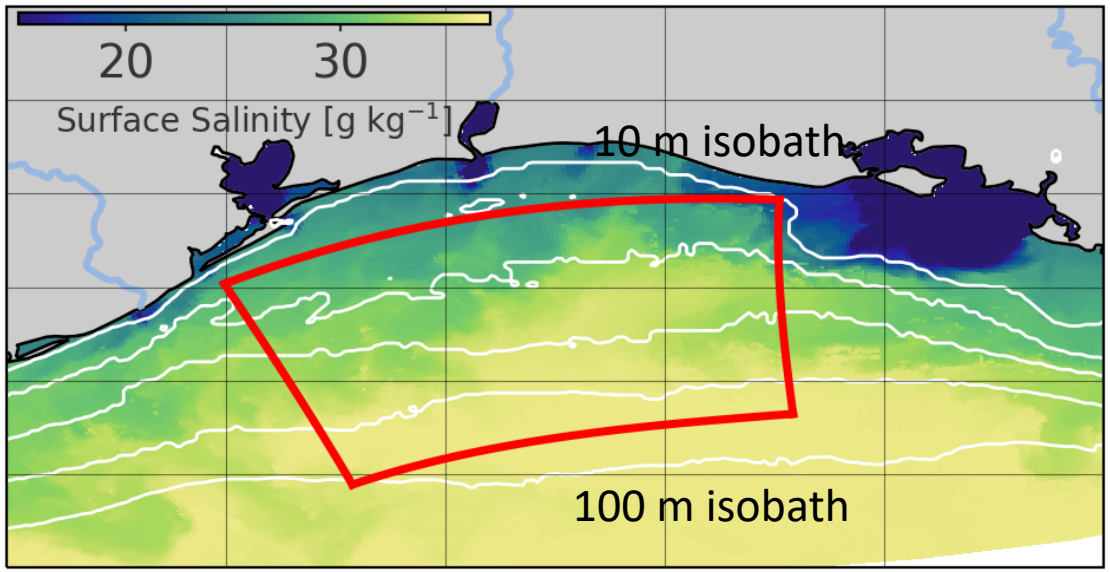
Tank Reactor: Constant K_s and linear $\frac{ds}{dz}$

