Seasonal Salinification of the US Northeast Continental Shelf Driven by an Imbalance Between Cross-Shelf Fluxes and Vertical Mixing

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A) The US Northeast Continental Shelf hosts …

- … a **bottom-trapped freshwater plume** [1], carrying cold/fresh transformed Labrador Sea and Gulf of Maine Water toward Cape Hatteras.
- .. a **predominantly salinity-driven Shelfbreak Front**, separating fresh Coastal Water and salty Subtropical Water of Gulf Stream origin [2].
- … the so-called **Cold Pool**, a body of **winter-cooled Shelf Water** that **preserves winter conditions** during the stratified summer [3].
- … a **rich ecosystem** of high **economic value** to the region, which relies on the cold pool for recruitment and settlement [4].

Here, we use salinity **as a tracer** to investigate the **seasonal cycle** of observed **cold pool erosion [5], using a budget approach** described in section B).

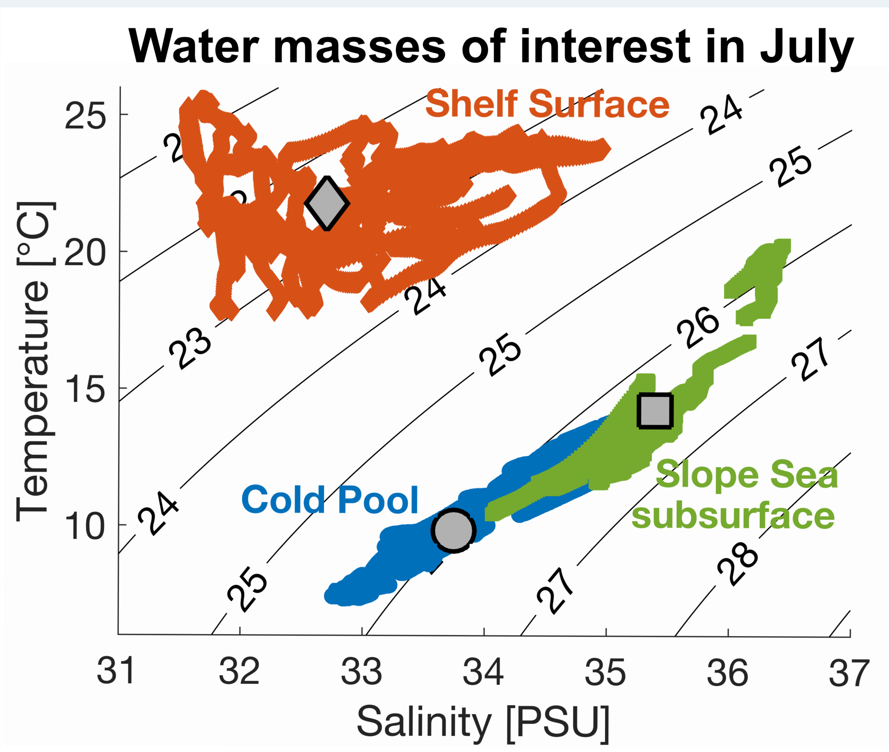

Fig. 1: Water mass characteristics of the US Northeast cold pool and its surrounding water during July. Data originates from the OOI Coastal Pioneer Mooring of corresponding color (Fig. 2). Subsurface data has been collected around 67 m depth. Contours are lines of equal potential density (p=0) - 1000 kg/m³.

