Salinity field structure and freshwater pathways over the Gulf of Alaska

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Northern Gulf of Alaska (NGA)

- The NGA is a productive ecosystem that sustains commercial, recreational, and subsistence fish harvests important for the socioeconomic well-being of coastal Alaskan communities.
- The NGA is surrounded by steep glaciated terrain that outputs large quantities of freshwater.
- Salinity (primarily) structures the NGA water column density.
- Density mediates nutrient fluxes into the euphotic zone.

Objective: In this study, we examine the NGA hydrographic structure with particular focus on spatial and temporal variability based on spring, summer, and fall shipboard surveys. The in-situ data depict seasonally varying pan-NGA salinity distributions and pathways, allowing us to examine factors that control the fate of riverine freshwater entering the marine environment, its spatial and temporal structure, and its eventual influence on biological productivity.

Datasets

- Conductivity-temperature-depth (CTD) profiles repeated every spring, summer and fall (Figure 1)
- *In situ* towed-undulating CTD (Acrobat) and bio-optics measurement package capturing high-resolution data over the upper 50 meters of the water column (Figure 2) during July 2019 and 2020
- Hourly-binned satellite-tracked drifters (July 2019)
- Satellite true color imagery (2002-2021) from Moderate Resolution Imaging Spectroradiometer (MODIS)

