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Supporting Information for

Do salinity variations along the East Greenland Shelf show imprints of increasing meltwater runoff?

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Introduction

This supporting information includes a description of the methods to distinguish the East Greenland Coastal Current (EGCC) from the outer East Greenland Current (EGC) in Text S1 along with an example diagram in Figure S1. Further, validation of the VIKING20X and GLORYS12 model output is provided using mooring measurements at the Overturning in the Subpolar North Atlantic Program (OSNAP, Lozier et al., 2019) East section; results are presented in Figure S2 and discussed in Text S2.

The differences in freshwater transport (FWT) at Fram Strait between the models and observations are discussed in Text S3. The mean FWT along the section and the resulting changes in FWT along the section if the shelf is included or excluded is shown in Figure S3.

The January FWC anomalies based on the composite analysis focuses on differences in preconditioning in the Labrador and Irminger Seas in January. This is described in Text S4 and shown in Figure S4.

Text S1 - Cross Sections along East Greenland

The maximum spatial extent of the outer EGC is determined by depth integrating the transports and cumulatively summing over the section from the coast to offshore. The local extrema represent current separations across a given section (Handmann, 2019), shown in Figure S1a. There are seasonal differences in the local maxima of the cumulative transport with the maximum extent of the outer EGC occurring in winter and indicative of positional changes in the salinity front.

The averaged velocity field for VIKING20x (Figure S1b) demonstrates the existence of two southward flowing velocity cores off the East Greenland shelf. There is a faster flowing current closest to the shelf and then the mean velocity increases to 0 m/s and decreases sharply again just beyond the shelf break, signifying the outer EGC. The EGCC is not distinguishable in the local extrema when looking at the cumulative transport, but the two intensified velocity cores at the shelf and beyond the shelfbreak are identifiable. We define the EGCC extent to be the distance where the velocity becomes zero just where the shelf break occurs.

Since the position of the salinity front off the Greenland shelf is observed to change due to local wind events, seasonality, and interannual variability (Duyck et al., 2022), we use a time-varying salinity and velocity threshold mask to capture the temporal changes of the EGCC and outer EGC as well as separate the two inner and outer EGC cores. Since the EGC is observed to meander, particularly north of Denmark Strait (de Steur et al., 2016, Håvik et al., 2017), a rigid minimum distance and depth-based boundary between the shelfbreak and exterior EGC may not account for the dynamics of the current.

The summer salinity over the section is shown in Figure S1c where salinities less than 34.8~psu deepen near the shelf, and further offshore the mask shallows and salinities less than the threshold extend to the top 200 m. The polar surface water flowing along the EGCC is seen by the wedge of fresh and cooler water just along the shelf shown in Figure S1c and d. At the second velocity core of the EGC system at the Helheim cross section, where the current speeds up just beyond the shelfbreak, there is a dip in the isopycnals where less dense (warmer though more saline) water is advected southward clearly separating the EGCC from the outer EGC. This denser water west of the outer EGC carries the signature of water masses from the interior basin.