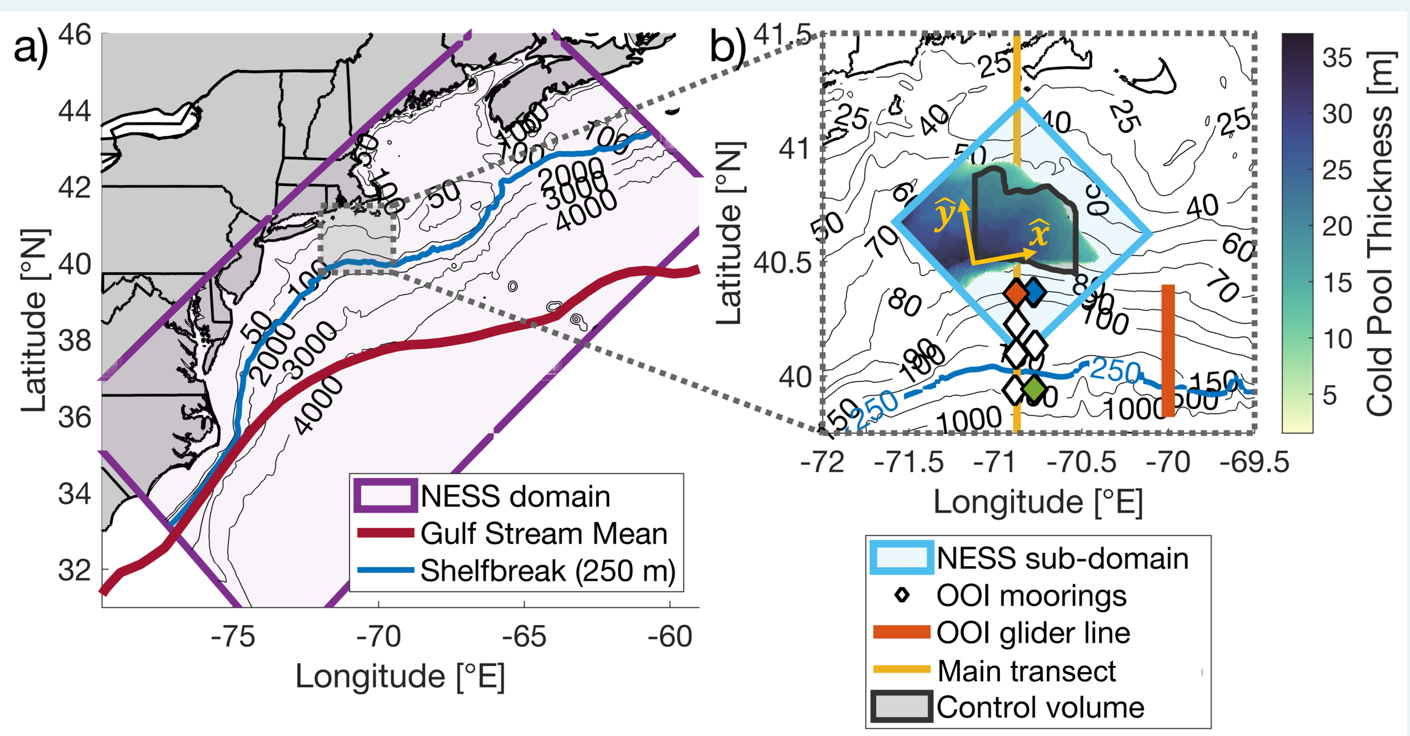

Fig. 2: Map of the US Northeast shelf and Slope Sea (a) with a focus on the region of interest south of New England (b). The OOI Coastal Pioneer Array Assets [6] provide observations, complemented by output from the high-resolution realistic regional NorthEast Shelf and Slope (NESS) model output [5].

Observation: The US Northeast shelf subsurface "*Cold Pool*" gets saltier (and warmer) each year during the stratified summer:

