Diagnosing the pathways of freshwater across the Arctic Ocean via tracer release experiments

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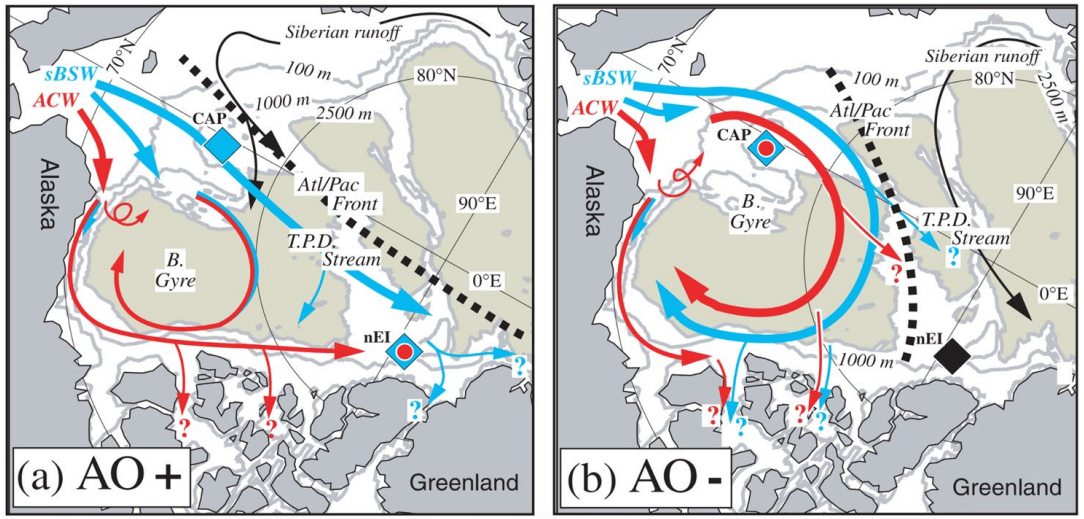
Studying a Changing Arctic Ocean by Jill Pelto

Background and motivation

- The distribution of freshwater in the Arctic Ocean sets stratification and drives circulation pathways
  - Impacts sea ice, ocean ecosystems, and the global climate system
- Freshwater content in the Arctic Ocean is highly variable in time and space[1] and strongly impacted by the inflow from the Pacific and Atlantic Oceans[2] , as well as rivers[3]

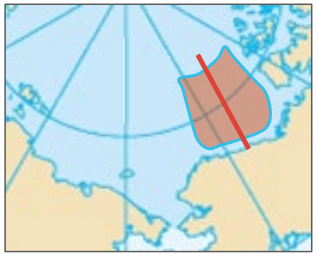


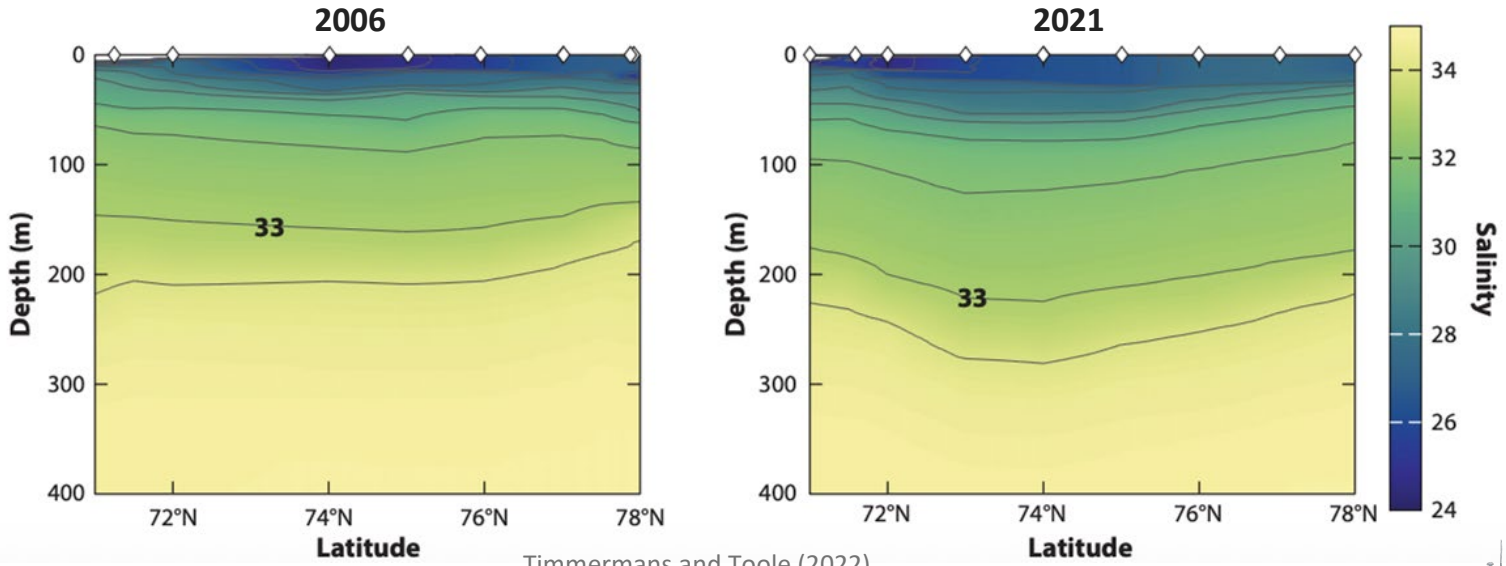
Steele et al. (2004)

References: [1] Morison, J., et al. (2012). [2] Le Bras, I. A.-A., & Timmermans, M.-L. (2025). [3] Aagaard, K., and E. C. Carmack (1989)

Freshwater changes in the Arctic Ocean

The amount of freshwater stored in the Arctic Ocean has increased since the late 1990's, especially in the Beaufort Gyre within the Canada Basin.