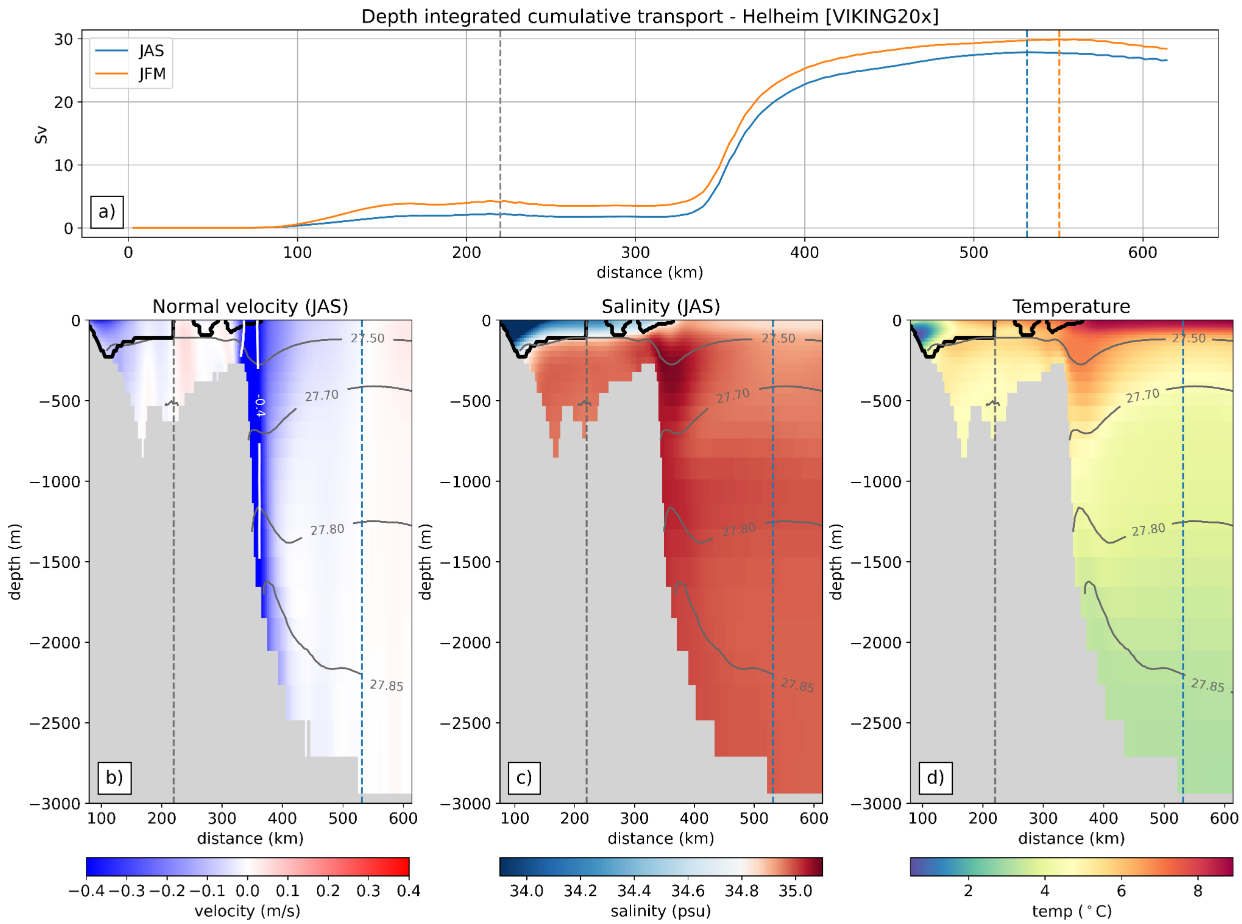

Figure S1: a) Depth integrated cumulative transport across the section for the cross section south of Helheim glacier in VIKING20X. Blue and orange dashed lines indicate the maximum extent of the EGC in summer and winter. b) Summer mean (July - September) velocity across the Helheim section. The grey and blue dashed lines indicate the EGCC and outer EGC separations, and the grey solid lines show the density contours referenced to the surface. c) Mean salinity across the section during summer. d) Mean summer temperature across the section. The black contour shows the salinity and southward-only velocity threshold applied to isolate the EGCC and outer EGC. The white contour shows where mean velocities are greater than .4 m/s.

Text S2 - Model Validation with Observational Cross-Section

We use temperature and salinity from moored sensors extending from August 2014 to 2018 along the OSNAP East section from Cape Farewell (Lozier et al., 2019, Straneo et al., 2018, Straneo et al., 2021) to validate VIKING20X and GLORYS12 model output. The moored sensors typically record in every 15 minutes but the data was upsampled to monthly time steps for the application here.

In Figure S2 we compare the seasonal evolution of the temperature-salinity (TS) diagrams of VIKING20X and GLORYS12 with CTD data. Using OSNAP East moored CTD measurements below 50~m depth from CF1 to CF7, CF1 being closest to the shore, for both summer and winter, the freshest and coolest water is within the top 50 - 100 m and closest to the shelf. The mooring closest to the shelf (CF1) and farthest away from the shelf (CF7) had limited sampling due to mooring degradation overtime (Le Bras et al., 2018).

Figure S2a - c shows the TS diagrams in summer at OSNAP East for each data set. Closest to the shelf from 50 - 100 m depth OSNAP East in-situ measurements are found to be only slightly fresher and cooler than the simulations by VIKING20X.