Figure 1: Location & names of sampling stations, the cruise track for the July 2020 Acrobat tow, the July 2019 drifter deployment locations, and ERA-5 wind reanalysis bounding box.
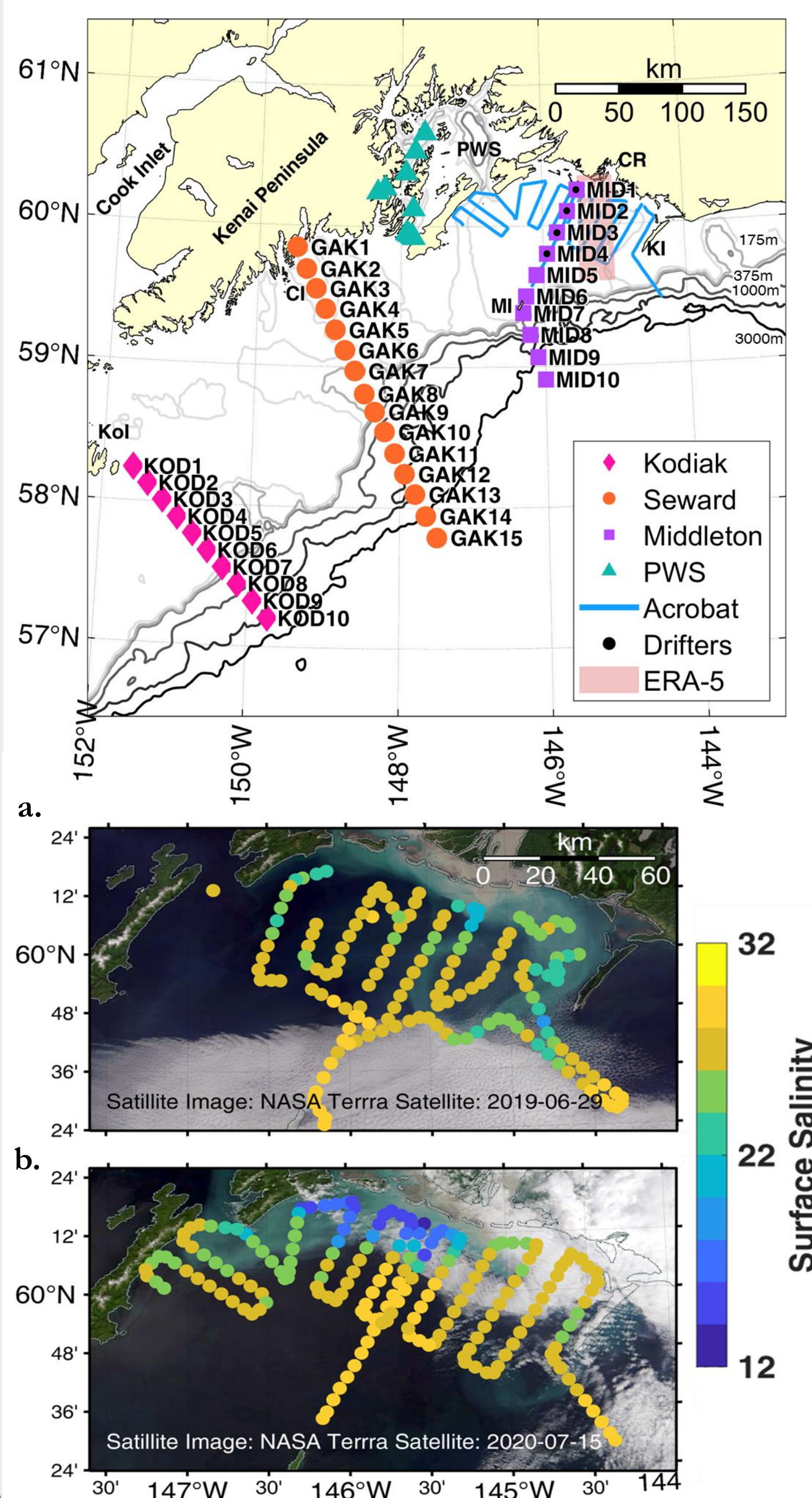