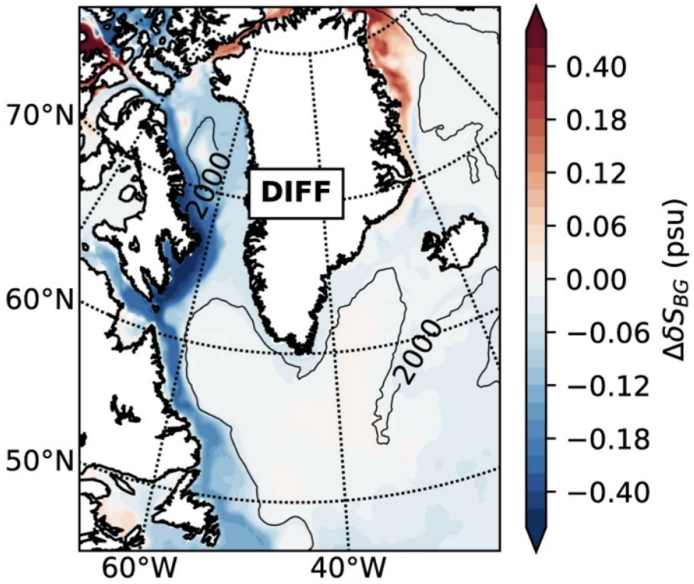




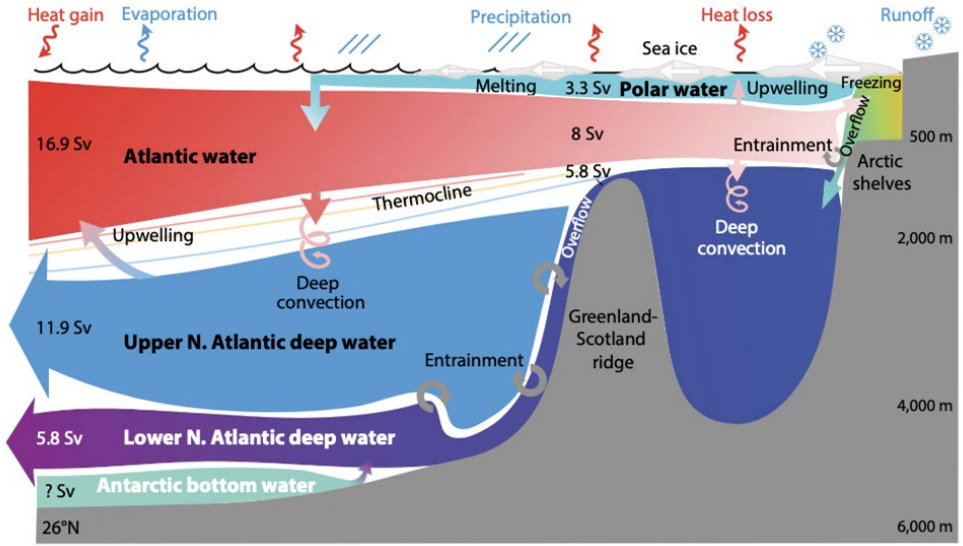
Timmermans and Toole (2022)

Connection to global climate

Freshwater release from the Arctic Ocean impacts sub-Arctic ocean circulation, including the Atlantic Meridional Overturning Circulation.



Zhang et al.(2021)



Weijer et al.(2022)

Project goals

1. Diagnose the pathways and variability of sub-Arctic ocean inflow into Arctic Ocean within E3SM-Arctic
2. Connect the pathways of sub-Arctic ocean inflow to changes in freshwater content and stratification
3. Explore the interannual variability of these processes and their dependence upon atmospheric forcing conditions

To pursue these research goals, we are carrying out a series of novel Eulerian dye tracer release experiments in E3SM-Arctic tagging sources and sinks of freshwater in the Arctic Ocean.

Here, we focus on the tracers tagging inflow from the Pacific and Atlantic.