From 100 - 200 m depth, VIKING20X is comparable to in-situ measurements but the freshest waters are warmer in the model. While GLORYS12 is more saline from 100 - 200 m. Particularly in the summertime means, GLORYS12 and OSNAP both become fresher with increasing depth beyond 400 m where the tail end of the TS diagram tilts toward fresher isohalines, which is not seen in VIKING20X.

For the winter season (Figure S2d, e, f) OSNAP East and VIKING20x closest to the shelf are comparable in minimum temperatures while GLORYS12 is almost 1°C warmer. OSNAP moorings are slightly fresher, as indicated by a linear fit (blue line), where the minimum salinities for VIKING20X and GLORYS12 fall just under this best fit.

Salinity and temperature values between the 50 - 100 m and 100 - 200 m depth ranges are dispersed in the mooring data, while VIKING20X shows slightly higher temperatures from 100 - 200 m but the salinities are comparable to those at 0-100 m. While GLORYS12 shows a defined separation between the top 100 to 200 m, where the fresh and cooler waters are primarily contained within the top 100 m.

In both summer and winter averaged months, VIKING20X has surface and shelf salinities comparable to OSNAP East observational data while GLORYS12 is markedly more saline near the shelf and surface.

For both models and observations, the seasonal dependence of salinity and temperature changes are evident: close to the shelf and at depths less than 50 m, the salinity decreases but temperature increases during the summer months versus winter where there is a clear linear trend in decreasing temperatures and salinities dependent on depth and proximity to the shelf.

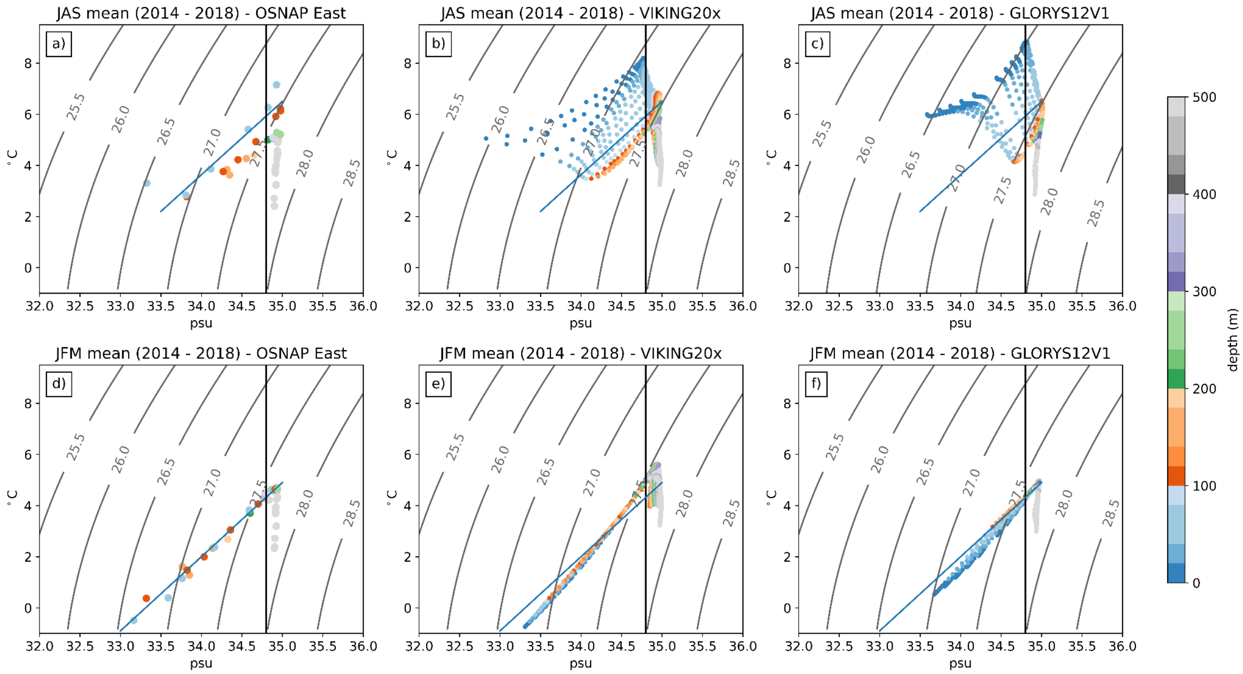

Figure S2: TS diagrams at OSNAP East for summer (July to September, JAS) mean conditions (top row) and winter mean (January to March, JFM, bottom row) from OSNAP East moored observations, panels (a) and (d), VIKING20X monthly mean model output, (b) and (e), and GLORYS12 reanalysis, (c) nad (f). The colorbar indicates the depth, the grey vertical line shows the 34.8 isohaline.