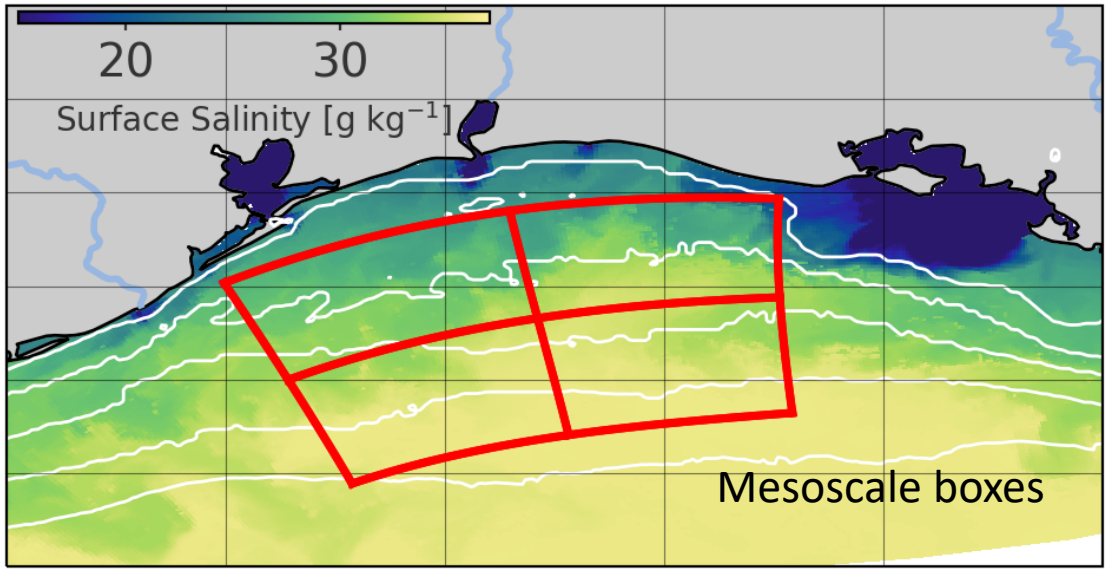


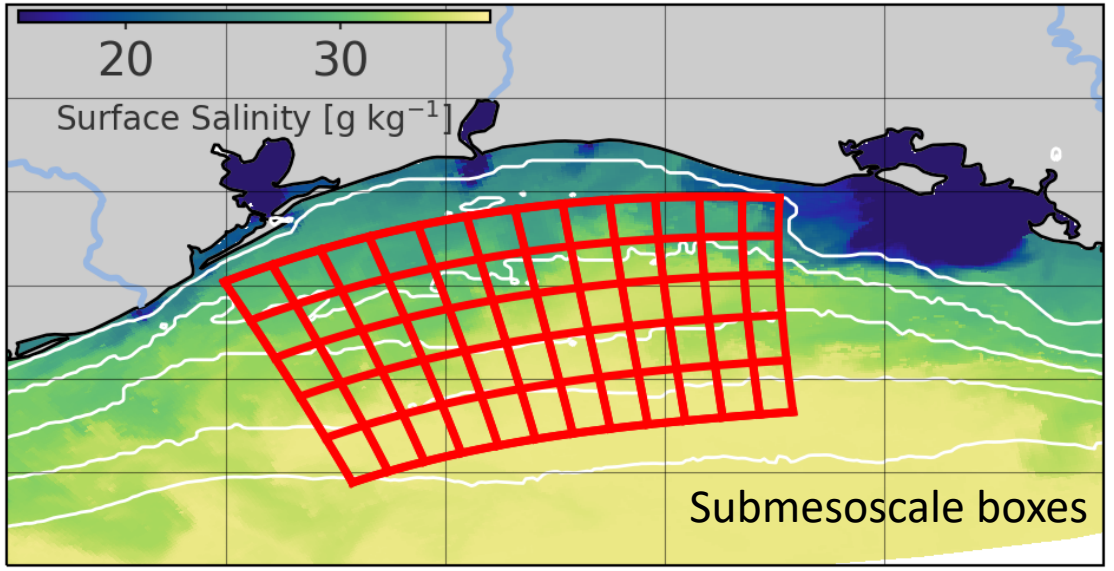




Address objective 1: Differentiate the scales of mixing by breaking up the shelf into boxes