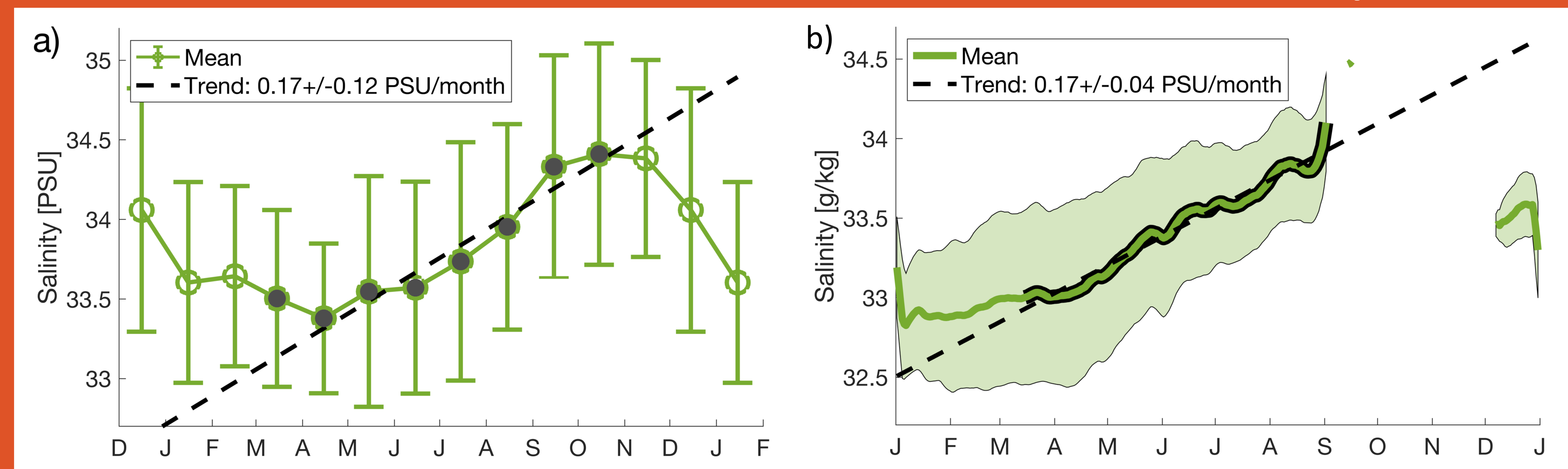

Fig. 3: Seasonal cycle of salinity and interannual variability ($\pm1\sigma$). a) OOI Coastal Pioneer Inshore Mooring data at 67 m depth (2015-2022). b) Conditions within a canonically defined Cold Pool (all <10°C waters) along 70.875°W in NESS model output (2010-2017). The linear trend is based on the grey-highlighted data.

Question: What causes this cold pool erosion?

Answer: An imbalance between i) steady eddy-advection fluxes and diminished vertical mixing under ii) seasonal stratification:

