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

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I. What are submesoscales and why are they important?

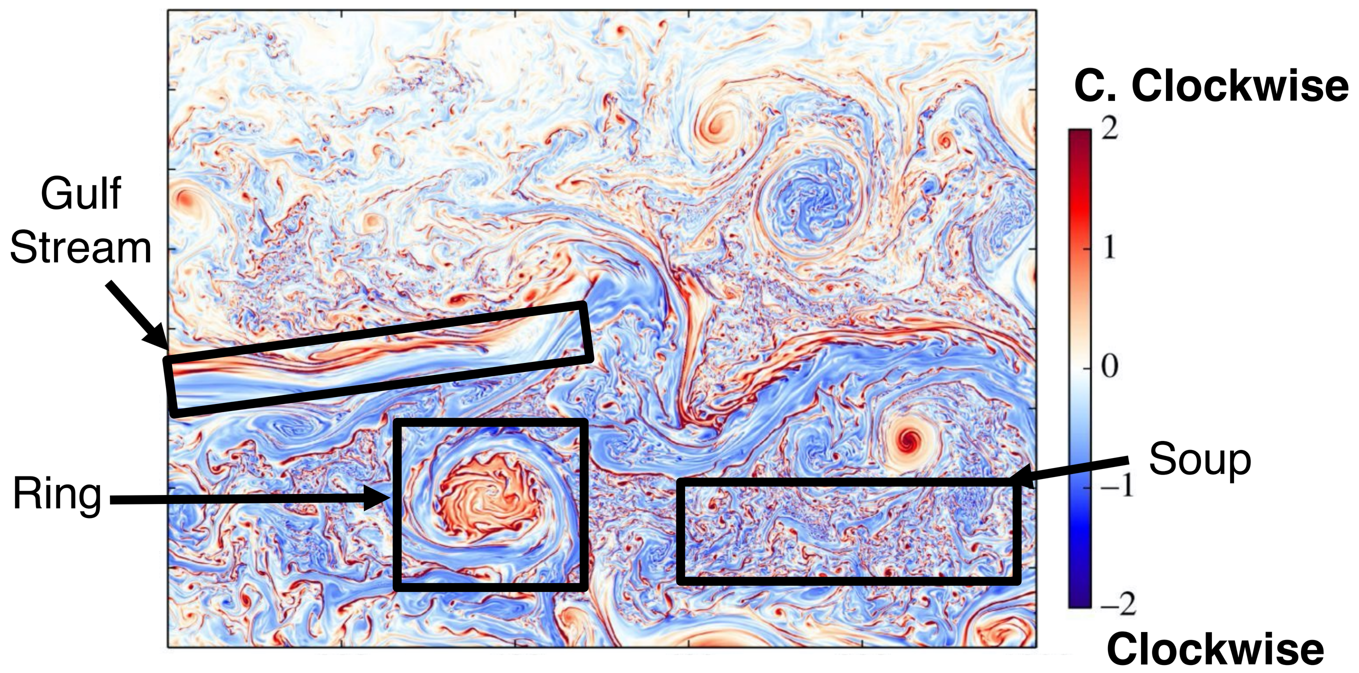


Figure 1: Realistic simulation of normalized vertical relative vorticity, $(\partial_x v + \partial_y u)/f$. Taken from McWilliams (2016).