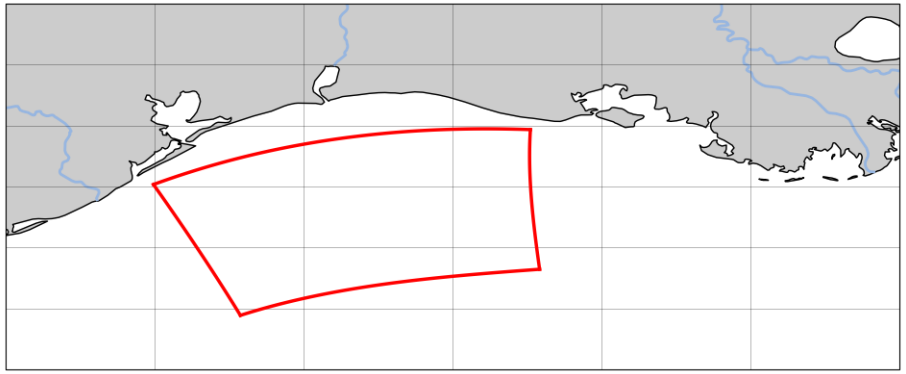




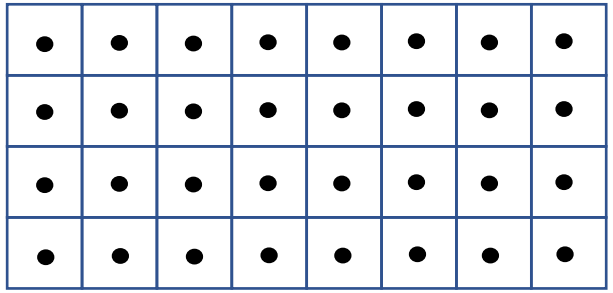


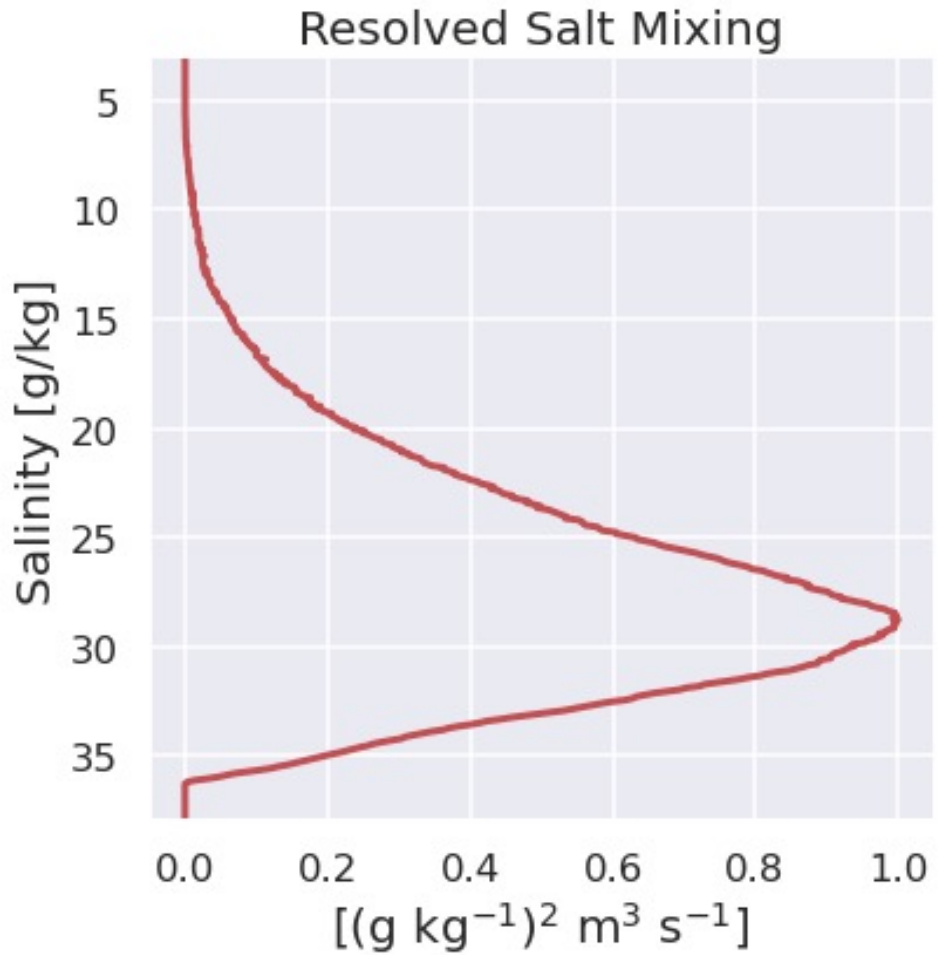
- Control volume bound loosely by inner shelf
- Compute mixing for each configuration normalize by volume size
- **Hypothesis:** Mixing increases the smaller I make the boxes, but more complex

