**Supplementary Information for**

# Vertical redistribution of principle water masses on the Northeast Greenland Shelf

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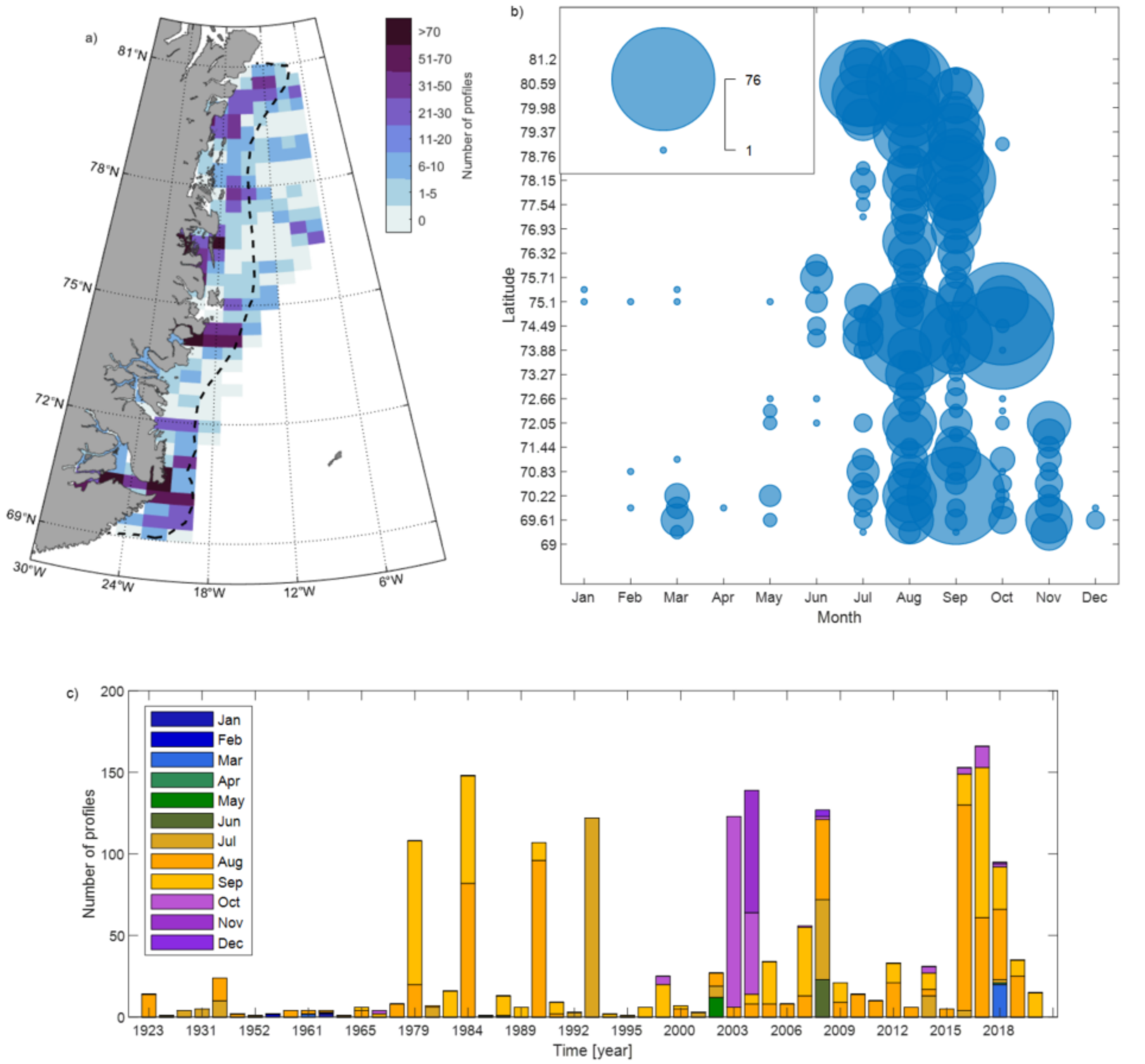


**Fig. S1. Spatial and temporal distribution of the hydrographic data set complied for the current study.** a) Total number of profiles per 1° longitude by 1/3° latitude bin. The black dashed line indicates the near-shore shelf region. b) Profile density for each month per 1/3° latitude bin within the near-shore shelf region. The number of profiles is given by the area of the bubble. c) Number of profiles per year colored by month within the near-shore shelf region.

