Supporting Information for "Surface salinity under transitioning ice cover in the Canada Basin: Climate model biases linked to vertical distribution of freshwater"

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Introduction Here we include a brief derivation of the seaonsal freshwater content (sFWC), figures as in the main text, but for different months, and tables that indicate the CESM variable names used in the analysis and statistics associated with histograms included in the main text.

Text S1. Here, we follow (Rosenblum et al., 2021), who considered a closed ice-ocean 1D system with an ocean that only evolved in response to sea ice melt and vertical mixing. Instead of ice melt, we consider a source of near-surface freshwater (sFWC(t)) and neglect ice draft within the ocean (as is done in the models). The system has the following initial conditions ($t = t_0$): a well-mixed ocean, with vertically uniform salinity (S_0) and potential density (ρ_0). If freshwater is vertically mixed to some depth, Z_{fw}, then the salinity below this depth remains fixed at S_0 (i.e., $S(z) = S_0$ for $z \leq Z_{fw}$, where z and Z_{fw} are both negative). The conservation of salt and mass for time $t > t_0$ over any depth $D \geq Z_{fw}$ can be written as:

$$\int_{Z_{fw}(t)}^{0} \rho(t,z)S(t,z) \cdot dz - \rho_0 S_0(-Z_{fw}(t)) \;=\; 0 \tag{1}$$

$$\int_{Z_{fw}(t)}^{0} \rho(t,z) \cdot dz - \rho_0(-Z_{fw}(t)) \;=\; \rho_{fw} \cdot sFWC(t). \tag{2}$$

ρ_{fw} is the density of the added freshwater, $\rho(t,z)$ and $S(t,z)$ are the ocean potential density and salinity, respectively. The above expressions, therefore, represent the change in mass and salt in the ocean (left-hand side) in response to freshwater input (right-hand side). These equations can be algebraically combined to obtain an estimate for the freshwater necessary to explain the transition from the initial, well-mixed ocean (S_0, ρ_0) to the subsequent ocean profile that includes vertically mixed freshwater ($S(t,z)$, $\rho(t,z)$) at any time $t > t_0$:

$$sFWC(t) = \int_{Z_{fw}(t)}^{0} \frac{\rho(t,z)(S_0 - S(t,z))}{\rho_{fw} S_0} \cdot dz. \tag{3}$$

In the ITP and AIDJEX data, $\rho(t,z)/\rho_{fw} \sim 1.03$, where $\rho_{fw} = 1000$ kg/m^3, implying that a reasonable estimate of sFWC can be given by:

$$sFWC(t) = \int_{Z_{fw}(t)}^{0} \frac{(S_0 - S(t,z))}{S_0} \cdot dz. \qquad (4)$$

We note that sFWC is closely related to sea ice melt in the observations (Rosenblum et al., 2021) and in the models. Specifically, we find that the May-December sFWC and virtual freshwater flux from sea ice melt (MELT and VSFSIT in CESM1 and CESM2, respectively) is highly correlated (R=0.88 and R=0.89 in CESM1 and CESM2 using each gridpoint of each simulation of 1970-2020). Simulated sea ice melt makes up the majority of the simulated freshwater flux in both models (VSF/VSFSIT=0.98).

References

Rosenblum, E., Stroeve, J. S., Gille, S., Tremblay, L., Carmack, E. C., Barber, D. G., ... Fajber, R. (2021). Freshwater input and vertical distribution in the Canada Basin's seasonal halocline: 1975 versus 2006-2012. *Preprint: https://doi.org/10.1002/essoar.10507192.1*.