Salinity is an intuitive coordinate system for dynamical processes



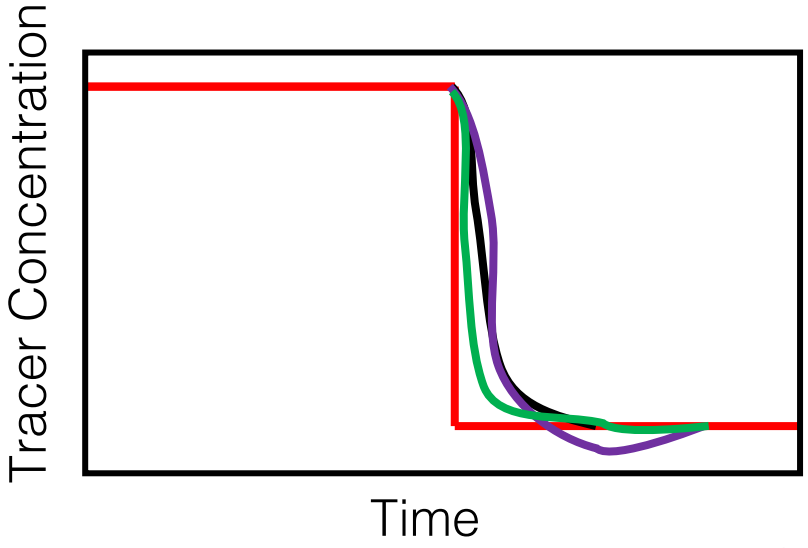
Simple numerical grid





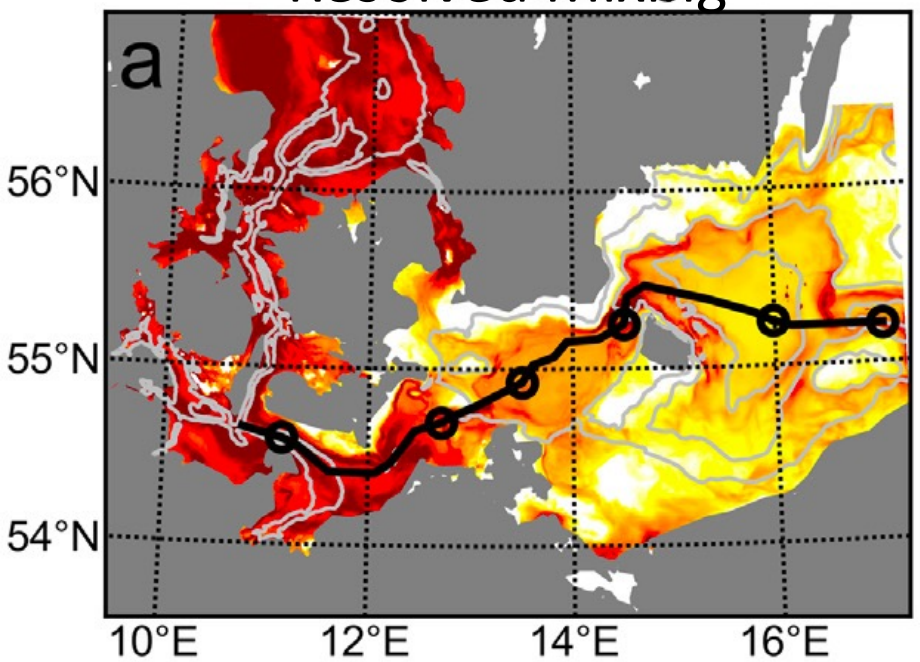
- Condense M from summer 2010 into single plot
- Mixing would look like noise if binned by depth

