Riverine Freshwater Effects on Fall Sea Ice Freeze-Up in the Beaufort Sea

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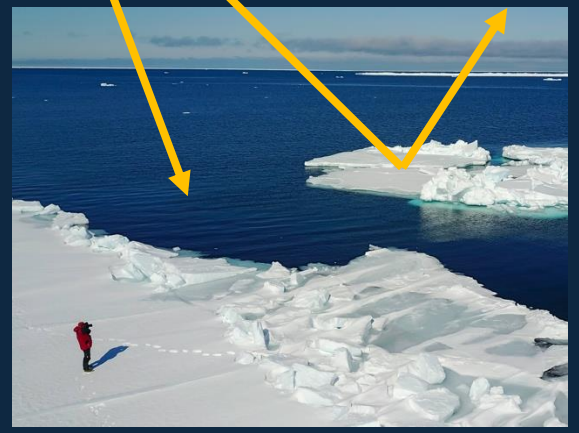
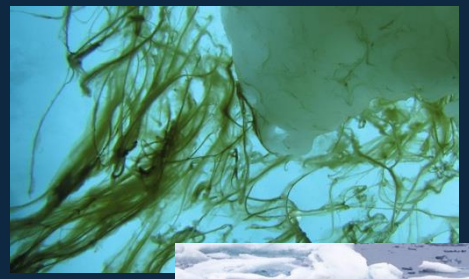
Jet Propulsion Laboratory
California Institute of Technology

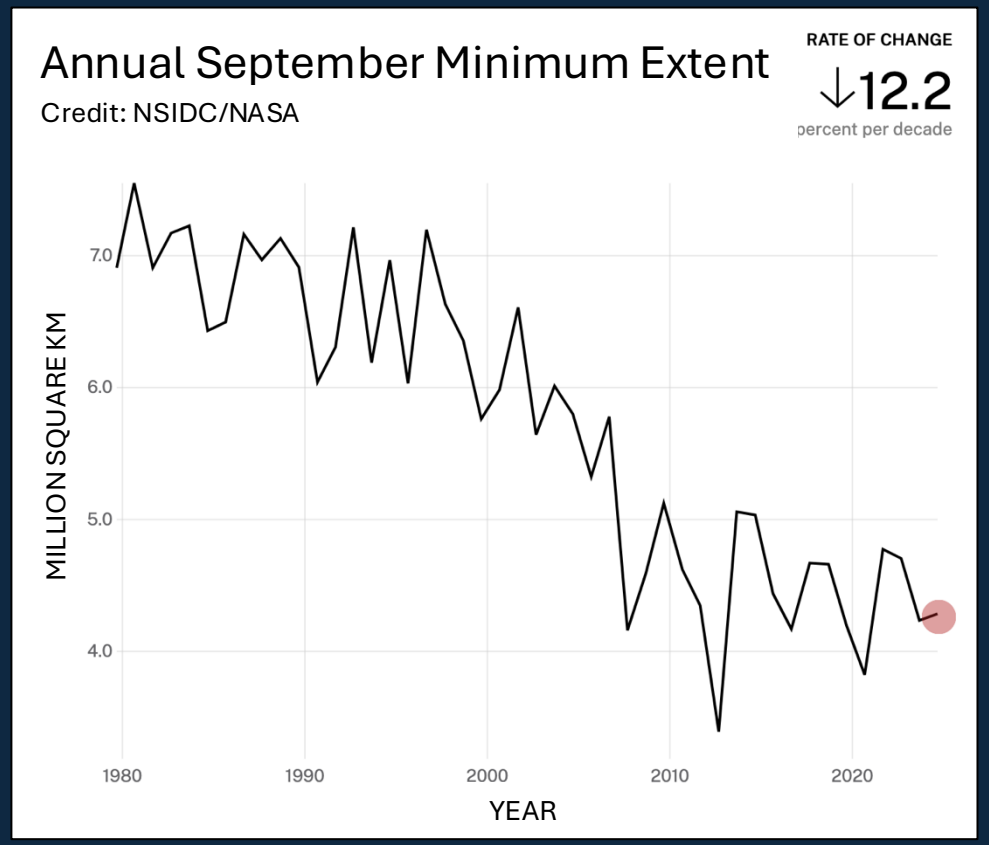
Why Sea Ice Matters: Climate, Ecosystems, People

Plays a critical role in Earth's climate system



Provides habitat for marine animals and algae



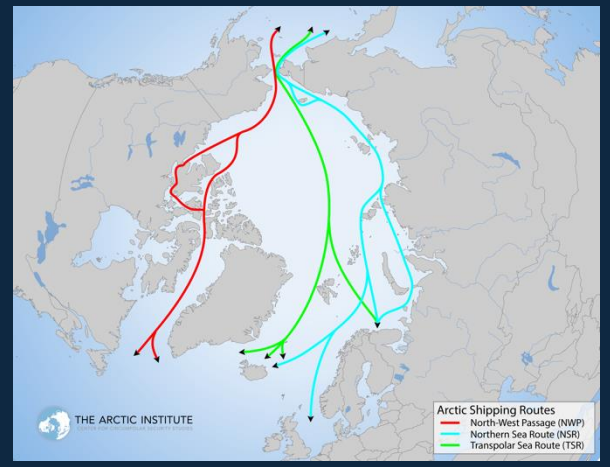


Sea ice predictions are challenging due to complex ice-ocean-atmosphere interactions