**Supplementary note 1.** Spatial variability of temperature and salinity within the fjords was evaluated by calculating semivariance as a function of the geographical distance separating a pair of observations. Observations close in space are expected to be more similar (lower semivariance) than those separated by large distances. Calculating the semivariance for all possible pairs of observations and separation distances allows us to assess the spatial continuity of temperature and salinity and thus gives an indication of the extent of spatial variability within each fjord. Semivariance, $\gamma_x$, as a function of separation distance $h$ associated with variable $x$ is calculated as follows:

$$\gamma_x(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \big(Z(u_i) - Z(u_i + h)\big)^2 \tag{S1}$$

Where, $N$ is the number of data pairs for a given separation distance and $Z$ is the numeric value of the observation at the location given by $u_i$. A separation distance increment of 5 km was chosen for each iteration of the computation. Due to non-uniformly spaced data, a distance tolerance of half the separation distance increment was applied.

Equation (S1) was evaluated based on 1 m binned profiles and only calculated between observations collected in the same year as not to alias temporal with spatial variability. The semivariance was then averaged across years to arrive at the final estimate. All data pairs regardless of direction were included. The resulting statistic is therefore independent of direction.

Semivariances were generally small for depth levels greater than 30 m, and no systematic relationships between semivariance and separation distance were found (Supplementary Figure 2). Surface waters showed a higher degree of variability, but was neither related to separation distance. An exception was seen for the 15 m depth level in Dijmphna Sound where semivariance for both temperature and salinity increased as the distance between the observations increased (Supplementary Figure 2 b&c). The overall small and spatially unstructured semivariances give confidence that temporal trends in fjord properties are not an artefact of spatial variability.

