



Influences on Chemical Distribution Patterns across the west Greenland Shelf: The Roles of Ocean Currents, Sea Ice Melt, and Freshwater Runoff

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Abstract The west Greenland shelf is a dynamic marine environment influenced by various physicochemical and biological processes. This study provides an overview of the main factors affecting the distribution of macronutrients, carbonate system parameters, and dissolved trace elements during late summer. Key drivers include major ocean currents, melting sea ice, and terrestrial freshwater runoff, each uniquely contributing to the cycling and spatial distribution of chemical constituents. Major ocean currents, such as the southward-moving Baffin Island Current (BIC) and the northward-moving West Greenland Current (WGC), shape the chemical composition of shelf waters by introducing water masses with distinct chemical signatures. Melting sea ice is an important source of freshwater and dissolved constituents for the marine environment. The east-to-west direction of sea ice retreat creates nutrient gradients, with low nutrient levels in highly productive shelf waters and high nutrient levels in areas with prolonged ice cover. This process also affects the carbonate system, leading to changes in pH and aragonite saturation states, which is critical for the health of marine organisms. Terrestrial freshwater runoff, particularly from the Greenland Ice Sheet (GIS), replenishes macronutrients in the photic zone, stimulating primary production and creating important CO₂ sinks. However, surface waters become more susceptible to acidification by the input of poorly buffered glacial freshwater. Understanding these key drivers is essential for forecasting future changes in the marine chemistry and biology of the west Greenland shelf, especially in the context of ongoing climate change within this high-latitude region.



1 Introduction

The physical system of the Arctic Ocean is inevitably changing, with profound implications for primary productivity (PP) and the biogeochemical cycling of nutrients and carbon on shelves and in deep basins (Juranek, 2022). The complex coastal current system that connects the continental shelves of Greenland with the Arctic Ocean, the North Atlantic Ocean, and the Pacific Ocean strongly impacts PP (Vernet et al., 2021), creating an important environment for biota and fisheries (Krawczyk et al., 2021). The major ocean currents on the west side of Greenland are shown in Fig. 1 a. The circulation across the west Greenland shelf and Baffin Bay is dominated by the opposing direction of the Baffin Island Current (BIC) and West Greenland Current (WGC) (Curry et al., 2011). On the western side of Baffin Bay, the surface-intensified BIC transports water from the Alaskan shelf and the western Beaufort Sea through the narrow and shallow channels of the Canadian Arctic Archipelago (CAA) across Davis Strait into the Labrador Sea (Nares Strait, Jones Sound, and Lancaster Sound) (Aksenov et al., 2016; Curry et al., 2011; Tang et al., 2004). Arctic waters of Pacific origin that enter Baffin Bay through the CAA have been described to be a source of dissolved trace elements (e.g., dMn, dFe, dCu, dNi) (Colombo et al., 2020; Colombo et al., 2021; Jensen et al., 2022) and carbon (Azetsu-Scott et al., 2010; Burgers et al., 2024; Shadwick et al., 2011b). Further south, Davis Strait has been suggested as a gateway for the transport of dissolved trace elements (Krisch et al., 2022a) and dissolved inorganic nitrogen (Juranek, 2022) from the Arctic to the North Atlantic Ocean. On the eastern side of Baffin Bay, the West Greenland Current (WGC) flows northward across Davis Strait and consists of the warm and low-salinity West Greenland Coastal Current (WGCC) on the shelf and the warm and high-salinity West Greenland Slope Current (WGSC) (Curry et al., 2011). Waters of North Atlantic origin have been associated with anthropogenically elevated dissolved lead (dPb) concentrations (Colombo et al., 2019), but also higher productivity and species richness across the west Greenland shelf waters (Krawczyk et al., 2021).

In the last two decades, sea ice concentrations in Baffin Bay and the Labrador Sea have decreased significantly due to climate change (Krawczyk et al., 2021). Reduced sea ice cover has been correlated with an overall increase in productivity and species richness along the west Greenland shelf (Krawczyk et al., 2021; Møller et al., 2023). In all seasonally ice-covered areas, intense but short-lived phytoplankton blooms develop in low-salinity waters at the edge of melting and retreating sea ice from spring to late summer (Niebauer et al., 1995; Perrette et al., 2011). Phytoplankton growth is triggered by the stabilizing effect of sea ice meltwater-induced stratification in surface waters and the increased solar irradiance as the ice cover shrinks (Strass and Nöthig, 1996; Perrette et al., 2011). The newly exposed waters are still nutrient-rich but quickly become depleted after the onset of the bloom (Niebauer et al., 1995). This is why macronutrient distributions (NO_x = nitrate + nitrite; phosphate, PO_4^{3-} ; silicate, $\text{Si}(\text{OH})_4$) in surface waters of Baffin Bay decrease along a west-to-east gradient as they generally follow the ice coverage (Lafond et al., 2019; Tremblay et al., 2002). Although sea ice meltwater is considered a negligible net source of macronutrients, it can significantly enhance trace element concentrations in the receiving waters (Evans and Nishioka, 2019; Hölemann et al., 1999; Kanna et al., 2014; Tovar-Sánchez et al., 2010). Elevated trace element concentrations in Arctic sea ice have been linked to entrained sediments (Measures, 1999) or atmospheric deposition from continuous emissions in highly industrialized countries (McConnell and Edwards, 2008). The carbonate system of Baffin Bay is influenced by sea ice



meltwater, as it has the potential to supply additional alkalinity (AT) (Jones et al., 1983). During sea ice formation, ikaite ($\text{CaCO}_3 \cdot 6\text{H}_2\text{O}$) precipitates within the sea ice and is reintroduced to the water column during ice melt, resulting in higher AT concentrations relative to dissolved inorganic carbon (CT), lower $p\text{CO}_2$ conditions, and higher pH as well as aragonite saturation state (Ω Aragonite) in surface waters (Fransson et al., 2013; Rysgaard et al., 2011; Rysgaard et al., 2012).

65 The mass loss of the Greenland Ice Sheet (GIS) has increased sixfold since the 1980s, with the region northwards of Davis Strait experiencing the largest mass loss (Mouginot et al., 2019; Wouters and Sasgen, 2022). The export of glacial runoff from the GIS alters shelf and slope waters significantly, thus impacting PP in near-coastal regions (Hawkings et al., 2015; Juul-Pedersen et al., 2015). The glacier-derived freshwater alters marine concentrations of macronutrients (Hawkings et al., 2015; Hawkings et al., 2016; Hawkings et al., 2017; Hendry et al., 2019) and dissolved trace elements (Hawkings et al., 2020; Krause

70 et al., 2021), impacts the hydrography, and facilitates the upwelling of nutrient-rich deep water (Meire et al., 2017; Juul-Pedersen et al., 2015). This fertilizes adjacent marine systems and promotes high levels of biological productivity (Bhatia et al., 2013; Hawkings et al., 2020; Oksman et al., 2022). Glacial freshwater exhibits low AT and carbonate ion concentration (CO_3^{2-}) relative to marine waters, reducing the capacity of glacially modified waters to resist changes in pH from the uptake of atmospheric CO_2 (Bates and Mathis, 2009; Chierici and Fransson, 2009; Fransson et al., 2015). In surface waters of the

75 Greenlandic coast, AT dilution from glacial meltwater has been observed to drive corrosive conditions with an overall decrease in Ω Aragonite and pH (Henson et al., 2023; Shadwick et al., 2013). Photosynthetic CO_2 uptake can mitigate this negative effect of AT dilution, as PP reduces CT and $p\text{CO}_2$ concentrations in surface waters and increases the carbonate saturation state (Chierici and Fransson, 2009; Hopwood et al., 2020; Meire et al., 2015).

In this study, we present recent (July 2021) measurements of the marine carbonate system, along with nutrient concentrations

80 and dissolved ($d; < 0.45 \mu\text{m}$) trace element concentrations across the west Greenland shelf in southern Baffin Bay between 64°N and 71°N (Fig. 1 b). Given the above considerations, the objectives of this study are to: (a) understand the physicochemical processes that influence the internal cycling of chemical constituents in the different water masses of shelf waters; and (b) resolve the regional and spatial differences in the distribution patterns on the west Greenland shelf during late summer that are driven by (i) major ocean currents, (ii) melting sea ice, and (iii) terrestrial freshwater runoff.

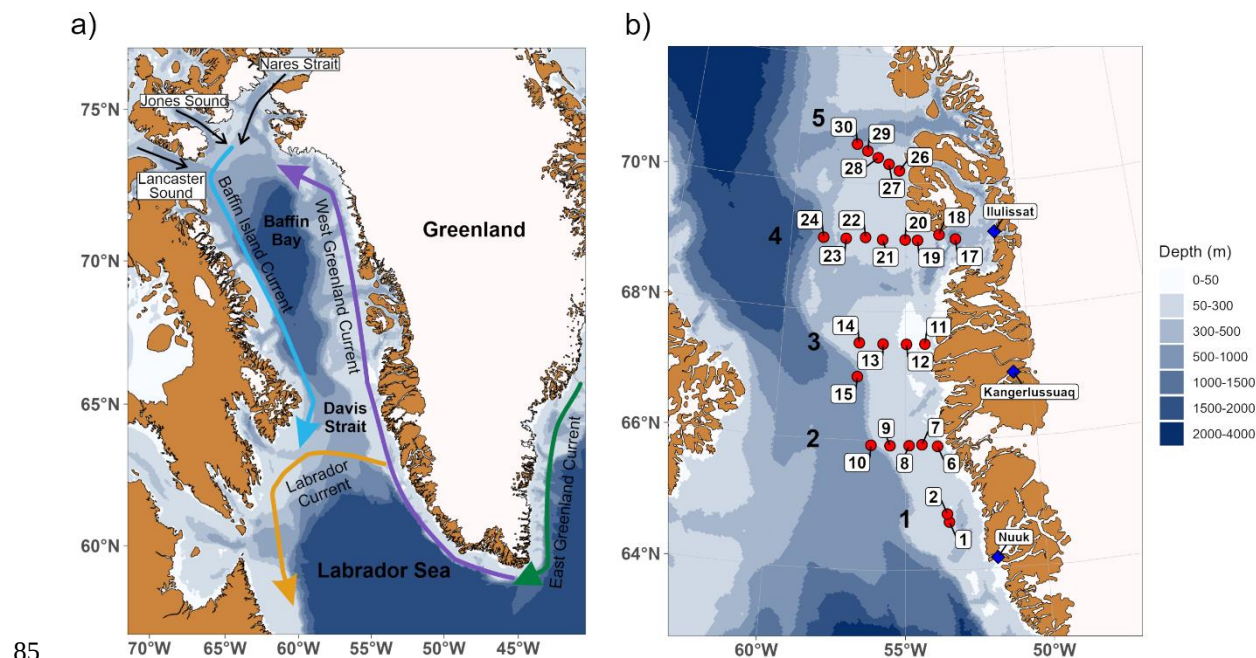


Figure 1: a) Schematic overview of the ocean currents and bathymetry in Baffin Bay and Davis Strait. Colored lines with arrows indicate the direction of different ocean currents. Bathymetry data from the GEBCO 2023 grid (GEBCO Bathymetric Compilation Group 2023, 2023). b) Map of the study area during DANA 6/21 with red points indicating the sampling locations and their affiliation to a certain transect (1-5).

