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Meltwater chemistry and solute export from a Greenland Ice Sheet catchment, Watson River, West Greenland

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SUMMARY

Solute export from the Greenland Ice Sheet (GrIS) to coastal regions around Greenland is likely to increase in the future as a consequence of increasing icemelt production. Here, we present hydrochemical characteristics, solute and major ion exports and chemical denudation rates for 2007–2010 for the Watson River sector of the GrIS that drains into the fjord Kangerlussuaq. The hydrochemistry is dominated by Ca^{2+} and HCO_3^- with a relatively high molar K^+/Na^+ ratio of 0.6 ± 0.1, typical for meltwaters draining a gneissic lithology. Low molar Ca^{2+}/Na^+ and Mg^{2+}/Na^+ ratios indicate that weathering of disseminated carbonates contributes less than silicate weathering to the chemical composition. The solute export varied between 33×10^3 (2009) and 61×10^3 tons (2010), showing that increasing discharge leads to increasing solute export at the catchment scale. Deviations between ion yield estimates derived from use of discharge-weighted and mean daily concentrations methods were generally less than 5%, indicating that the choice of method is of less importance. The chemical denudation rates ranged between 36 and 56 Σ^* meq$^+$ m^{-2} per year, which are lower than previous records from glacierized catchments. However, when normalized by discharge the denudation rates are comparable to other Arctic sites. When extrapolating the results from the Watson River catchment to the entire Greenland for 2007–2010, the solute export from Greenland meltwater varied between 7.1×10^6 and 7.8×10^6 tons, whilst the major ion export was between 6.4×10^6 and 7.3×10^6 tons. Dissolved Fe, a potential biolimiting nutrient for primary productivity in the North Atlantic, had annual export rates from Greenland between 15×10^3 and 52×10^3 tons.

1. Introduction

Solute export from the Greenland Ice Sheet (GrIS) is likely to increase in the future because (1) meltwater discharge is the primary control on solute transport in glacial waters (e.g. Tranter, 2006) and (2) the on-going climate-forced decrease in glacier mass balance induces a corresponding increase in meltwater discharge from the GrIS (Hanna et al., 2005, 2008). The freshwater flux from the GrIS to the North Atlantic Ocean has increased by 36% in recent decades, 1992–2010, (Bamber et al., 2012) and enhanced discharge is expected as long as rapid deglaciation occurs (Braithwaite, 2011). Annual melting records in 2007, 2010 and 2012 associated with early onsets of the melt season and large positive temperature anomalies indicate that extreme melting years are likely to occur more frequently in the future (Tedesco, 2007; Tedesco et al., 2011, 2013; van As et al., 2012), resulting in associated extreme annual solute fluxes.

Recently, Frajka-Williams and Rhines (2010) proposed that freshwater from the GrIS is a significant source for nutrients to the adjacent sea areas. They found a significant correlation between discharge from Greenland and the spring phytoplankton bloom intensity in the northern Labrador Sea off the coast of West Greenland. A likely explanation could be a direct link between peak bloom intensity and delivery of bioavailable dissolved and particulate iron (Fe) from discharge and icebergs, as bioavailable Fe is considered as a potentially limiting nutrient in the North Atlantic Ocean (Blain et al., 2004; Bhatia et al., 2013). However, our current knowledge about the temporal and spatial variability of individual ion concentrations in GrIS discharge is very limited. For instance, there are only few reports of Fe concentrations (Yde and Knudsen, 2004; Statham et al., 2008; Ryo and Jacobson, 2012; Bhatia et al., 2013) and no multi-year hydrochemistry studies exist.

Studies on GrIS meltwater chemistry have been restricted to siliceous catchments in central West Greenland. From Imersuaq Glacier, Yde and Knudsen (2004) reported that ion concentrations of the major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) varied contemporaneously

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with SO_4^{2-} and $\delta^{18}O$ on a diurnal scale, whereas the major cations' relation to marine-derived Cl^- was weak. From Manitsoq Glacier, Tranter (2003) showed that seasonal variations in Ca^{2+} flux were associated with an early season meltwater outburst and discharge variations during the ablation season. The best documented basin is the Watson River catchment, where an international airport and easy access to the ice sheet margin reduce the costs of fieldwork. This site is also interesting from a scientific perspective because the land-terminating outlet glaciers and ice sheet margin within the Watson River catchment have almost similar geological, glaciological and hydrometeorological conditions as the rest of the ice sheet margin in West and Southwest Greenland (Jakobsen et al., 2000). Several studies have collected spot samples along Watson River and its tributaries (Friberg et al., 2001; Wimpenny et al., 2010, 2011; Ryo and Jacobson, 2012). Friberg et al. (2001) linked low solute concentrations and low abundance of macroinvertebrates. Further, Wimpenny et al. (2010) revealed that glacier cover has insignificant impact on the Li isotopic flux to the ocean, and Wimpenny et al. (2011) showed that the Mg isotopic composition can be attributed to incongruent weathering of rock surfaces. Ryo and Jacobson (2012) examined CO_2 partial pressure in the meltwater and used theoretical mass balance calculations and a reactive transport model to conclude that CO_2 evasion from the GrIS could represent a positive carbon-climate feedback in worst-case scenarios. However, despite the importance of the GrIS for Arctic fjord and sea ecology and global elemental cycling, there is still limited knowledge of the magnitude, composition and variability of solute export from the GrIS.

In this study we aim to improve our understanding of solute export and hydrochemical characteristics in meltwater drainage from the GrIS. Our objectives are (i) to present the hydrochemical characteristics of Watson River and assess the interannual variability in meltwater composition; (ii) to estimate the export and interannual variability of major ions, Si and Fe in the Watson River catchment by applying two solute yield calculation methods; (iii) to determine the chemical weathering rate in the Watson River catchment; and (iv) to provide a first-order quantitative assessment of the solute and major ion exports from Greenland.