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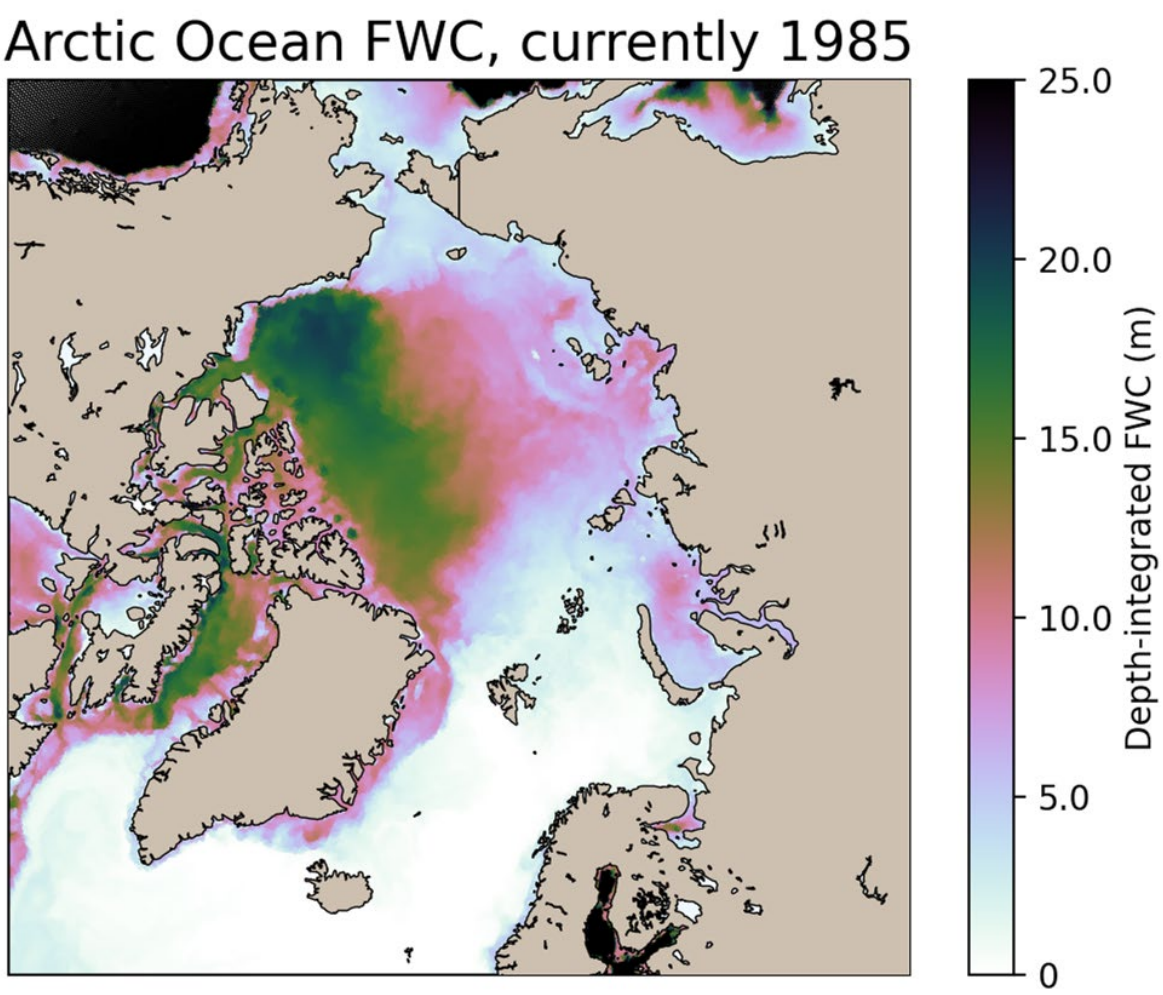
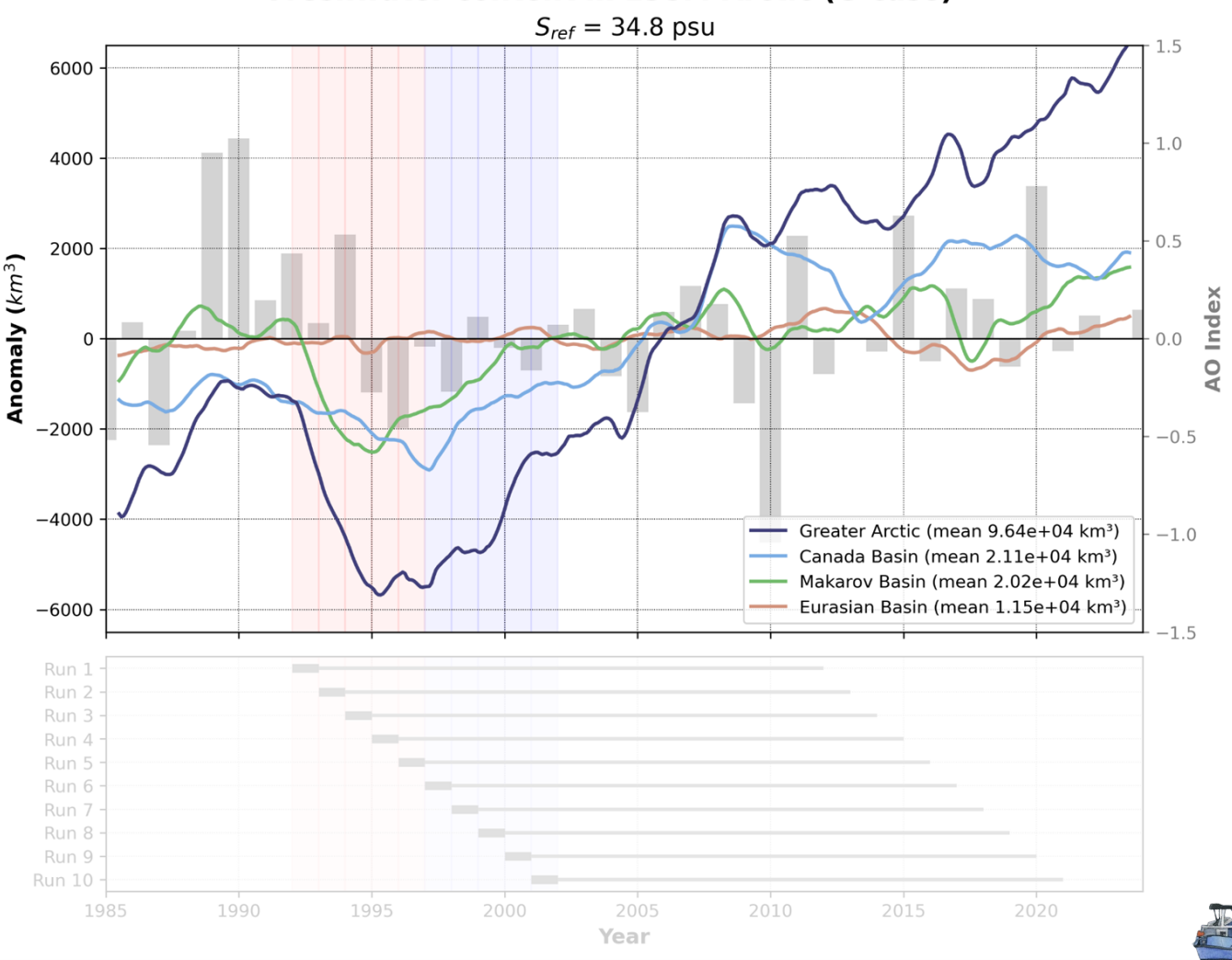


Freshwater content in E3SM-Arctic

Monthly-averaged September FWC for each year, computed relative to S_{ref} ~ 34.8