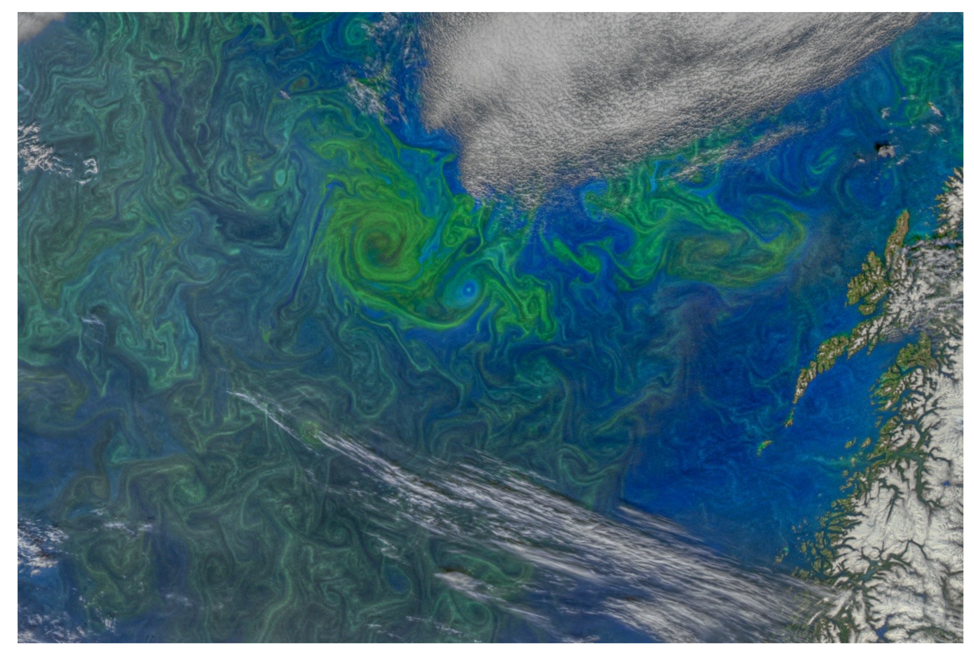


Figure 2: Ocean color data showing Norwegian Sea phytoplankton bloom. Taken from NASA (n.d.).

- Spatial scales of $O(1\text{ km})$, time scales of $O(1\text{ d})$
- $O(1)$ Rossby and Richardson numbers
- Strong relative vorticity and vertical velocities
- Modulate surface biogeochemistry and energetics

II. Current research focuses on *local* processes, not *net* processes

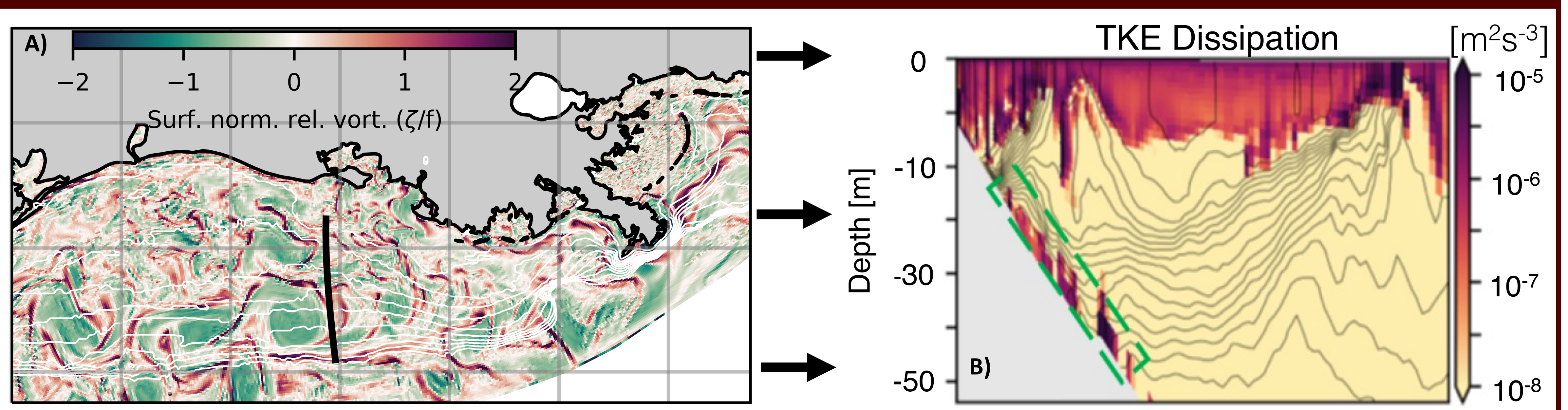


Figure 3: Snapshots of TXLA model surface normalized relative vorticity (A) during June of 2016 and cross section of total kinetic energy dissipation (TKE) at the black line (B). White lines indicate isobaths every 10 m until the end of the inner shelf; grey lines are isopycnals.