Figure 2: In situ surface salinity overlaying near simultaneous satellite imagery for 4-8 July 2019 (a) and 11-14 July 2020 (b) cruises.
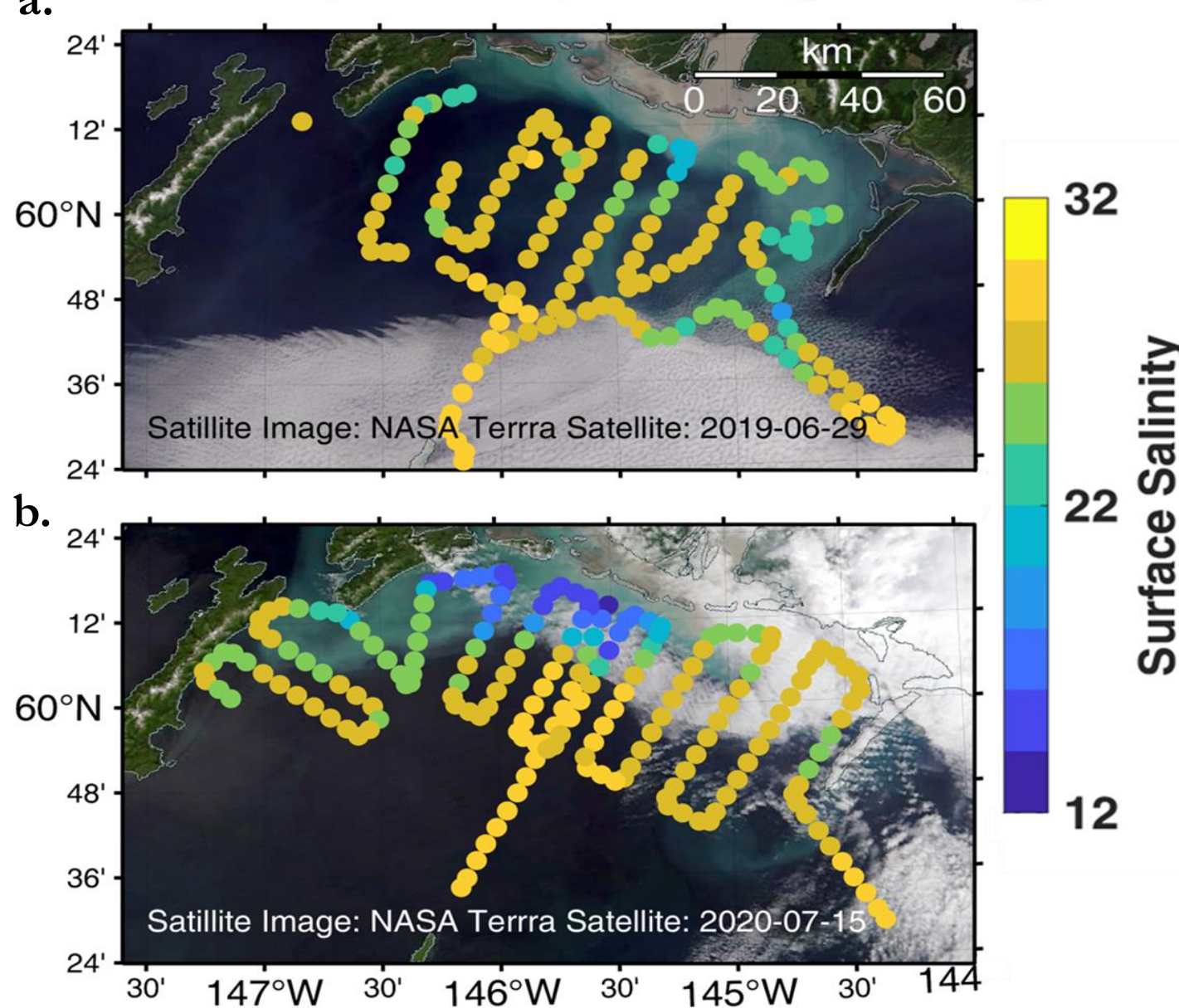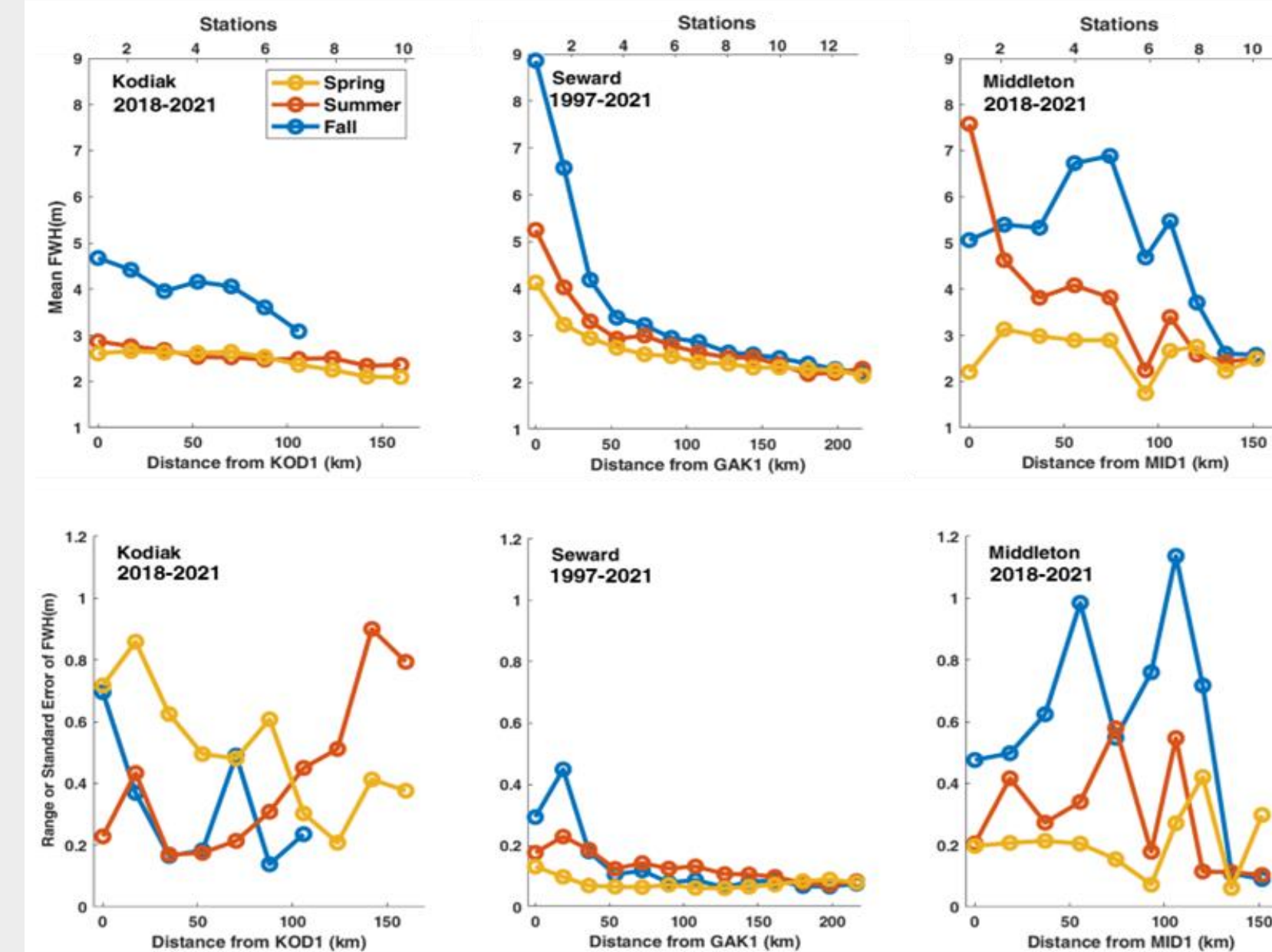
## Re-assessing freshwater distributions and pathways