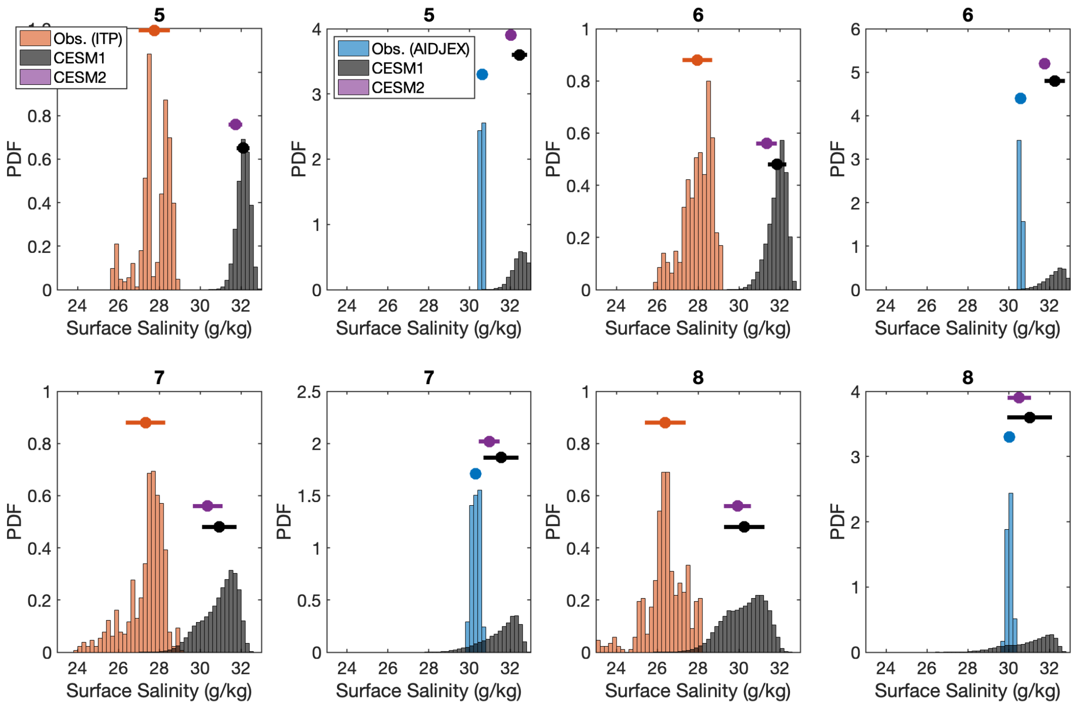

Figure S1. As in Figure 2d-e, but for May-August (5-8).

Table S1. List variable names used in the study

Description	CESM1	CESM2
Salinity	SALT	SALT
Eff. Sea Ice Thickness	hi	sivol
Sea Ice Concentration	aice	siconc

Table S2. Mean and standard deviation of histograms provided in the main text, using all observations and all grid points from each simulation.

	Years	Observations/PIOMAS	CESM1	CESM2
August Surface Salinity (g/kg)	1975	30.0±0.1	31.0±1.1	30.5±0.6
	2006-2012	26.4±1.0	30.3±1.0	29.9±0.7
Seasonal Sea Ice Change (m)	1979-1998	0.9±0.6	0.8±0.6	1.0±0.5
	1999-2018	1.1±0.6	1.1±0.6	1.3±0.5
August sFWC (m)	1975	0.5±0.2	1.0±0.5	1.1±0.3
	2006-2012	0.9±0.4	1.3±0.5	1.3±0.3
August $Z_{90\%}$ (m)	1975	22.9±3.5	24.6±2.8	25.1±1.7
	2006-2012	14.6±3.7	24.2±2.4	25.1±2.4