Text S3 - Freshwater Transport at Fram Strait

We compute the freshwater transport (FWT) for the EGC system, based on the time-varying salinity (S < 34.8 psu) and velocity (V < 0 m/s) masks for the interpolated moored observations, VIKING20X, and GLORYS12 (see description of the method in Supporting Information section S1). Note that the EGCC was not observed at Fram Strait, based on the criteria for two distinct, surface-intensified southward velocity cores. Thus we will refer to the southward flowing current from the shelf to just off the shelfbreak as the EGC.

Figure S3a, c, and e show the normalized, mean FWT from September 2003 - 2019 averaged over the entire cross section at Fram Strait for the observations, VIKING20X, and GLORYS12. The FWT normalized by dividing the horizontal grid cell area to account for variations in grid cell sizes and compare the magnitudes between the observations and models. The observations range from 8°W to 2°W starting just off the shelf, while VIKING20X and GLORYS12 reach from the shelf to 2°W.

The observations show the greatest FWT near the surface, where salinities are lower and southward current speeds are intensified over the top 100m throughout the entire section in the Figure S3a. While VIKING20X and GLORYS12 show an increased mean FWT near the surface and further offshore between the mooring array limits defined by the black dashed lines in Figure S3c and e. Mean FWT values reach depths up to 1000m in the observations with a deepening just off the shelfbreak, while VIKING20X and GLORYS12 are shallower. The FWT in VIKING20X reaches a maximum depth of ~600m, while GLORYS12 shows the FWT reaching depths only ~350m.

The time series of freshwater transport for the observations is greater than for both models shown in Figure S3d and e, however there are differences in FWT magnitudes when the shelf is included in both models, particularly for VIKING20X. Figure S3d shows the monthly FWT for the observations with the FWT for VIKING20X over the region of the mooring array extent (dashed orange line) and then the FWT with VIKING20X extended to the shelf (solid orange line). The FWT shows similar variability and comparable magnitudes with the observations when the shelf is included, indicating the freshwater is exported closer to the shelf rather than further offshore beyond the shelfbreak. GLORYS12 on the other hand still has lower FWT magnitudes within the mooring array limits (dashed green line) and when the shelf is included (solid green line).