Sea surface salinity data remain underutilized for sea ice predictions

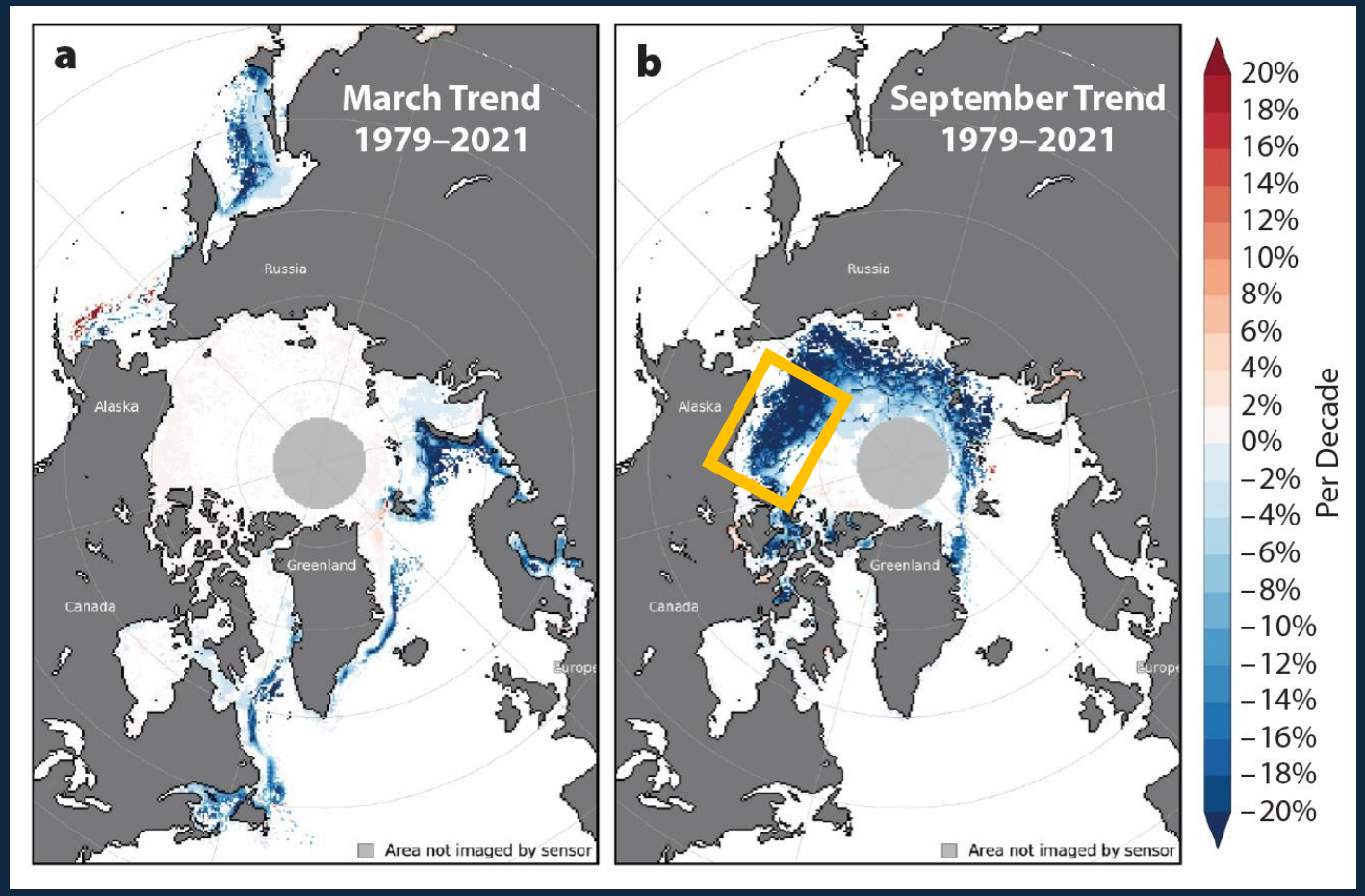
Important for coastal communities

Mapping and predictions are critical for Arctic marine navigation and defense



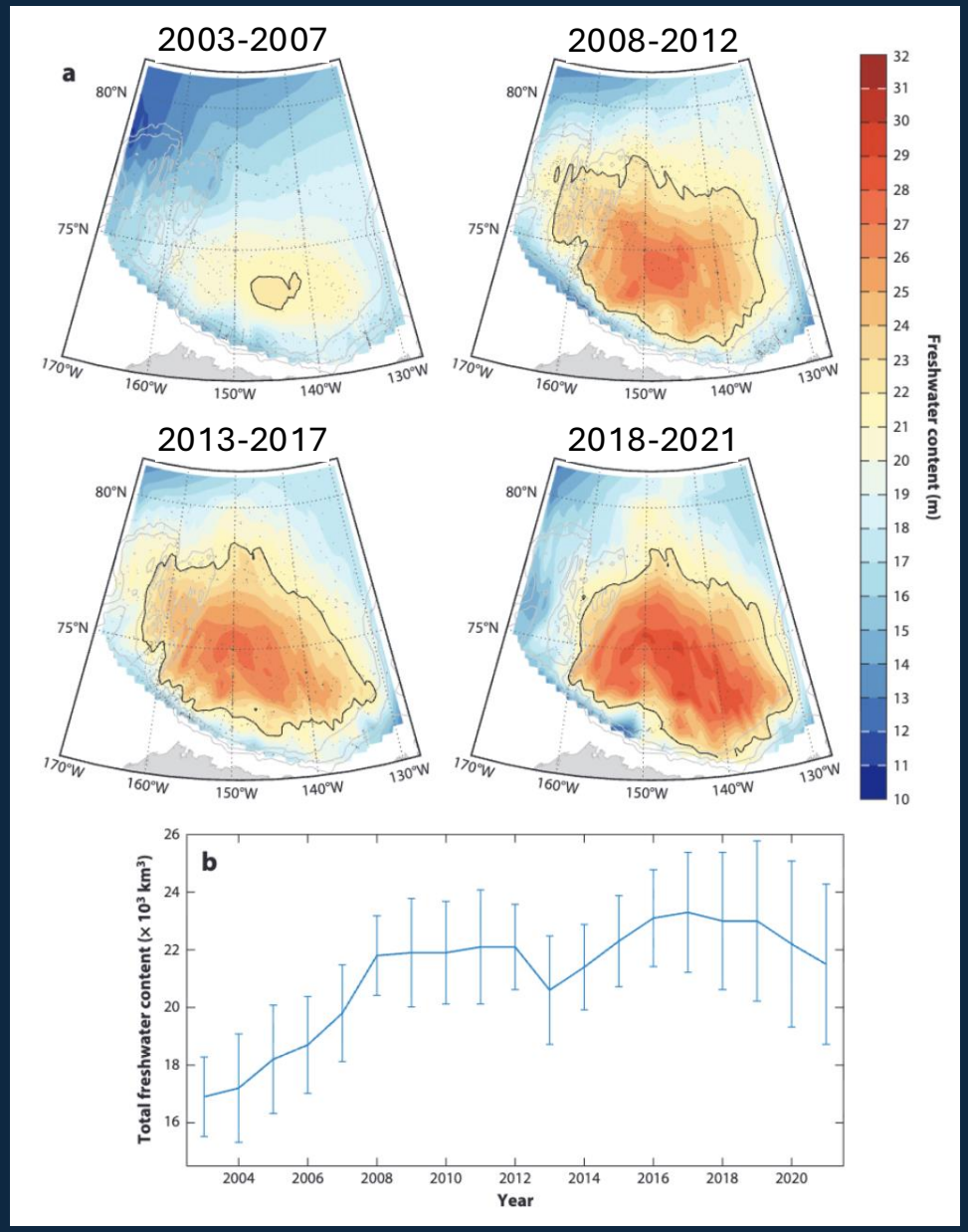
Why Study the Beaufort Sea?

Dominates trends in sea ice loss, freshwater accumulation, and sea level rise

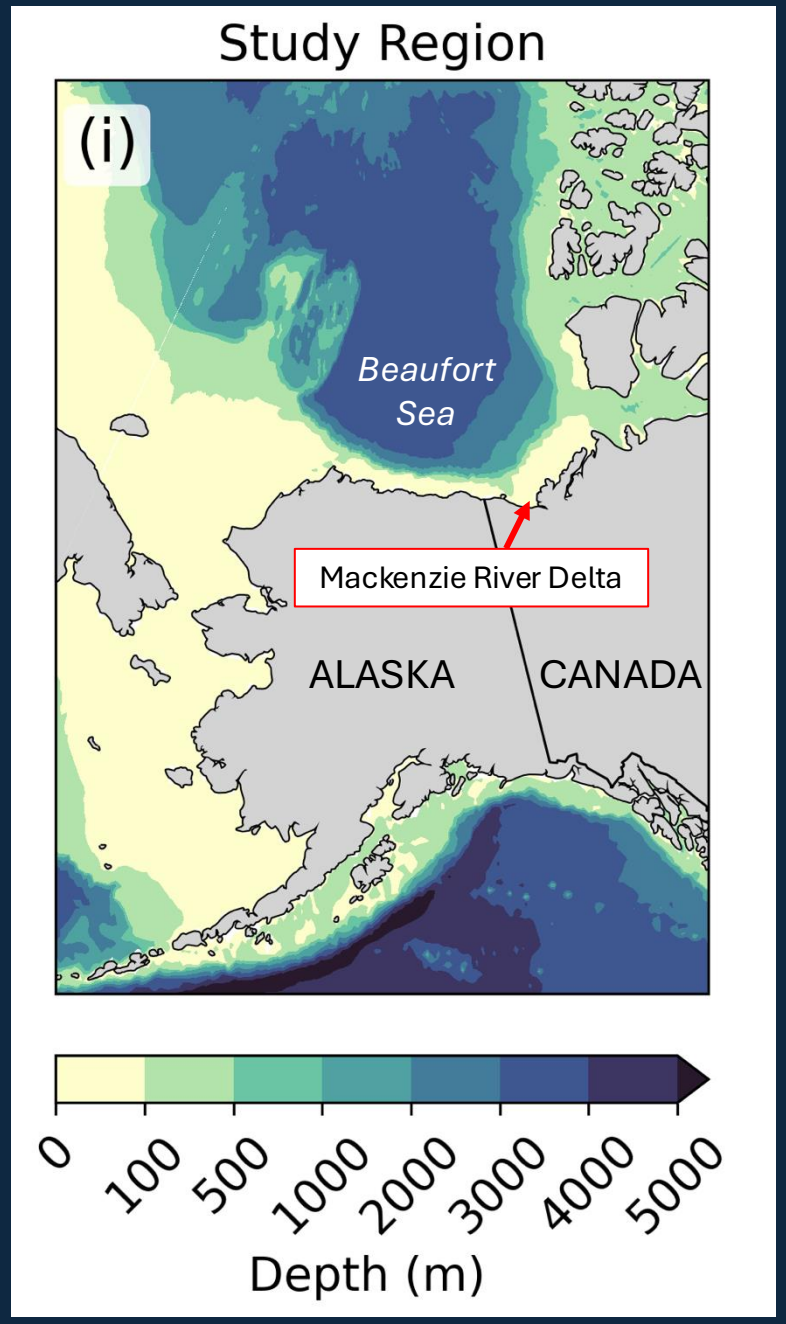


Meier and Stroeve (2022)