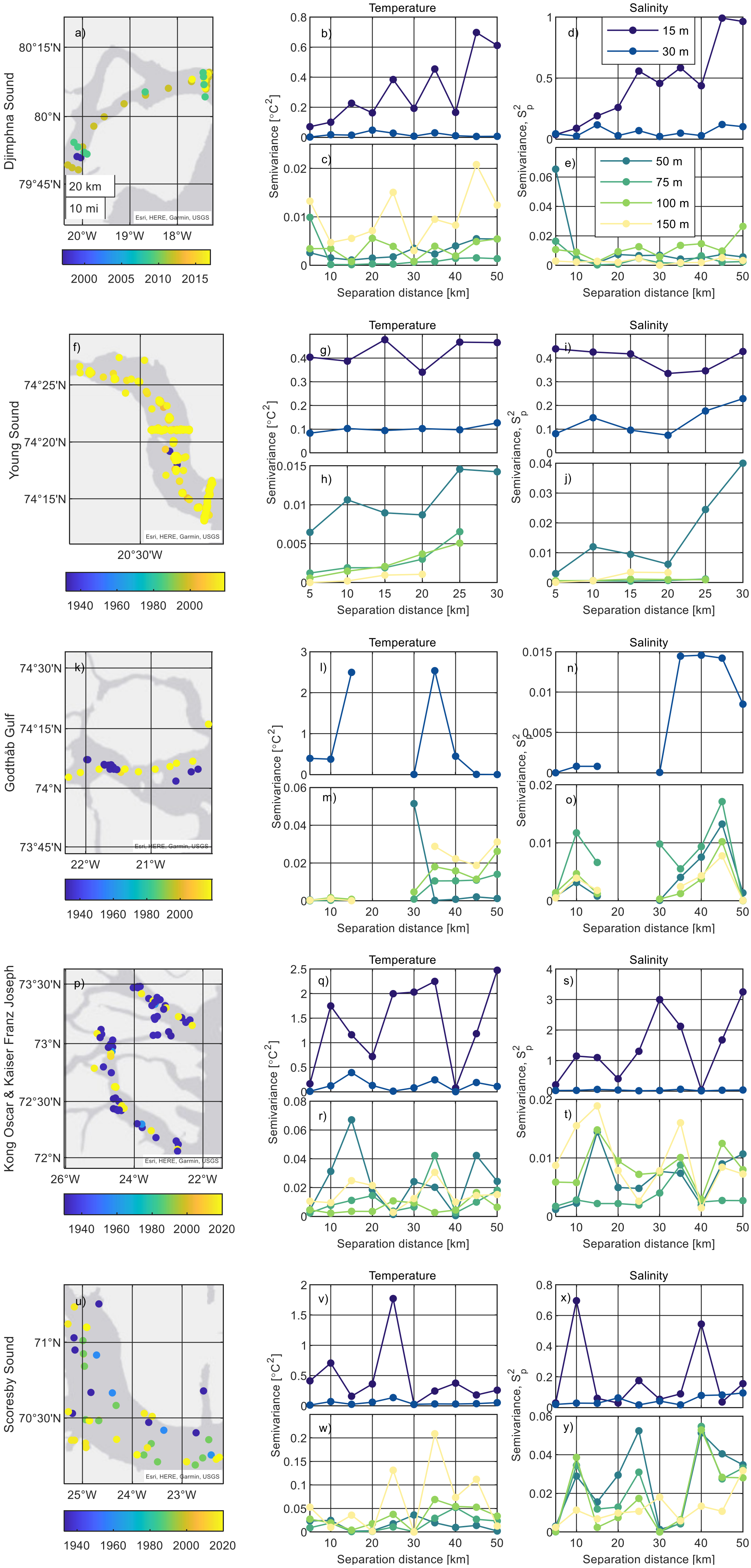
Djimphna Sound
Young Sound
Godthåb Gulf
Kong Oscar & Kaiser Franz Joseph
Scoresby Sound
Temperature
Salinity
Semivariance [°C$^2$]
Semivariance, $S_p^2$
Separation distance [km]
15 m
30 m
50 m
75 m
100 m
150 m
20 km
10 mi
Esri, HERE, Garmin, USGS
80°15'N
80°N
79°45'N
20°W
19°W
18°W
2000 2005 2010 2015
74°25'N
74°20'N
74°15'N
20°30'W
1940 1960 1980 2000
74°30'N
74°15'N
74°N
73°45'N
22°W
21°W
73°30'N
73°N
72°30'N
72°N
26°W
24°W
22°W
1940 1960 1980 2000 2020
71°N
70°30'N
25°W
24°W
23°W

**Fig. S2. Spatial variability of fjord properties**. Spatial distribution of observations by year (left column) and semivariograms for temperature (middle column) and salinity (right column) at the 15 m, 30 m, 50 m, 75 m, 100 m and 150 m depth levels for Dijmphna Sound (a-e), Young Sound(f-j), Godthåb Gulf (k-o), Kong Oscar and Kaiser Franz Joseph fjord (p-t) and Scoresby Sound (u-y). Panels a, f, k, p & u were prepared with the Mapping Toolbox for MATLAB version 5.1.