2 Material and Methods

2.1 Study Area

A map of the study area with stations indicated by red dots is given in Fig. 1 b. General information about the selected stations and samples used in this study is provided in Table S 1. Samples were taken along two transects to the south and three transects to the north of Davis Strait along the west Greenland shelf. Transect 1 was located in a shallow area (< 120 m depth) north of Nuuk. Transects 2 and 3 started close to the mouth of Kangerlussuaq Fjord and Nassuttooq Fjord, respectively. Station 15, which is part of transect 3, had to be moved further south because of the presence of sea ice. Transect 4 started in Disko Bay approximately 70 km from the mouth of the Ilulissat Icefjord, where the Jakobshavn Isbræ terminates. Transects 2, 3, and 4 continued westward away from the coast towards the shelf edge. Transect 5 started close to Disko Island and continued towards the northwest.

2.2 Sampling

Water column samples were taken at 25 stations as conductivity-temperature-depth (CTD) casts along five transects during ten consecutive sampling days between 18 and 28 July 2021 on board RV *Dana* (DANA 6/21, Fig. 1 b, Table S 1). A SBE 911 CTD+ unit (Sea-Bird Scientific; Bellevue, USA) was used to collect hydrographic profiles, including temperature, salinity,



pressure, and dissolved oxygen. Samples were collected in 10 L Niskin water samplers (Ocean Test Equipment; Fort
105 Lauderdale, USA). Detailed information about each sample is given in Table S 1, with sample IDs corresponding to the
respective station and sampling depth.

2.2.1 Macronutrients

Water samples for nutrient analysis were collected in acid-washed 100 mL HDPE (high-density polyethylene) bottles. The
bottles were preconditioned three times with sample water before being filled. The samples were stored frozen at -20°C until
110 analysis.

2.2.2 Dissolved trace elements

Bulk samples for multi-element analysis were filled into acid-cleaned 2 L HDPE bottles. The bottles were rinsed three times
with sample water before being filled. Immediately after sampling, the water samples were filtered as duplicates using high-
purity PFA (Perfluoroalkoxy alkane) filtration bombs (Savillex, Eden Prairie, USA) pressurized with nitrogen 5.0 (Air Liquide
115 Danmark; Taastrup, Denmark) and acid-washed polycarbonate filters (0.45 µm, 47 mm diameter, Whatman, UK) in a clean
bench (Erlab; Val de Reuil Cedex, France). More information about the filtration procedure can be found in Przibilla *et al.*
(2023). The filtered samples were collected in pre-cleaned 250 mL HDPE bottles and stabilized using trace metal grade HCl
(Fisher Scientific; Waltham, USA) before storage and shipping.

2.2.3 Carbonate system parameters

120 Samples for AT and CT were collected in 300 mL BOD (biological oxygen demand) bottles (Environmental Express,
Charleston, USA) with an addition of 300 µL saturated mercury chloride solution (Carl Roth, Karlsruhe, Germany). The bottles
were sealed with ground-glass stoppers (Wheaton Science Products, New Jersey, USA), silicone- and halogen-free grease
(type M, Apiezon, Manchester, UK), and plastic caps (Wheaton Science Products, New Jersey, USA), leaving no headspace.
The samples were stored in darkness at ambient temperature until analysis.

2.3 Sample preparation and chemical analysis

2.3.1 Macronutrients

Nitrite, phosphate, and silicate were measured on a SmartChem 200 discrete analyser (AMS Alliance, Rome, Italy) following
the reagent concentrations for the manual method in Hansen and Koroleff (1999), with the inclusion of a 150 g L⁻¹ solution of
sodium dodecylsulfate as a dispersant for phosphate analysis. Nitrate was measured following the vanadium chloride reduction
130 technique described by Schnetger and Lehnert (2014). Community reference material for nutrients in seawater supplied by
Kanso Technos Co. LTD, Japan, was used for quality control.



2.3.2 Dissolved trace elements

All equipment for trace metal analysis was acid-washed prior to use and rinsed with type I reagent-grade water (resistivity: 18.2 MΩ·cm) obtained from a Milli-Q Integral water purification system (Merck; Darmstadt, Germany) to prevent contamination. Dissolved trace elements (dV, dFe, dMn, dCo, dNi, dCu, dCd, and dPb) in seawater were measured with a seaFAST SP2 system (Elemental Scientific; Omaha, USA) coupled online to an inductively coupled plasma mass spectrometer (ICP-MS) (Agilent 7900, Agilent Technologies; Tokyo, Japan). The seaFAST SP2 system contained two columns filled with Nobias chelate-PA1 resin (HITACHI High-Tech Fielding Corporation; Tokyo, Japan). Detailed operating parameters and instrument configurations are given in Table S 2. More information about the analytical procedure can be found in Ebeling *et al.* (2022). For method validation, the certified reference material (CRM) NASS 7 (National Research Council Canada; Ottawa, Canada) as well as an in-house reference material (KBA-QC) mixed from single element standards (Carl Roth GmbH, Karlsruhe, Germany or Sigma-Aldrich, Missouri, USA) and custom-made multi-element standards (all traceable to NIST standards) of different compositions (Inorganic Ventures, Christiansburg, USA) were used. Recovery rates (between 97 % and 119 %) are given in Table S 3.

2.3.3 Carbonate system parameters

Measurements of AT and CT were performed using a VINDTA 3 C system (Marianda; Kiel, Germany). AT and CT were determined simultaneously by potentiometric titration using an 800 Dosino (Metrohm; Filderstadt, Germany) with an Aquatrode plus (Metrohm; Filderstadt, Germany) and coulometric titration using a CM5017O coulometer (UIC; Illinois, USA), respectively. Both instruments were calibrated against seawater CRMs (Scripps Institution of Oceanography; San Diego, USA) to ensure a precision of $\pm 1 \mu\text{mol kg}^{-1}$ for each parameter.

2.4 Data analysis

The raw CTD data were processed and averaged into 0.5 dbar pressure bins. The processed CTD data were used to construct water depth profiles of potential temperature, salinity, potential density, and oxygen (Fig. S 1 to S 5). Calculations were performed using R (version 4.2.2; (R Core Team, 2022)) and RStudio (version 2023.06.0; (Posit team, 2023)). Bivariate, linear data interpolation in combination with a surface approximation using multilevel B-splines with the “interp” function (package akima; (Akima and Gebhardt, 2022)) and the “mba.surf” function (package MBA; (Finley et al., 2022)) was used before plotting.

For trace elements analysis, filtration duplicates were obtained and measured as triplicates ($n = 6$). Outliers were identified using a Dean-Dixon outliers test and removed from further analysis. Mean concentrations (μ) and standard deviation (SD ; σ) were estimated, considering twice the SD to represent $\mu \pm 2\sigma$. Limits of detection (LOD) and limits of quantification (LOQ) are given in Table S 3 and were calculated according to DIN 32645:2008-11 by measuring filtrations blanks ($n = 8$), with LOD defined as $3 \times SD$ and LOQ as $10 \times SD$ of the blank (DIN e.V., 2008).



The sum parameter NO_x for nitrate and nitrite (NO_x = nitrate + nitrite) was established and used throughout the discussion. The LOQs for the nutrient analysis are given in Table S 3.

165 Parameters of the carbonate system (pH, $p\text{CO}_2$, Revelle factor, and Ω Aragonite) were calculated using the CO2Sys Macro (Pierrot et al., 2011) with salinity, temperature, AT and CT as input variables. As input parameters, we used the dissociation constant by Mehrbach et al. (1973), refit by Dickson and Millero (1987), the HSO₄⁻ dissociation constant by Dickson (1990) and the seawater pH-scale (Dickson, 1990; Dickson and Millero, 1987; Mehrbach et al., 1973). We used the CO2Sys Macro to calculate temperature-normalized CT (CT_{temp}) according to Wu *et al.* (2019). The calculation was based on the median
 170 potential temperature of WGSW (3.23°C) within a depth range of 30 to 50 m, using observed salinity and AT, and the in situ $p\text{CO}_2$ as input parameters.

For statistical analysis, the data of the different parameters were merged according to station and sampling depth, obtaining one data matrix with 17 parameters and 41 observations. Values below LOD were replaced with a random value between zero and LOD. Each parameter was tested for normality (Shapiro-Wilk test, $\alpha = 0.01$) and transformed (log- or Box Cox-
 175 transformation) if the normality criteria was not met (Table S 4). The data were standardized, and principal component analysis (PCA) with varimax rotation was performed using the “principal” function (package psych; (Revelle, 2024)). Three principal components (PCs) were selected, considering the Guttman-Kaiser criterion and the trend of the scree plot. A broken stick analysis was performed to distinguish the loading significance of each variable.

3 Results

180 The distributions of basic oceanographic parameters (salinity, potential temperature, oxygen, Apparent Oxygen Utilization (AOU)), macronutrients (NO_x, silicate, phosphate), carbonate system parameters (AT, CT, pH, $p\text{CO}_2$, Revelle factor, Ω Aragonite), and dissolved trace elements (dV, dMn, dFe, dCo, dNi, dCu, dCd, and dPb) are presented in separate sections. The supplementary material (Fig. S 1 to Fig. S 12) provides detailed information on water column profiles and surface water concentration plots for individual parameters. Minimum and maximum values of macronutrients, carbonate system parameters,
 185 and trace elements are presented in Table 1.