We need to talk about the elephant in the room…

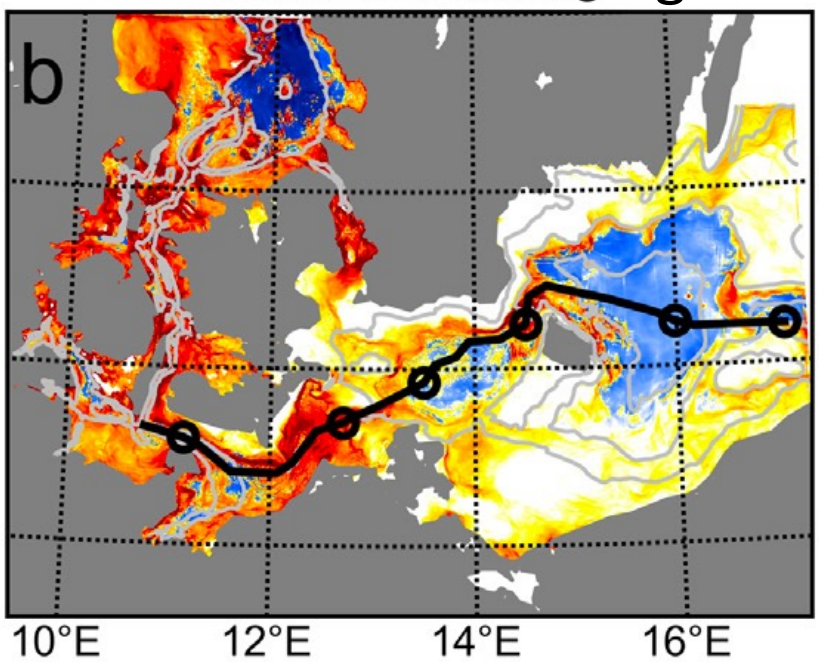


Red - exact solution
Other colors – different solvers

Resolved Mixing

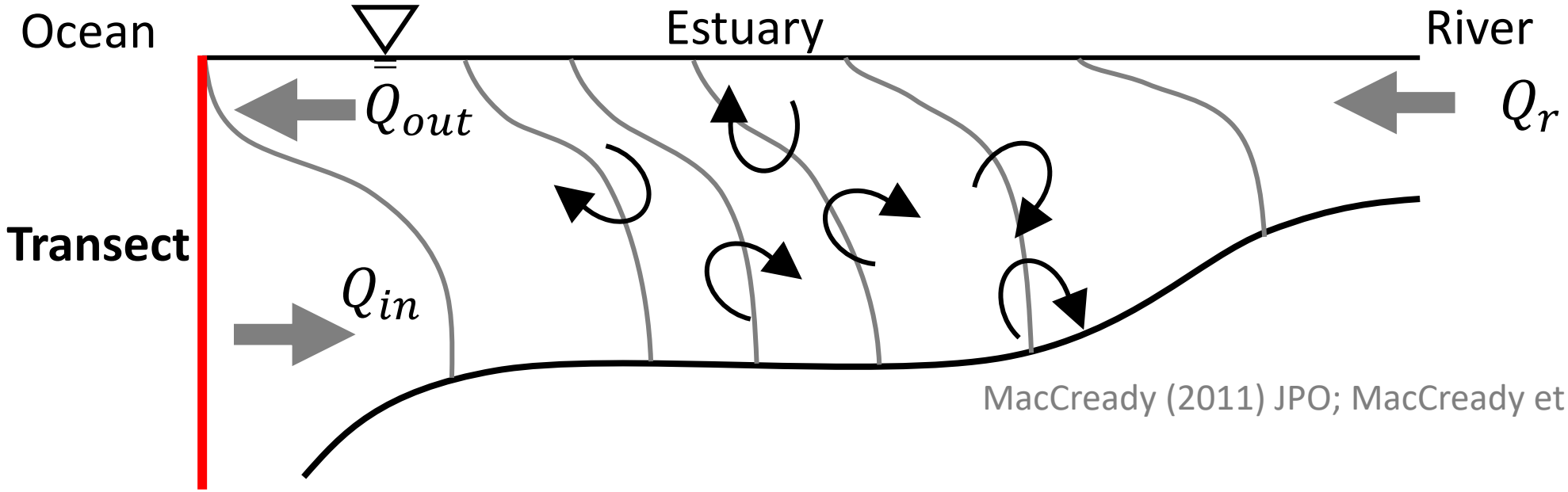


Numerical Mixing



Klingbeil et al. (2014) OM

Total exchange flow involves binning bulk circulation in tracer coordinates

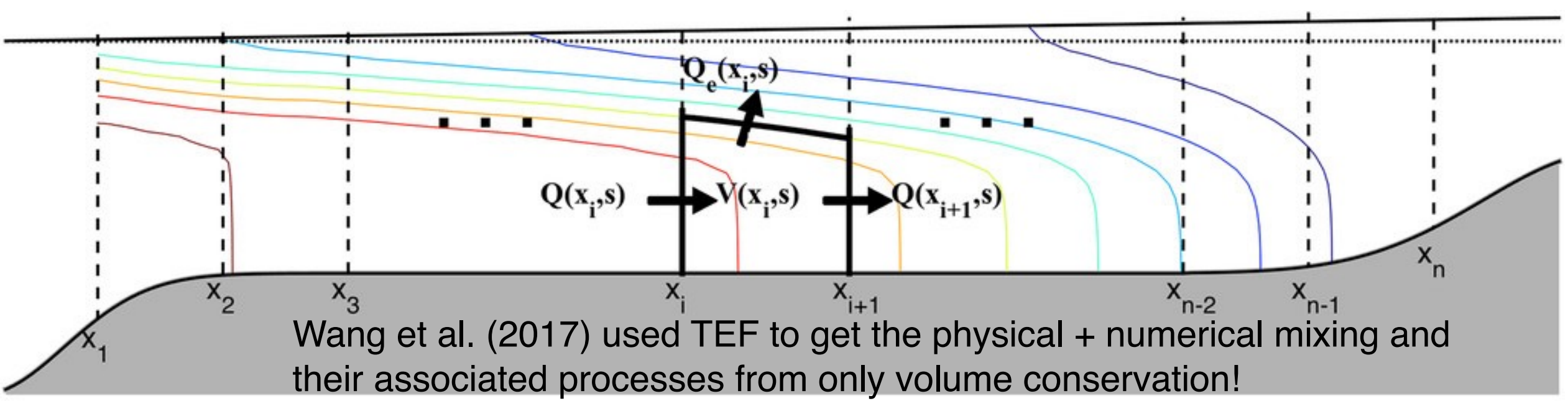


MacCready (2011) JPO; MacCready et al. (2018) JPO

- Q^c= bulk exchange flow. Calculated with velocity and the tracer concentration
- Example application: Salinity variance conservation

Volume integrate: $\frac{d}{dt}\int s'^2\, dV = Q_{in}{s'^2}_{in} + Q_{out}\,{s'^2}_{out} + Q_R\bar{s}^2 - M$

Tendency | Mouth Advection | River Advection | Dissipation



Wang et al. (2017) used TEF to get the physical + numerical mixing and their associated processes from only volume conservation!