**Supplementary note 2.** Variance in the hydrographic metrics used throughout the study was investigated with the objective of comparing the variance arising due to sampling location and the variance arising due to temporal change in water mass properties. This was done for the repeat shelf transect outside Young Sound and the shelf area bounded by [“-16.97”, “78.00”, “-13.45”, “79.06”] sampled as part of the Fram Strait monitoring programme as well as several research cruises. The Young Sound shelf transect is 27 km long and has been sampled every year since 2003. Data from within the second area is available for 1956, 1979, 1984, 1993, 1998, 2000, 2002, 2012, 2016-2019. The variance of each metric is calculated for each year. Taking the average of these variances, gives a robust estimate of the variance arising due to differences in sampling location within the two areas. This value is compared with the total variance in each metric, calculated from all available summer samples collected within the two areas, respectively. Supplementary table 2 shows that variance is small when evaluated for a single year compared to when data from all years is included. This is formally corroborated with a two-sided F-test evaluating the null hypothesis, $H_0$: $\sigma_1^2 = \sigma_2^2$ against the alternative hypothesis, $H_A$: $\sigma_1^2 \neq \sigma_2^2$. The null hypothesis is rejected in all cases with minimum significance level of 5 %. Thus, the variance arising due to difference in sampling location is statistically different from the variance due to temporal changes in the hydrographic metrics at the two locations investigated.

**Table S1. Variance in four hydrographic metrics for the shelf transect outside Young Sound and Fram Strait.** Group 1 is the mean of the variance calculated for each individual year and therefore represents the variance arising due to sampling location along the transect. Group 2 represents the total variance in each metric. N gives the number of observations in each group. The F-test statistic for comparison of variances is given in the bottom row.

| | *N* | *PW temperature* | *PW salinity* | *AW temperature* | *AW salinity* |
|---|---|---|---|---|---|
| | | | Young Sound | | |
| *Group 1* | 17 | 0.0004 | 0.0078 | 0.1313 | 0.0101 |
| *Group 2* | 130 | 0.0026 | 0.2723 | 0.2723 | 0.0128 |
| $F_0$ | | 5.87 | 3.68 | 1.59 | 1.27 |
| | | | Fram Strait | | |
| *Group 1* | 12 | 0.0002 | 0.0236 | 0.0715 | 0.0038 |
| *Group 2* | 95 | 0.0031 | 0.1508 | 0.2692 | 0.0064 |
| $F_0$ | | 13.75 | 6.39 | 3.76 | 1.66 |