- Freshwater Height (FWH) denotes the distribution of upper water column (0-50 m) fresh water relative to reference salinity 33.8 (Figure 3).

- **Eq. 1** $\quad \text{FWH} = \frac{S_r * \rho_r * d}{S_s * \rho_s} - d$

- Long term records on the Seward Line help distinguish recurring freshwater pathways (Figure 4).
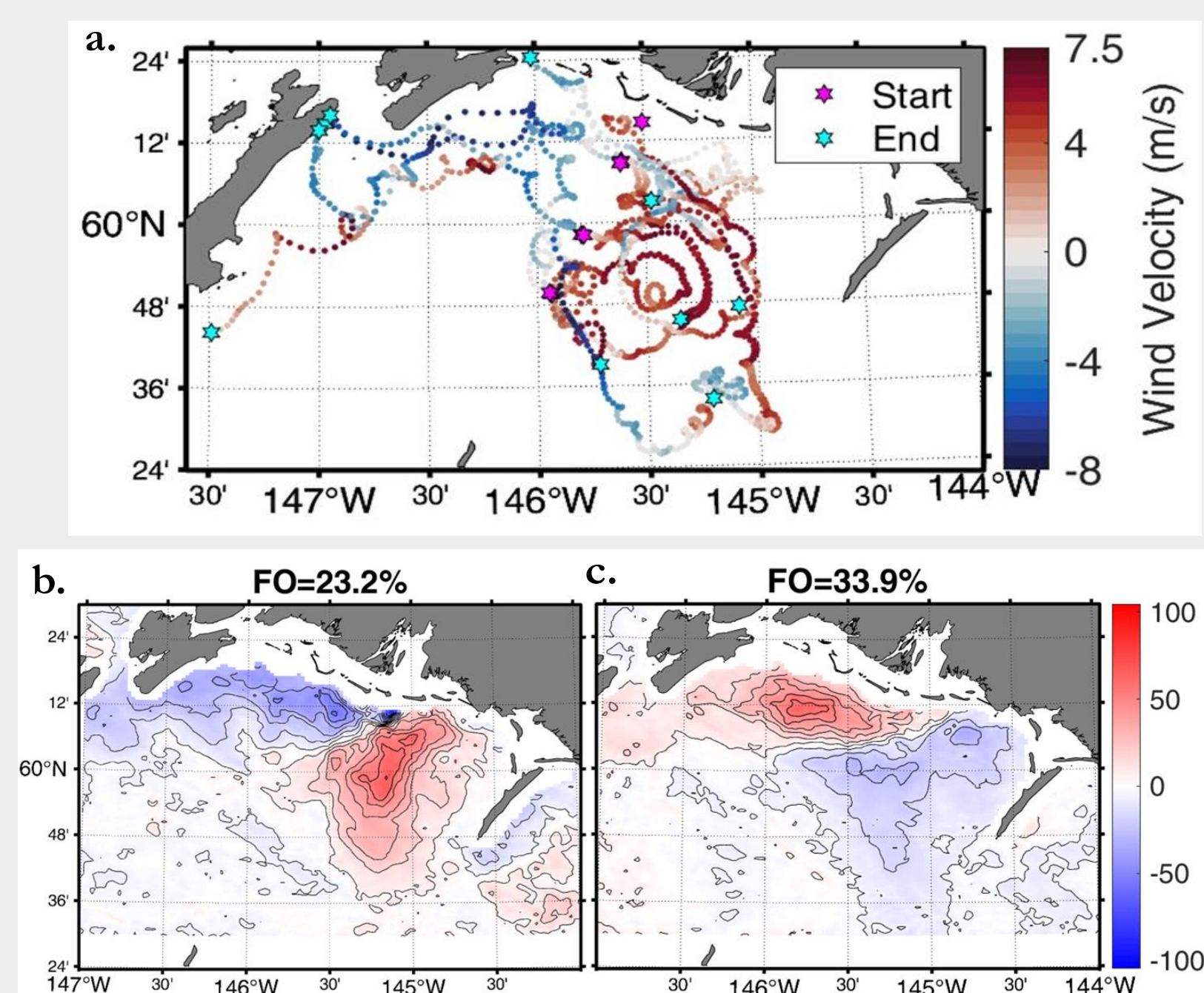