$$Q_e = Q(x_i) - Q(x_{i+1}, s) - \frac{\partial V(x_i,s)}{\partial t}$$

$$F_d = \int_s^{s_0} Q_e \, ds$$

$$M_{tot} = 2\int_s^{s_0} F_d \, ds$$

$$M_{tot} = M + M_{num}$$

Entrainment: Diahaline tracer transport

↓

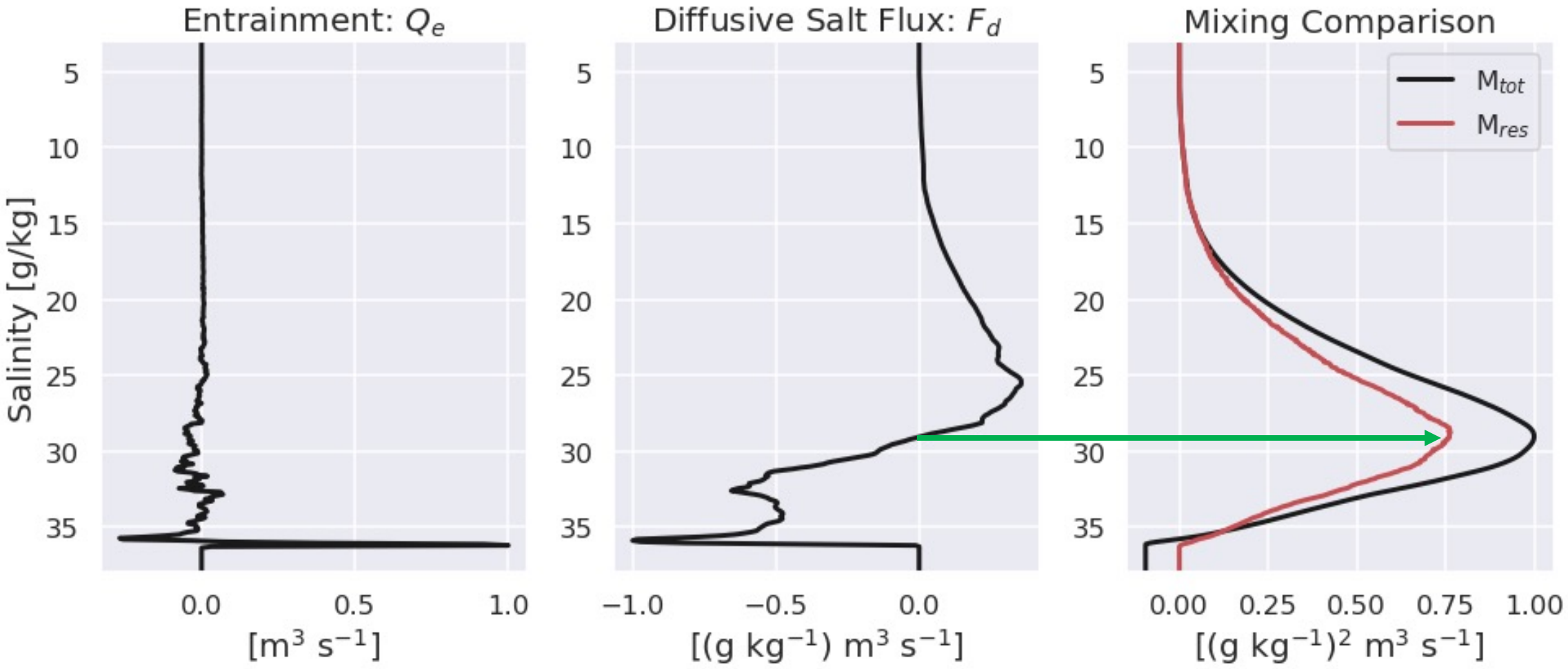
Diahaline diffusive salt flux

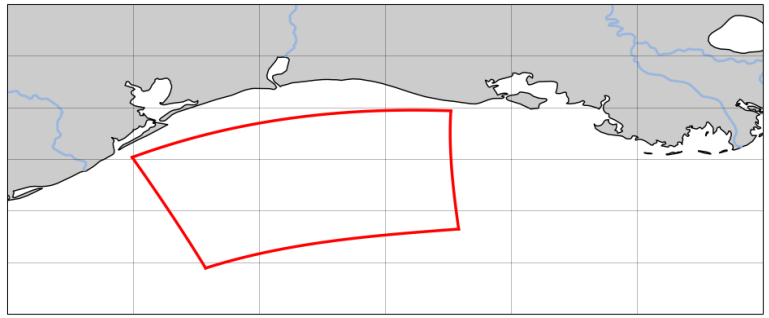
↓

Total salt mixing

↓

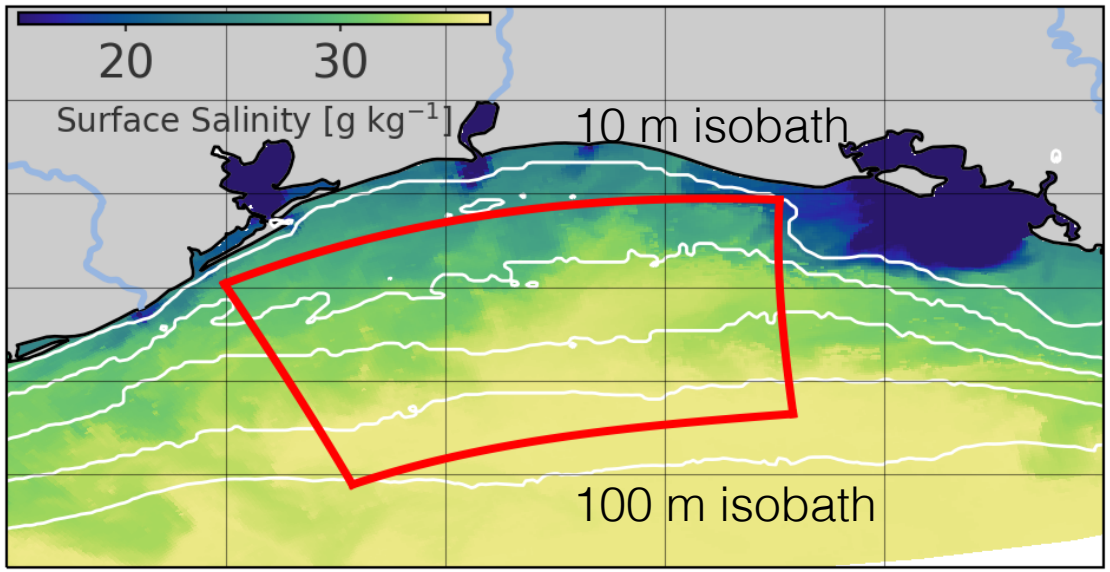
Total salt mixing = resolved + numerical