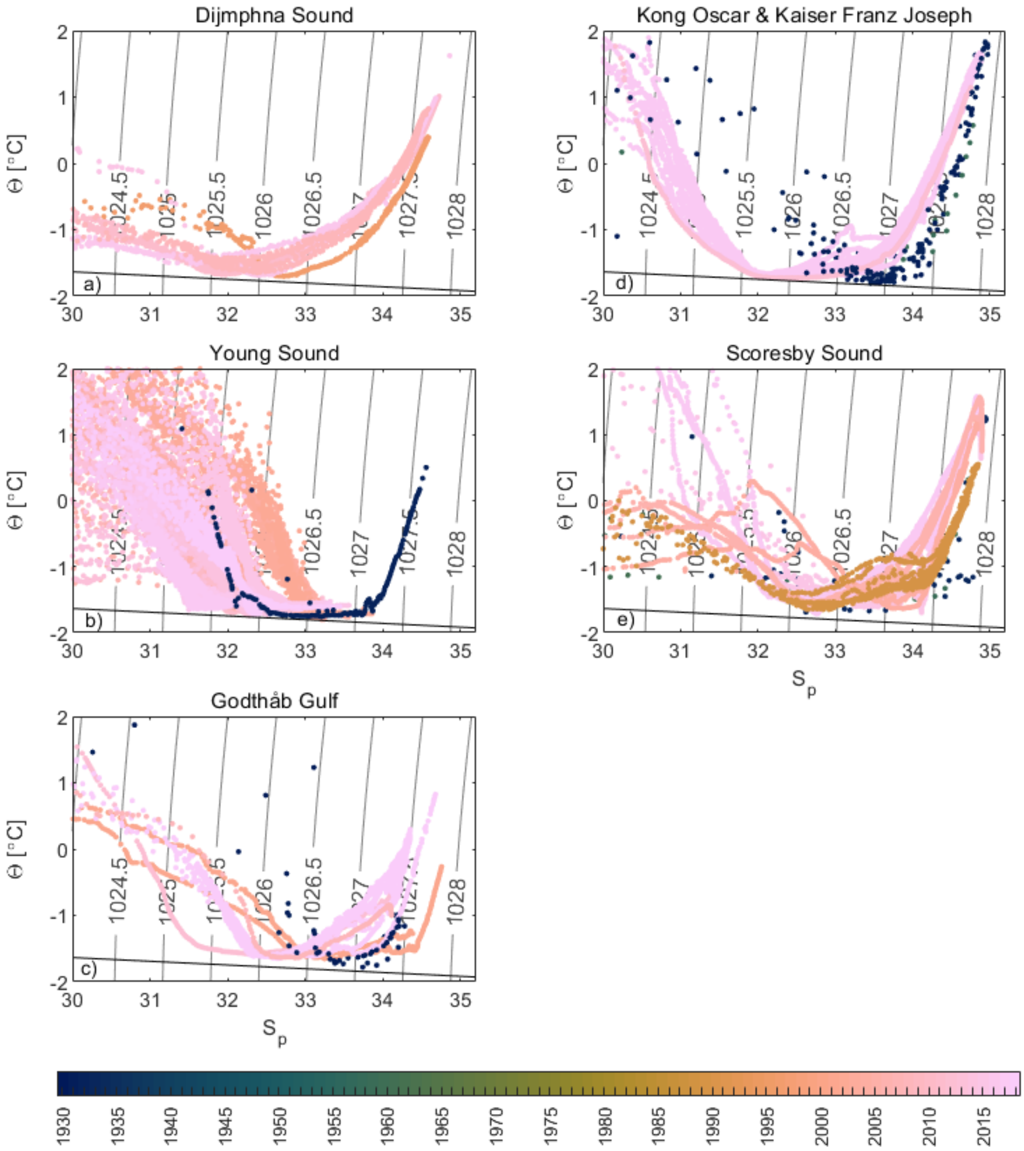


**Fig. S3. Temperature-salinity (T/S) diagrams of all available fjord data during July/August/September.** a) Dijmphna Sound, b) Young Sound, c) Godthåb Gulf, d) Kong Oscar & Kaiser Franz Joesph Fjord and e) Scoresby Sound. Measurements are colored by year of sampling. Mean T/S diagrams are provided on Fig. 2 in the main text.