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195 **Table 1: Minimum and maximum values of macronutrients, carbonate system parameters and trace elements across the study area.**

Parameter	Unit	Minimum		Maximum		Literature data
		Value	Station [Depth in m]	Value	Station [Depth in m]	Min – Max range
NOx	$\mu\text{mol L}^{-1}$	0.21	13 [30]	17.85	15 [667]	2015: 0.032 – 24.3 ¹ 2016: 0.05 – 28.5 ²
Silicate	$\mu\text{mol L}^{-1}$	0.51	22 [3]	35.95	15 [667]	2015: 0.32 – 103.7 ¹ 2016: 0.11 – 131.4 ²
Phosphate	$\mu\text{mol L}^{-1}$	0.12	22 [3]	1.43	15 [667]	2015: 0.46 – 1.97 ¹ 2016: 0.06 – 2.2 ²
AT	$\mu\text{mol kg}^{-1}$	2062	15 [3]	2305	10 [551]	2015: 2156 – 2294 ⁴ 2016: 2176 – 2310 ³
CT	$\mu\text{mol kg}^{-1}$	1949	15 [3]	2214	15 [667]	2015: 2008 – 2255 ⁴ 2016: 1937 – 2277 ³
CT:AT		0.907	17 [3]	0.968	15 [667]	NA
pH		7.86	15 [667]	8.20	15 [32]	2015: 7.40 – 7.81 ¹
$p\text{CO}_2$	μatm	249	15 [32]	559	15 [667]	NA
Revelle factor		11.85	17 [3]	17.80	15 [667]	NA
Ω Aragonite		0.90	15 [667]	2.17	17 [3]	NA
dV	ng L^{-1}	1270 ± 30	24 [3]	1810 ± 60	10 [551]	NA
dMn	ng L^{-1}	54.8 ± 1.8	24 [317]	503 ± 20	12 [37]	$13.5 \pm 1.7 - 306.0 \pm 2.6$ ¹
dFe	ng L^{-1}	56.9 ± 2.5	27 [15]	630 ± 30	18 [256]	$20.0 \pm 0.6 - 112 \pm 8$ ¹
dCo	ng L^{-1}	3.81 ± 0.15	10 [551]	14.7 ± 0.6	11 [3]	NA
dNi	ng L^{-1}	232 ± 7	6 [3]	381 ± 4	24 [35]	$240 \pm 12 - 376 \pm 5$ ¹
dCu	ng L^{-1}	85.4 ± 2.5	10 [551]	206 ± 3	24 [3]	$115 \pm 10 - 333.0 \pm 0.7$ ¹
dCd	ng L^{-1}	3.1 ± 0.7	8 [4]	52.2 ± 1.2	15 [667]	$20.0 \pm 0.5 - 49.0 \pm 0.6$ ¹
dPb	ng L^{-1}	0.99 ± 0.08	28 [186]	4.04 ± 0.13	10 [551]	$0.52 - 6.0$ ¹

Note. The measurement uncertainty of trace elements corresponds to twice the SD with $\mu \pm 2\sigma$. Literature data from Geotraces cruise GN02 in 2015 (station BB1, BB2 and BB3) and GreenEdge cruise in 2016 (stations G100 to G3000). ¹(GEOTRACES Intermediate Data Product Group, 2023). ²(Bruyant et al., 2022). ³(Miller et al., 2020). ⁴(H. Thomas, personal communication, June 28, 2024).



200 3.1 Basic oceanographic parameters

Because of the high resolution of the CTD data, we give ranges of minimum and maximum values for salinity, potential temperature, oxygen and AOU in Table S 5. Salinity values were the lowest in surface waters of stations close to the coast (stations 6, 11 and 17) and towards the west of each transect (stations 14, 15, 24, 29 and 30), ranging between 29.70 and 32.60. In the deep waters of station 10, the salinity was the highest with 34.88 over a depth range from 500 to 558 m. Minimum potential temperature values between -1.50 to -1.61°C were reached in the intermediate waters (20 to 75 m) of stations 24 and 30. Maximum potential temperature values between 5.6 to 6.7°C were measured in surface waters of transect 2 (stations 6, 7, 8 and 10), and in surface waters of station 17 in Disko Bay. Overall, temperatures were higher in the southeast of Davis Strait along the west Greenland coast and lower in the northwest of Davis Strait further offshore. In the deep waters of station 15, minimum oxygen concentrations between 203 to 210 $\mu\text{mol L}^{-1}$ and maximum AOU values between 140 to 147 $\mu\text{mol L}^{-1}$ were present over a depth range from 640 to 667 m. Maximum oxygen concentrations between 355 to 406 $\mu\text{mol L}^{-1}$ and minimum AOU values between -26 to -72 $\mu\text{mol L}^{-1}$ were measured in the photic zone (1.5 to 40 m) either close to the Greenlandic coast at the beginning of a transect (stations 6 and 17) or towards the west of each transect (stations 10, 14, 15 and 24).

3.2 Macronutrients

The overall nutrient distribution is shown as vertical profiles in Fig. S 6 and as sea surface concentration plots in Fig. S 7. In surface waters, nutrient concentrations were uniformly low across the shelf. Especially NO_x ($< \text{LOQ} = 0.21 \mu\text{mol L}^{-1}$) was extremely low in surface waters and shallow shelf waters. Exceptions to this are surface waters with higher nutrient concentrations at station 17 in Disko Bay and at stations 14, 15, 24 and 30 toward the west of each transect. Below the biological productive zone, nutrient concentrations gradually increased with depth, reaching maximum concentrations at station 15 (667 m) (refer to Table 1). In comparison to data collected during 2015 (GEOTRACES Intermediate Data Product Group, 2023) and 2016 (Bruyant et al., 2022), maximum nutrient concentrations of this study are lower, which we attribute to regional differences in the study areas, especially referring to the maximum sampling depth. We measured maximum values at the shelf edge at 667 m, whereas the references reported maximum values at stations more central to Baffin Bay in much greater depths.

3.3 Dissolved trace elements

The distributions of trace elements are shown as vertical profiles in Fig. S 8 and surface water concentrations in Fig. S 9. The vertical profiles of dV and dCu showed opposing trends (refer to Fig. S 8 a and f). With depth, dV concentrations increased, while dCu concentrations decreased. The dV concentrations ranged from $1270 \pm 30 \text{ ng L}^{-1}$ (station 24; 3 m) to $1810 \pm 60 \text{ ng L}^{-1}$ (station 10; 551 m), while dCu concentrations ranged from $206 \pm 3 \text{ ng L}^{-1}$ (station 24; 3 m) to $85.4 \pm 2.5 \text{ ng L}^{-1}$ (station 10; 551 m), both matching minimum and maximum occurrences of salinity. Surface waters close to the coast of Greenland and at the western end of each transect showed lower dV concentrations (Fig. S 9 a) and higher dCu concentrations (Fig. S 9 f),



respectively. The distributions of dFe, dNi and dCd showed low concentrations in surface and subsurface waters, which gradually increased with depth (refer to Fig. S 8 c, e and g), reaching maximum concentrations for dFe of $630 \pm 30 \text{ ng L}^{-1}$ (station 18; 256 m), for dNi of $307 \pm 9 \text{ ng L}^{-1}$ (station 15; 667 m) and for dCd of $52.2 \pm 1.2 \text{ ng L}^{-1}$ (station 15; 667 m). Minimum concentrations of dFe, dNi and dCd were present in surface waters (refer to Table 1) of stations with some distance to the coast, with dFe concentrations below the LOQ ($< 50 \text{ ng L}^{-1}$) at certain stations. The concentration of dFe and dNi in surface waters (Fig. S 9 c and e) followed a similar pattern as the surface water nutrient concentrations (Fig. S 7). The concentrations were higher close to the coast, decreased with distance along each transect and increased again towards the west of each transect. The surface water concentrations of dCd were rather uniform and increased only towards the west of each transect (Fig. S 9 g). The concentrations of dMn and dCo decreased from surface to subsurface waters and increased again with depth at stations located on the shelf (refer to Fig. S 8 b and d). On the shelf edge, concentrations of dMn and dCo remained stable with depth, leading to minimum concentrations for dMn of $54.8 \pm 1.8 \text{ ng L}^{-1}$ (station 24; 317 m) and for dCo of $3.81 \pm 0.15 \text{ ng L}^{-1}$ (station 10; 551 m). In surface waters, high concentrations of dMn and dCo were present at station 17 in Disko Bay and at stations 11 and 12, where the mouth of the Nassuttooq Fjord is located (Fig. S 9 b and d). The dMn and dCo concentrations in surface waters decreased with increasing distance from the coast. The depth profile of dPb does not follow a clear pattern (refer to Fig. S 8 h). South of Davis Strait, high dPb concentrations were observed across transect 2, alongside a maximum dPb concentration of $4.04 \pm 0.13 \text{ ng L}^{-1}$ in the deep waters of station 10. North of Davis Strait, dPb concentrations were below the LOQ ($< 0.98 \text{ ng L}^{-1}$) in the deep waters of station 15, intermediate to deep waters of Disko Bay (stations 17 and 18) and in deep waters of station 28, along with a minimum concentration of $1.1 \pm 0.4 \text{ ng L}^{-1}$ in deep waters of station 30. In comparison to literature values, our results for trace element concentrations are in a similar range as data collected during the 2015 Geotraces cruise GN02 (GEOTRACES Intermediate Data Product Group, 2023). Variations of minimum and maximum values occur because of differences in sampling locations. While this study took place on the shelf, capturing the influence of coastal runoff as well as sea ice meltwater, the Geotraces cruise focused on stations off the shelf and further north in central Baffin Bay.

3.4 Carbonate system parameters

The vertical profiles of AT and CT (Fig. S 10 a and b) show a gradual increase with depth. Minimum concentrations of AT and CT were present in the low-salinity surface waters of station 15 (AT: $2062 \mu\text{mol kg}^{-1}$; CT: $1949 \mu\text{mol kg}^{-1}$). While maximum CT concentrations of $2214 \mu\text{mol kg}^{-1}$ were observed in the deep waters of station 15, AT concentrations followed the salinity gradient, reaching a maximum value of $2305 \mu\text{mol kg}^{-1}$ in the deep waters of station 10. The vertical profiles of pH and $p\text{CO}_2$ (Fig. S 10 d and e) show opposing trends, with pH increasing and $p\text{CO}_2$ decreasing towards intermediate waters of the photic zone. Below the photic zone, pH decreases and $p\text{CO}_2$ increases gradually with depth. This led to a pH maximum (8.20) and $p\text{CO}_2$ minimum ($249 \mu\text{atm}$) in the photic zone of station 15 at 32 m, as well as minimum pH values of 7.86 and maximum $p\text{CO}_2$ values of $559 \mu\text{atm}$ in the deep waters of station 15. The vertical profiles of the CT:AT ratio, the Revelle factor and Ω Aragonite (Fig. S 10 c, f and g) show that these parameters remain relatively stable in the first 25 m of the water



column and gradually increase (CT:AT ratio and Revelle factor) or decrease (Ω Aragonite). In the surface waters of Disko Bay
 265 (station 17; 3 m) a minimum CT:AT ratio of 0.907, together with a minimum Revelle factor of 11.85 and a maximum
 Ω Aragonite value of 2.17 were present. The maximum CT:AT ratio (0.968) was found in the deep waters of station 15, which
 coincides with a maximum Revelle factor of 17.80 and a minimum Ω Aragonite value of 0.90. The surface water concentrations
 of the carbonate system parameters are given in Fig. S 11. In general, stations closest to the coast of Greenland showed lower
 AT and CT values that increased with distance to the coast. Following this trend, the pH in surface waters increased and $p\text{CO}_2$
 270 values decreased with distance to the coast along each transect. The lower CT:AT ratios of coastal stations coincided with
 higher Revelle factors and lower Ω Aragonite values, reflecting the lower buffering capacity of coastal waters. An exception
 to this was the surface waters of Disko Bay (station 17; 3 m). Here, the CT:AT ratio reached a minimum (0.907), caused by
 low CT values of $1972 \mu\text{mol kg}^{-1}$, corresponding to low $p\text{CO}_2$ values of 255 μatm . Coupled to this, the pH is high (8.19) and
 the Revelle factor low (11.85), indicating the higher buffering capacity of this water, which is also reflected by a maximum
 275 Ω Aragonite value of 2.17. The westernmost surface waters of each transect showed lower AT and CT values with overall
 highest CT:AT ratios in surface waters. Consequently, $p\text{CO}_2$ values and Revelle factors followed this trend and were higher at
 these stations, whereas pH and Ω Aragonite values were lower.