Increased Freshwater In The Beaufort Gyre

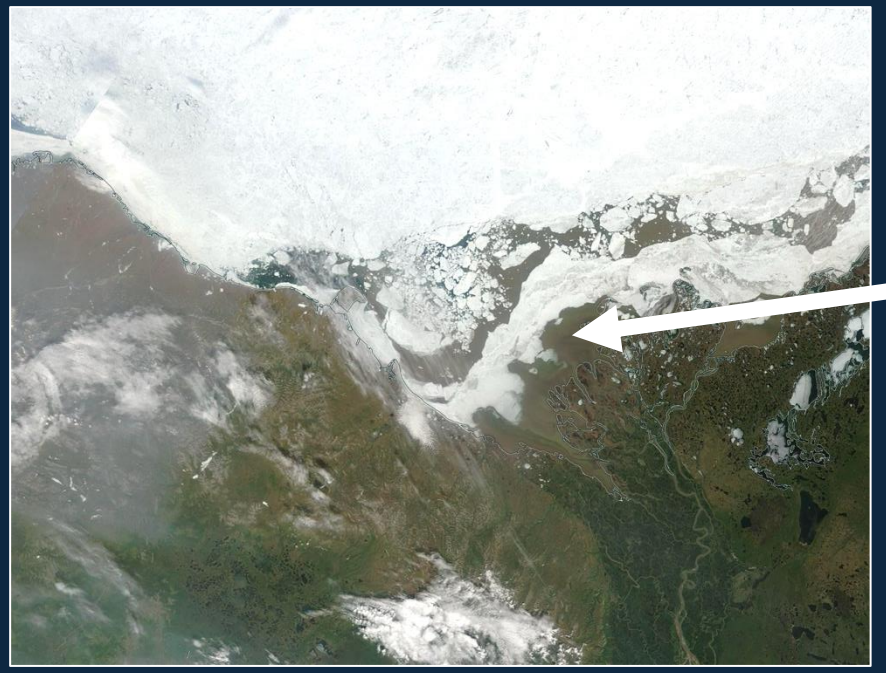


Timmermans and Toole (2023)



Mackenzie River discharge is one of the main contributors to freshening of the Beaufort Sea[1]

MODIS image of lower Mackenzie River delta
June 23, 2025



Discharges warm water in spring, initiating sea ice retreat[2,3]

How does Mackenzie River discharge influence fall sea ice formation?

[1] Proshutinsky et al., 2019; [2] Dean et al., 1994; [3] Nghiem et al., 2014

Objective

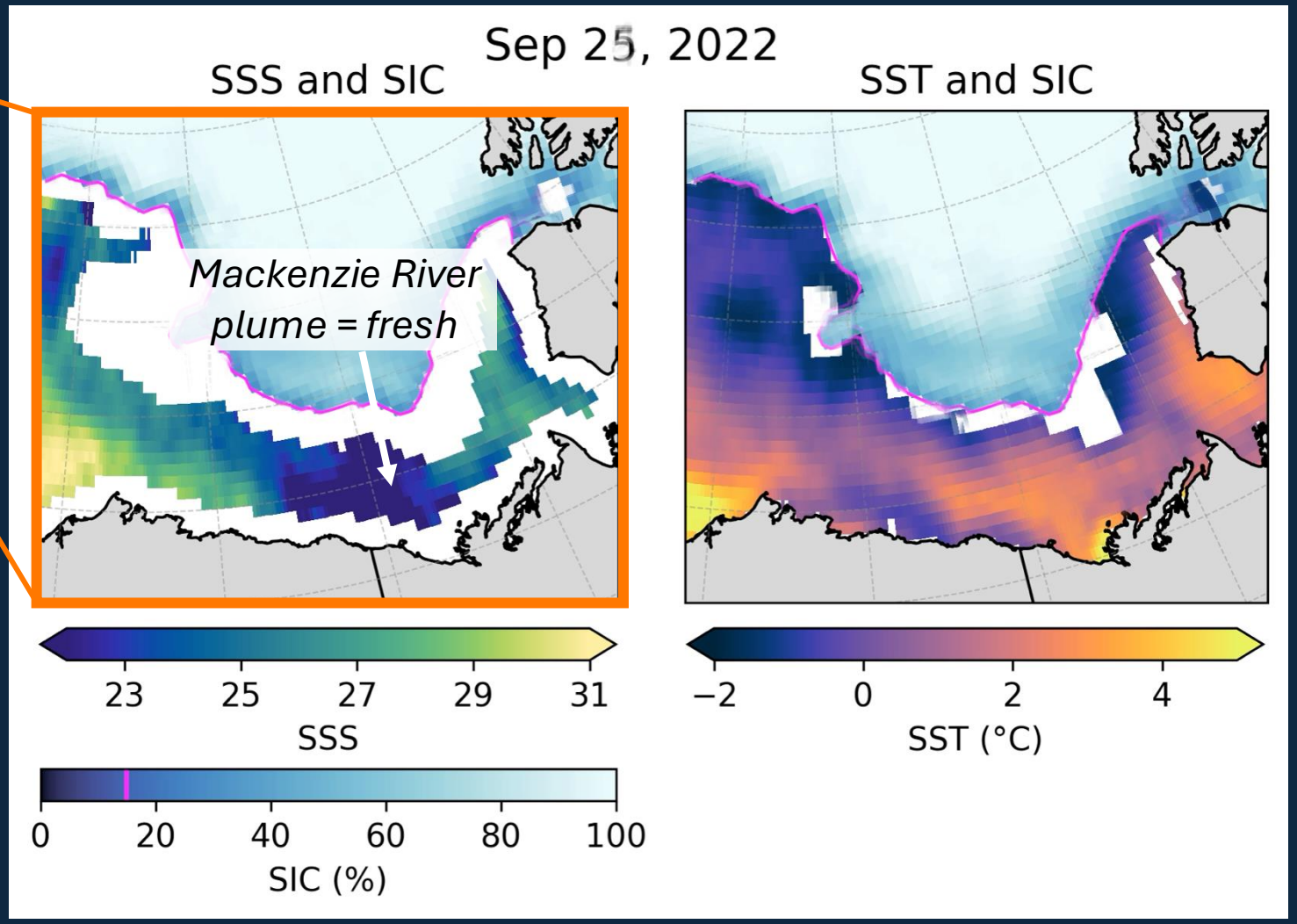
To examine how freshwater from the Mackenzie River influences the timing of fall sea ice onset in the Beaufort Sea

Hypothesis:
Fresh Surface Layers → Stronger Stratification → Less Upward Heat → Earlier Sea Ice Formation

Approach:

- Use **satellite observations** to characterize spatiotemporal variability in autumn sea ice formation in the Beaufort Sea
- Use **coupled ocean-sea ice model** to analyze 3D ocean structure within and outside the Mackenzie river plume

