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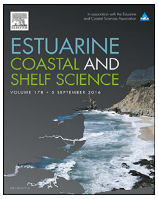

Inorganic carbon in a high latitude estuary-fjord system in Canada's eastern Arctic

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ABSTRACT

Rapidly changing conditions in the Arctic can have a significant impact on biogeochemical cycles and can be particularly important in high latitude estuary-fjord systems with abundant and diverse freshwater sources. This study provides a first look into the inorganic carbon system and its relation to freshwater sources in Cumberland Sound in the east coast of Baffin Island, Nunavut, Canada. These data contribute to the very limited set of inorganic carbon measurements in high latitude estuary-fjord systems. During the ice-free conditions in August 2011, the meteoric freshwater fractions (MW) in the upper 40 m ranged from 11 to 21% and no sea ice melt (SIM) was present in the Sound. Surface waters were undersaturated with pCO_2 (260 and 300 μatm), and DIC and TA ranged between 1779 and 1966 μmol DIC kg^{-1}, and 1922 and 2140 μmol TA kg^{-1}, respectively. Aragonite saturation (Ω_{Ar}) state ranged from 1.9 in the surface to 1.4 in the subsurface waters. Data show decreasing TA and Ω_{Ar} with increasing MW fraction and suggest that Cumberland Sound waters would become aragonite undersaturated ($\Omega_{Ar} < 1$) at MW = 0.37 (95% CI: 0.29 to 0.56). Estimated local $\delta^{18}O$ (−19.2‰) and TA (174 μmol TA kg^{-1}) end-members indicate MW was most likely a mixture of river water and glacial melt. In August 2012, MW fractions at the surface were between 8 and 11.5%, and SIM between 7 and 23%. Significant interannual variability of summertime SIM could potentially result in Ω_{Ar} undersaturation.

1. Introduction

High latitude surface waters are particularly responsive to increases in atmospheric CO_2 and are predicted to be among the earliest to experience the detrimental effects of ocean acidification [Orr et al., 2005; Thomas et al., 2007; Fabry et al., 2009; Azetsu-Scott et al., 2010; Parmentier et al., 2013]. For example, a significant decrease in Ω_{Ar} values over 1997–2008 was observed in Canada Basin due to increase in ice melt [Yamamoto-Kawai et al., 2009]. According to Robbins et al., (2013) approximately 20% of Canadian Basin surface waters are already undersaturated with respect to aragonite ($\Omega_{Ar} < 1$). Low pH and local Ω_{Ar} undersaturation have also been observed in the surface waters (<200 m) of the western Arctic and southern part of the Canadian Arctic Archipelago [Bates and Mathis et al., 2011; Bates et al., 2009; Chierici and Fransson, 2009; Robbins et al., 2013] and Amundsen Gulf [Shadwick et al., 2011a; Fransson et al., 2013]. It is anticipated these waters to become corrosive to $CaCO_3$ shell-building organisms such as cold water corals, coralline algae, coccolithophorids, foraminifera, pteropods, bivalves, and echinoderms [Andersson et al., 2015]. Studies have already shown evidence of $CaCO_3$ dissolution affecting polar pteropods in Ω_{Ar} undersaturated waters [Bednaršek et al., 2012].

Low Ω_{Ar} in these areas are mainly related to abundant freshwater supply from sea ice melt and meteoric sources (river runoff, glacial meltwater and local precipitation) which are low in total

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alkalinity (TA) relative to marine waters [Reisdorph and Mathis, 2014; Evans et al., 2014]. Both TA and Ω_{Ar} generally decrease with increasing contributions of sea ice melt water or river water, but correlations between freshwater fraction, and TA and Ω_A vary regionally [Chierici and Fransson, 2009; Yamamoto-Kawai et al., 2009; Fransson et al., 2013; Robbins et al., 2013; Azetsu-Scott et al., 2014]. Decreases in Ω_{Ar} are relatively greater when seawater is mixed with sea ice meltwater than for its dilution with river runoff with its higher concentration of TA [Azetsu-Scott et al., 2014]. Consequently, it is important to examine relationships between TA and Ω_{Ar} and freshwater fraction to determine the freshwater fraction (%), and the particular freshwater source partitioning (river, glacial and sea ice melt) where these systems likely become Ω_{Ar} undersaturated.

High latitude estuary-fjord systems, such as Cumberland Sound, are ubiquitous in the northern oceans. They host commercially viable fish populations, bivalves, cold-water corals, large mammals (whales, seals) and seabirds and hence are of great importance to local communities. Changing water conditions such as ocean acidification may have a significant adverse impact on the benthic and pelagic calcifiers that form an important part of the food chain. Only a few studies of inorganic carbon dynamics in high latitude estuary-fjord systems have been performed [Torres et al., 2011; Crabeck et al., 2014; Reisdorph and Mathis, 2014; Fransson et al., 2015; Meire et al., 2015; Omar et al., 2016]. Those that estimate Ω_{Ar} [Fransson et al., 2015; Omar et al., 2016], reported low values and seasonal Ω_{Ar} undersaturation [Reisdorph and Mathis, 2014]. This is because, in addition to riverine input, precipitation and sea ice melt, these systems are strongly influenced by freshwater discharge from melting glaciers, which has lower TA compared to marine waters [Fransson et al., 2015, Meire et al., 2015]. With elevated CO_2 levels leading to climate change, increases in freshwater inputs due to melting glaciers, and sea ice reduction, ocean acidification are anticipated to have broad scale effects in the Arctic Ocean [Orr et al., 2005; Morison et al., 2012]. High latitude estuary-fjord systems may be even more strongly affected, and on shorter time scales, than the open ocean due to their unique mixture of freshwater sources (each with distinct chemical signatures) and their consequent effect on inorganic carbon dynamics. The site-specific nature of these variables may serve to make some estuary-fjord systems particularly susceptible to further reductions in Ω_{Ar} and the effects of ocean acidification. Furthermore, estuary-fjord systems generally show variability that exceeds the forecasted global mean changes. These highly variable ecosystems may have evolved to be more resilient to changes in carbonate chemistry and abiotic factors [Johnson et al., 2014], but it also may make them more vulnerable to extreme values. This study examines the inorganic carbon chemistry of Cumberland Sound and its relation to freshwater sources, and further compares these results to the limited set of studies available for other high latitude estuaries/fjords.