In comparison to AT and CT data collected during 2015 (H. Thomas, personal communication, June 28, 2024) and 2016
 (Miller et al., 2020), our results are in a similar range as previous studies, but with minimum values being slightly lower as we
 280 were able to capture the sea ice meltwater signal.

4 Discussion

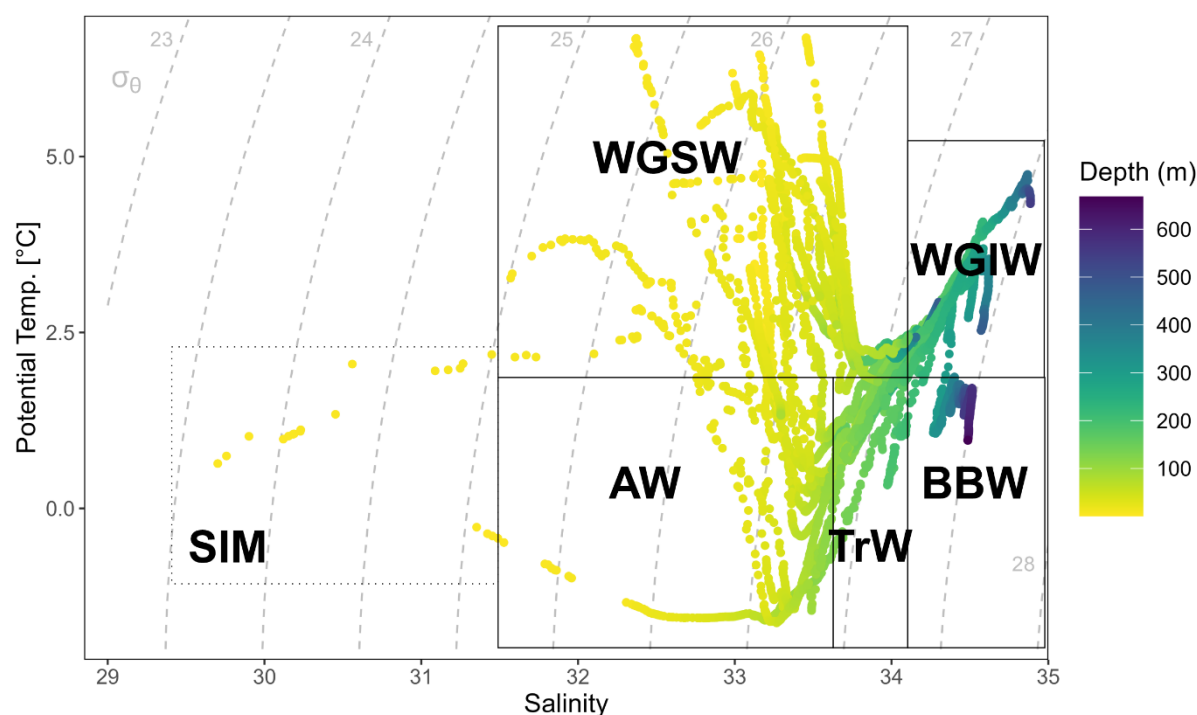
4.1 Characterization of water masses

4.1.1 Temperature-salinity properties

The water masses along the west Greenland shelf were identified using salinity and potential temperature (Curry et al., 2014;
 285 Tang et al., 2004; Curry et al., 2011; Sherwood et al., 2021) as shown in Fig. 2. Water depth profiles displaying potential
 temperature, salinity, potential density, and oxygen along the transects are provided in Fig. S1 to S5. The West Greenland
 Shelf Water (WGSW; $\theta < 7^\circ\text{C}$; $S < 34.1$) was the dominant water mass in the study area, occurring in each transect across the
 shelf above a water depth of 200 m. The West Greenland Intermediate Water (WGIW; $\theta > 2^\circ\text{C}$; $S > 34.1$) was present in
 deeper waters along the slope below 200 m. Arctic Water (AW; $\theta \leq 2^\circ\text{C}$; $S \leq 33.7$) was encountered north of Davis Strait at
 290 transects 3, 4, and 5 as an interlayer between WGSW and WGIW above 100 m on the west side of the transects, forming cold
 and low-salinity pockets of water (Fig. S 3 to S 5). At transect 4, AW was found at station 17 approximately 70 km off the
 coast of Greenland, reaching far into Disko Bay. Transitional Water (TrW; $\theta \leq 2^\circ\text{C}$; $S > 33.7$) was present mainly at transects
 4 and 5 between 100 and 200 m, separating AW from WGIW (Fig. S 4 to S 5). At station 15, the waters below 300 m were
 defined as Baffin Bay Water (BBW; $\theta \leq 2$, $S > 34.1$), a shallower extension of the Baffin Bay Deep Water, presenting as a



295 distinct tail on the θ -S diagram (Sherwood et al., 2021). Due to very low surface salinity values at stations 14, 15, and 24 ($S < 31.5$), we introduced sea ice meltwater (SIM) as an additional source water to distinguish areas affected by sea ice melt.



300 **Figure 2: Water masses in the study area were characterized using potential temperature and salinity: West Greenland Shelf Water (WGSW; $\theta < 7^\circ\text{C}$; $S < 34.1$), West Greenland Intermediate Water (WGIW; $\theta > 2^\circ\text{C}$; $S > 34.1$), Transitional Water (TrW; $\theta \leq 2^\circ\text{C}$; $S > 33.7$), Arctic Water (AW; $\theta \leq 2^\circ\text{C}$; $S \leq 33.7$) and Baffin Bay Water (BBW; $\theta \leq 2$, $S > 34.1$), according to Curry *et al.* (2011), Curry *et al.* (2014), Sherwood *et al.* (2021), and Tang *et al.* (2004). Surface water with $S < 31.5$ is indicative of sea ice meltwater (SIM).**

4.1.2 Influence of physicochemical processes on biogeochemical properties

305 The extensive data set was processed using PCA to further characterize the water masses and to find physicochemical processes that alter the distribution of carbon, macronutrients, and trace elements. The results of the PCA analysis are summarized in Table S 6, with significant PC loadings of each parameter marked in bold. Overall, 82 % of the total variance in the normalized data set can be explained by three PCs. The majority of variance is explained by PC 1 with 52 %, followed by PC 2 with 18 % and PC 3 with 12 %. Salinity, depth, oxygen, AT, CT, dV, and dCu significantly load on PC 1; potential temperature, AOU, NO_x, silicate, phosphate, dNi, dCd, and dPb significantly load on PC 2; and dFe, dMn, dCo, dNi, and dCu significantly load on PC 3. Figure 3 shows the results of the PCA as biplots with colors indicating the water mass affiliation of each sample.

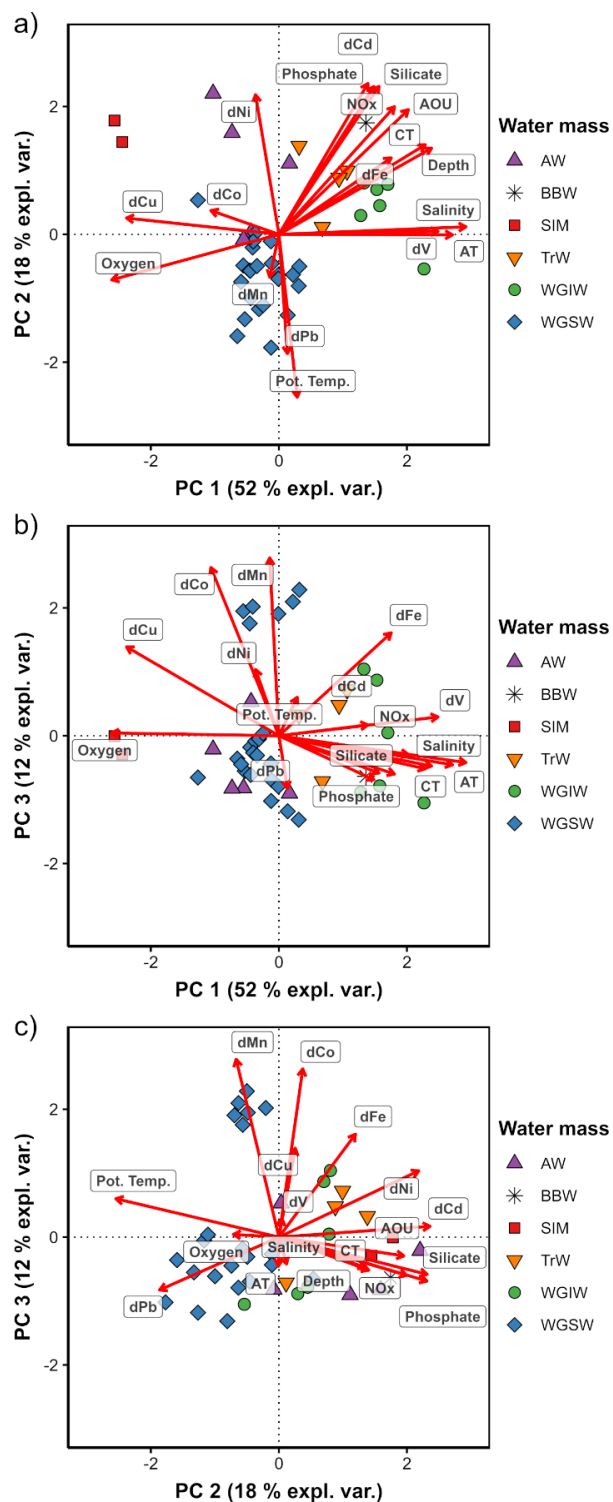


Figure 3: Biplots according to PCA results for a) PC 1 score vs PC 2 score; b) PC 1 score vs PC 3 score; and c) PC 2 score vs PC 3 score, with colors indicating the water mass affiliation of each sample. The loading of each parameter is indicated by a red arrow.