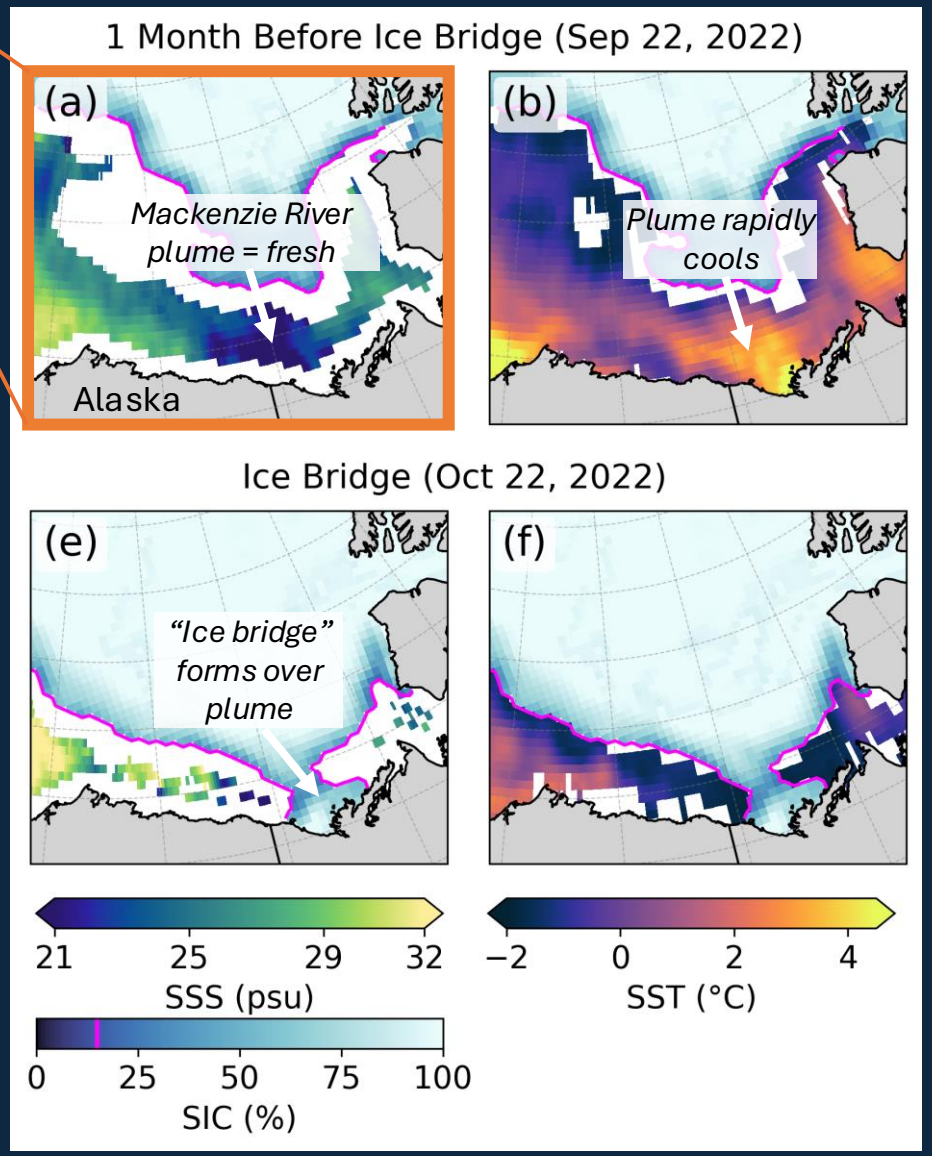
Investigating Sea Ice Advance Using Satellite Data



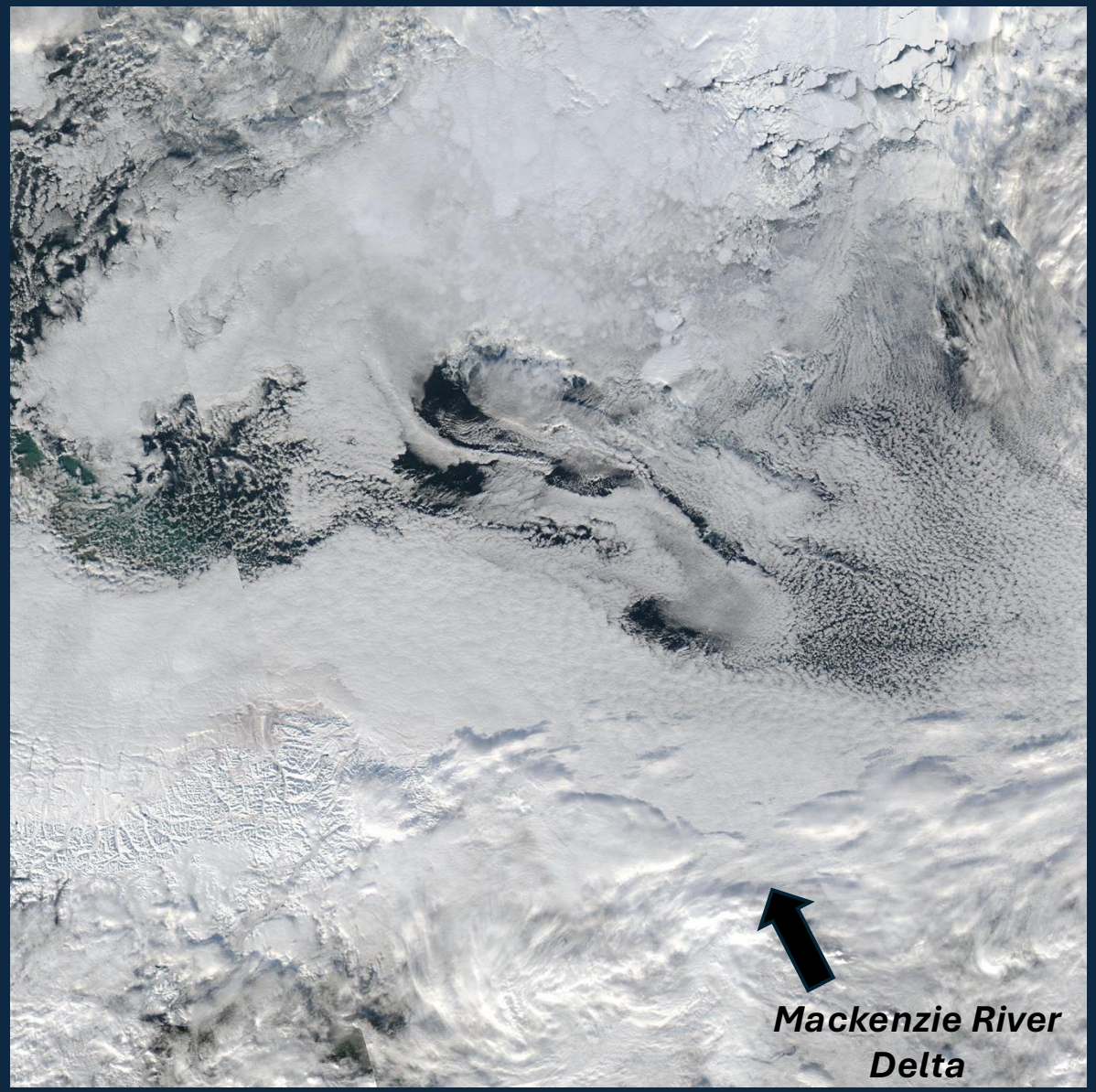
- Sea ice concentration (**SIC**): NOAA/NSDIC CDR
- Sea surface salinity (**SSS**): RSS SMAP V6
- Sea surface temperature (**SST**): OISST