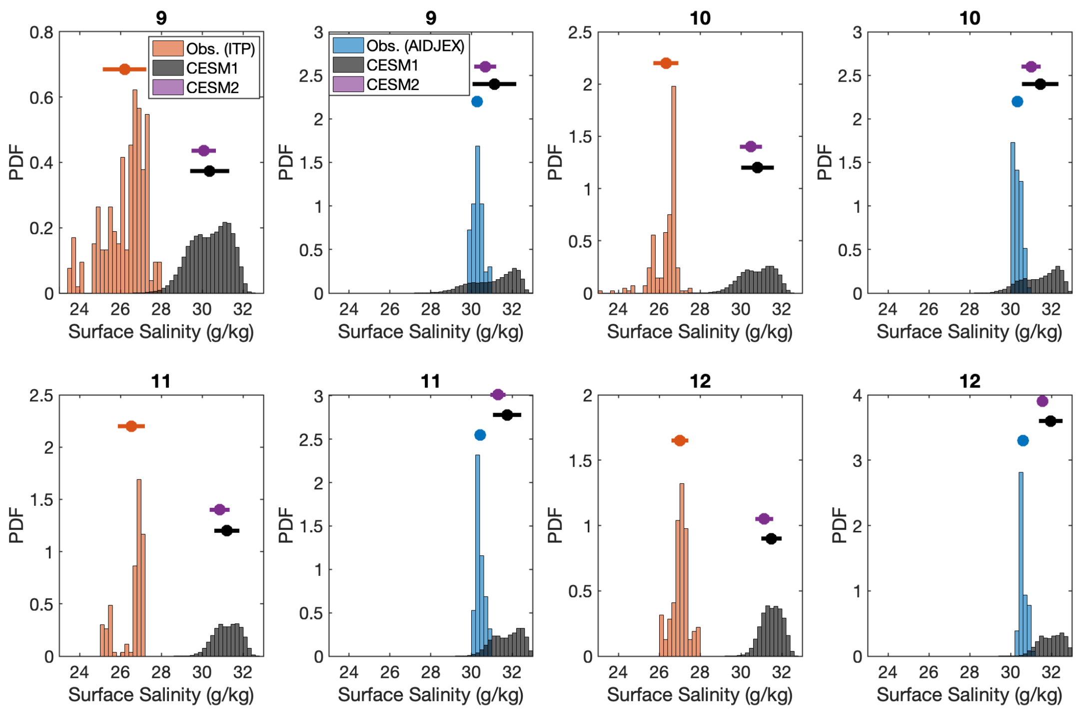

Figure S2. As in Figure S1, but for September-December (9-12).

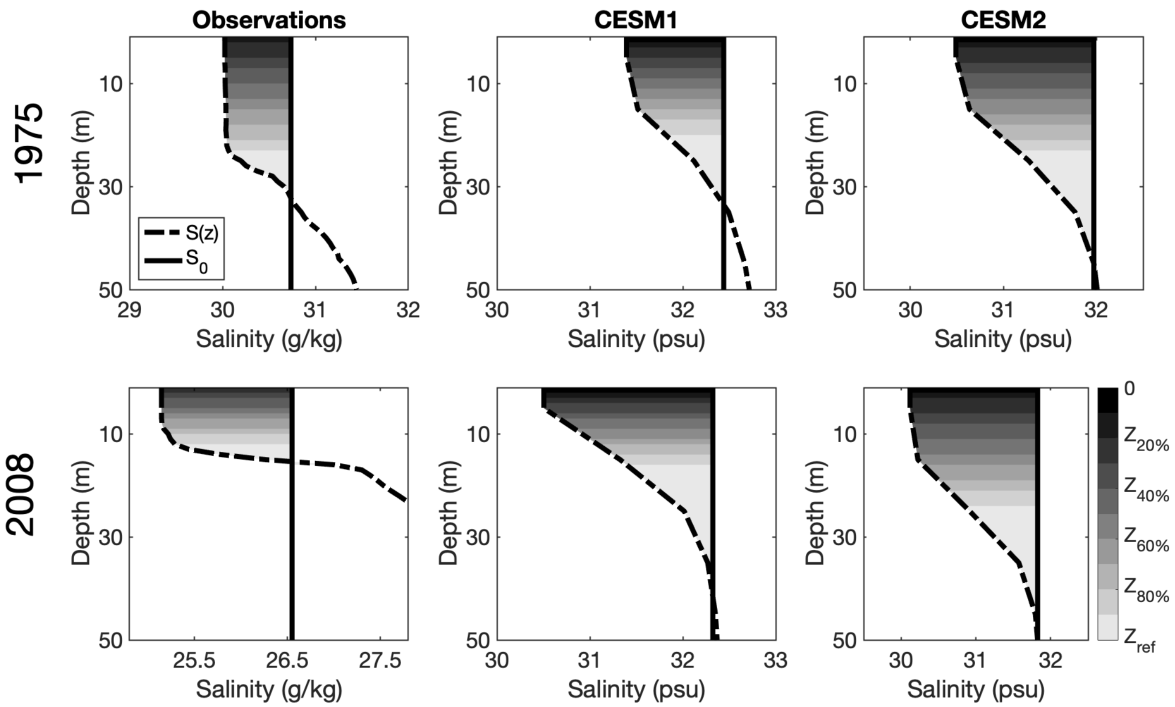

Figure S3. Examples of how sFWC and $Z_{10\%}, Z_{20\%}, ..., Z_{fw}$ are computed in the observations (left column), CESM1 (middle column), and CESM2 (right column) using data from 1975 (top row) and 2008 (bottom row).