Figure 3. Top row: Seasonal mean FWH for Middleton, Seward and Kodiak stations. Bottom row: Standard error for Middleton and Seward lines and range of observations for the Kodiak Line.
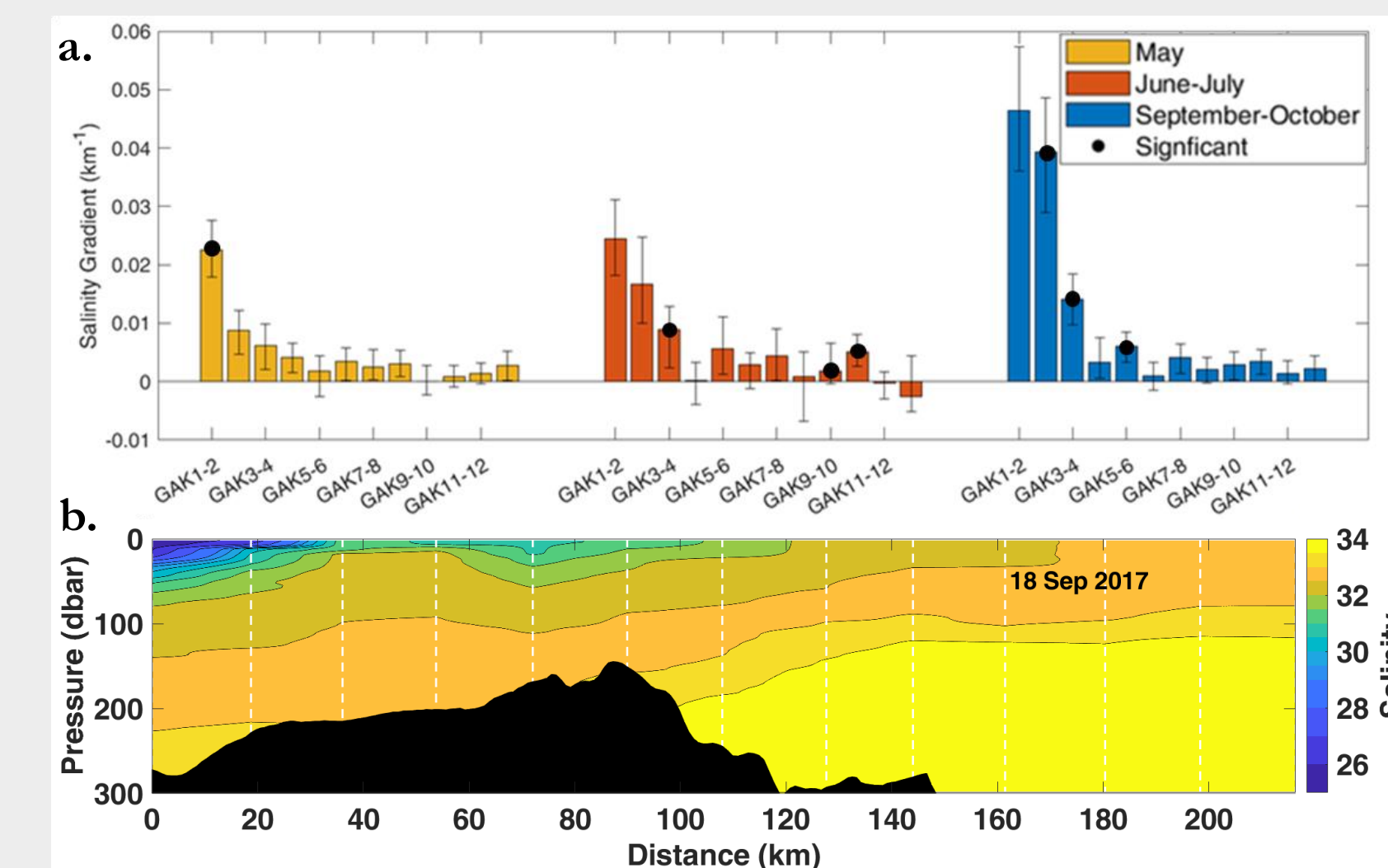
Figure 4. (a) Mean cross-shelf salinity gradients along the Seward Line (1997-2021), averaged from 0-100 m. (b) Hydrographic transect of salinity along the Seward Line showing a FW plume over the mid-shelf moraine.
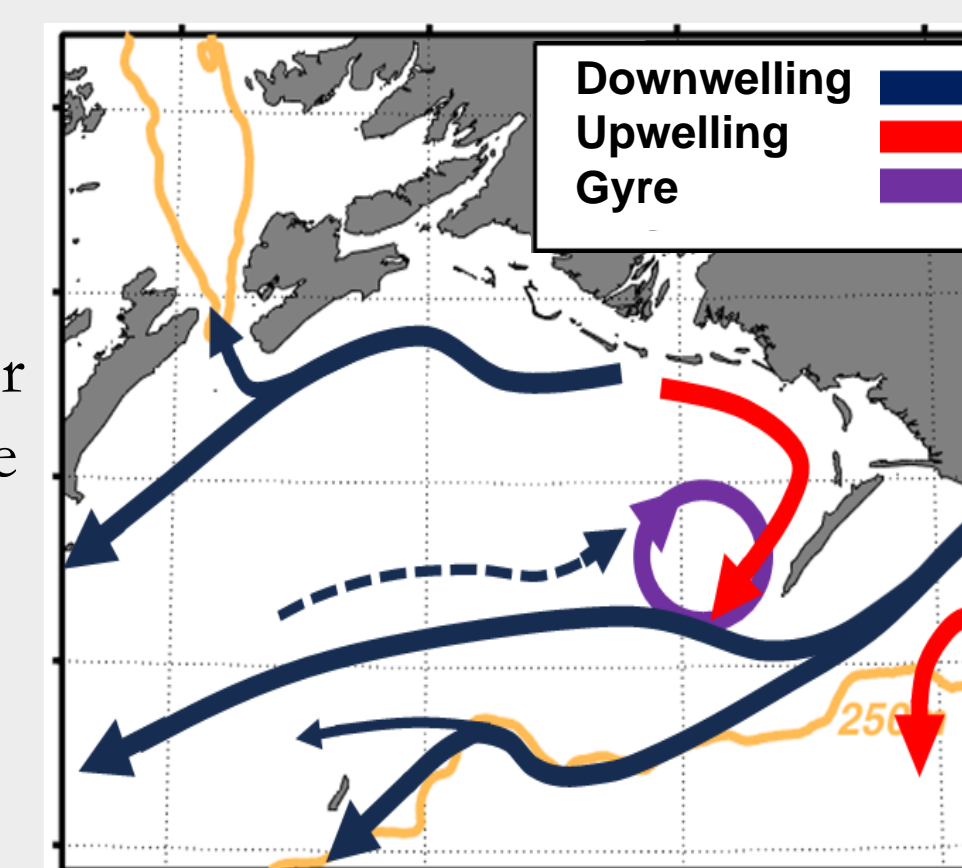
Fate of the Copper River Plume