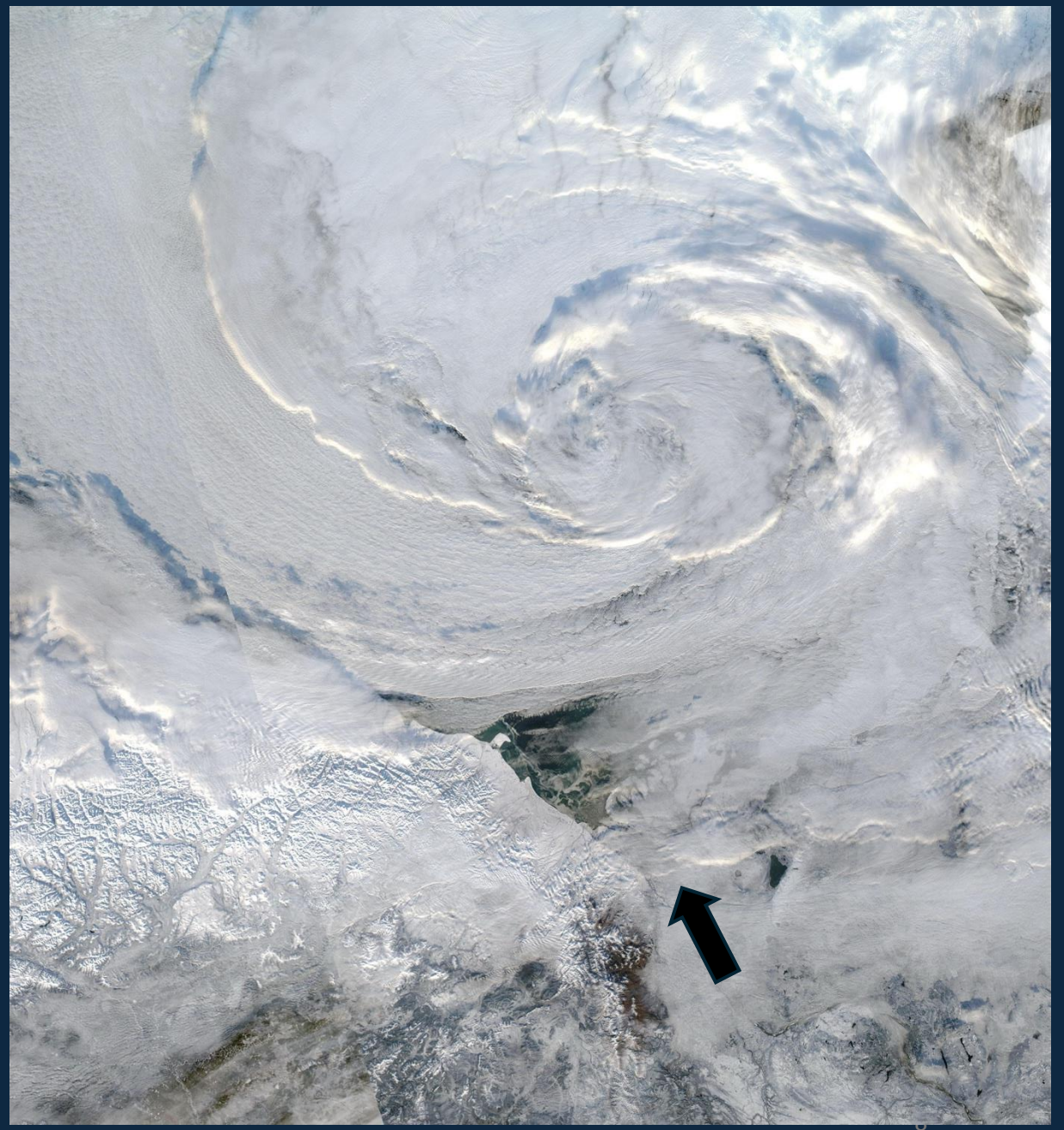
Investigating Sea Ice Advance Using Satellite Data

SSS and SIC SST and SIC

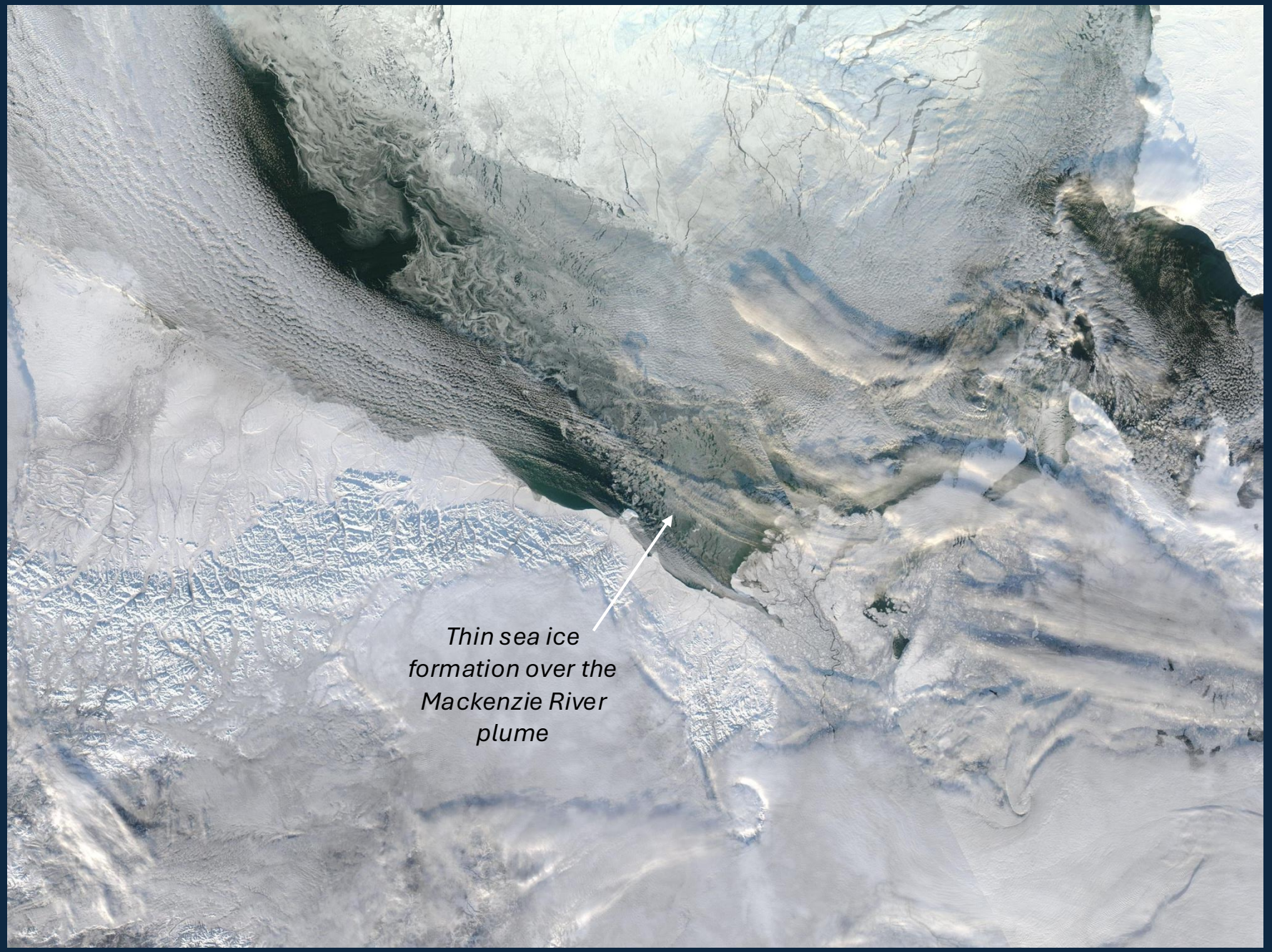


- ***Observed the formation of an "ice bridge" from coastline to offshore ice edge within the Mackenzie River plume***
- Mackenzie river plume generates low SSS and high SST anomalies throughout the summer
- Plume waters reach freezing point faster than adjacent waters and form ice earlier





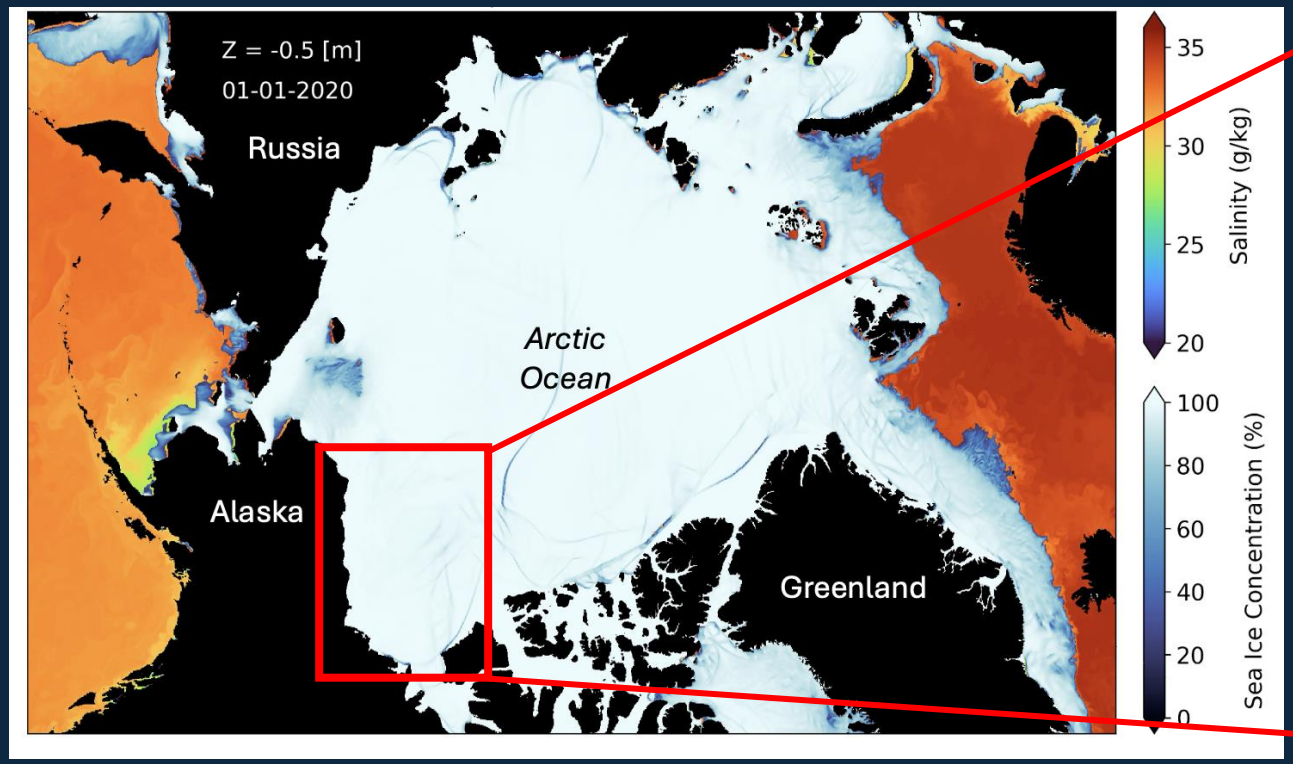
MODIS Aqua Images from Oct 2, 2022 (left) and Oct 18, 2022 (right)