- Study submesoscales with Texas-Louisiana shelf model (TXLA): 1 km horizontal resolution (Zhang et al., 2012)
- Model captures submesoscales well

Research Questions

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

III. Break the TXLA shelf into boxes to differentiate scales of mixing

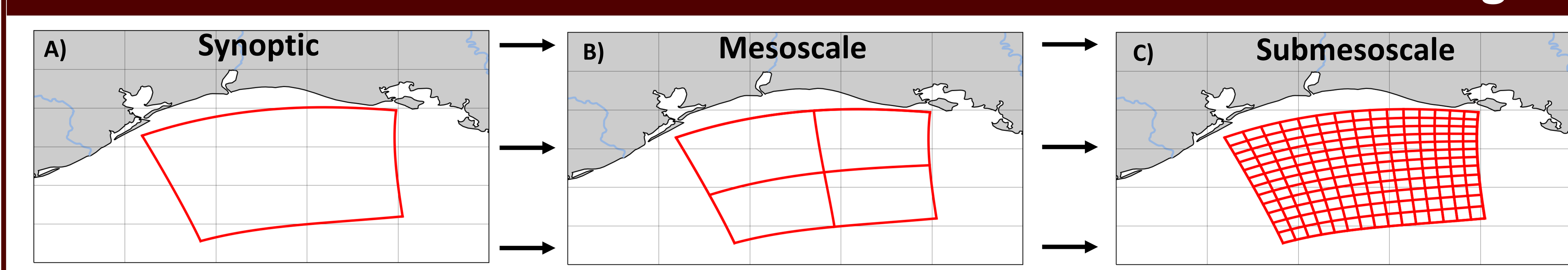


Figure 4: Different control volume configurations for the shelf, with synoptic in (A), mesoscale in (B), and submesoscale in (C).

Salinity variance

$s' = (s - \bar{s})$

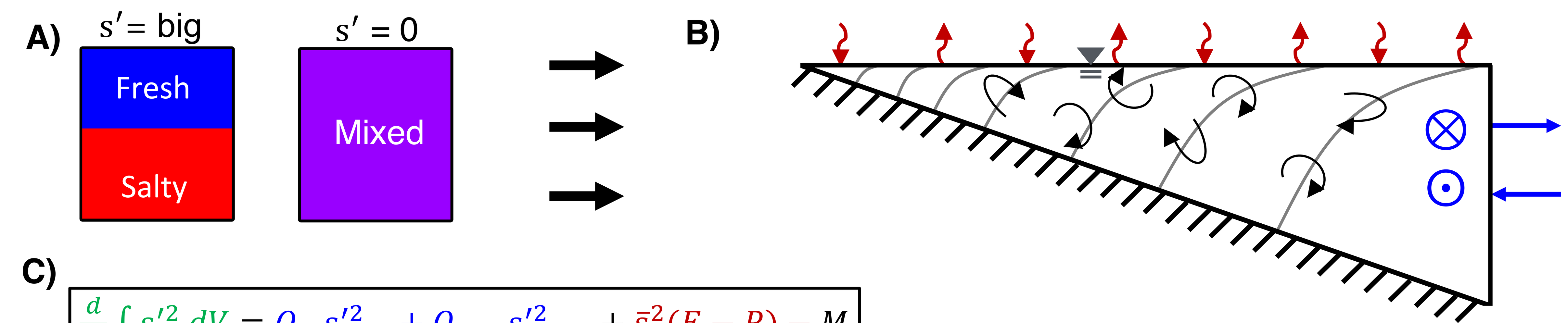
$\bar{s}$ = (salt-vol avg)

$$M = 2 \iiint_V K_s (\nabla s')^2 \, dV$$

M = (diffusivity)(variance gradients)^2

- Compute variance dissipation for different boxes in salinity coordinates
- Use model output for summer 2010
- **Hypothesis:** mixing per unit volume increases for smaller boxes

IV. Use TEF to quantify processes that drive mixing



C)

$$\frac{d}{dt}\int s'^2 \, dV = Q_{in} s'^2_{in} + Q_{out} s'^2_{out} + \bar{s}^2(E - P) - M$$