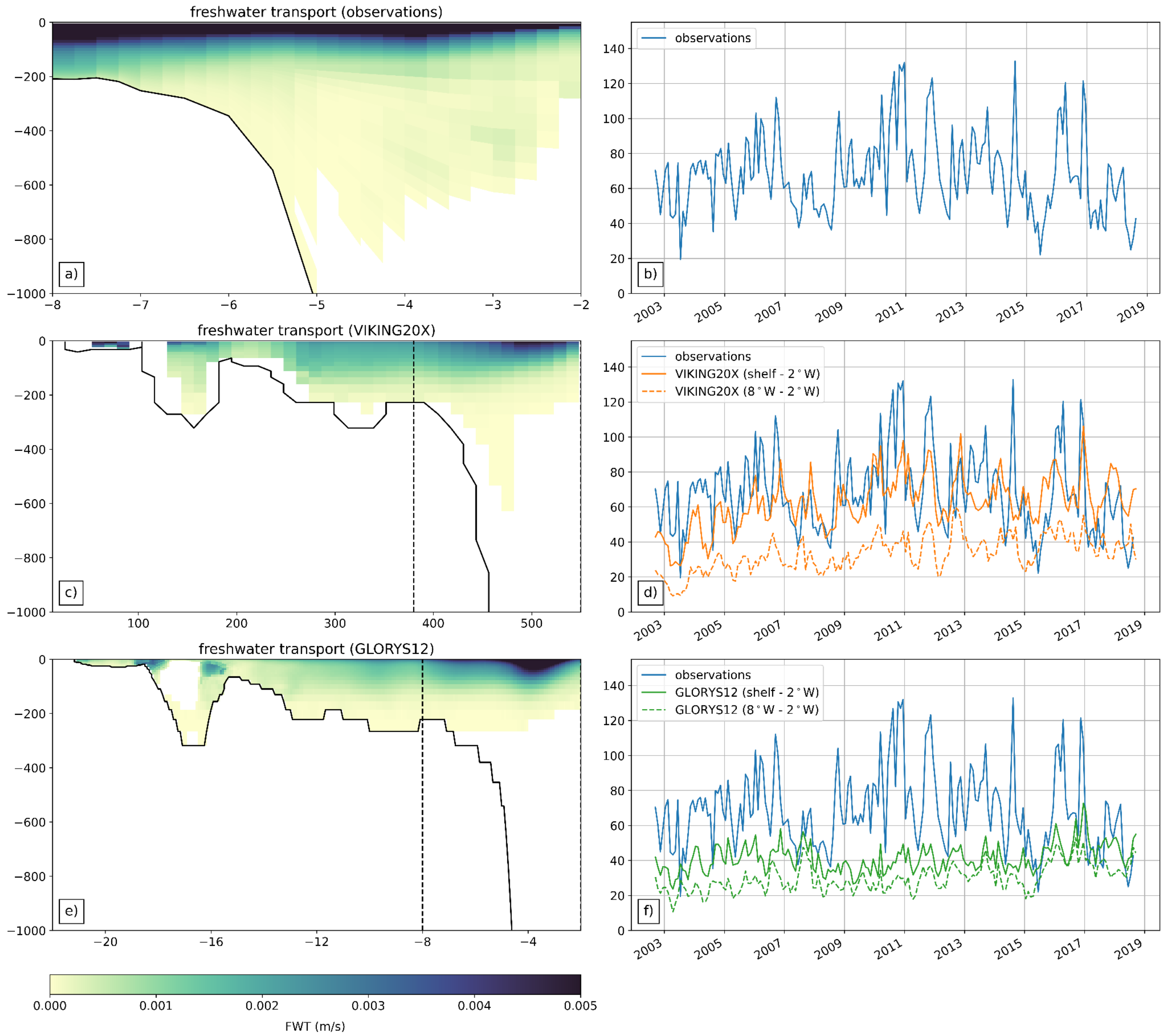

Figure S3: a, c, d) The mean FWT from 2003--2019 divided by the grid cell area along Fram Strait. The FWT per grid cell area is masked based on the EGC properties (salinities less than 34.8 psu and southward only velocities). Panel a is from the mooring observations from 8°W - 2°W, panel c is for VIKING20X (shelf - 2°W), and panel e is for GLORYS12 (shelf - 2°W). The solid black line is the bathymetric contour. The black dashed lines in panel c and e define the mooring array limits (8°W - 2°W), where the mean FWT for the observations extends from 8°W - 2°W in panel a. Note the change in the x-axis limits. The distance along the section from the shelf is in meters for VIKING20X, while the observations and GLORYS12 are in longitude. b, d, f) Panels b, d, f show the monthly FWT time series for the observations, model, and reanalysis output. The blue line is for the observations the orange solid/dashed line shows FWT from VIKING20X taken over the shelf to 2°W/8°W to 2°W. The green line shows the FWT from GLORYS12, with the solid and dashed lines corresponding to the same distances as in VIKING20X.

Text S4 - January FWC Anomalies from the Composite Analysis

As FWC plays a role in the preconditioning of ocean deep convection, the composite analysis is carried out for following January based on the same years from the composite shown in section 3.4. We focus on the spatial distributions of FWC anomalies. We choose to focus on January for the composite proxies and FWC for a few key reasons. It takes about 4 - 8 months for freshwater to propagate downstream from Fram Strait to Cape Farewell, as discussed in section 3.2, where Greenland meltwater peaks in July and August adding additional freshwater all along the East Greenland shelf. By selecting January, which is 5 - 6 months after Greenland runoff and sea ice melt freshwater input increases, the timing of the previous summer's runoff plus the are likely included in the FWC. We note, that due to the short advective timescale (1 month for the Irminger region, 4 - 8 for north of Denmark Strait), most of the meltwater likely has left the region with the boundary current but some of it likely has been mixed into the central Irminger and Labrador Seas by eddy processes. Lastly, January falls just before the onset of deep convection, reducing the chance of freshwater near the shelf to be mixed away from convective processes.