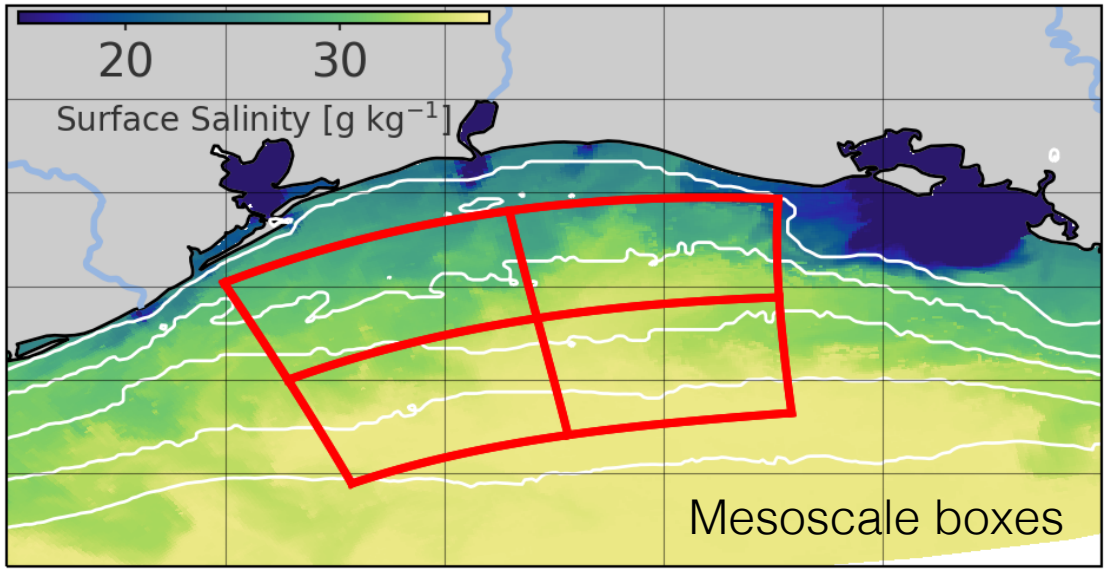


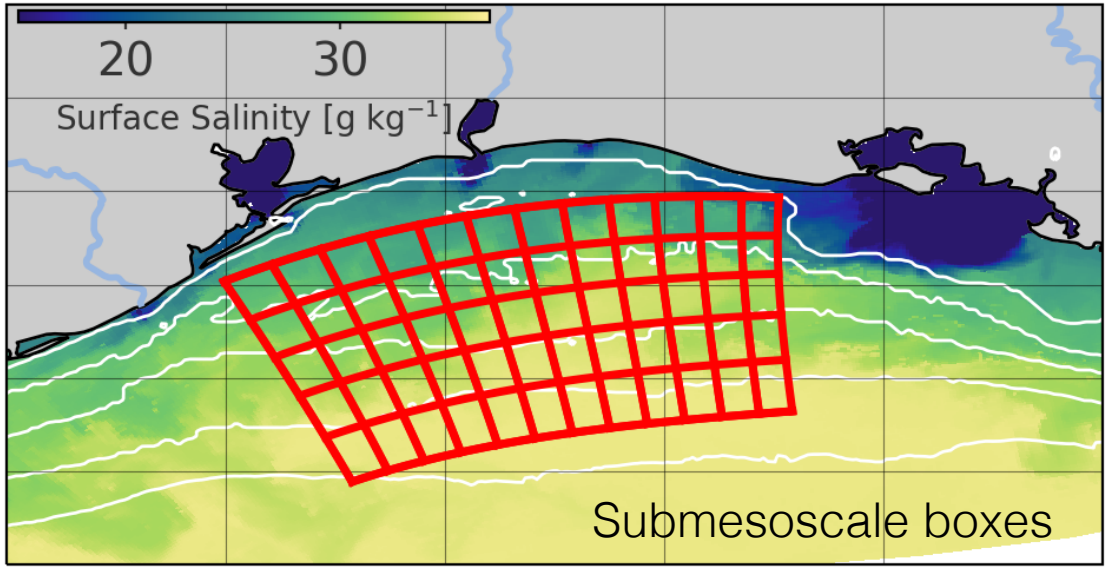


- Two isohalines of interest: ~28 psu & ~36 psu
- 28 psu is where diffusive salt flux = 0
- 36 psu is where the shelf break is >>> aka more volume & transport