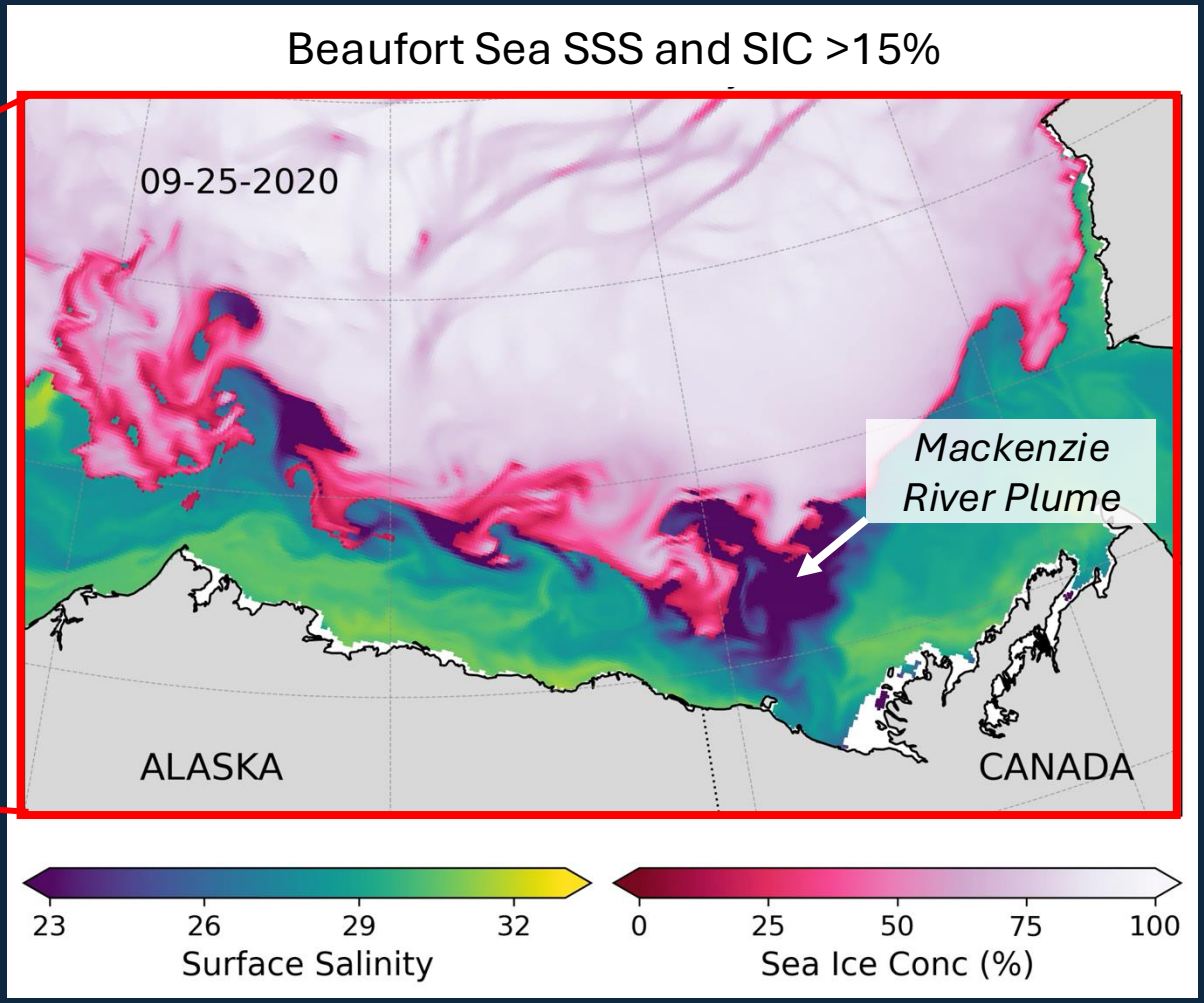
MODIS Aqua: Oct 24, 2022

Employed Coupled Sea Ice-Ocean Model to Analyze Ocean Interior

Model Domain



Beaufort Sea SSS and SIC >15%



- High resolution model (~3.5 km horizontal grid, 90 vertical levels)
- Daily means for 7 years (2014 – 2020)

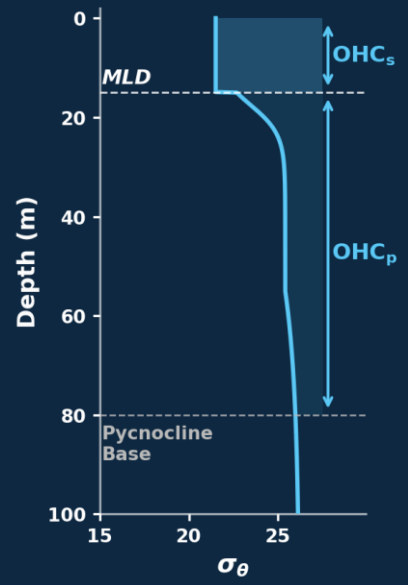
Ice bridge observed in all years of model simulation

Analyzed Ocean Conditions Within and Outside Mackenzie River Plume

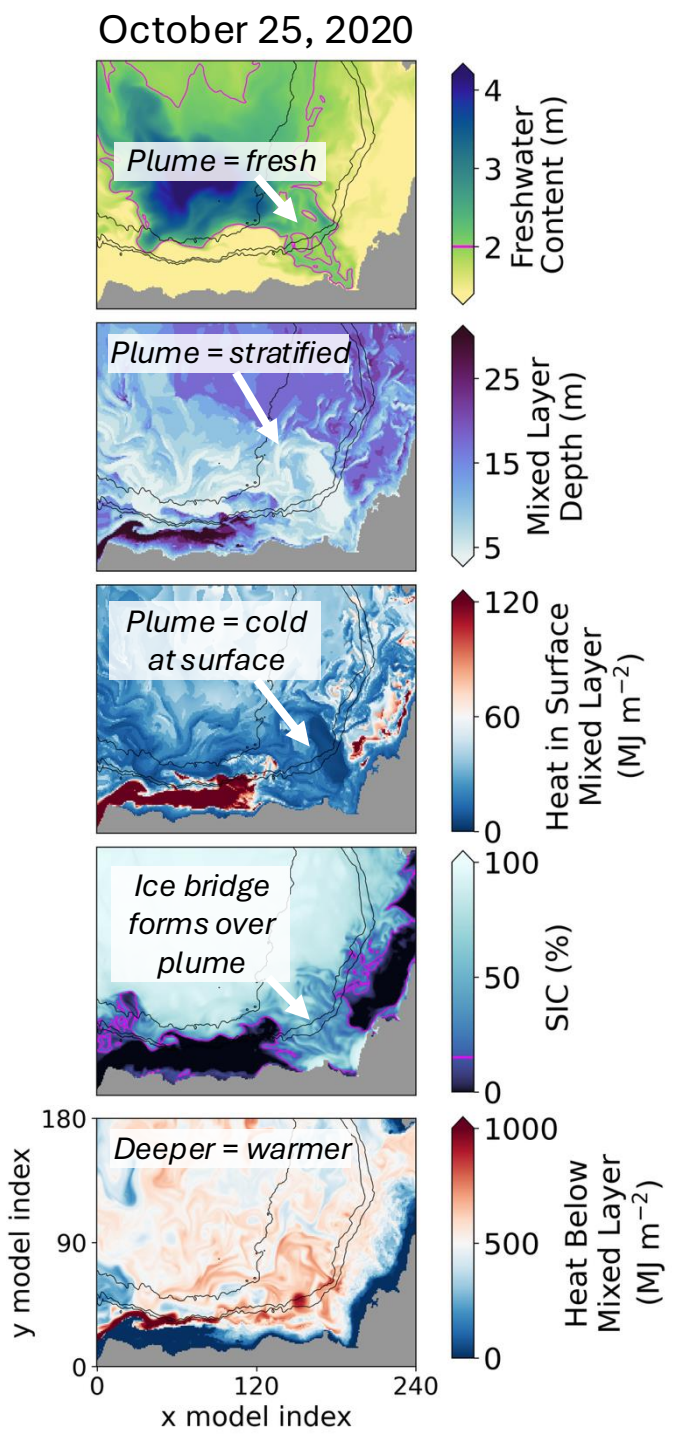
- Calculated **freshwater content (FWC)** in the upper 10 m, **mixed layer depth (MLD),** and **ocean heat content (OHC)** to assess stratification and the vertical distribution of heat