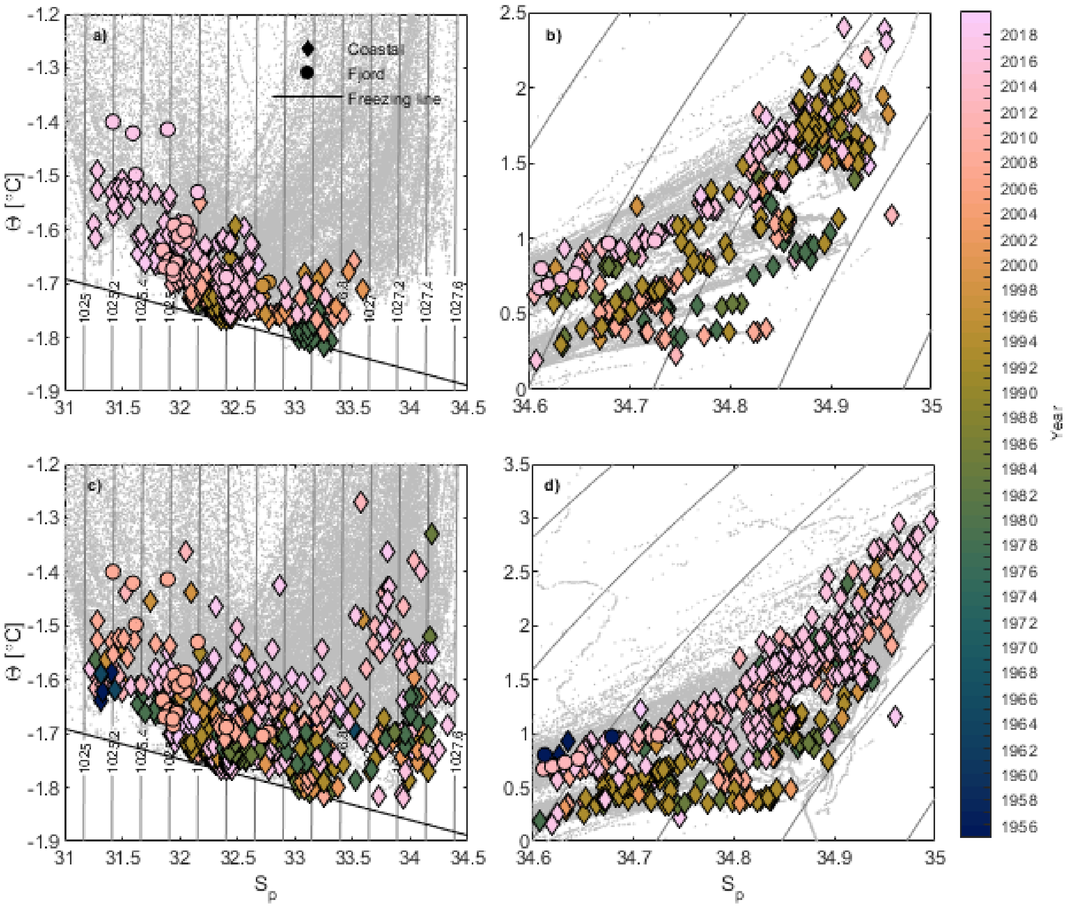


**Fig. S4. Temperature-salinity (T/S) diagrams showing core Polar Water (panels a & c) and Atlantic Water (panels b & d) properties during July/August/September for the region 81.3°N-74.71°N.** Fjord (circles) and shelf (diamonds) stations are superimposed. Time is given by color. Grey dots represent entire profiles. In the case of coarse vertical resolution these have been interpolated using the GSW function ”gsw_SA_CT_interp” designed to respect the shape of the profile in T/S space. This is done solely for visualisation purposes. Panels a & b are based on data from within the near-shore shelf region defined by a polygon extending 100 km seaward from the shoreline unless the shelf is narrower, in which case the 500 m isobaths was used instead (see Fig. 1 in the main text). Panels c & d are based on shelf data west of the 500 m isobath. Note, increased scatter in Polar Water properties, and the appearance of warmer and more saline Atlantic Water in comparison to panels a & b.