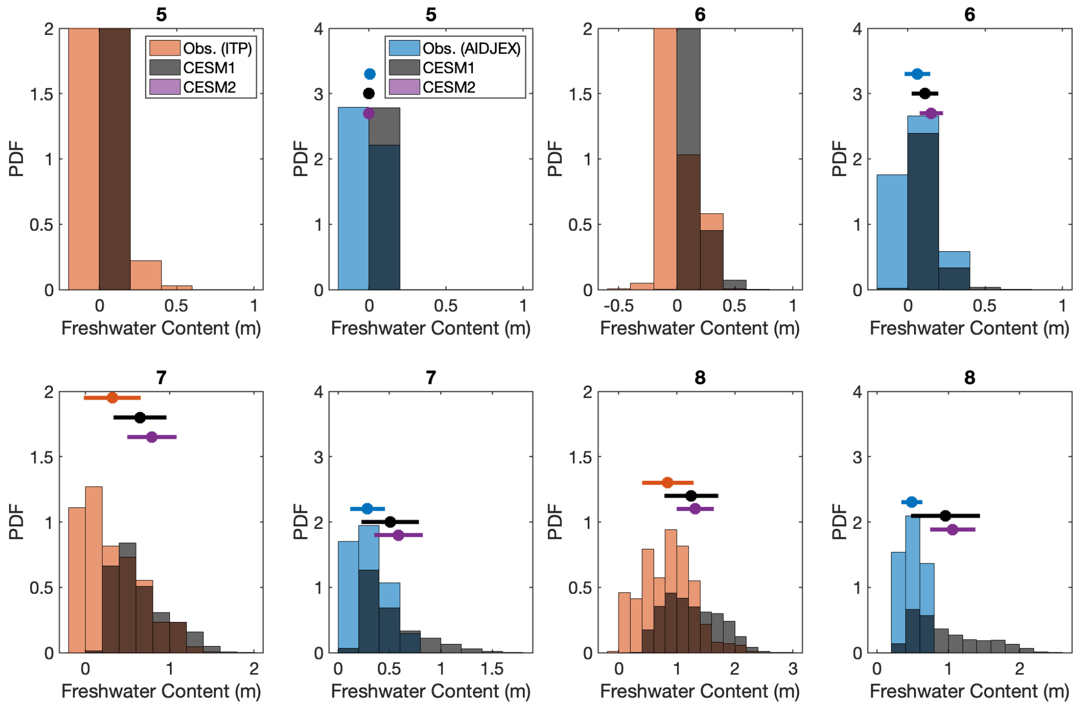

Figure S4. As in Figure 4d-e, but for May-August (5-8). Only the mean and standard deviation are included for CESM2 (purple).

