How will Beaufort Gyre liquid freshwater respond to warming climate and impact the AMOC? – Answers from an eddy resolving climate simulation

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Introduction

The Beaufort Gyre is the largest reservoir of liquid freshwater in the Arctic Ocean. Freshwater released from the gyre can be exported to the subpolar North Atlantic and potentially disrupts the Atlantic overturning circulation. Although extensive efforts have been made to monitor the Beaufort Gyre liquid freshwater content (LFWC) in recent decades, how it may respond to greenhouse warming remains elusive to date. Typical climate models in CMIP are too coarse to simulate oceanic and atmospheric eddy processes that are important for the gyre dynamics. Here, we use an eddy-resolving (~5 km in the Beaufort Gyre region) CESM historical and RCP8.5 simulation (1850-2100) to address the gap, discussing the Beaufort Gyre LFWC changes in response to anthropogenic warming, its underlying dynamics, and influences on the subpolar region.

Projected increase of the Beaufort Gyre LFWC and its variability

Largely reproducing the observed LFWC changes, our model projects a long-term Beaufort Gyre LFWC increase until 2080s and an intensification of its decadal variability during the second half of the 21st century (*Figure 1*).

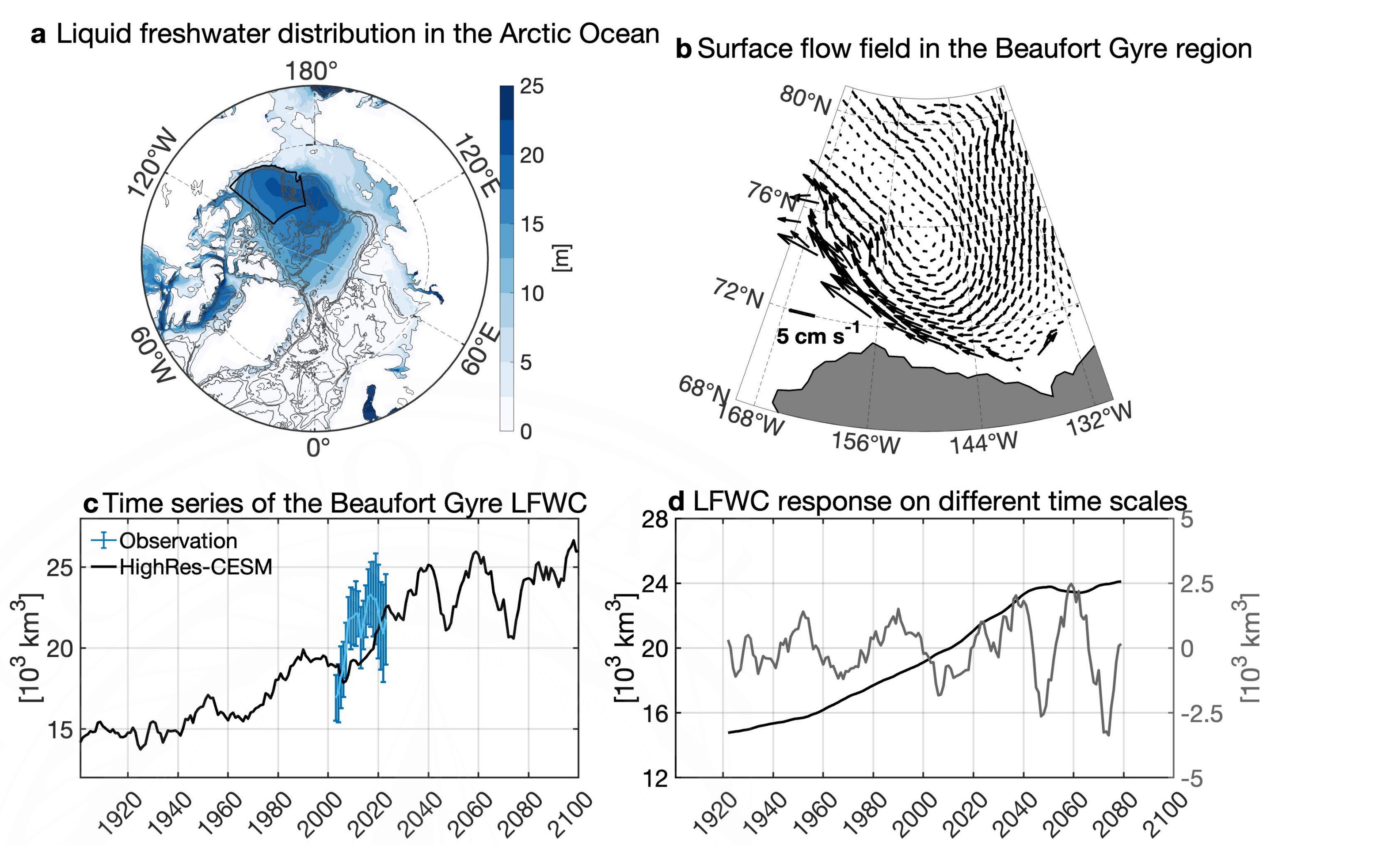

Figure 1. (a) Simulated climatological liquid freshwater distribution in the Arctic Ocean. The study region (BGR) is denoted by the black box. (b) Simulated climatological surface flow field in the BGR (plot every 10 grid points). (c) Annual-mean LFWC in the BGR in our simulation (black) and from observed estimation (blue). (d) Decomposition of the LFWC on decadal (gray) and longer (black) time scales using a 41-year moving average.

Two mechanisms by which sea ice melt increases the LFWC in the long-term

By conducting a freshwater budget analysis on multi-decadal time scales, we find both the air/ice-sea freshwater flux and the Ekman freshwater convergence are essential for the LFWC increase (*Figure 2b*). The former is dominated by meltwater from sea ice (*Figure 2c*). The enhancement of the latter in a warming climate is due to more efficient air-sea momentum transfer associated with sea ice loss rather than a stronger anticyclonic wind above the gyre (*Figure 2d*).