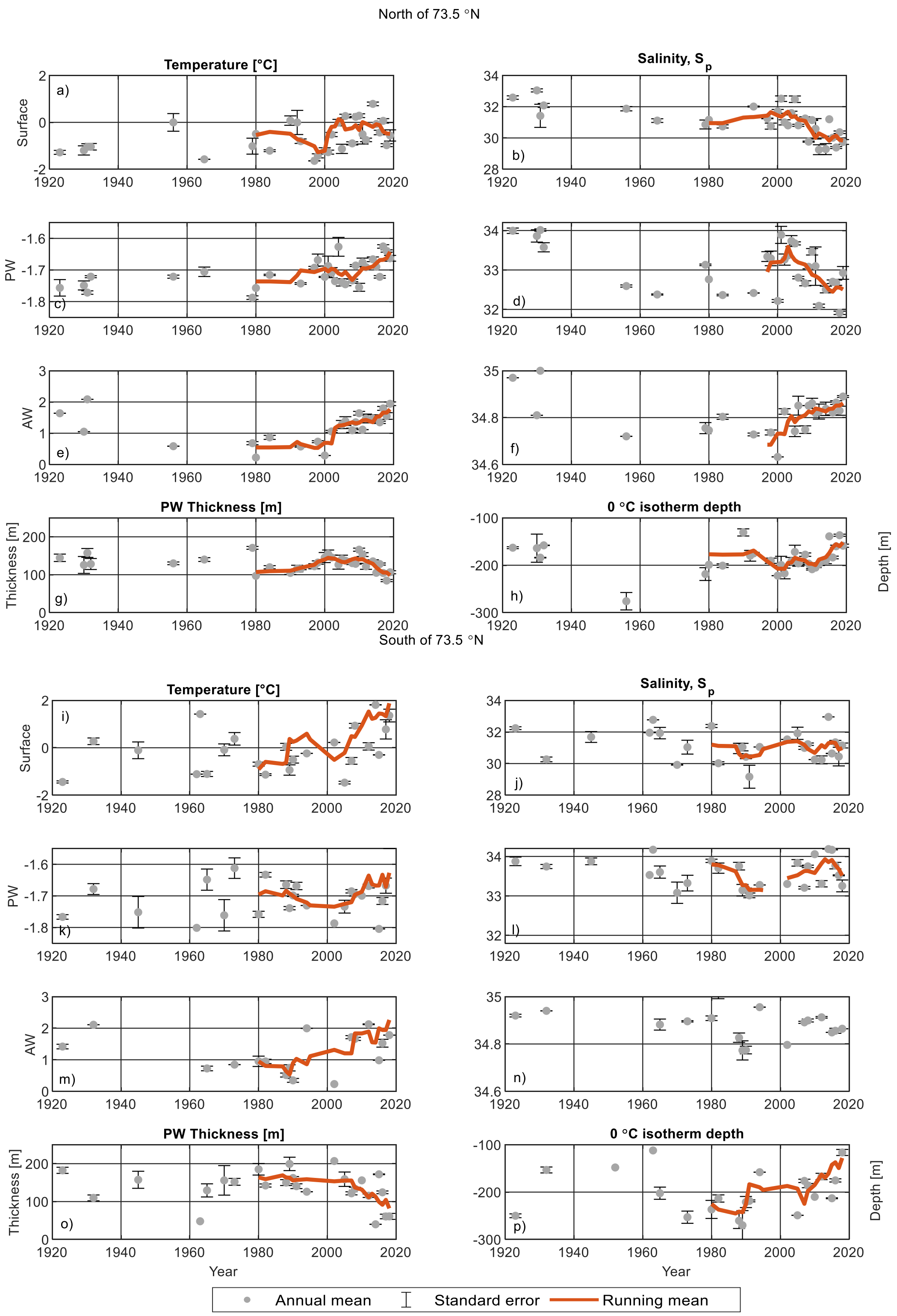


**Fig. S5. Time series of summer (July/August/September) shelf water properties north (panels a-h) and south (panels i-p) of 73.5 °N.** Surface water temperature (a & i) and salinity (b & j) defined as the mean of the 0-20 m depth interval, Polar Water (PW) core temperature (c & k), salinity (d & l) and layer thickness (g & o). Atlantic Water (AW) core temperature (e & m), salinity (f & n) and depth of the upper boundary of AW (h & p). Orange line shows the five-year running means and error bars are indicate the standard error.

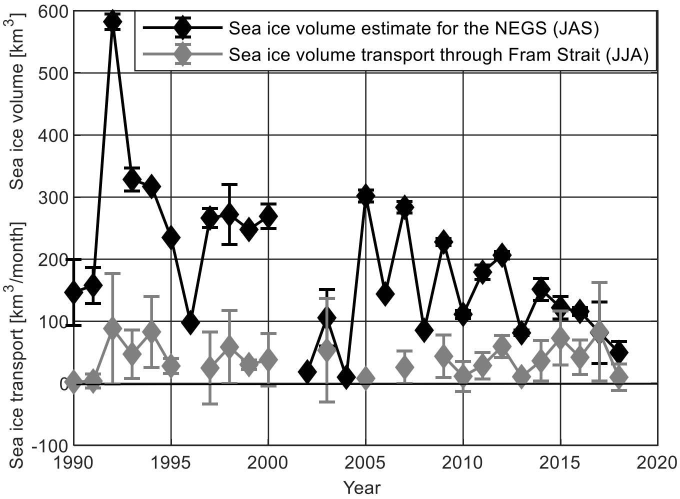


**Fig. S6. Summer time sea-ice volume and transport.** July-August-September (JAS) mean sea ice volume estimated over the Northeast Greenland Shelf (NEGS) and June-July-August (JJA) mean sea ice volume transport through the western Fram Strait. Error bars indicate one standard deviation.