2. Study area

The Watson River catchment (67° N; 50° W) is situated in central West Greenland (Fig. 1). It comprises the two proglacial, east–west oriented valley systems Sandflugtsdalen (Akuliarusiarsuup Kuua) [English: Sand Drift Valley] to the north and Ørkendalen (Quinnguata Kuusua) [English: Desert Valley] to the south, and a sector of the western part of the Greenland Ice Sheet (glacier inventory codes 1DG02 and 1DG03; Weidick et al., 1992). As expressed in the names of the valley systems, the climate is characterized as a Low Arctic polar desert (Hobbs, 1931). At the local meteorological station in the town of Kangerlussuaq, the mean annual air temperature is −5.7 °C (1961–1990) and the mean annual precipitation is 149 mm (1961–1990), respectively (Cappelen, 2013). The upper part of the catchment on the GrIS is considerably colder and more humid (van den Broeke et al., 2009). The proglacial area is characterized by continuous permafrost with an active layer thickness of 0.5 m in peat and more than 1.0 m on unvegetated outwash deposits (Yde et al., 2010).

The geology comprises Archaean amphibolite and granulite facies gneisses with basic to intermediate intrusive dykes belonging to the Nagssugtoqidian mobile belt (Escher et al., 1976). The

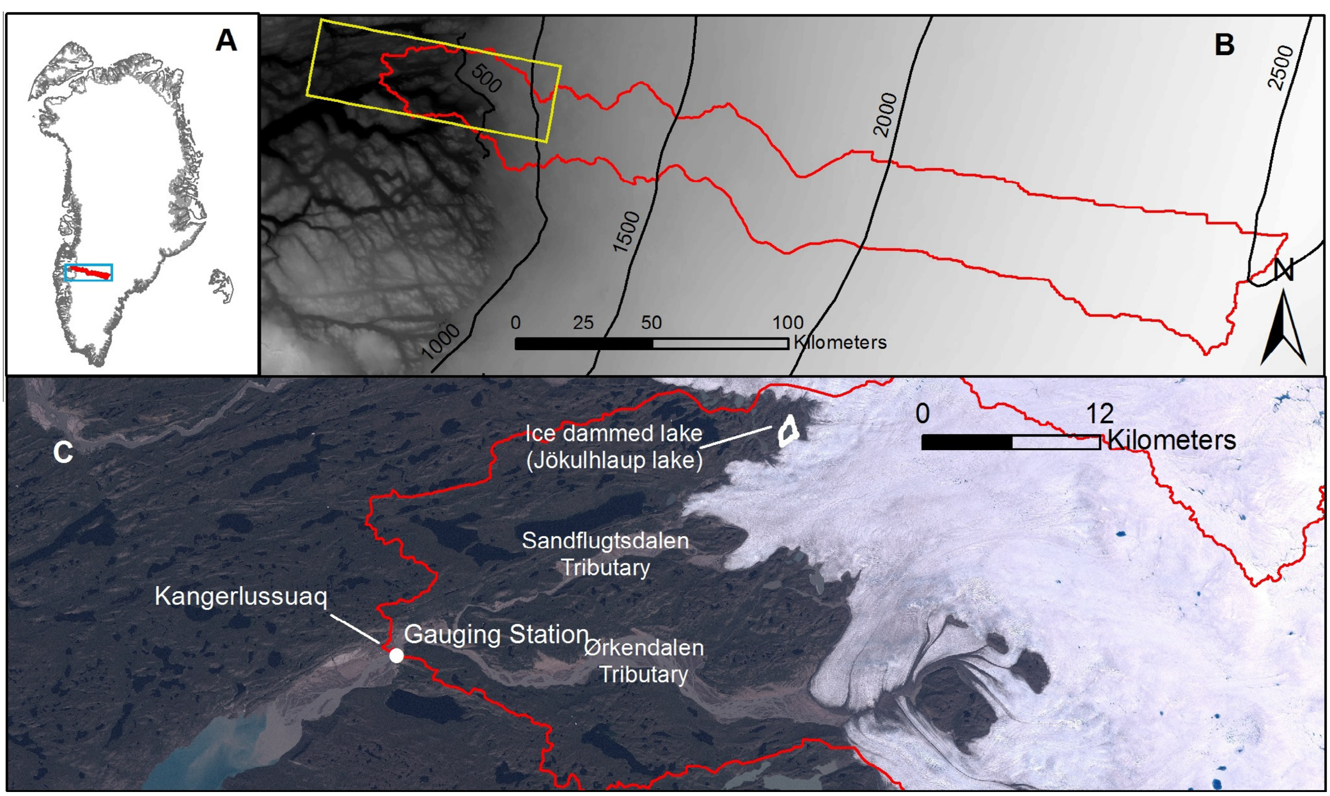

Fig. 1. Location maps of the Watson River catchment, West Greenland. (A) A map of Greenland showing the location of the catchment area (marked by red color). The blue box in (A) indicates the location of panel (B), which shows a digital elevation model of the catchment based on a composite of ASTER data and data presented by DiMarzio et al. (2007). The yellow box in (B) indicates the location of panel (C), which shows the ice marginal and proglacial area, including the locations of the village of Kangerlussuaq, the gauging station, the ice dammed lake (jökulhlaup lake) and the two proglacial valleys Sandflugtsdalen and Ørkendalen. The background picture in panel (C) is a pan-sharpened Landsat 7 ETM+ image. The red lines in (B) and (C) denote the boundary of the catchment area. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article).