Freshwater content in E3SM-Arctic (G-case)
S_{ref} = 34.8 psu
Anomaly (km^3)
AO Index
Greater Arctic (mean 9.64e+04 km³)
Canada Basin (mean 2.11e+04 km³)
Makarov Basin (mean 2.02e+04 km³)
Eurasian Basin (mean 1.15e+04 km³)
Run 1
Run 2
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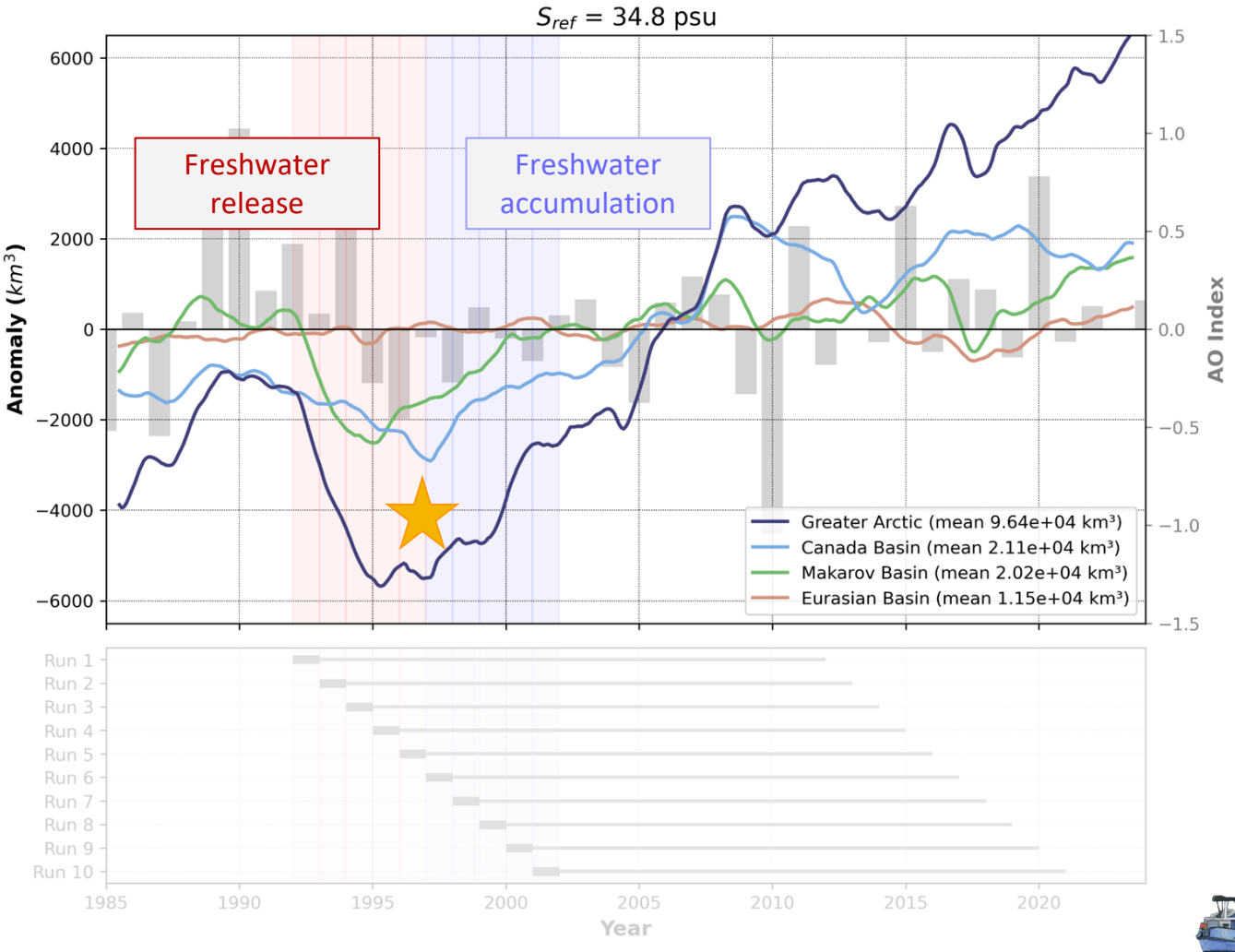
Run 7
Run 8
Run 9
Run 10
Year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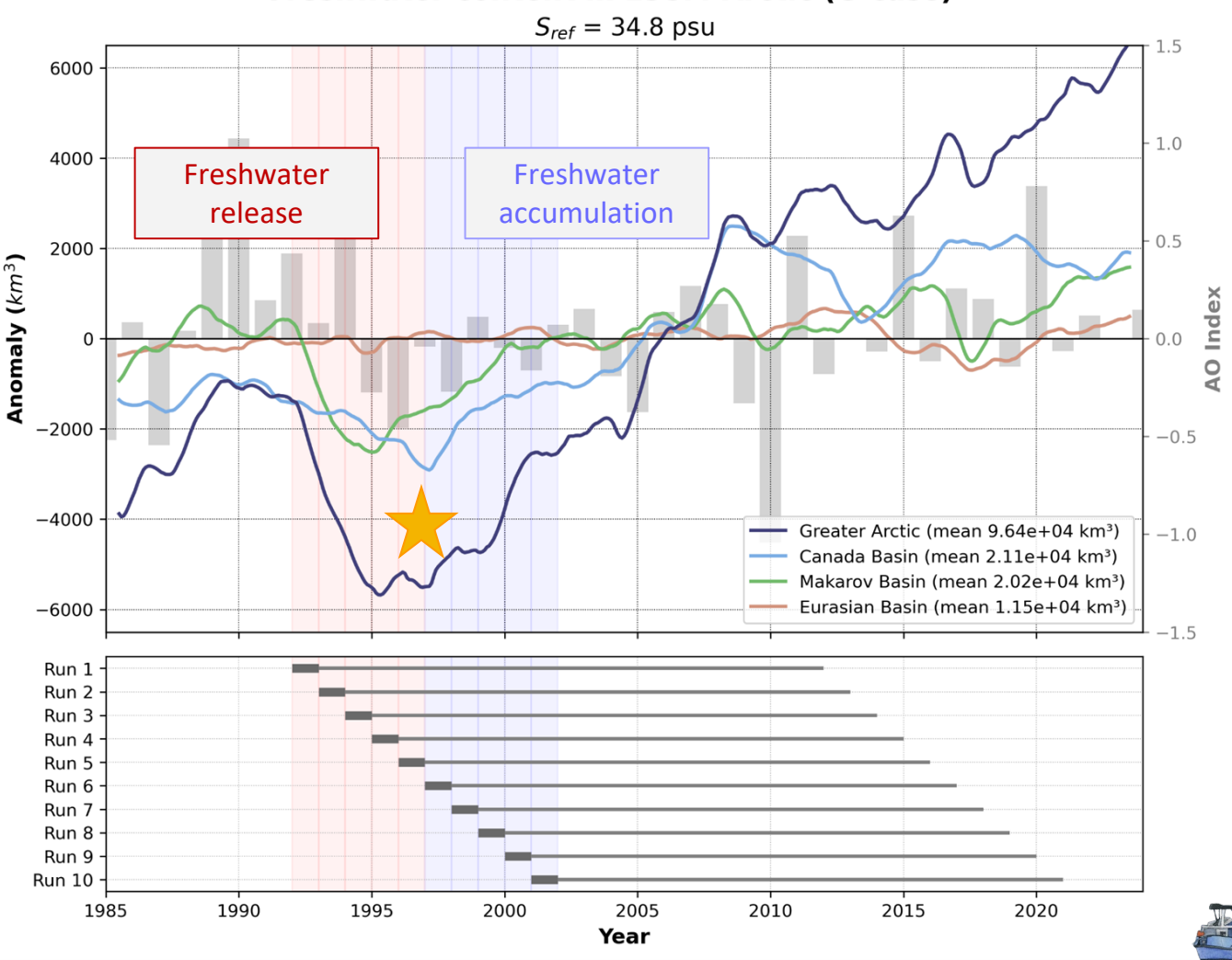
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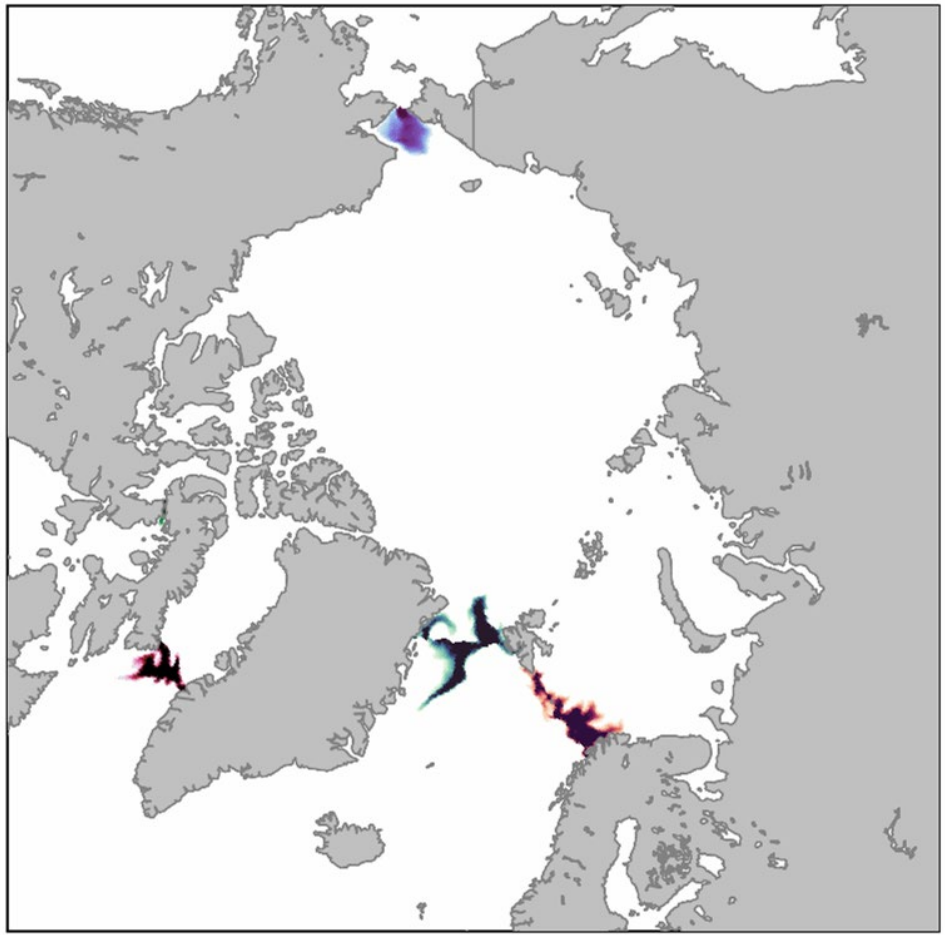