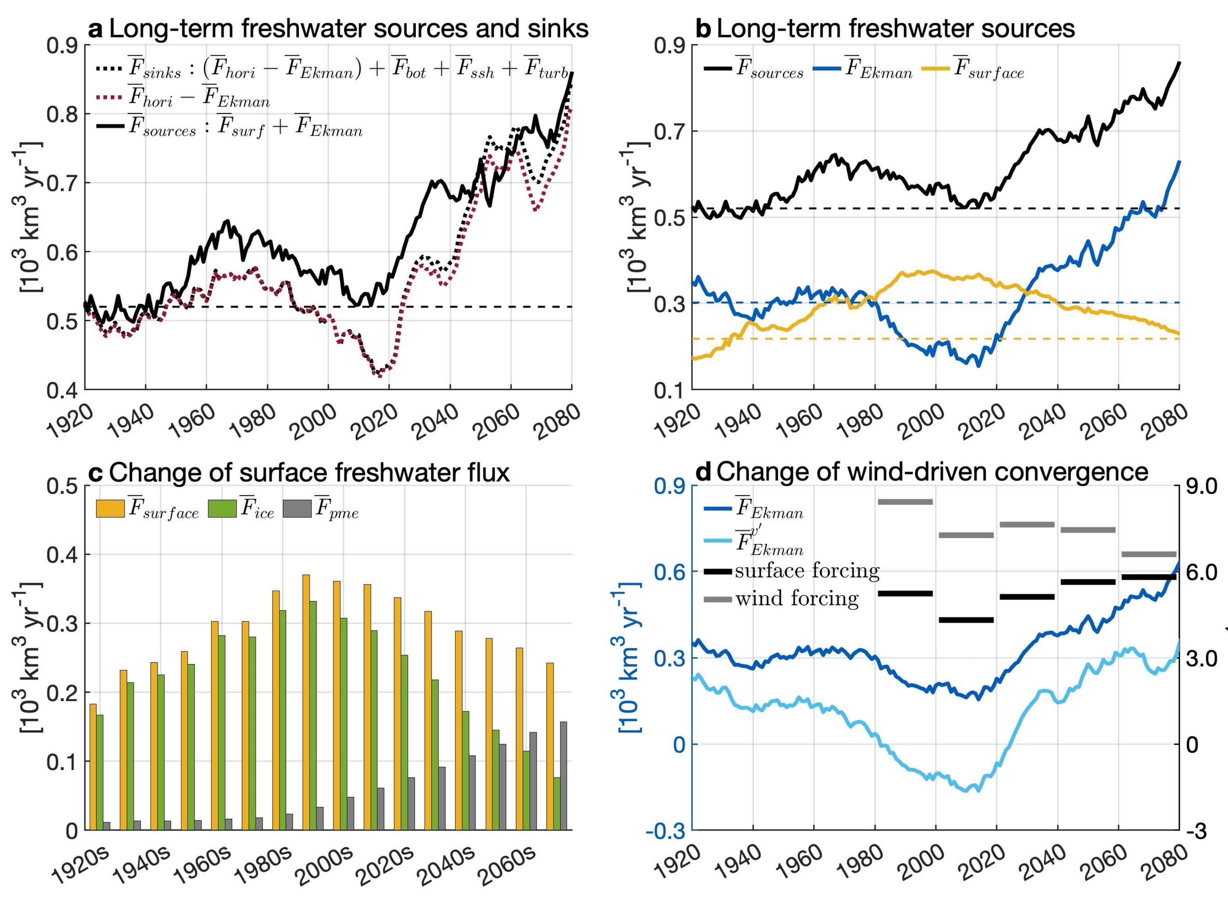

Figure 2. (a) Time series of the long-term freshwater sources and sinks in the BGR. (b) Time series of the long-term freshwater source, composed of the surface freshwater flux (yellow) and the Ekman freshwater convergence (blue). (c) The long-term surface freshwater flux in each decade (yellow), composed of the ice-ocean flux due to ice melt and formation (green), net precipitation (gray), and river runoff (negligible and thus not shown). (d) Time series of long-term Ekman freshwater convergence (dark blue) and the contribution from varying Ekman volume transport (light blue). The 20-year averaged surface and wind forcing, measured by Ekman pumping, are indicated by the black and gray line, respectively.

Sea ice retreat amplifies the LFWC variability on decadal time scales

Freshwater budget indicates that the intensified variability of the LFWC is mainly due to that of the horizontal freshwater convergence driven by the surface stress curl (*Figure 3a-b*). The variability of the surface forcing almost doubled from 1970-2000 to 2050-2080 (*Figure 3c*). Half of the increase is due to enhanced wind variability, and the other half is owing to more efficient air-sea momentum transfer (*Figure 3d-e*) which is most evident in January-June. It is because sea ice concentration in the seasons drops below 90% after 2050 (*Figure 3f*), providing better condition for the momentum transfer.