**Table S2. Observations complied for the current study.**

| Expedition/monitoring programme | Time | Month | Number of stations | Data source/reference |
|---|---|---|---|---|
| Various | 1923, 1925-1926, 1929-1933, 1935-1936, 1938-1939, 1945, 1947-1952, 1954-1971, 1973-2019 | Jan, Feb, Mar, Jul, Aug, Sep, Oct, Nov | 344 | ICES https://www.ices.dk/ |
| Various | 1929-1933, 1935-1936, 1938-1941, 1947-1952, 1954-1955, 1973, 1979-2019 | Jan, Feb, Mar, Apr, May, Jun, Jul, Aug, Sep, Oct, Nov, Dec | 1030 | WOD https://www.ncei.noaa.gov/products/world-ocean-database |
| Various | 1990-2019 | Jul, Aug, Sep, Oct, Nov | 1000 | GTSPP https://www.ncei.noaa.gov/products/global-temperature-and-salinity-profile-programme |
| Norwegian expeditions to East Greenland (VESLEKARI and POLARBJØRN) | 1930-1932 | Jul, Aug | 42 | 1 |
| ARK-VII/3 (POLARSTERN) | 1990 | Jun, Jul, Aug, Sep | 9 | 2 |
| ARK-IX/3 (POLARSTERN) | 1993 | Jun, Jul, Aug | 169 | 3 |
| Nioghalvfjerdsfjorden glacier project | 1997-1998 | Jul, Aug | 9 | 4 |
| ARK-XIV/2 (POLARSTERN) | 1998 | Aug, Sep, Oct | 24 | 5 |
| ARK-XVII/1 (POLARSTERN) | 2001 | Jun, Jul | 16 | 6 |
| ARK XVIII/1a (POLARSTERN) | 2002 | Jul | 7 | 7 |
| ARK-XVIII/1b (POLARSTERN) | 2002 | Jul, Aug | 24 | 8 |
| ARK-XXIII/1 (POLARSTERN) | 2008 | Jun | 28 | 9 |
| ARK-XXIII/2 (POLARSTERN) | 2008 | Jul, Aug | 70 | 10 |
| ARCTIC SUNRISE | 2009 | Sep | 27 | 11 |
| ARK-XXIX/2.1 (POLARSTERN) | 2015 | Jul | 2 | 12 |
| MSM56 (MARIA S. MERIAN) | 2016 | Jul | 10 | 13 |
| PS100 (POLARSTERN) | 2016 | Jul, Aug, Sep | 22 | 14 |
| PS109 (POLARSTERN) | 2017 | Sep, Oct | 127 | 15 |
| Oceans Melting Greenland | 2016-2019 | Aug, Sep, Oct | 130 | NASA https://omg.jpl.nasa.gov/portal |
| TUNU expeditions | 2002-2003, 2005, 2007, 2010, 2013, 2015 | Aug, Sep, Oct | 28 | Christiansen pers coms. |
| Greenland Ecosystem Monitoring Programme | 2003-2019 | Jul, Aug, Sep | 861 | GEM https://data.g-e-m.dk/ Sejr & Winding pers coms. |
| Fram Strait | 2012, 2015-2016 | Aug, Sep | 150 | Dodd, de Steur, Pavlov and Kowalczuk pers coms. |
| NAACOS expedition (DANA) | 2012 | Aug | 10 | Stedmon pers coms. |
| NEG Ecosystem Assessment (DANA) | 2017 | Aug, Sep | 83 | Friis Møller pers coms. |
| East Greenland Fjords (LAKO) | 2018 | Aug | 25 | Sejr pers coms. |

## Supplementary References


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