1995 tracer release

Bering Strait

Barents Sea Opening

Fram Strait

Davis Strait

Fury and Hecla Strait

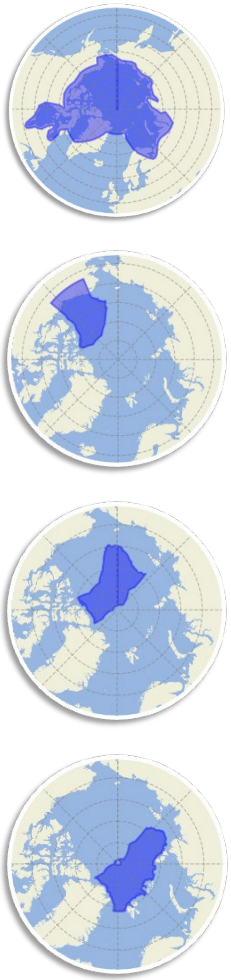
How do we measure tracer pathways?

To quantify how tracer pulses move through the Arctic Ocean, we compute integrals of tracer volumes across different Arctic Ocean regions:

$$V_{\text{tracer}}(t) = \int_{A_{\text{region}}} \int_{z_{\text{bot}}}^{z_{\text{surf}}} \alpha_{\text{tracer}}(t)\, dA\, dz$$

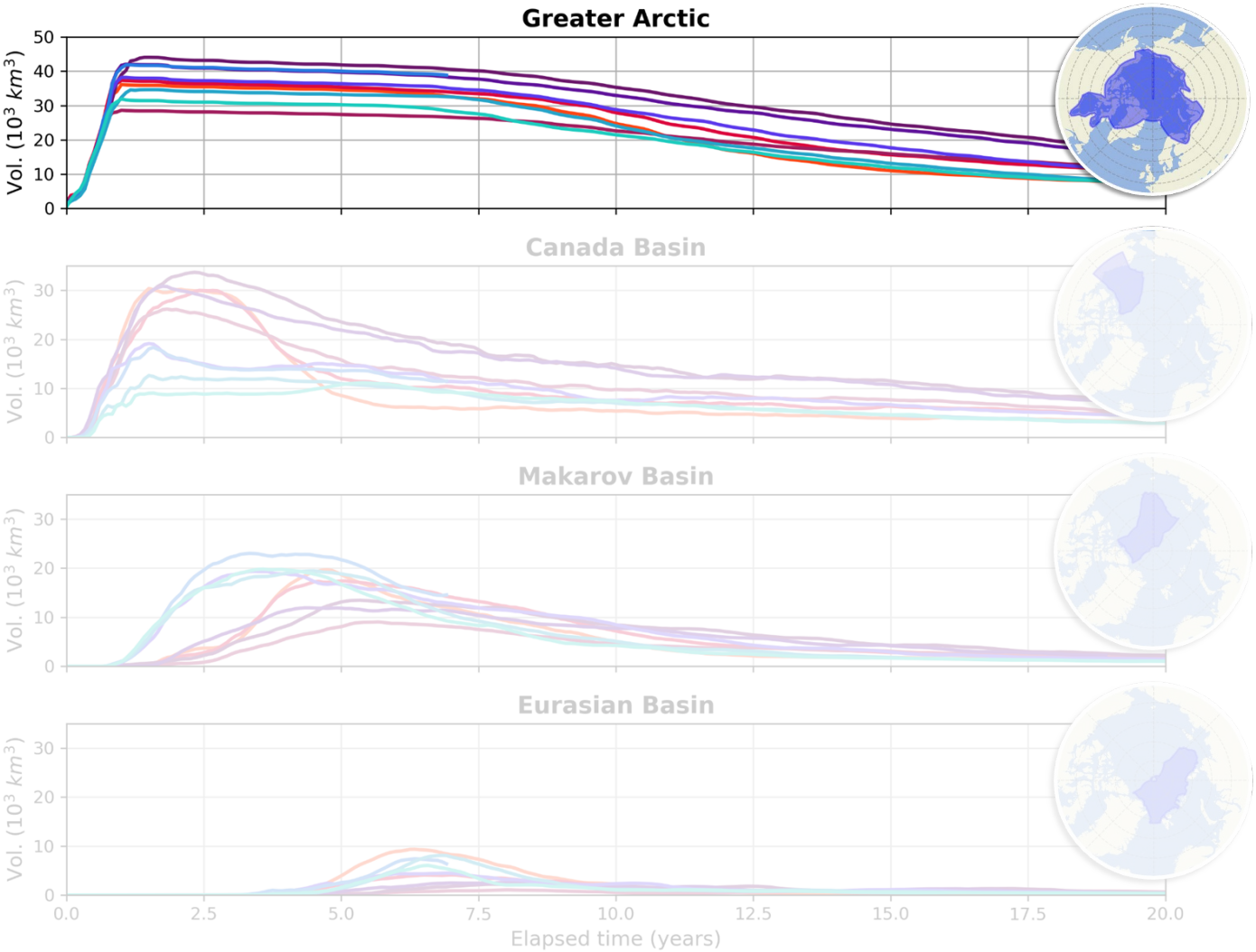
where A_{region} is a mask defining the region, and $\alpha_{\text{tracer}}(t)$ is the time-varying fractional volume tracer.