- Calculated OHC in two layers:
  1. Between surface and MLD
  2. Between MLD and base of pycnocline

$$\mathrm{OHC} = \int_{z_1}^{z_2} \rho(z)\, c_p(z)\, [T(z) - T_{fr}]\, dz$$

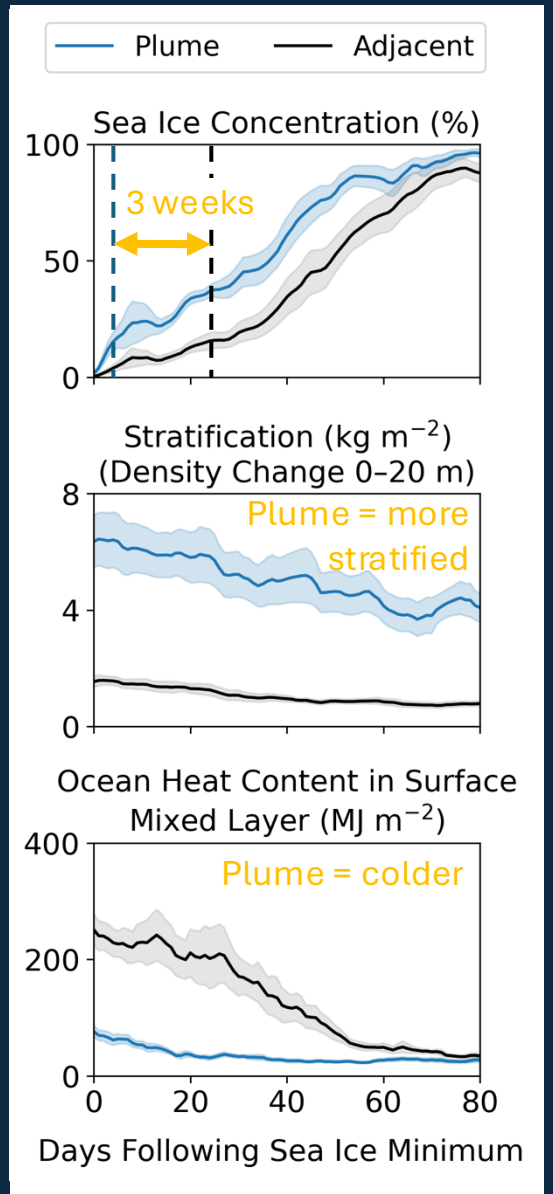


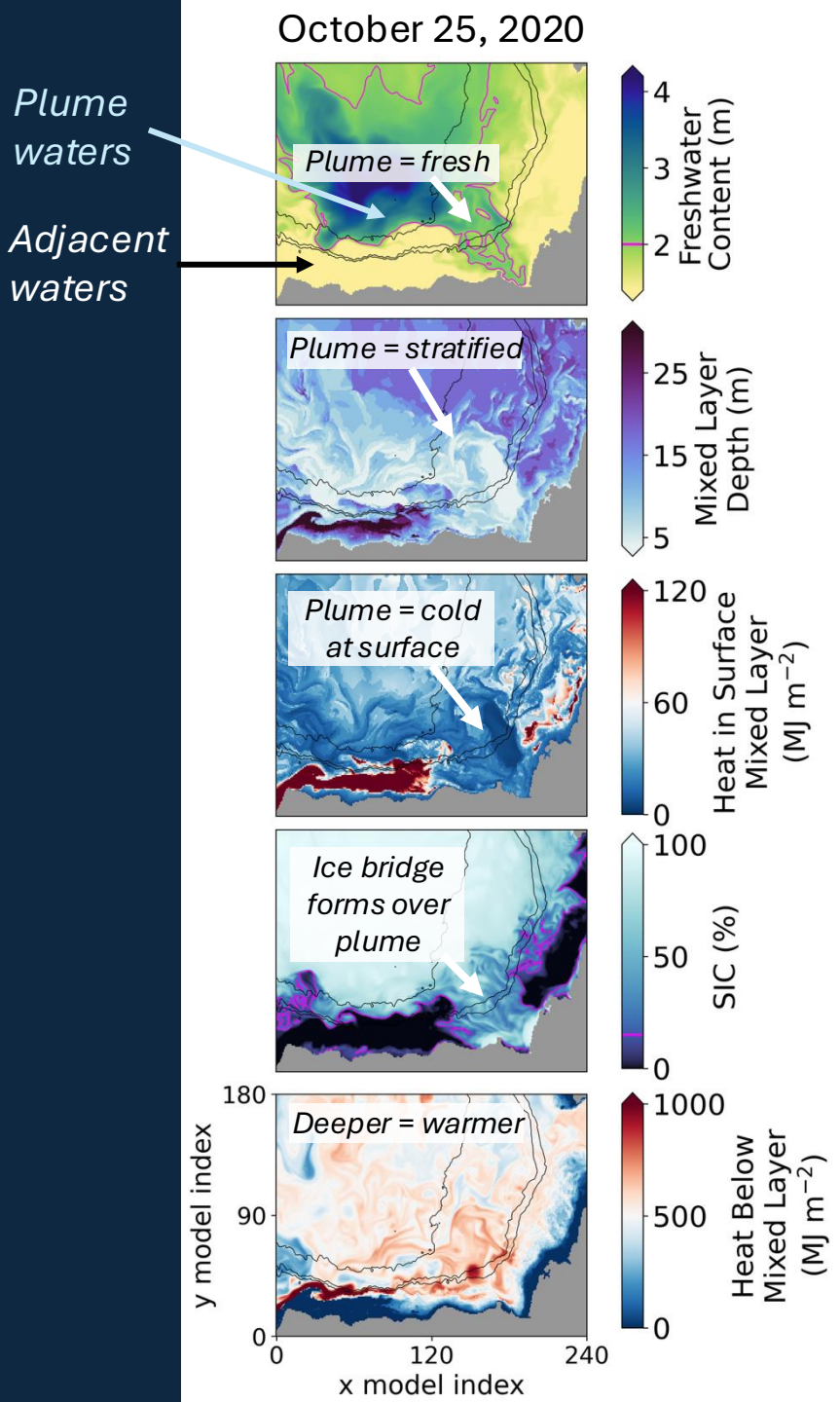
Plume waters have greater FWC, shallower mixed layers, and lower OHC in surface mixed layer compared to adjacent waters