- Surface waters in the Copper River region responded to upwelling-favorable winds and reached the shelf break while entrained by the Kayak gyre. Downwelling-favorable winds constrained the drifters to the coast in 1-4 days. (Figure 5a).

- Self Organized Mapping (SOM) was used to produce patterns of satellite image plume distributions (Figure 5b,c).

Figure 5. (a) Surface drifter tracks, colored by the alongshore wind velocity. (b,c) Anomaly maps resolved by the SOM analysis and generated by subtracting a mean image collection from each of four resolved SOM patterns (two not shown). FO denotes the proportion of images ascribed to a particular pattern.

Figure 6. Potential current patterns in the Copper River region with mean currents under downwelling-favorable wind velocities (dark blue) including a weak counter current (dashed); and mean currents under upwelling-favorable wind velocities (red) that more often occur in summer. The gyre west of Kayak Island (purple) is observed under both wind conditions.


Conclusions

- Seasonal discharge from the Copper River plume and the diversion of low salinity ACC water by Kayak Island contribute to the structure of FWH along the Middleton Line and along the shelf break.
- In addition to the ACC, freshwater pathways likely exist over the mid-shelf (GAK5) and the shelf break (GAK9/GAK10).
- The Copper River plume distribution over the shelf responds to upwelling and downwelling wind conditions.
- Upwelling-favorable winds help fuel new production and establish bulk characteristics of the plume by modifying macronutrient concentrations and physical properties.

Plume Response to Upwelling-Favorable Winds

- During the 2019 and 2020 process studies the Copper River plume responded to contrasting wind stress scenarios (Figure 7).