i) Eddy-advection vs. Vertical mixing

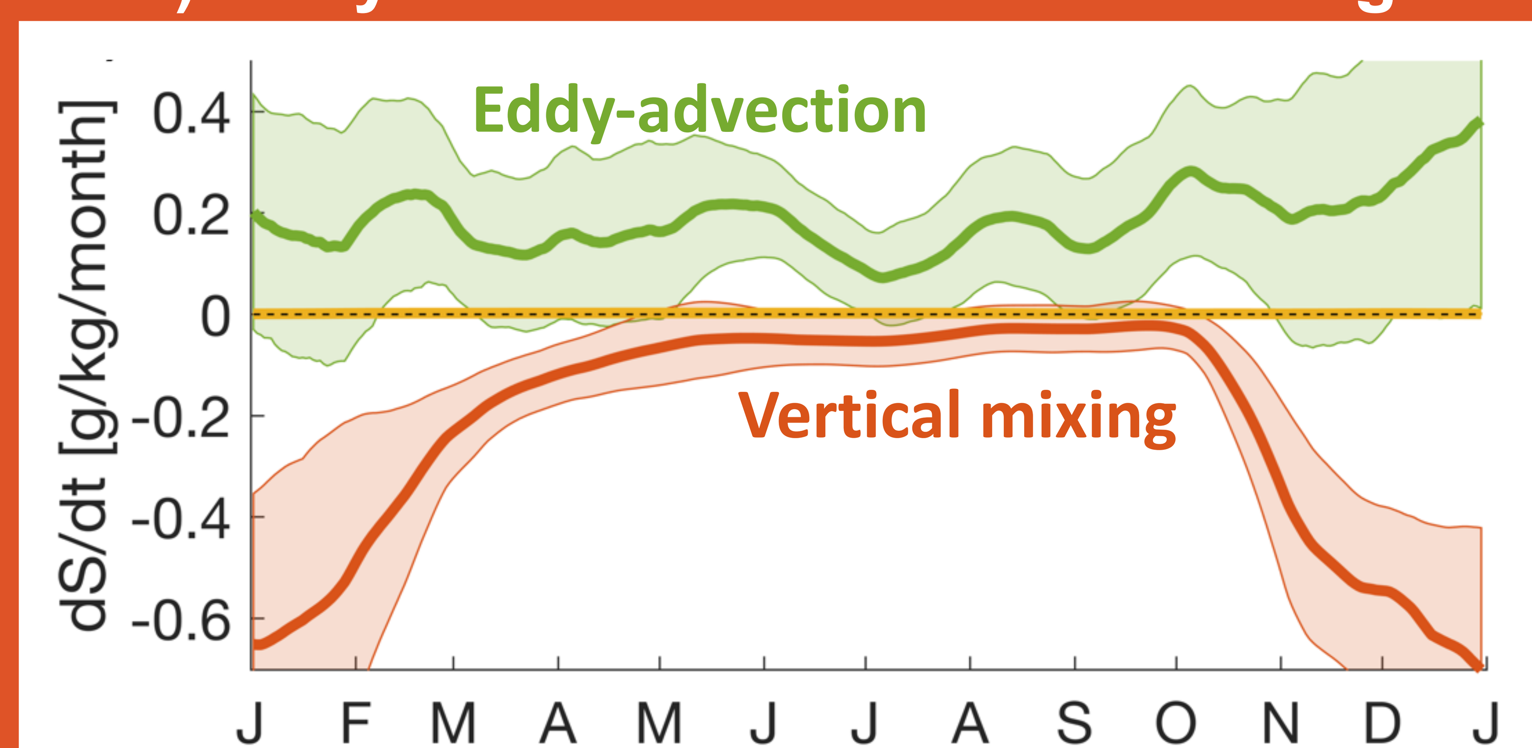

Fig. 4: Eddy-advection and diffusion flux contributions to the cold pool salinity budget, using NESS output [5]. Budget terms are described in section B) and averaged across a cold pool control volume (Fig. 2b). The $\pm1\sigma$ envelope depicts interannual variability (2010-2017).