For this talk, we will focus on the greater Arctic region, as well as its major basins– the Canada, Makarov, and Eurasian basins.



Bering Strait Tracer

- 1992
- 1993
- 1994
- 1995
- 1996
- 1997
- 1998
- 1999
- 2001



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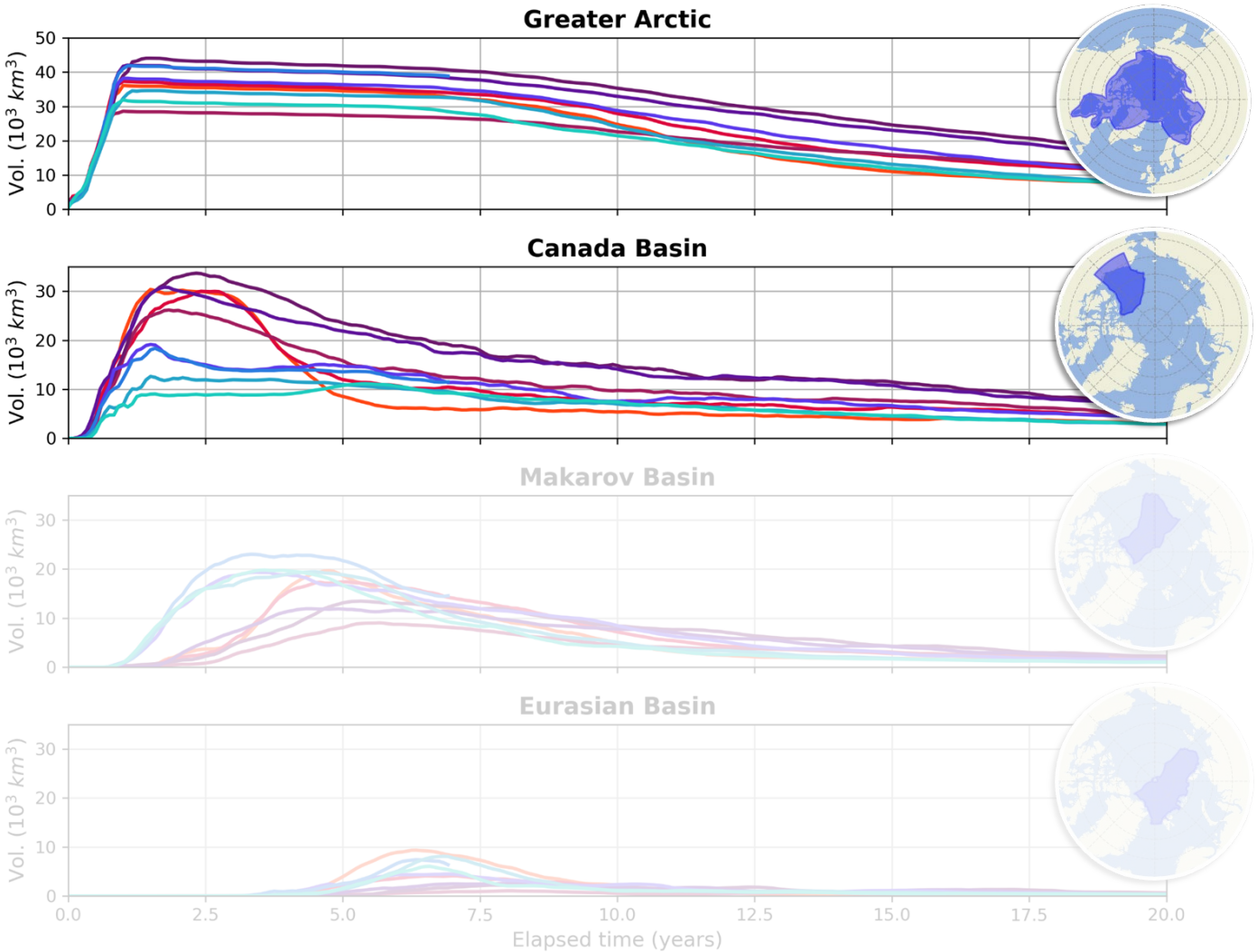

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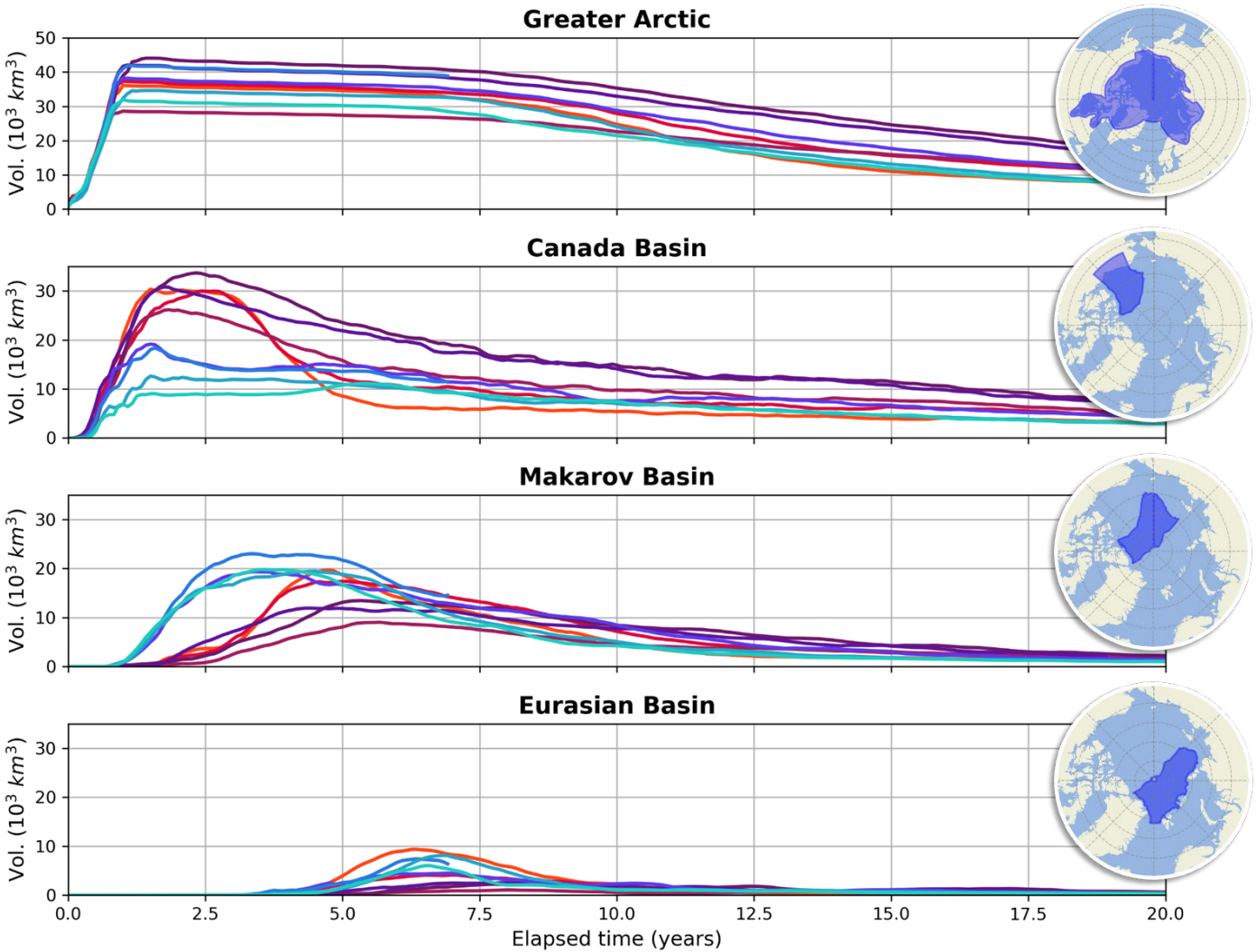