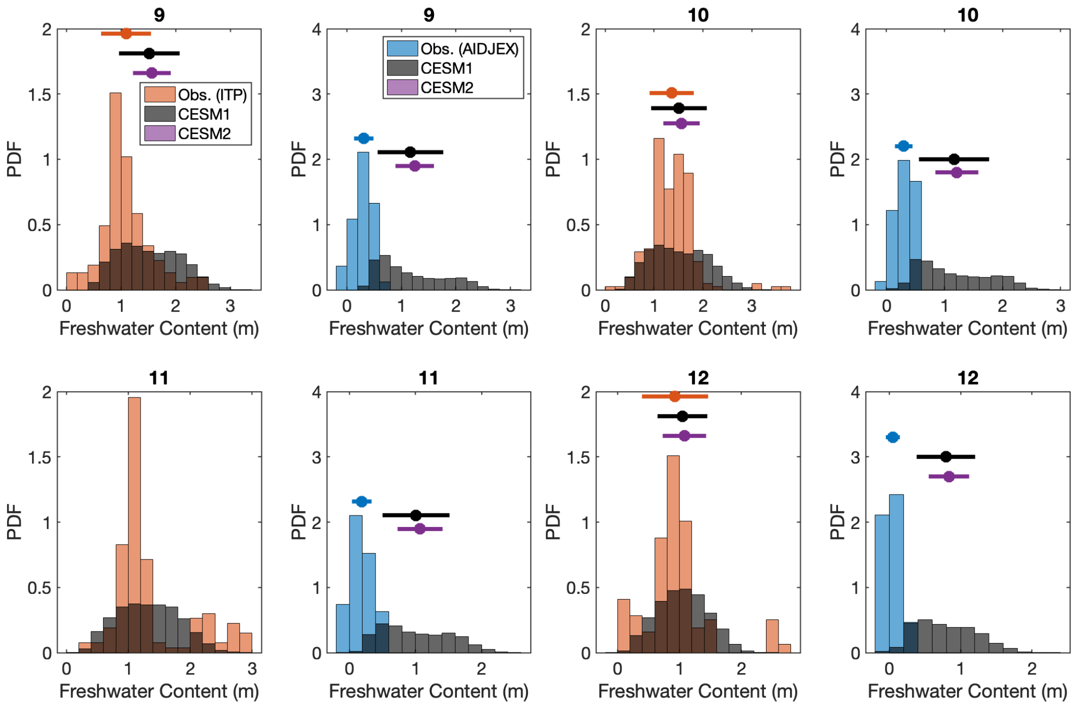

Figure S5. As in Figure S5, but for September-December (9-12).

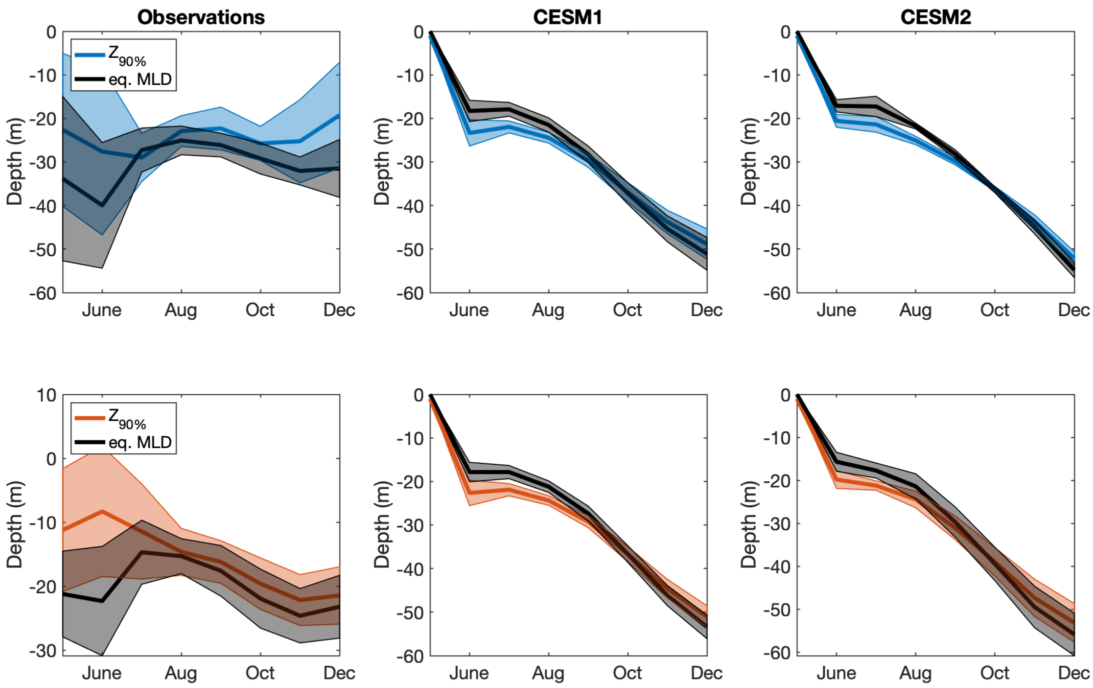

Figure S6. $Z_{90\%}$ (blue, red) and equivalent mixed-layer depth (black) in 1975 (top row), 2006-2012 (bottom row). Solid line indicates basin ensemble mean, and shading indicates the spread across the ensemble members using one standard deviation.