The January of the following year is computed to focus on the net effect of the respective wind or meltwater forcing on winter FWC and stratification. The composites of the January FWC anomalies under differing conditions (maximum minus minimum years freshwater input and weak minus strong winds) are computed (Figure S4a, b, c).

The spatial pattern of FWC composite differences (Figure S4a) from Greenland runoff as the composite proxy shows reduced FWC around the southeast Greenland shelf for strong runoff years compared to low years. There are slightly higher FWC anomalies around southeast Greenland, the Labrador, and Irminger seas with a patch of increased FWC along the northern western coast of Greenland. However the positive FWC appears minimal. Greenland runoff from August in the following year is likely mixed away in the boundary current.

Figures S4b the associated January FWC composite difference from strong minus weaker sea ice melting conditions. In Figure S4c, there are positive FWC anomalies along west Greenland, south of Baffin Bay as well as flowing along southern Greenland with the boundary current, reaching further offshore into the northern Labrador Sea. The magnitudes of the anomalies are much lower than the magnitudes right after the peak input of freshwater, as mixing and boundary current processes have likely advected and salinified the meltwater input.

Figure S4c shows the January FWC anomaly just one month after the December alongshore wind stress (weaker minus stronger alongshore winds). As alongshore winds strengthen starting early winter, the FWC anomaly shows a fresher EGCC particularly south of 70°N, where a clear shelfbreak is seen. The FWC anomaly difference becomes minimal but is weakly positive over the interior Irminger and Labrador Sea.

There is primarily offshore Ekman transport anomalies showing the different between strong onshore minus weak onshore transport. However just along the southern coast of Greenland south of 63°N, there is a small area where there is an onshore Ekman transport anomaly, suggesting that there was a point where the potential for offshore transport (weaker alongshore winds) was greater than onshore Ekman transport (strong alongshore winds).

Prior to deep convection occurring primarily in February or March, the January FWC has weakly positive FWC anomalies for Greenland FWFs and sea ice production. For the alongshore wind stress, there is enhanced FWC particularly along the EGCC south of 70°N as weaker onshore Ekman transport allows for freshwater in the EGCC to laterally expand and intrude into the outer EGC.

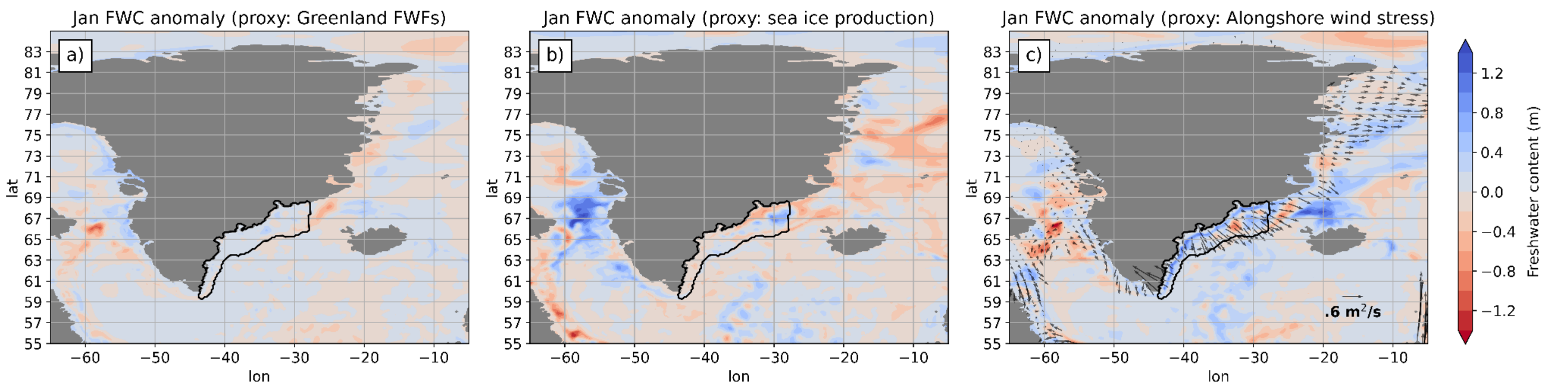

Figure S4: Panels a and b show the following year's FWC anomaly in January based on August and May composites of Greenland runoff and sea ice melt. Panel c shows the January FWC anomaly from weaker minus stronger alongshore winds. The black vectors signify the December Ekman transport anomalies. The black contour shows the southeast Greenland partition.

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