ii) Seasonal Stratification

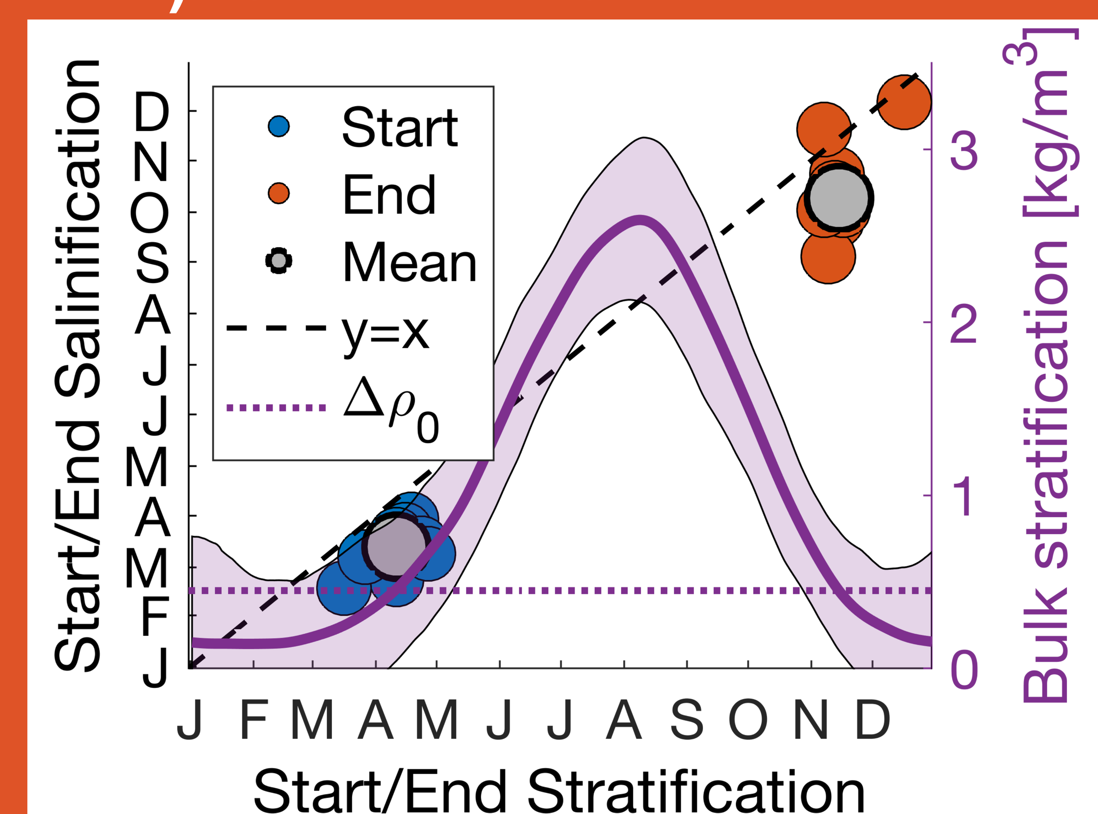

Fig. 5: Comparing the start/end of the salinification signal with the start/end of seasonal bulk stratification ($\Delta\rho \gtrless \Delta\rho_0 = 0.45$ kg/m³) on the continental shelf.

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Abstract

B) Approach to identify the cause behind the seasonal cold pool erosion signal:

A cold pool salinity budget, separating mean flow advection and grid-resolved eddy advection fluxes (with an eddy-mean scale separation of 30 days):

$$\int_V \underbrace{\frac{\partial S}{\partial t}}_{\text{Rate}} \mathrm{d}V = \int_V \overbrace{-\bar{u}\cdot\frac{\partial \bar{S}}{\partial x} - \bar{v}\cdot\frac{\partial \bar{S}}{\partial y}}^{\text{along-shelf }(x)/\text{cross-shelf }(y)\text{ Mean-flux}} \underbrace{-\left(\nabla_h \cdot \langle \mathbf{u}_h' S' \rangle + w\cdot\frac{\partial S}{\partial z}\right)}_{\text{Eddy-advection flux}} + \overbrace{\kappa_h \nabla_h^2 S}^{\text{horz. diffusion}} + \underbrace{\kappa_v \frac{\partial^2 S}{\partial z^2}}_{\text{vert. diffusion}} \mathrm{d}V$$

- Cross-shelfbreak advection (eddy and mean) contribute salt.
- Vertical diffusion/mixing contributes the seasonal cycle.
- Along-shelf advection contributes little.