Figure 7. (a,b) Alongshore wind in June/July 2019 and 2020. (c,d) Towed-instrument salinity cross-sections along the Middleton Line, starting at MID1.
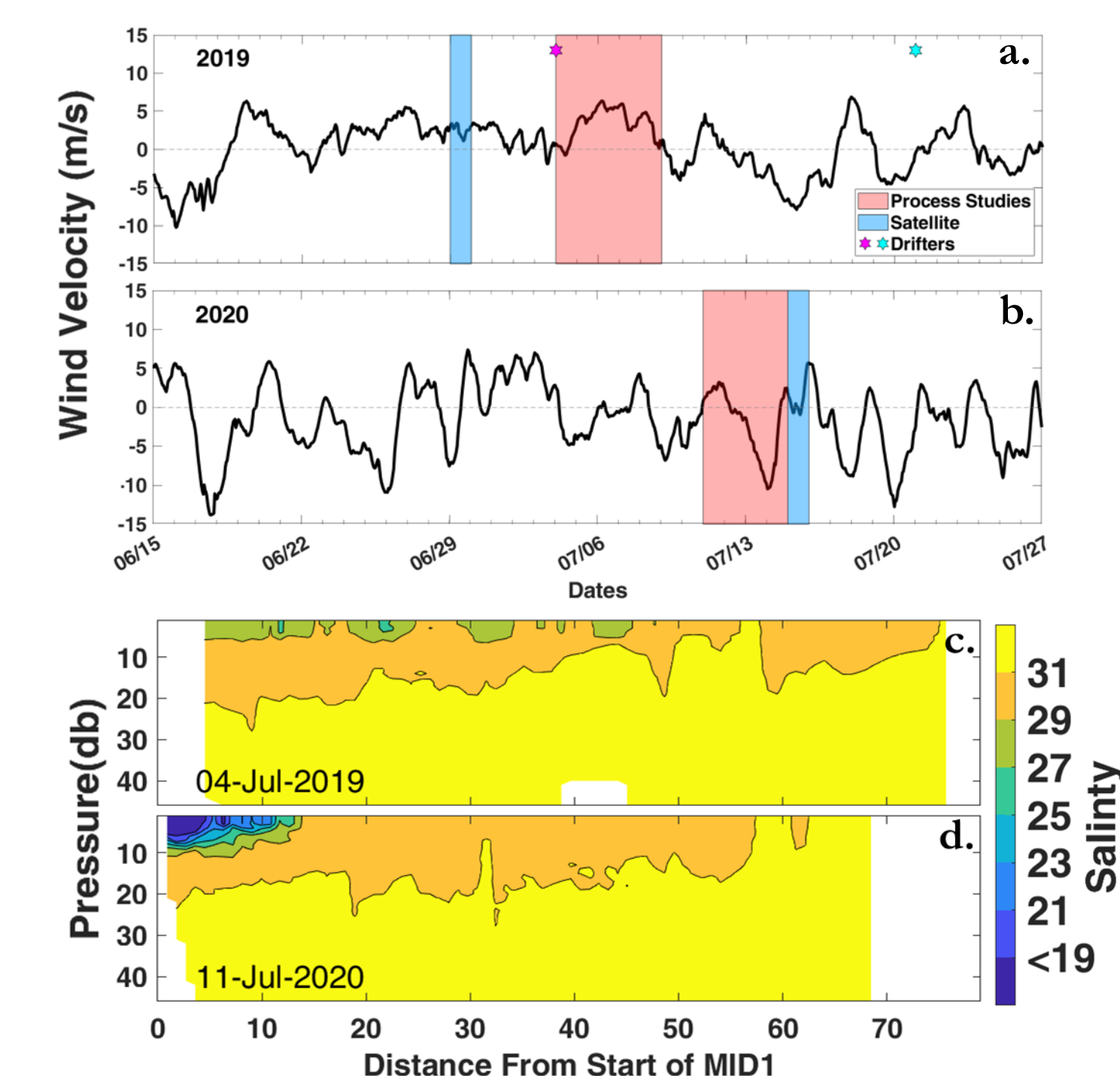
The upwelling-induced change in observed plume salinity and nutrient concentrations during July 2019 can be modeled using Lentz (2004). The rate at which the plume area increases (Eq. 2) is used to estimate plume entrainment. Theoretical predictions agree with observations for plume density anomalies (Figure 8). We extended the analysis with a simple mixing relationship (Eq. 3) to assess macronutrient changes and production in the plume. Relative to observations, predicted concentrations within the modified plume accounted for ~50% of the change in salinity and silicic acid and, using nitrate concentrations, at least 44% of chlorophyll-a levels. New production accounted for a range of $1/20^{th} - 1/3^{rd}$ of the estimated production in the plume.