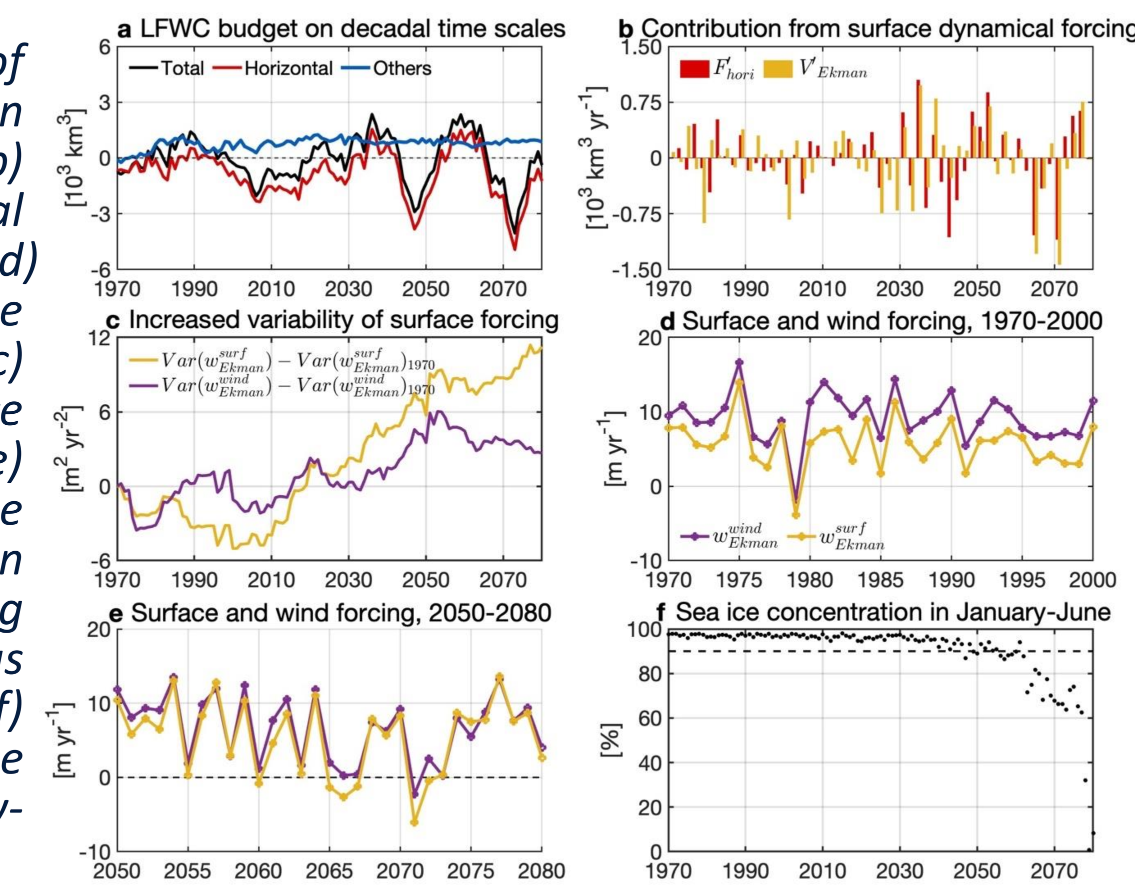

Figure 3. (a) Time series of the LFWC and its budget on decadal time scales. (b) Time series of the horizontal freshwater convergence (red) and the Ekman volume convergence (yellow). (c) Intensification of the surface (yellow) and wind (purple) forcing variability. (d) Time series of the annual-mean surface and wind forcing over 1970-2000. (e) Same as (d) but for 2050-2080. (f) Decrease of the BGR sea ice concentration in January-June .

Limited influence on the AMOC?

Although the release and accumulation of the Beaufort Gyre LFWC are coincident with the increase and decrease of the freshwater flux through the Davis Strait and the Fram Strait on decadal time scales, they have limited effects on the overturning circulation in our simulation (*Figure 4*). The OSNAP-West overturning variability is small, ~0.5 Sv, compared to its strength which is ~4.5 Sv, over 2050-2100. The OSNAP-East