315 **Conservative mixing along the salinity gradient (PC 1)**

The comparison of low PC 1 scores of surface water samples with lower salinity (WGSW, AW, and SIM) and high PC 1 scores of deep water samples with higher salinity (WGIW, TrW, and BBW) indicates that PC 1 is resolving the salinity gradient of the study area (Fig. 3 a and b). The WGSW integrates freshwater contributions from the GIS (Foukal and Pickart, 2023), while AW mixes winter-cooled water entering Baffin Bay on the eastern side of Davis Strait with inflow of cold and fresh Arctic Ocean water of Pacific origin through the CAA (Curry et al., 2014). Melt water from sea ice promotes a fresh surface layer that tends to remain concentrated in the upper part of the water column (Haine et al., 2015). The statistical results illustrate the importance of freshwater input on the chemical properties of the study area. The high loading of AT, CT, dV, and dCu on PC 1 indicates that these parameters behave conservatively, with freshwater either being a source (dCu) or a cause for dilution (AT, CT, and dV) of parameter concentrations. The positive loadings of AT and CT on PC 1 are in line with the general understanding of freshwater inputs from sea ice meltwater and glacial meltwater, which are characterized by low AT and CT values (Bates and Mathis, 2009; Chierici and Fransson, 2009; Fransson et al., 2015). The positive correlation of AT and CT are illustrated in Fig. S 12 a and b. The distribution of dV shows a positive correlation with salinity (Fig. S 12 c) as both sea ice melt and coastal freshwater inputs were characterized by low dV concentrations (Marsay et al., 2018; Whitmore et al., 2019). The distribution of dCu correlated negatively with salinity and was influenced by coastal freshwater input and sea ice meltwater as a dCu source (Fig. S 12 d). Cu-binding ligands play an important role in maintaining Cu in the dissolved phase (Ruacho et al., 2022) and facilitate the transport of dCu across the Arctic (Arnøne et al., 2023). This is reflected in the consistent decrease of dCu concentrations in the lateral direction away from the coastal source along the shelf transects (refer to Sect. 3.3). The influence of freshwater input on the chemical properties of the water column is further discussed regarding sea ice meltwater in Sect. 4.4 and coastal runoff in Sect. 4.5.

335 **Biological uptake and recycling (PC 2)**

The high positive loading of AOU, NO_x, silicate, phosphate, dNi, and dCd on PC 2 suggests that PC 2 describes distributions that are controlled by biological cycling. The nutrient-type behavior of dNi and dCd was mentioned in Sect. 3.3 and agrees well with the PCA results. In addition, dFe shows high loadings on PC 2, reflecting its nutrient-type character. This in good agreement with previously published data for the Nansen Basin and the Barents Sea (Gerringa et al., 2021), the Chukchi Sea (Vieira et al., 2019), the Fram Strait (Krisch et al., 2022a) and the Canadian Arctic (Colombo et al., 2020). The anticorrelation of nutrients (positive PC 2 loading) and potential temperature (negative PC 2 loading) derives from the distribution of those parameters across the study area. The low PC 2 scores of WGSW indicate that the warmer shelf waters are highly productive, resulting in low nutrient concentrations. The colder deep waters of TrW, WGIW and BBW are characterized by high PC 2 scores which implies that remineralization occurred with nutrients and trace elements being returned to the water column. Similarly, water samples of AW and SIM show high PC 2 scores with higher nutrient concentrations alongside colder



temperatures. The difference in nutrient concentrations between AW and WGSW is further discussed in Sect. 4.3 and the influence of the retreating sea ice in Sect. 4.4.

The remineralization of organic matter (OM) led to elevated concentrations of NO_x, silicate, phosphate, and dCd, together with maximum AOU values (refer to Sect. 3.1 and 3.2) in the deep waters of BBW (640 to 667 m; station 15). Although we only encountered BBW at this station, our results agree well with Sherwood *et al.* (2021), who observed a similar trend with similar AOU and nutrient concentrations in BBW. Remineralized nutrients accumulate at depth because of the long residence time of deep and bottom waters in Baffin Bay in combination with an enclosed bathymetry that restricts circulation (Sherwood *et al.*, 2021; Lehmann *et al.*, 2019). Besides nutrients, CT also has a high loading on PC 2, while AT only loads on PC 1. This statistical feature illustrates the different biogeochemical behavior of AT and CT. While AT distributions are dominated by freshwater dynamics, CT distributions are also equally driven by biological processes. This resulted in elevated CT concentrations in BBW (refer to Sect. 3.4). Here, high CT values coincided with the restricted circulation, which led to overall more corrosive conditions for the Baffin Bay shelf sediments and benthic ecosystem. Similar to other studies of Baffin Bay (Beaupré-Laperrière *et al.*, 2020; Burgers *et al.*, 2024), respiration of OM drove deep waters to become undersaturated with respect to Ω Aragonite, with $p\text{CO}_2$ increasing and pH decreasing proportionally to each other (refer to Sect. 3.4).

Alongside potential temperature, dPb has a negative loading on PC 2, which stems from the latitudinal trend of potential temperature and dPb concentrations (refer to Sect. 3.1 and 3.3). The distribution of dPb is mainly controlled by the mixing of warm Atlantic-origin waters with high dPb signatures and cold Arctic-origin waters with low dPb signatures (Colombo *et al.*, 2019). This resulted in high dPb concentrations in the warmer waters southeast of Davis Strait, which decreased towards the northwest as temperatures decreased.

365 Scavenging and benthic processes (PC 3)

The third PC associates with the trace elements dMn, dFe, dCo, dNi, and dCu. It is known that during estuarine mixing, dCo, dNi and dCu are co-cycled with dMn and dFe during their transformation into the respective (oxy)hydroxide minerals (Smrzka *et al.*, 2019). We suggest that PC 3 indicates particle-driven mixing of these trace elements with coastal runoff as a source. High PC 3 scores (Fig. 3 b and c) of surface samples taken at stations 11 and 12 (mouth of Nassuttooq Fjord) as well as station 17 (Disko Bay) illustrate the prevailing role of coastal freshwater inputs on the distribution of these trace elements. The influence of coastal runoff on trace element distribution is further discussed in Sect. 4.5.

The biplots (Fig. 3 b and c) reveal an interesting feature of deep water samples (111 to 667 m), identified as TrW and WGIW. At these shelf stations, deep water concentrations of dMn, dFe, dCo, and dNi are increased (refer to Sect. 3.2), which we suggest is caused by benthic processes in surface sediments, i.e., reversible scavenging linked to mineral dissolution and remineralization of organic material. Release from the benthic boundary layer has been described for dCo, dFe, and dMn in the Barents Sea (Gerringa *et al.*, 2021), the Chukchi Sea (Vieira *et al.*, 2019), the Canadian Arctic (Colombo *et al.*, 2020) and throughout the Arctic basin (Bundy *et al.*, 2020) and for dNi in the Bering Sea and Chukchi Sea (Jensen *et al.*, 2022). In contrast, dCu showed no benthic source or evidence of biological cycling and instead remained dominated by freshwater runoff



from coastal sources, similar to what has been observed by Jensen *et al.* (2022). Noticeable for these deep water shelf samples
380 is a dissociation of corresponding PC 3 scores into negative scores (stations 8, 10, 15, 24, 30) and positive scores (stations 17,
20, 22, 28). We believe this division to be caused by differences in return fluxes at the sediment-water interface. Stations with
a positive PC 3 score are closer to the coast, where more biogenic and terrigenous material is exported, which can be recycled
in deep waters. Stations that are further away from the coast do not receive as much material for remineralization and have,
thus, a negative PC 3 score with lower concentrations of the trace elements dMn, dFe, dCo and dNi. A similar observation was
385 made for dMn, dFe, and dCo in the Ulleung Basin of the East Sea by Seo *et al.* (2022). Concentrations were significantly
higher on the slopes and bottom layer of the Ulleung Basin in contrast to the Japan Basin, which the authors associated with a
large sedimentary release by OM degradation caused by the high OM content of the shelf sediments (Seo et al., 2022).

4.3 Influence of major current systems on biogeochemical properties

The spatial distribution of parameters revealed significant differences in eastern and western shelf waters. We decided to
390 directly compare the three major water masses present along the west Greenland shelf: the northward-moving WGSW (1 to
220 m) and WGIW (130 to 560 m) with the southward-moving AW (2 to 165 m). For each parameter, the median and the
mean $\pm$ SD values are summarized in Table 2. The median is used throughout the data discussion because of its robustness
against outliers.



395 **Table 2: Comparison of the median and mean $\pm$ SD concentrations between WGSW, WGIW and AW. The number of samples (n) used for the calculation is given in brackets.**

	Parameter	WGSW (Median; Mean $\pm$ SD)	WGIW (Median; Mean $\pm$ SD)	AW (Median; Mean $\pm$ SD)
Basic oceanographic parameters (WGSW: $n = 3021$; WGIW: $n = 3034$; AW: $n = 2301$)	Salinity	33.57 33.52 ± 0.42	34.45 34.45 ± 0.23	33.48 33.42 ± 0.27
	Pot. Temp. (°C)	2.68 3.20 ± 1.15	2.93 3.16 ± 0.73	0.38 0.15 ± 1.02
	Oxygen ($\mu\text{mol L}^{-1}$)	336 344 ± 23	273 278 ± 21	332 332 ± 23
	AOU ($\mu\text{mol L}^{-1}$)	-4 0 ± 26	62 55 ± 23	36 30 ± 24
	NOx ($\mu\text{mol L}^{-1}$)	1.7 2.4 ± 2.8	13.5 13.7 ± 1.7	5.7 6.0 ± 2.8
	Silicate ($\mu\text{mol L}^{-1}$)	1.5 2.0 ± 1.8	10.6 11.5 ± 4.1	4.2 5.2 ± 3.5
	Phosphate ($\mu\text{mol L}^{-1}$)	0.23 0.31 ± 0.18	1.02 0.99 ± 0.13	0.66 0.68 ± 0.21
Macronutrients (WGSW: $n = 54$; WGIW: $n = 9$; AW: $n = 29$)	AT ($\mu\text{mol kg}^{-1}$)	2226 2228 ± 19	2275 2278 ± 11	2237 2237 ± 6
	CT ($\mu\text{mol kg}^{-1}$)	2051 2056 ± 28	2164 2159 ± 16	2104 2104 ± 27
	CT:AT	0.922 0.923 ± 0.007	0.950 0.948 ± 0.006	0.941 0.941 ± 0.010
	pH	8.14 8.14 ± 0.03	7.99 7.99 ± 0.04	8.10 8.09 ± 0.06
	$p\text{CO}_2$ (μatm)	292 295 ± 22	433 425 ± 37	321 332 ± 52
	Ω Aragonite	1.88 1.86 ± 0.15	1.30 1.34 ± 0.12	1.48 1.49 ± 0.20