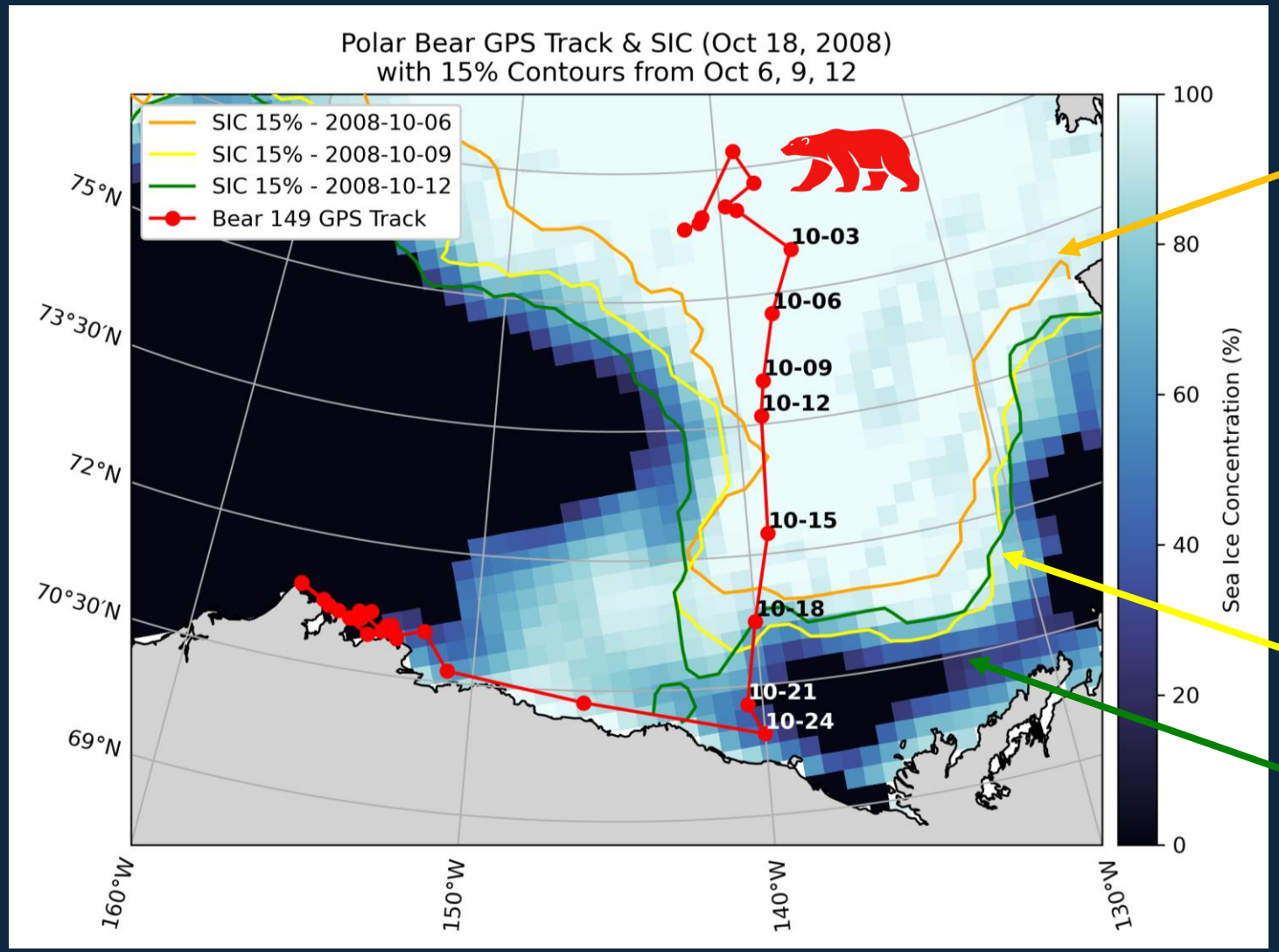
Mean SIC, Stratification, and OHC for Plume and Adjacent Waters (2014–2020)

- Defined two groups: **plume and adjacent waters**
- Used FWC threshold of 2 m
  - Plume waters: FWC > 2 m
  - Adjacent waters: FWC < 2 m
- Mackenzie River freshwater plume freezes 3 weeks earlier than adjacent saltier waters
  - *Freezing point depression: 1-2 day difference*
- Stratified **plume** layers trap heat at depth, allowing the surface to cool and freeze first





Tracking Polar Bear Movement Across The Ice Bridge



- SIC from NOAA/NSIDC Climate Data Record
- Polar bear GPS track from USGS (Durner, 2019)

Summary

- Sea ice onset occurs earlier in the Mackenzie River plume where freshwater promotes the formation of an ice bridge
- The Mackenzie River plume has fresher surface waters, stronger stratification, shallower mixed layers, and less surface heat than surrounding Beaufort Sea waters
- The plume forms sea ice on average 3 weeks earlier than saltier regions, primarily due to enhanced salinity stratification
- **Adding SSS observations to model forecasts may improve sea ice predictions**

Thank You

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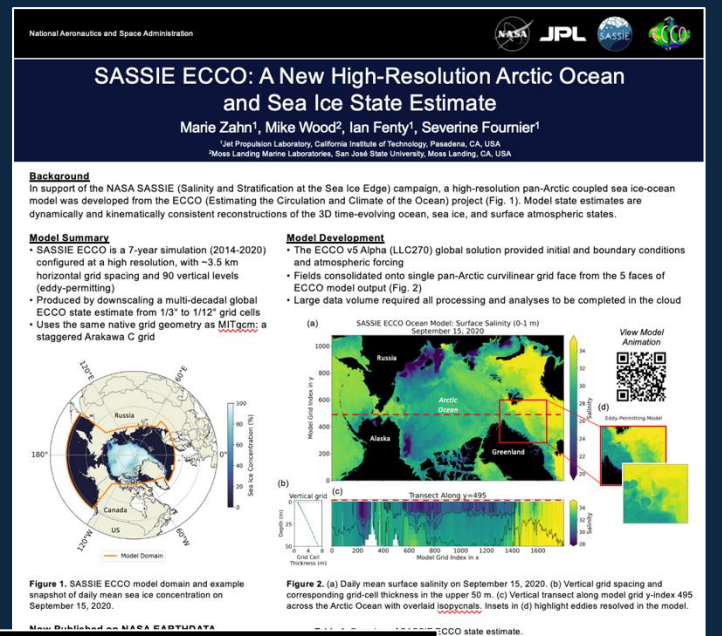
Published Manuscript

Come by my poster!

SASSIE ECCO Datasets on Earthdata



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RESEARCH LETTER
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Mackenzie River Freshwater Controls Early Sea Ice Formation in the Eastern Beaufort Sea

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Key Points:

- Sea ice onset occurs earlier in the Mackenzie River plume where freshwater promotes the formation of an ice bridge
- Model simulations reveal that sea ice forms on average 3 weeks earlier in the Mackenzie River freshwater plume than in adjacent, saltier areas
- The Mackenzie River freshwater plume has stronger stratification, shallower mixed layers, and less surface heat than surrounding waters

Supporting Information:

Supporting Information may be found in the online version of this article.

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Citation:

Zahn, M. J., Fournier, S., Fenty, I. G., Steele, M., Wood, M., & Gaube, P. (2026). Mackenzie River freshwater controls early

Abstract Arctic sea ice plays a critical role in Earth's climate system, and as it continues to thin and retreat, understanding the processes driving its variability is increasingly important. Using satellite data and a coupled ocean–sea ice model, we examined how freshwater from the Mackenzie River influences fall sea ice formation in the Beaufort Sea. An "ice bridge" between the coast and offshore ice edge consistently forms over the river's freshwater plume, with its location and extent varying interannually with freshwater distribution. Regions influenced by the plume experienced sea ice onset an average of 3 weeks earlier than adjacent, saltier waters. Earlier ice formation was associated with enhanced stratification, shallower mixed layers, and reduced upper ocean heat content, all of which promotes faster surface cooling. Our findings highlight the importance of river discharge in shaping sea ice formation and suggest continued Arctic freshening will impact future sea ice timing and extent.

Plain Language Summary The Arctic Ocean has lost nearly half of its summer sea ice cover over the past four decades. Understanding the mechanisms that control when and how sea ice forms is critical for predicting future changes in the Arctic climate system. Freshwater from large Arctic rivers, like the Mackenzie River in Canada, plays an important role in sea ice melt and formation by changing how salt and heat are distributed in the ocean. Here, we used satellite observations and a computer model to