To the best of our knowledge, this study presents the first measurements of inorganic carbon parameters and $\delta^{18}O$ in the Cumberland Sound, in the southeast of Baffin Island, including: concentration of dissolved inorganic carbon (DIC), total alkalinity (TA) from discrete water samples, and partial pressure of CO_2 (pCO_2) from a moored sensor. The main objectives of this scoping study are: 1) to provide the first baseline summer-time values for inorganic carbon parameters (DIC, TA, pCO_2, and Ω_{Ar}) in the surface waters of Cumberland Sound, and 2) to determine their relation to freshwater additions (river runoff, glacial melt and sea ice melt) using $\delta^{18}O$ as a tracer. We also determined the values of local meteoric $\delta^{18}O$, TA and DIC freshwater end-members. A Submersible Autonomous Moored Instrument for CO_2 (SAMI-CO_2) sensor (Sunburst Sensors LLC) enabled us to investigate the range of temporal variability of measured pCO_2 in the Sound. Physical oceanographic observations and nutrient concentrations taken during the time period of our study in the Sound were described by Bedard et al., (2015).

2. Materials and methods

2.1. Study area

Cumberland Sound is a large inlet, 250 km long, with an average width of 65 km, on the east coast of Baffin Island, Nunavut, Canada (Fig. 1). It opens to Davis Strait and the Labrador Sea, where observations have indicated that DIC in 150–500 m depth range in the past two decades is increasing steadily, resulting in decreases in both the pH, and the saturation state of seawater with respect to $CaCO_3$ [Yashayaev et al., 2014]. Acid-sensitive taxa (coccolithophores, forams, pteropods, cold water corals and coralline algae) have been observed in the surrounding areas of the Labrador Sea and the eastern Canadian shelf [Yashayaev et al., 2014], and some of these organisms may be also present in the Sound. Ecosystem integrity is important for commercially viable fish populations [Peklova et al., 2012] which provide economic support to the Inuit community of Pangnirtung. The Sound has an irregular rocky bottom with deep pools extending beyond 1100 m separated by 200 m deep sub-surface ridges (Fig. 1). The water properties in Cumberland Sound are dominated by two water masses that originate from outside of the basin [Bedard et al., 2015]. At shallow to mid-depths (>300 m), the cold Baffin Island Current (BIC) bends into the Sound along its east coast, circulates, and exits along the south shore. As reported by previous studies of Davis Strait, the BIC waters have low Ω_{Ar} (<1.6) and the depth of aragonite saturation horizon ($\Omega_{Ar} = 1$) is around 200 m [Azetsu-Scott et al., 2010]. Deep water is occasionally replenished from the warmer and saltier re-circulated arm of the West Greenland Current (WGC). In addition to BIC and WGC, a local mixed layer and estuarine flow is observed at the surface in the upper 25 m. The Sound is also strongly affected by multiple freshwater sources, including the Isuituq River system at the head of Clearwater Fjord, the McKeand River at the western side of the Sound, and a glacial ice cap (the Penny Ice Cap) at the end of Pangnirtung Fjord (Fig. 1). There is additional freshwater input from terrestrial snow and ice melt, sea ice melt, and numerous smaller seasonal rivers and streams. The freshwater input from these sources is usually highest in July and August when air temperature is highest [Zdanowicz et al., 2012; Bedard et al., 2015]. Tides are strong within the Sound. Bedard et al., (2015) however suggests that these local processes affect the surface layer, but do not play a significant role in influencing water properties deeper in the water column (>300 m). Cumberland Sound is far enough north to experience seasonal ice cover, and is typically frozen over during the winter and spring. It is mostly ice free in late summer and early fall, but there are some interannual variation in summer sea ice occurrence (Canadian Ice Service archives; http://www.ec.gc.ca/glaces-ice/).

Consistent with trends in glacier mass loss in the Canadian High Arctic, the Penny Ice Cap, positioned at the end of the Pangnirtung Fjord has also been thinning and its valley glaciers have been retreating in recent decades related to rising summer and winter air temperatures across the eastern Arctic [Zdanowicz et al., 2012]. In addition, a significant reduction in sea ice extent and thickness in the past few decades has been observed in Baffin Bay and Labrador Sea [Cavalieri and Parkinson, 2012] as well as freshening of BIC in Baffin Bay/Davis Strait [Steiner et al., 2013]. These reductions would have likely resulted in increased freshwater input into the Sound.