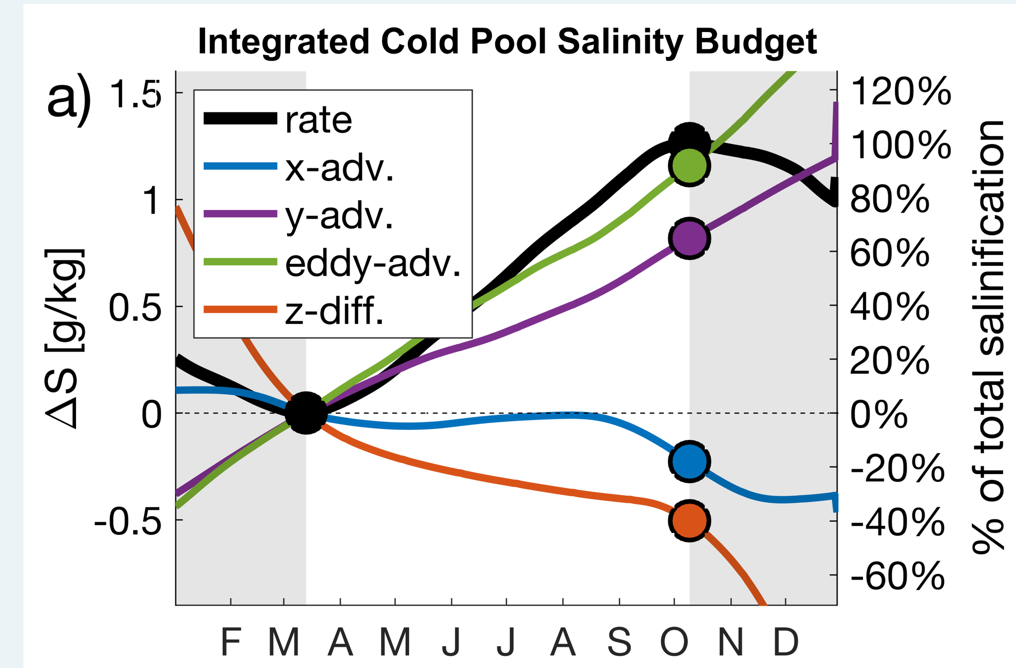

Fig. 6: Cumulative Cold pool salinity budget, using output from the realistic high-resolution NorthEast Shelf and Slope (NESS) model [5], averaged across a cold pool control volume on the continental shelf south of New England (see Fig. 2b). Individual terms are described in section B). The budget is a multi-year seasonal average (2010-2017).

C) Ruling out other causes: Could the observed salinification just originate from movements of the US Northeast shelfbreak front?

No! The seasonal cycles of salinity (a) and the location of the max. cross-frontal buoyancy gradient (b) do not align:

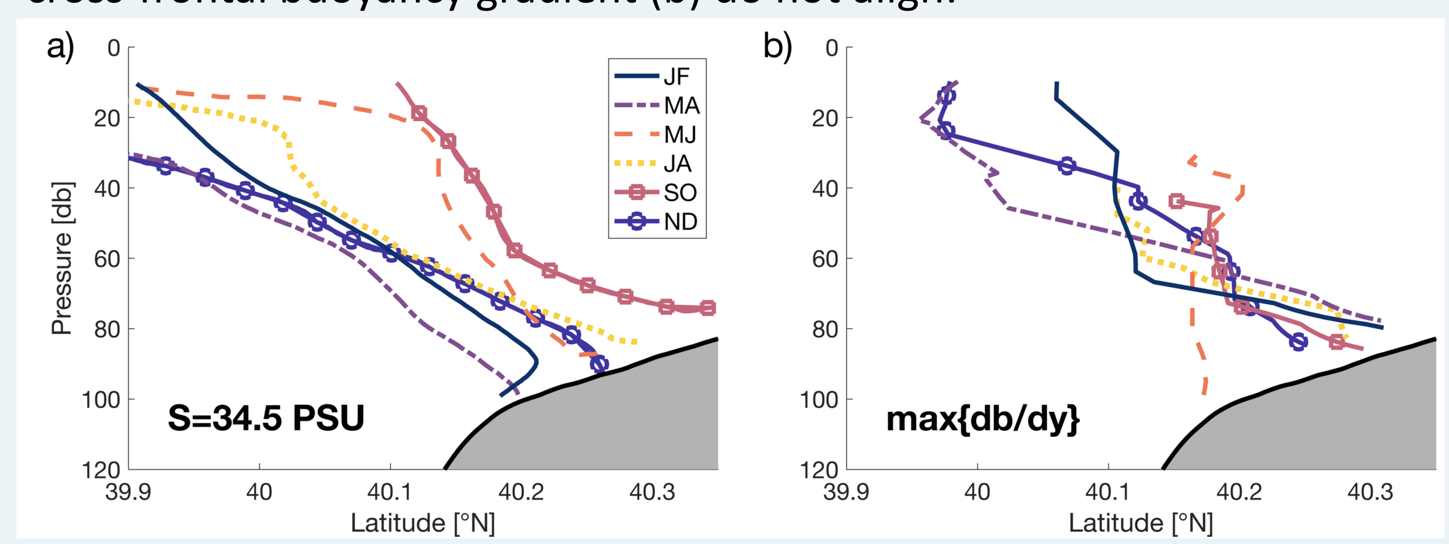

Fig. 7: Location of the US Northeast shelfbreak front south of New England based on bimonthly-averaged multi-year OOI glider data (2014-2022). a) 34.5 PSU isohaline as a frontal proxy. b) Maximum cross-shelfbreak buoyancy gradient below the seasonal pycnocline.

References

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[6] OOI Coastal Pioneer Array: ooinet.oceanobservatories.org

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