400 **Continuation of Table 2: Comparison of the median and mean $\pm$ SD concentrations between WGSW, WGIW and AW. The number of samples (n) used for the calculation is given in brackets.**

		WGSW	WGIW	AW
Parameter		(Median; Mean $\pm$ SD)	(Median; Mean $\pm$ SD)	(Median; Mean $\pm$ SD)
Trace elements (WGSW: $n = 31$; WGIW: $n = 8$; AW: $n = 8$)	dV (ng L ⁻¹)	1490 1486 $\pm$ 234	1735 1713 $\pm$ 121	1480 1478 $\pm$ 127
	dFe (ng L ⁻¹)	116 138 $\pm$ 67	262 329 $\pm$ 55	162 174 $\pm$ 26
	dMn (ng L ⁻¹)	237 261 $\pm$ 71	89 164 $\pm$ 13	186 184 $\pm$ 20
	dCo (ng L ⁻¹)	8.0 8.5 $\pm$ 2.5	5.0 5.7 $\pm$ 0.5	9.0 9.2 $\pm$ 0.8
	dNi (ng L ⁻¹)	254 258 $\pm$ 51	269 270 $\pm$ 22	266 280 $\pm$ 20
	dCu (ng L ⁻¹)	161 158 $\pm$ 44	111 111 $\pm$ 13	160 162 $\pm$ 16
	dCd (ng L ⁻¹)	13 13 $\pm$ 6	31.6 32.2 $\pm$ 2.7	21.6 22.0 $\pm$ 2.3
	dPb (ng L ⁻¹)	2.4 2.5 $\pm$ 0.8	2.4 2.4 $\pm$ 0.5	1.7 1.8 $\pm$ 0.4

405 The median values of salinity and potential temperature reflect the origin of the water masses and the freshwater dynamics of this area. In the upper water column, AW is slightly fresher (33.48) and colder (0.38°C) than WGSW (33.57; 2.68°C). This east–west gradient in temperature and salinity was also described by Tang *et al.* (2004) between Baffin Island and the Greenland coast. When the warmer WGSW flows cyclonically around Baffin Bay and mixes with adjacent water of the CAA, the water becomes colder and fresher before returning as the southward AW current (Tang *et al.*, 2004). The WGIW is part of the deep water WGSC that transports warm (2.93°C) and salty (34.45) waters from the North Atlantic (Curry *et al.*, 2014). The AOU concentrations are reflective of respiration and the biological activity of the water (Sarmiento and Gruber, 2006).
 410 Lower AOU values in WGSW ($-4 \mu\text{mol L}^{-1}$) than in AW ($36 \mu\text{mol L}^{-1}$) indicate that the warmer shelf waters are more productive than the colder AW. This is also in agreement with overall lower nutrient concentrations in WGSW than AW (refer to Sect. 4.1.2 and Table 2), as nutrients are removed from the water column through PP. With depth, respiration returns nutrients to the water column as seen by high AOU values in WGIW ($62 \mu\text{mol L}^{-1}$) and overall higher nutrient concentrations (refer to Table 2). Fig. 4 a shows the NO_x concentrations against longitude in a depth range of 30 to 50 m, including literature

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This carbon enrichment in AW can be traced back to the CAA outflow, which contains higher CT concentrations of Pacific-origin (Shadwick et al., 2011b; Azetsu-Scott et al., 2010). The slightly higher CT:AT ratios in AW than WGSW were also reflected by a higher median $p\text{CO}_2$ concentration and lower median pH value and median Ω Aragonite concentration (refer to Table 2). For a more detailed discussion about CT values in AW and WGSW, we looked at a depth range of 30 to 50 m to eliminate any depth dependency. It is known that colder sea surface temperatures at high latitudes explain the majority of the surface CT latitudinal gradient due to the increased CO_2 solubility of colder waters (Wu et al., 2019; Li and Tsui, 1971). We examined the extent of the CT change induced by the temperature difference between AW and WGSW. Therefore, we calculated temperature-normalized CT (CT_{temp}) according to Wu *et al.* (2019) (refer to Sect. 2.4.) based on the median potential temperature of WGSW (3.23°C) within a depth range of 30 to 50 m. The observed CT (CT_{obs}) and CT_{temp} values are shown in Fig. 4 c and d for AW and WGSW. We included literature data from the Green Edge cruise (Miller et al., 2020) and Geotraces GN02 in 2015 (BB1-BB3, CAA2) (H. Thomas, personal communication, June 28, 2024), filtered for a depth range of 30 to 50 m. Including literature data, the difference between the median CT values of AW and WGSW is $\Delta\text{CT} = 35 \mu\text{mol kg}^{-1}$. After temperature normalization, the difference is significantly reduced to $\Delta\text{CT}_{\text{temp}} = 12 \mu\text{mol kg}^{-1}$. Therefore, we conclude that most of the CT difference in AW and WGSW is induced by the temperature difference of both water masses. The remaining CT difference could be caused by the higher productivity in WGSW, which lowers CT concentrations, combined with the mixing of AW and the CAA outflow, which is known to transport additional CT to Baffin Bay (Shadwick et al., 2011b; Burgers et al., 2024; Azetsu-Scott et al., 2010). Towards the deeper water of WGIW, AT and CT median concentrations were higher as they increased along the salinity gradient and respiration of OM released CT to the water column. This is also reflected in higher median $p\text{CO}_2$ concentrations and lower median Ω Aragonite concentrations in WGIW (refer to Table 2), similar to observations by Burgers *et al.* (2024).

All median concentrations of trace elements that showed a nutrient-type profile (dFe, dNi, and dCd) are lower in WGSW than AW. This difference is caused by their uptake during PP, which was higher in WGSW than AW. The return of these elements to the water column due to remineralization of OM can be seen in higher median concentrations in WGIW (refer to Table 2). Furthermore, variations in source water concentrations could lead to differences in trace element concentrations. AW showed elevated concentrations for dFe, dMn, dCo, dNi, and (refer to Table 2). We attribute these high concentrations to the CAA outflow into Baffin Bay, which was found to have higher dFe and dMn concentrations caused by sediment resuspension in the benthic boundary layer (Colombo et al., 2020; Colombo et al., 2021), as well as higher dNi and dCu concentrations due to waters advected from the Canada Basin through the CAA and out into Baffin Bay (Jensen et al., 2022). In contrast, higher dPb median concentrations were present in WGSW and WGIW than AW (refer to Table 2). As mentioned in Sect. 3.3, there is a difference in dPb concentrations between the south and the north of Davis Strait, with dPb concentrations decreasing along the west coast of Greenland. We illustrated this trend by plotting dPb against latitude in a depth range between 30 and 50 m (Fig. 4 b) as a combination of our results with literature data from the Geotraces GA01 cruise in 2014 (stations 64 to 71) and Geotraces GN02 in 2015 (BB1-BB3, CAA2), both: (GEOTRACES Intermediate Data Product Group, 2023). The results show that WGSW and WGIW entailed higher dPb concentrations, with freshwater from the GIS (Krisch et al., 2022b) and water



from the North Atlantic (Colombo et al., 2019) being as a source of dPb, respectively. In contrast, AW contained much lower dPb concentrations, which we relate to low dPb concentrations in the CAA outflow as this region is relatively remote from anthropogenic inputs (Colombo et al., 2019). Our results demonstrate that the distribution of dPb is mainly controlled by the mixing of water masses with different dPb signatures and can be used to illustrate the gradual mixing of the three water masses along the shelf.

4.4 Influence of retreating sea ice on biogeochemical properties

Baffin Bay and its surrounding areas are generally ice-free between July and October (Bi et al., 2019). The statistical analysis illustrated the importance of SIM on the chemical composition of surface waters (refer to Sect. 4.1.2). We used the ASI sea ice concentration product provided by the University of Bremen (Spreen et al., 2008) to visualize the decline in sea ice concentration over the sampling period. Figure 5 a shows the difference in sea ice concentration between 19 July and 28 July 2021. At the beginning of our sampling period on 19 July 2021, two large areas with high sea ice concentration were present between 66°N-68°N and 70°N-74°N. These areas had disappeared almost completely by the end of our sampling period on 28 July 2021, indicating the complete melting of sea ice in the study area over 10 days. The melt event affected sea surface salinity and potential temperature, depicted in Fig. 5 b and c. Both parameters decrease towards west along transects 3, 4 and 5 with salinity reaching a minimum of 29.70 (station 14; 3 m) and potential temperature of -0.36°C (station 24; 3 m). The category SIM (refer to Sect. 4.1) was identified in the top 4 m of stations 14 and 24 and in the top 8 m of station 15. Although not identified as SIM, a similar trend of decreasing surface salinity and potential temperature values can be seen at stations 10, 13, 23, 28, 29, and 30, adjacent to SIM stations (Fig. S 2 to S 5). We suggest that this trend is caused by the gradual advection of SIM from Baffin Bay towards the southeast.