Eq. 2 $\quad \frac{\partial A}{\partial t} \approx \frac{\tau_x}{2\rho_a f}\sqrt{Ri_c}$

Eq. 3 $\quad C_f = \frac{(C_p * A_p) + (C_a * A_e)}{A_p + A_e}$

Figure 8. (a) Plume response to winds stress. (b) Plume density anomaly ($\Delta\rho$) response to wind stress.
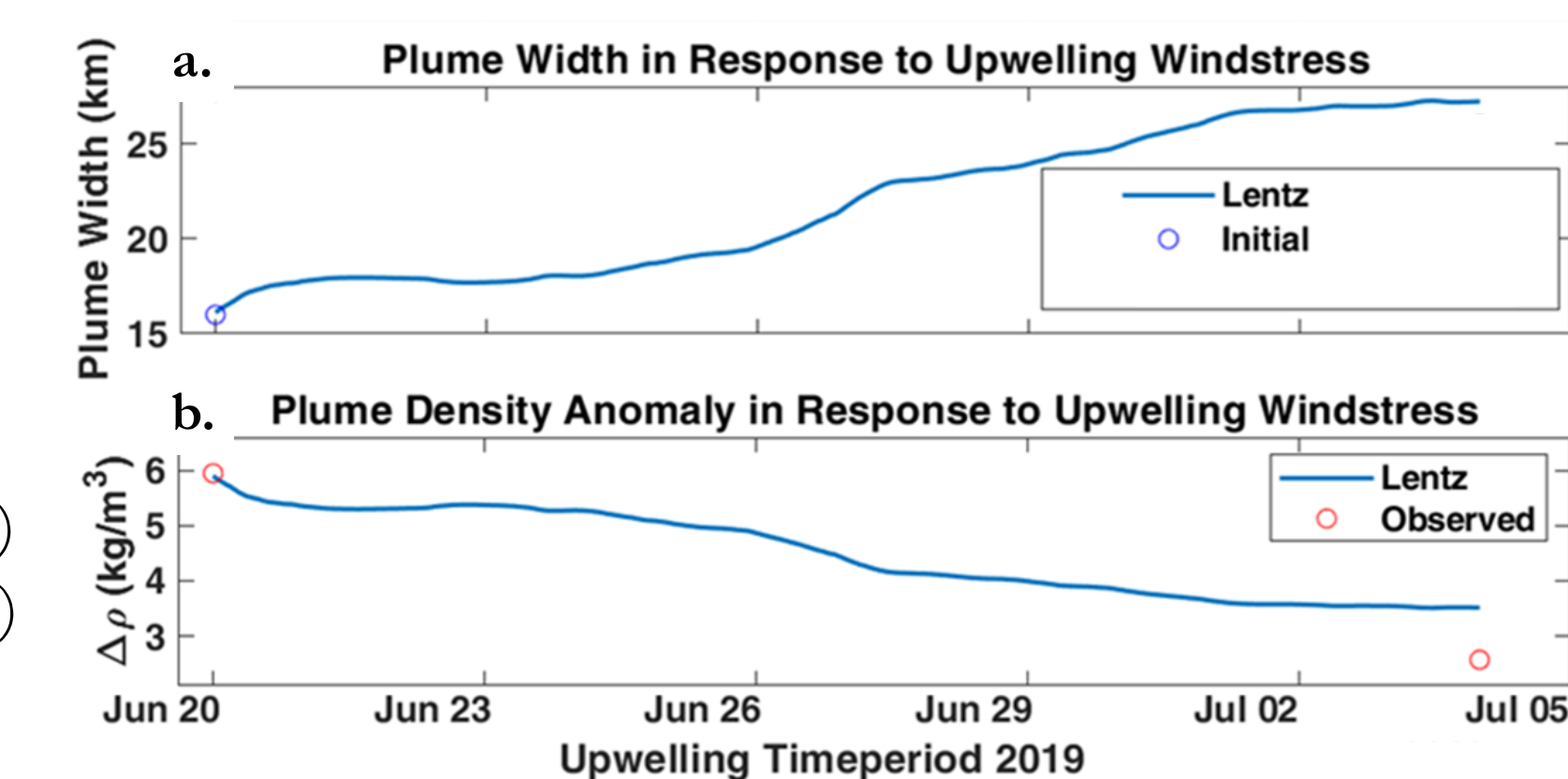
References:
1   Lentz, S. J. (2004). The response of buoyant coastal plumes to upwelling-favorable winds*. *Journal of Physical Oceanography*, 34(11), 2458–2469. https://doi.org/10.1175/JPO2647.1