Address objective 2: Look at salinity variance budget and ‘total mixing’ to different box configurations



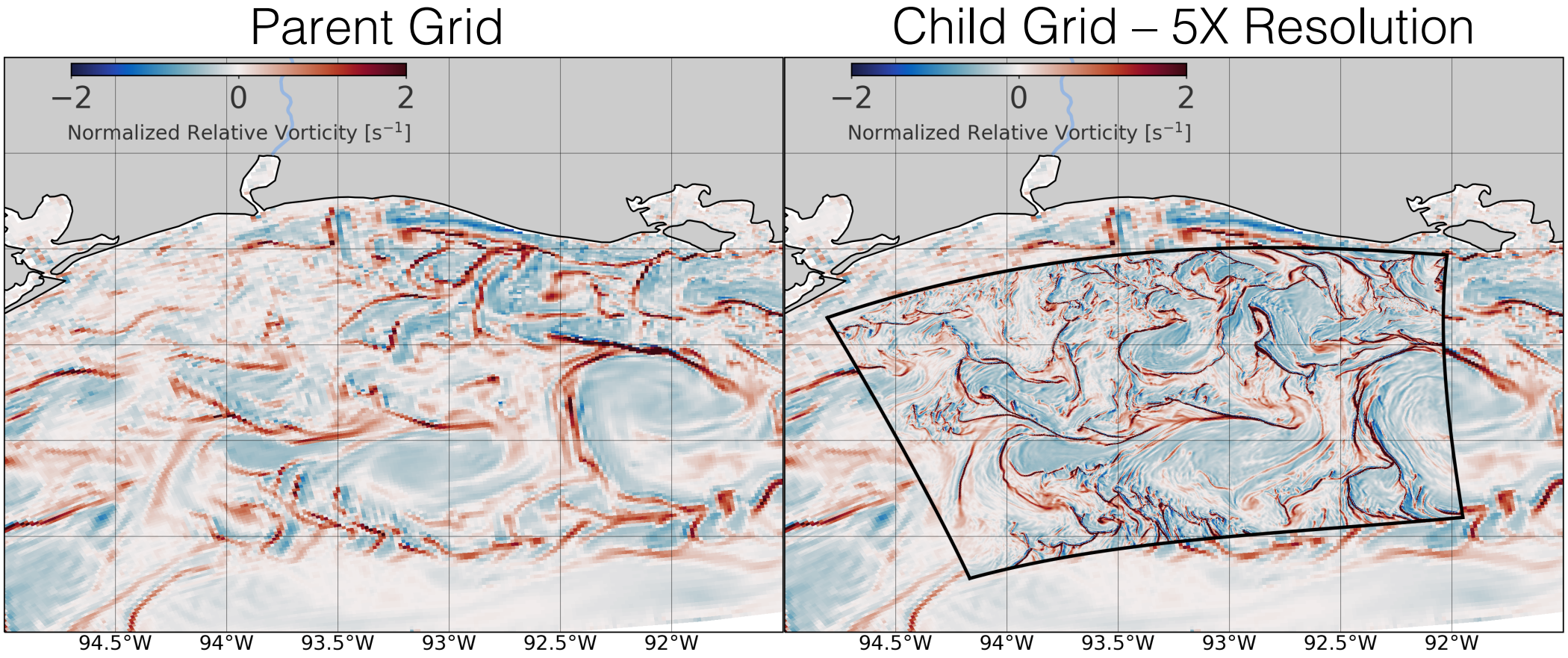




- Compute s’ budget and processes that influence total mixing for different control volumes

- **Hypothesis:** Advection becomes more dominant and the smaller the boxes.

Address objective 3: use nested model and repeat



- Child grid – 10s to 100s of meters horizontally
- Vorticity enhanced in smaller grid
- **Hypothesis:** All physical processes similar qualitatively but increase in magnitude.

Conclusions

- Submesoscales are important for surface ocean biogeochemistry and physics
- Study 1) how mixing varies over different scales, 2) what processes control it, and 3) the net effect of that mixing
- Break shelf up into boxes and compute mixing to address (1)
- Use total exchange flow, salinity coordinates, and the salinity variance budget to address (2)
- Use high resolution nested model to address (3)