Tendency = Boundary Advection + Surface Fluxes – Mixing

Figure 5: Conceptual schematic with lots of salinity variance versus no variance (A) and cross section of shelf with realistic forcing (B) with terms in the variance budget (C)

- TEF involves binning tracer fluxes and concentrations in salinity coordinates (MacCready, 2011; MacCready et al. 2018)
- Use salinity variance budget to study how net processes relate to mixing
- Use TEF to differentiate resolved versus numerical mixing (Wang et al., 2017)
- **Hypothesis:** Advection becomes more dominant the smaller the boxes, statistics become nosier

V. Repeat with high-resolution nested grid

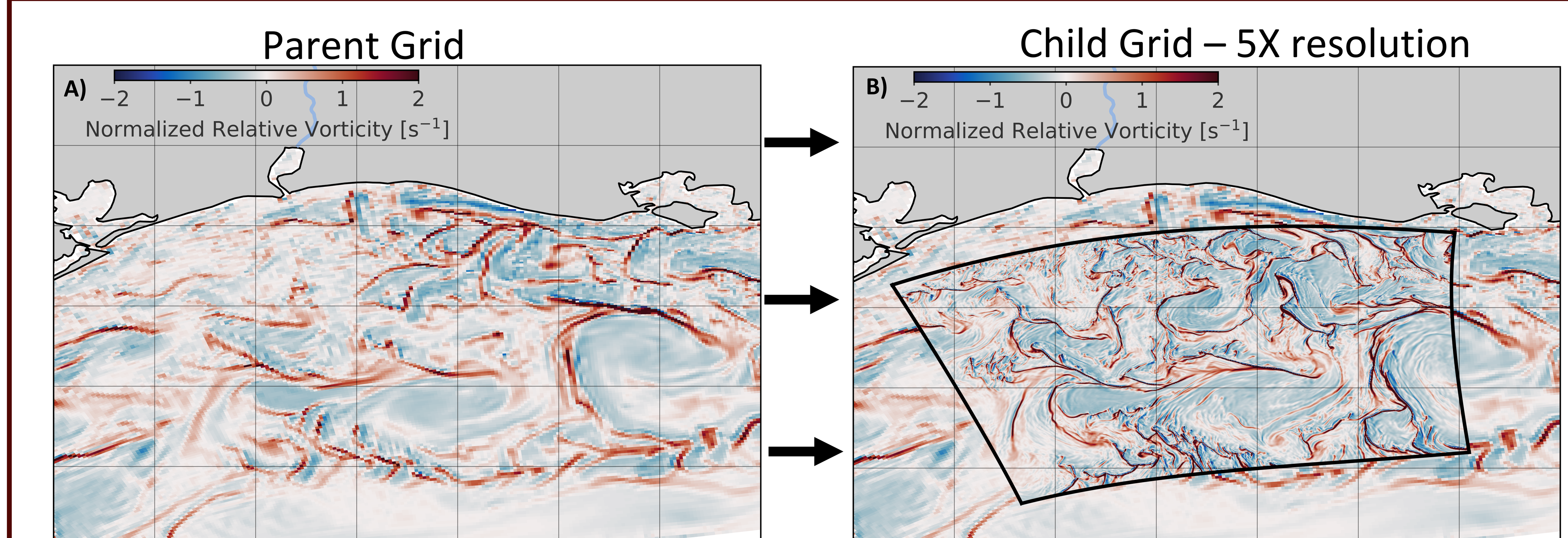


Figure 6: Snapshot of the parent TXLA model surface vorticity (A) and nested grid inside the black box (B) with a horizontal resolution of $O(100\text{ m})$

- Child grid has horizontal resolution $O(100\text{ m})$, output available for June 2010
- Repeat same analysis specified in boxes III and IV – but with nested grid
- **Hypothesis:** Terms in s' budget & total mixing approach increase in magnitude, but are qualitatively similar

VI. Conclusions

- Submesoscales modulate surface ocean biogeochemistry and energetics; current research focuses on *local* mixing processes, not *net* processes
- Compute salinity variance dissipation and budget for different sized control volumes over the TXLA shelf to compare scales of motion
- I hypothesize that mixing and terms in the variance budget increase for smaller control volumes, but become more chaotic and nonlinear

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