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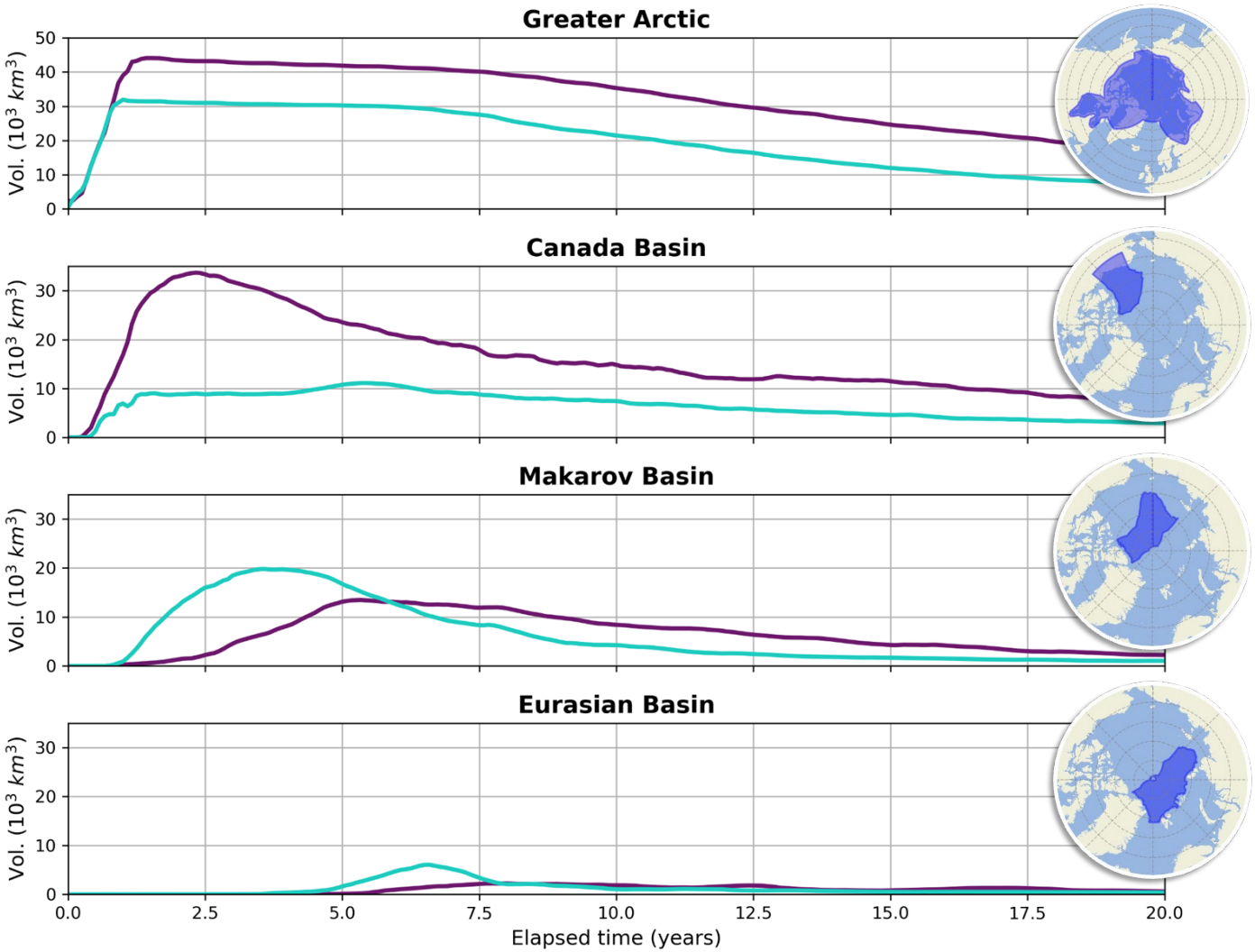
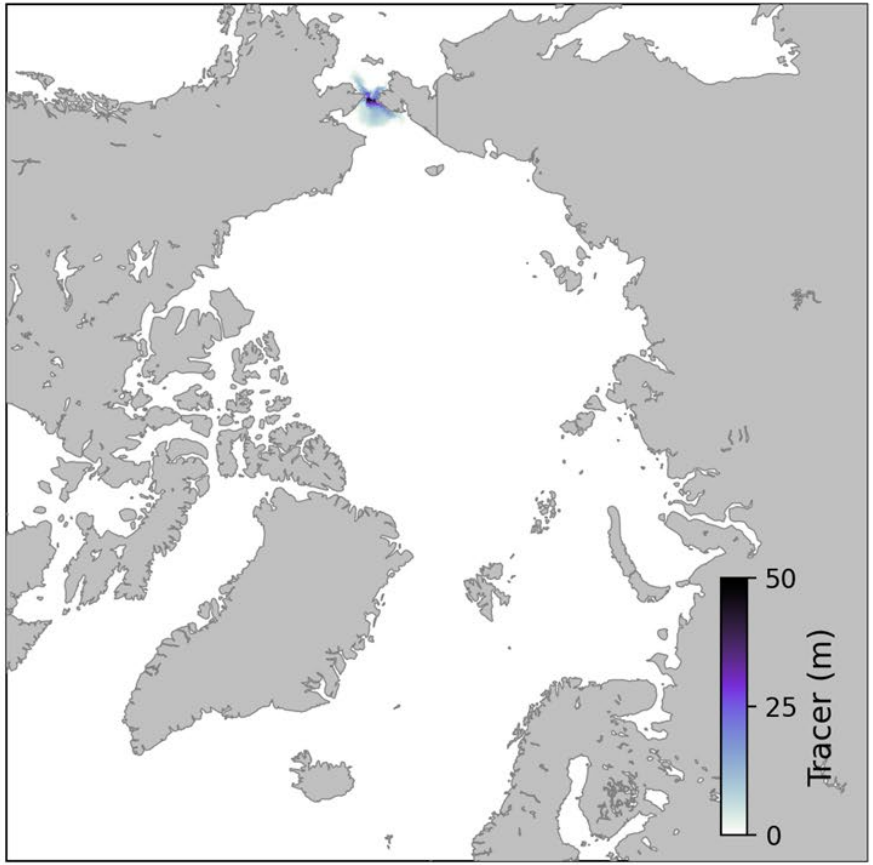