overturning variability is even smaller. The reason might be that the freshwater coming from the Arctic is carried by boundary currents and largely confined in shelf regions instead of going to the central basin where deep convection happens (Shan et al., 2024).

Shan, X.,Sun, S., Wu, L. et al. Role of the Labrador Current in the Atlantic Meridional Overturning Circulation response to greenhouse warming. *Nat Commun* 15, 7361 (2024).

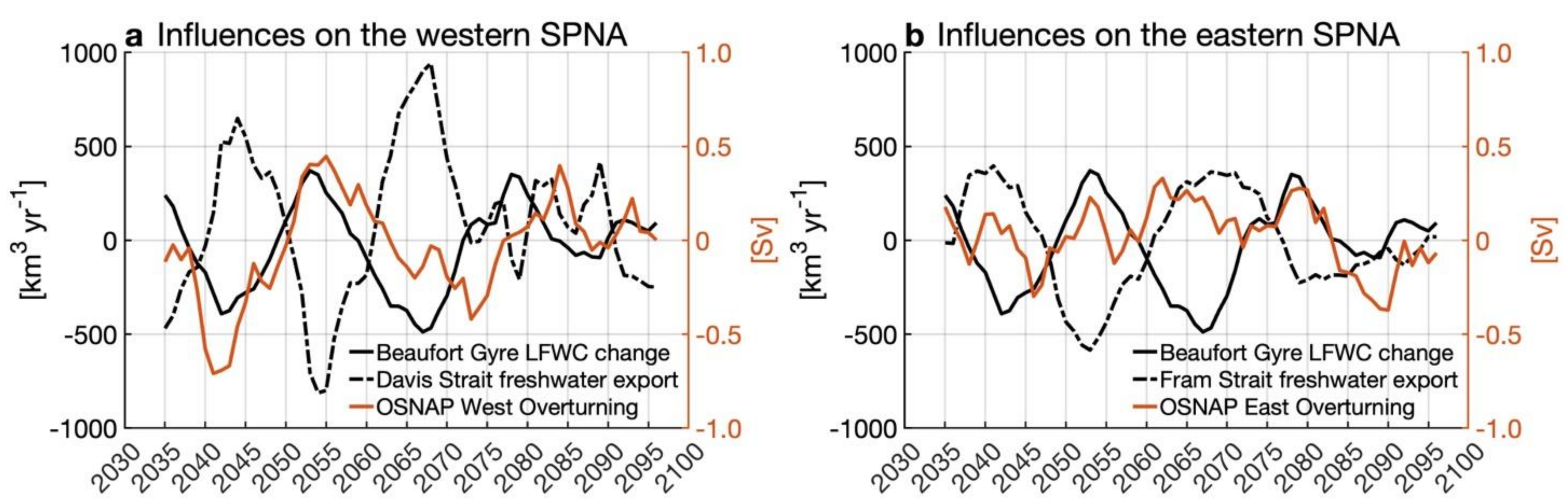

Figure 4. (a) Time series of the BGR LFWC (solid black, negative for freshwater release), Arctic freshwater export through the Davis Strait (dashed black, positive for more freshwater export), and the overturning across OSNAP West (orange, negative for weakened deep convection) on decadal time scales. (b) Same as (a) but for freshwater export through the Fram Strait and overturning across the OSNAP East.

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