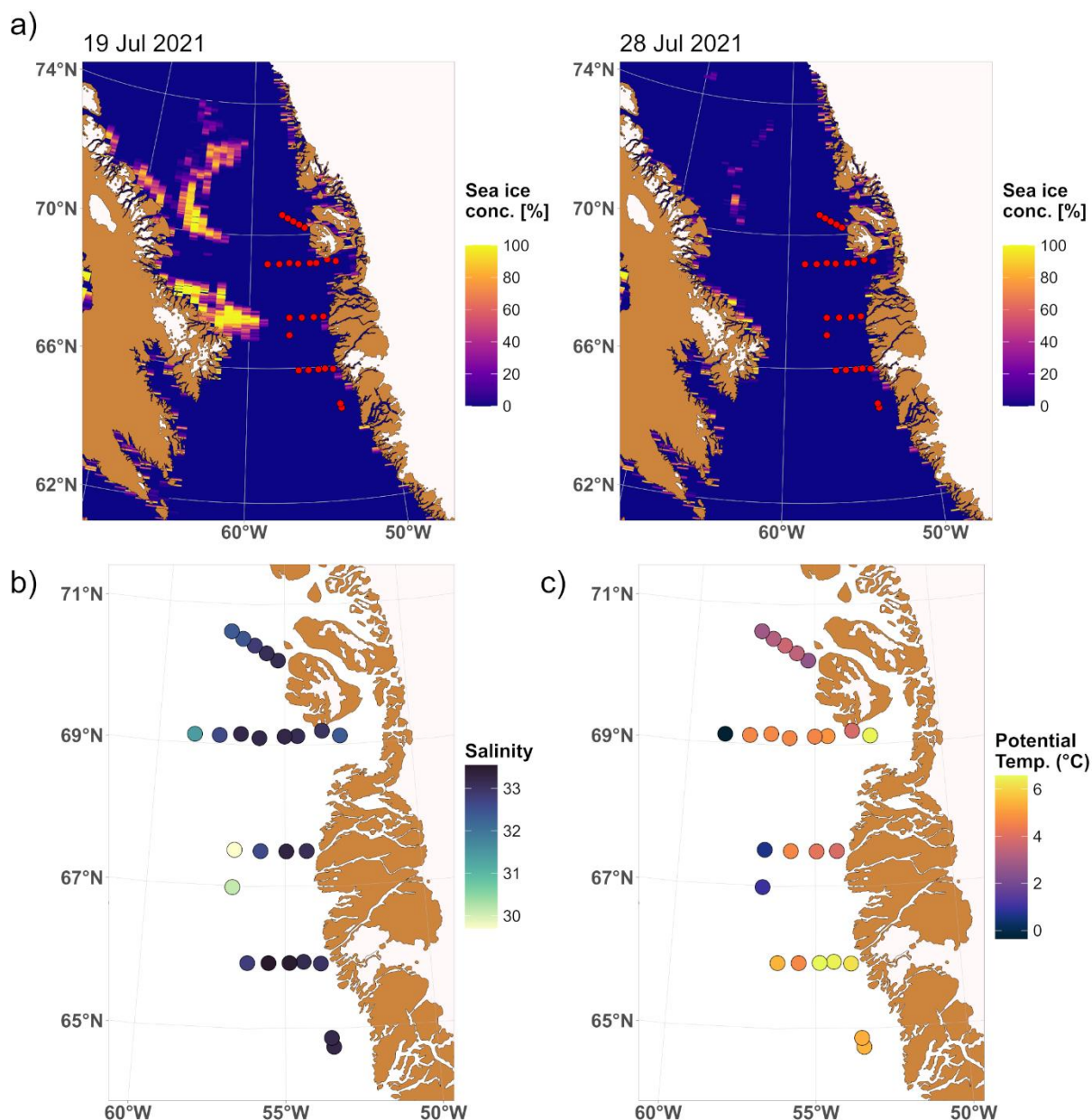


Figure 5: a) Sea ice concentration (%) in the study area during the sampling period on 19 July and 28 July 2021. Sea ice concentration data (ASI data, ASMR2, version 5.4, 3.125 km grid) was downloaded from the data archive of the University of Bremen (Spreen et al., 2008). Sea surface b) salinity and c) potential temperature from CTD sensor data.

Lafond *et al.* (2019) observed that stations covered by sea ice had higher surface nutrient concentrations than open-water stations located east of the ice edge, where nutrients were close to depletion. In this study, the distribution of nutrients in surface waters follows a similar trend (refer to Sect. 3.2). Along each transect, nutrient concentrations were higher towards the west, following the retreat of the sea ice. High oxygen and low AOU values in these areas (refer to Sect. 3.1) suggest that a



phytoplankton bloom started to develop. The timing of the study enabled us to observe that nutrients had not yet been consumed in these western areas, whereas shelf waters had already become depleted towards the east.

500 Our observations of the carbonate system show that surface waters of stations affected by SIM had lower AT and CT concentrations, with overall higher CT:AT ratios, resulting in higher $p\text{CO}_2$ values and lower Ω Aragonite values (refer to Sect. 3.4). Similar results of sea ice meltwater increasing $p\text{CO}_2$ and decreasing CaCO_3 mineral saturation states have been described along the east and west coast of Greenland (Henson et al., 2023), the Fram Strait (Tynan et al., 2016) but also in other parts of the Arctic such as the Canada Basin (Bates et al., 2009). To investigate the effect of sea ice on the first 50 m of the water column, which is the penetration depth of sea ice meltwater (Jones et al., 1983), we calculated salinity-normalized AT ($\text{AT}_{\text{sal}} = 35\text{AT}/S$) and temperature-salinity-normalized CT ($\text{CT}_{\text{temp}}^{\text{sal}} = 35\text{CT}_{\text{temp}}/S$) according to Wu *et al.* (2019) (refer to Sect. 2.4. and 4.3). We used normalized concentrations to account for temperature and salinity effects on the solubility of CO_2 . The normalized concentrations remain dependent on biological processes, air–sea gas exchange and mixing of water masses (Shadwick et al., 2011a). For AT_{sal} (Fig. 6 a), the majority of surface water concentrations range between 2330 and 2350 $\mu\text{mol kg}^{-1}$. We observed an addition in AT of ≈ 25 to 55 $\mu\text{mol kg}^{-1}$ for SIM stations and of ≈ 5 to 45 $\mu\text{mol kg}^{-1}$ for SIM adjacent stations. Our results agree well with Jones *et al.* (1983), who observed an AT addition of $\approx 100 \mu\text{mol kg}^{-1}$ further north in Baffin Bay, in a region that is more dominated by sea ice meltwater than our study area. The additional AT is released during melting of sea ice containing ikaite (Rysgaard et al., 2012; Rysgaard et al., 2011; Jones et al., 1983). The expected change in CT by ikaite dissolution should be one-half the corresponding change in AT (Jones et al., 1983), or approximately 515 15 to 30 $\mu\text{mol kg}^{-1}$. The $\text{CT}_{\text{temp}}^{\text{sal}}$ values are shown in Fig. 6 b with most surface water concentrations ranging between 2140 and 2170 $\mu\text{mol kg}^{-1}$. There is an addition in $\text{CT}_{\text{temp}}^{\text{sal}}$ for SIM stations of ≈ 60 to 75 $\mu\text{mol kg}^{-1}$ and of ≈ 10 to 60 $\mu\text{mol kg}^{-1}$ for SIM adjacent stations. Hence, the observed CT addition is much higher than what is expected from ikaite dissolution alone. Possible explanations for this high surplus in CT could be the release of CT derived from organic carbon remineralization under the ice (Tynan et al., 2016; Bates et al., 2009) and the inflow of additional CT transported through the CAA to Baffin Bay (Shadwick et al., 2011b; Henson et al., 2023; Azetsu-Scott et al., 2010). Our results show that the dissolution of ikaite in sea ice acted as a source of AT, providing a small geochemical buffer to meltwater-influenced surface waters (Jones et al., 2021). However, the inflow of Pacific-origin waters and remineralization under the ice led to overall higher CT:AT ratios, resulting in higher $p\text{CO}_2$ and lower pH and Ω Aragonite values in surface waters. There is evidence that once the sea ice melt facilitated bloom fully develops and CT is removed by PP from seawater, higher pH and Ω Aragonite values can be expected along the sea ice edge (Tynan et al., 2016). This can be seen in the photic zone of station 15 at 32 m, where an oxygen maximum (and AOU minimum) was present, which indicates high PP, resulting in a pH maximum (8.20) and $p\text{CO}_2$ minimum (249 μatm) (refer to Sect. 3.4).

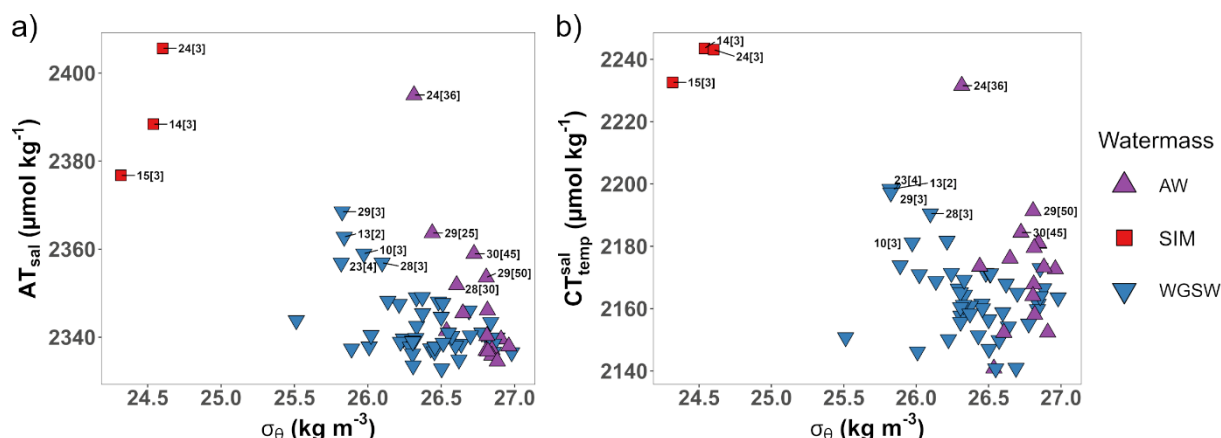


Figure 6: First 50 m of the water column for a) salinity-normalized AT values against pot. density and b) temperature-salinity-normalized CT values against pot. density. Different water mass categories are given in the legend. SIM affected stations (14, 15, 24) and stations adjacent to those (10, 13, 23, 28, 29, 30) are labeled. The number in brackets corresponds to the sampling depth.

We observed higher surface water concentrations of dFe, dCo, dNi, dCu, and dCd in areas that were recently covered by sea ice towards the west of each transect (refer to Sect. 3.3). This ties in nicely with a study by Tovar-Sánchez *et al.* (2010), who observed these trace elements to be enriched in sea ice relative to surface waters, suggesting that sea ice meltwater is a significant source of these trace elements to Baffin Bay surface waters. Especially, the additional input of dFe from melting sea ice could be biologically important in maintaining ice-edge blooms, as seen, e.g., in the Bering Sea (Aguilar-Islas *et al.*, 2008). Besides the additional input through sea ice meltwater, we suggest that much like macronutrients, trace elements have not yet been removed from surface waters by biological uptake. We hypothesize that after the occurrence of the bloom, both macronutrient as well as trace element concentrations would decrease, much like we already saw happening in surface waters of shelf stations closer to the Greenlandic coast. Similar to other regions of the Arctic (Kanna *et al.*, 2014; Nakanowatari *et al.*, 2007), the progressive melting and retreat of sea ice alters biogeochemical cycles of carbon and trace elements as well as the biological productivity in Baffin Bay and Davis Strait.