1995 release

2001 release



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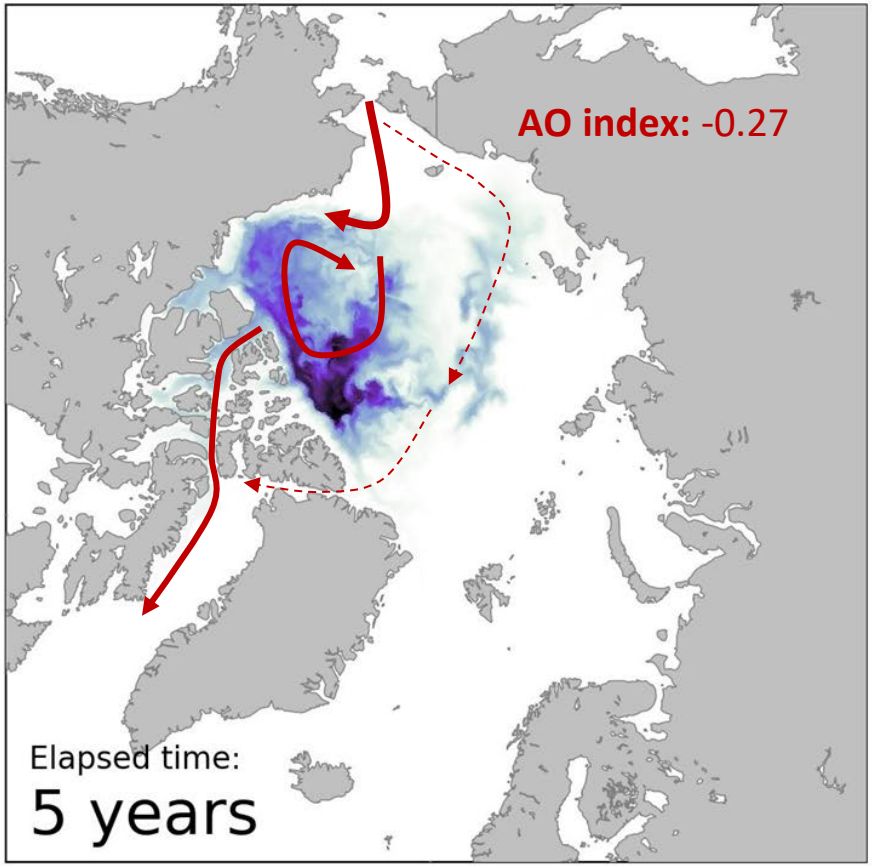

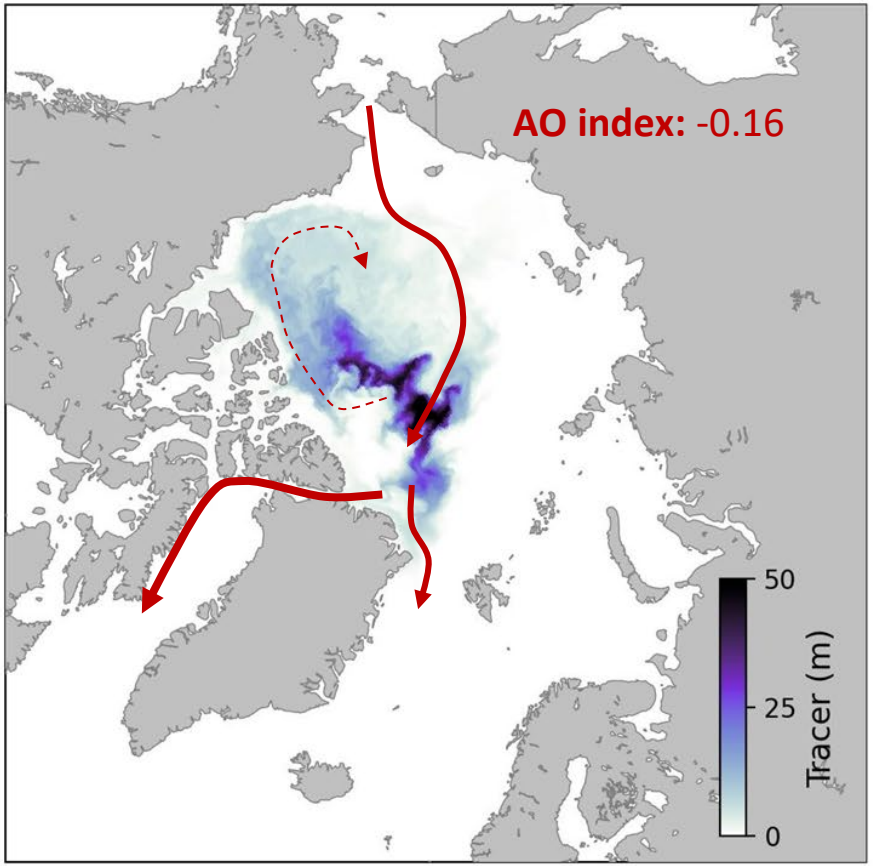

Summary of results (... so far!) and next steps

- **E3SM-Arctic tracer simulations exhibit strong interannual variability in tracer pathways and timescales**
    - The amount of Pacific-origin water entering the Canada Basin varies strongly year-to-year, with later years (1997-2001) displaying a greater tendency to enter the Transpolar Drift
- E3SM-Arctic tracer release experiments are 85% complete and will be fully complete within the next several weeks
    - With the full suite of experiments, we will piece together a coherent story of tracer evolution between years
    - Further analyze relationship between ocean pathways and their impact on freshening in the model, and connect these changes in pathways and FWC to model dynamics and atmospheric forcing

Thank you for listening!

Breakout session for MIP tomorrow morning!

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