4.5 Influence of freshwater runoff from coastal sources on biogeochemical properties

The influence of coastal freshwater runoff on the chemical composition of surface waters was demonstrated by statistical analysis (refer to Sect. 4.1.2) and is evident in minimum salinity values (refer to Sect. 3.1) in surface waters of stations 6, 11, and 17. Stations 6 and 11 are located close to the mouth of the Kangerlussuaq Fjord and the Nassuttooq Fjord, which receive glacial and riverine freshwater draining from the GIS (Monteban *et al.*, 2020). Station 17 is located in Disko Bay, approximately 70 km from the mouth of the Ilulissat Icefjord/Jakobshavn Isbræ system, where glacially modified waters form a buoyant coastal current outside the fjord (Beaird *et al.*, 2017). Minimum salinity values in surface waters coincide with higher macronutrient concentrations (refer to Sect. 3.2). A modeling study by Møller *et al.* (2023) has shown that part of the macronutrient input into Disko Bay is directly coupled to freshwater runoff as a source. Other mechanisms that replenish marine-sourced nutrients from deeper water into the photic zone are vertical mixing fueled by wind and tide (Møller *et al.*,



2023) or via the estuarine upwelling circulation forced by the glacier's freshwater input (Williams et al., 2021). Our results suggest that the continued replenishment of macronutrients into the photic zone of Disko Bay can sustain PP into the summer season, which is evident by high oxygen and low AOU concentrations in surface waters of station 17 (refer to Sect. 3.1). This has large implications on the carbonate system and the uptake of CO₂, which is reflected by low Revelle factors and low pCO₂ values in surface waters of Disko Bay (refer to Sect. 3.4). A similar observation for the Godthåbsfjord system in south Greenland revealed biological processes to be the most important drivers of CO₂ uptake, resulting in low pCO₂ concentrations in surface waters of the shelf area (Meire et al., 2015). Our results highlight that nutrient cycling in Disko Bay is strongly driven by GIS-derived freshwater input, which stimulates PP and creates an important sink for CO₂ long into the summer season.

Apart from the Disko Bay area, the surface water of stations closest to the coast of Greenland were corrosive with lower buffering capacities (refer to Sect. 3.4). Glacial freshwater from the GIS is known to have a strong AT dilution effect relative to CT, which impacts the buffering capacity of surface waters, resulting in lower Ω Aragonite saturation states and pH values (Henson et al., 2023; Burgers et al., 2024). The acidification of surface waters can be mitigated by PP, which removes CT from the photic zone and thus increases pH and Ω Aragonite (Chierici and Fransson, 2009), as seen for the Disko Bay area. Surface waters of coastal stations showed negative AOU values, indicating CT drawdown by PP. Simultaneously, extremely low NO_x values (< LOQ) were present, suggesting that PP was reaching a limit due to nutrient depletion. This could explain lower pH values coupled with higher Revelle factors and pCO₂ values, as the AT dilution effect caused by the GIS freshwater input is no longer compensated for by CT removal through biological processes. Our results indicate that surface waters along west Greenland become more susceptible to acidification through the input of poorly buffered glacial freshwater as the summer season progresses and PP decreases. Our results agree well with Henson *et al.* (2023), who observed AT dilution from glacial meltwater to drive corrosive conditions in surface waters of the Greenlandic coast, causing an overall decrease in Ω Aragonite and pH (refer to Sect. 3.4).

Besides the cycling of macronutrients and carbon, the distribution of trace elements is influenced by coastal freshwater input. Overall, the surface water concentrations of dMn, dFe, dCo, dNi, and dCu were highest close to the coast and decreased with distance along each transect. For stations 11 and 12 (mouth of Nassuttooq Fjord) as well as station 17 (Disko Bay, Ilulissat Icefjord) this trend was especially pronounced, reflecting the freshwater runoff from the GIS with a distinct chemical composition (refer to Sect. 4.2.3). Our work is confirmed by previous findings from different regions around Greenland, that suggest the freshwater flux from the GIS to be a source of dMn, dFe, dCo, dNi, and dCu (Chen et al., 2022; Krause et al., 2021; Hawkings et al., 2020; Krisch et al., 2022a; Colombo et al., 2020). Surface water concentrations of dNi in Disko Bay remained relatively constant, whereas stations at the mouth of Nassuttooq Fjord exhibited higher concentrations. A similar observation was done by Krause *et al.* (2021), who related varying dNi along coastal transects to outcrops of Ni-rich minerals across West Greenland. The input of bioactive trace elements, e.g., dMn, dFe, and dCo, via GIS freshwater runoff has been suggested to stimulate primary productivity in the surrounding shelf areas (Bhatia et al., 2013; Hawkings et al., 2020). Our



study provides further evidence that freshwater from the GIS could support biological processes by supplying bioactive trace elements.

5 Summary and Conclusion

590 The distribution of macronutrients, carbonate system species, and dissolved trace elements on the west Greenland shelf is highly dynamic and influenced by the complex interplay between physicochemical drivers, major ocean currents, sea ice melting, and terrestrial freshwater runoff from the GIS. The internal cycling of chemical constituents in the water column is driven by conservative mixing, with freshwater either being a source (dCu) or causing dilution (AT, CT, and dV) of parameter concentrations. Furthermore, we observed biological processes determining the pelagic flux of macronutrients, trace elements
 595 (dFe, dNi, and dCd) and carbonate system parameters. The long residence time of deep and bottom waters in Baffin Bay, along with an enclosed bathymetry that restricts circulation, facilitated the accumulation of remineralized nutrients and CT, which drove corrosive conditions and Ω Aragonite undersaturation in deep waters of southern Baffin Bay. Thus, the benthic ecosystem of the west Greenland shelf is potentially vulnerable to future ocean acidification and suppression of CaCO_3 saturation states. The distribution of trace elements in the study area was diverse and depended on both the intrinsic chemical
 600 behavior of each element and extrinsic factors such as biological processes (uptake and remineralization) or local sources (e.g., coastal runoff, sea ice, benthic processes). We described conservative (dV, dCu), nutrient-type (dFe, dNi, and dCd) and scavenged-type (dMn, dFe, dCo, dNi, and dCu) profiles, which correspond well with previously published data in the Arctic. Additionally, an increase in dMn, dFe, dCo, and dNi concentrations was noticeable for deep water shelf stations, which we relate to benthic fluxes at the sediment-water interface. We hypothesize that this return flux decreased with increasing distance
 605 from the Greenlandic coast as the amount of exported biogenic and terrigenous material available for remineralization and reversible scavenging also decreased. Further studies looking into Baffin Bay sediments are needed to disclose benthic fluxes of trace elements and reactions occurring therein. Our study provides a first insight into the importance of benthic inputs for trace element cycling on the west Greenland shelf and Baffin Bay.

The distribution of chemical constituents in the water column across the west Greenland shelf is mainly influenced by the
 610 opposing directions of the BIC and the WGC and their respective water masses. The southward-moving AW combines winter-cooled water in Baffin Bay with inflow of cold and fresh Arctic Ocean water of Pacific-origin through the CAA. We characterized this water mass as cold and fresh, exhibiting high nutrient contents and high CT:AT ratios due to lower biological activity and the inflow of additional CT transported through the CAA to Baffin Bay. Elevated concentrations of dFe, dMn, dCo, dNi, and dCu were present in AW because of the CAA outflow into Baffin Bay. In contrast, the northward-moving
 615 WGSW integrates freshwater of Arctic-origin from East Greenland that mixes with meltwater from the GIS. This water mass dominated the upper water column on the shelf, which we characterized as warm and fresh, highly productive, and therefore exhibiting low nutrient concentrations. Below the WGSW lies the warm and salty WGIW, which originates in the North Atlantic. This water mass is dominated by the remineralization of OM, leading to the enrichment of nutrients and carbon. We



described the gradual mixing of all three water masses along the shelf by using the latitudinal distribution of dPb, influenced
 620 by elevated dPb waters from the North Atlantic and low dPb waters from the CAA.

Our study provides evidence that the progressive melting and retreat of sea ice alters the biological productivity as well as
 biogeochemical cycles of carbon and trace elements in surface waters of southern Baffin Bay. The east-to-west direction of
 sea ice retreat during spring and summer caused a significant gradient in nutrient concentrations. Nutrients were low in highly
 productive shelf waters along the eastern side of the west Greenland coast, while nutrients were higher towards the west of
 625 southern Baffin Bay because of the prolonged sea ice cover. The timing of this study enabled us to capture the beginning of a
 phytoplankton bloom in areas that were previously covered by sea ice but where nutrients had not yet been consumed.
 Additionally, sea ice meltwater provided additional AT to surface waters, likely through the dissolution of ikaite. This
 geochemical buffer was offset by the presence of excess CT, potentially from organic carbon remineralization under the ice
 and the additional CT input through the CAA to Baffin Bay. Overall, sea ice meltwater and the inflow of Pacific-origin waters
 630 lowered AT relative to CT and are responsible for higher $p\text{CO}_2$ and lower pH and Ω Aragonite values in surface waters. Once
 the sea ice melt facilitated bloom fully develops and CT is removed by PP, higher pH and Ω Aragonite values could be expected
 along the sea ice edge. Furthermore, we observed sea ice meltwater as a source of dFe, dCo, dNi, dCu, and dCd to southern
 Baffin Bay surface waters. As an additional source of bioactive trace elements, this could maintain and prolong ice-edge
 blooms.

635 We observed freshwater runoff from the GIS influencing the chemical composition of coastal waters along west Greenland,
 especially in Disko Bay and at the mouth of the Nassuttooq Fjord. In the Disko Bay area, GIS-derived freshwater input
 replenished macronutrients in the photic zone, stimulating PP and creating an important sink for CO_2 long into the summer
 season. The supply of bioactive trace elements via GIS freshwater runoff, could further support biological processes in the
 surrounding shelf areas. However, in areas along the coastline where PP was reaching a limit due to low nutrient
 640 concentrations, surface waters became more susceptible to acidification through the input of poorly buffered glacial freshwater.
 This work successfully captured a high-resolution, large-scale snapshot of various water column parameters across the west
 Greenland shelf during July. However, we were not able to resolve any seasonal variations, which can only be provided by
 time series studies. We believe that higher temporal monitoring is necessary to fully assess the consequences of climate change
 in this climate-sensitive region.

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Data availability statement

The data set for the carbonate system and dissolved trace elements can be found online at:
<https://doi.org/10.5281/zenodo.14235091> (Schmidt et al., 2024).

Supplement link

650 The supplements to this article can be found online at: XXX

Author contribution

Claudia E. Schmidt: Conceptualization, Formal Analysis, Investigation, Methodology, Data curation, Visualization, Writing – original draft

Tristan Zimmermann: Writing – review & editing

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Daniel Proefrock: Resources, Supervision, Writing – review & editing

Helmuth Thomas: Funding acquisition, Project administration, Resources, Writing – review & editing

Declaration of competing interest

The authors declare that they have no conflict of interest.

660 Acknowledgement

The authors would like to thank the captain and crew of RV Dana for their support during the sampling campaign in 2021. Special thanks to Camilla Svensen and Ulrike Dietrich (both University of Tromsø) for the collection of the nutrient samples and Colin Stedmon and his team (Technical University of Denmark) for the nutrient analysis.

Financial support

665 This project has received funding from the European Union's Horizon 2020 research and innovation program under Grant Agreement No. 869383 (ECOTIP) and the European Union's Horizon 2023 research and innovation program under Grant Agreement No. 101136480 (SEA-Quester). The project was made possible through the program "Changing Earth – Sustaining our Future" (Subtopic 4.1) within the Helmholtz Association.



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