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The influence of glacial melt water on bio-optical properties in two contrasting Greenlandic fjords

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ABSTRACT

Scattering alters the path of photons, but ultimately their removal from the water column occurs by absorption by one of four components: water itself, coloured dissolved organic matter (CDOM), phytoplankton pigments or non-algal particulate matter (NAP). We calculated absorption budgets for two fjordal systems, Godthåbsfjord (SW Greenland) and Young Sound (NE Greenland), based on these components and evaluated the fate of solar radiation in each system. Absorption by phytoplankton pigment accounted for 15–32% of photons in Godthåbsfjord whilst in Young Sound the corresponding fraction was only 5–8%. NAP accounted for 13–25% of absorption in Young Sound and only 7–8% in Godthåbsfjord whilst fractions of absorption by CDOM were more similar: 6–13% in Godthåbsfjord and 6–18% in Young Sound.

In typical temperate estuarine systems, nutrients, CDOM and particulate matter are supplied by riverine sources. Increased nutrient supply will tend to increase productivity whilst increased concentrations of CDOM and particles will increase light attenuation, thereby reducing productivity. The two Greenlandic fjords differ from typical estuarine systems in that their supply of nutrients and particles is decoupled. Freshwater feeding them comes from glacial melt and contains particles but low concentrations of nutrients. New nutrients are supplied by entrainment of oceanic water at the mouths of the fjords and sediment–water exchange of remineralized nutrients. Attenuation and thereby light availability in the two fjords is strongly correlated with turbidity (Godthåbsfjord: $r^2 = 0.90$ $p < 0.01$, Young Sound: $r^2 = 0.82$ $p < 0.001$) and we conclude that loading of particulate matter controls light attenuation, and through this may influence primary production. Previous studies argue that warming due to climate change will increase productivity in the fjords. We suggest that increased runoff and particle load may have an opposite effect.

1. Introduction

Availability of light is a major factor structuring aquatic ecosystems, and in particular coastal and estuarine systems that are shallow enough that light can potentially reach the bottom. Light is essential for all primary producers; but also the fish community is affected by light attenuation, as many fish depend to some extent on visual predation for feeding (Aksnes and Giske, 1993). Thus, light attenuation sets the limits for their feeding habitat and competition with non-visual predators like jellyfish (Haraldsson et al., 2012). Light attenuation also determines the depth limit of macrophytes, both macroalgae (Markager and Sand-Jensen, 1992) and vascular plants (Duarte, 1991; Middelboe and Markager, 1997). Macrophytes give structure to the ecosystem, creating habitats for animals, and are important primary producers (Krause-Jensen et al., 2012b) so their depth limits and thus their areal coverage affects the entire ecosystem. Light attenuation also governs production of benthic microalgae (Krause-Jensen et al., 2012b), which in turn is a food source for the benthic fauna and affects nutrient fluxes across the sediments.

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Primary production by phytoplankton and in particular the distribution of primary production above and below the pycnocline, is strongly affected by light attenuation (Lyngsgaard et al., 2014). Surface waters are often depleted of nutrients but receive a surplus of light whereas the situation is reversed below the pycnocline where the phytoplankton have access to nutrients but are light limited. A key factor for the productivity of coastal systems is therefore whether there is sufficient light just below the pycnocline to allow a positive growth rate of the phytoplankton community (Lyngsgaard et al., 2014).

In the Arctic, sea ice and especially snow cover reduces light penetration to the water column (Søgaard et al., 2010) and primary production in the central Arctic Ocean has been estimated to increase in years with minimal ice cover (Arrigo et al., 2008). However, the relationship between sea ice cover and production is not a simple one. Arrigo et al. (2012) have reported massive phytoplankton blooms under sea-ice. In Greenland, large latitudinal scale differences in ice cover and thus annual light availability have been shown to influence the depth distribution and annual production of benthic primary producers (Krause-Jensen et al., 2012a) with cascading effects to secondary producers (Sejr et al., 2009). At meso-scale within fjord systems along the Greenland coast, glacial discharge of ice and melt water influence light conditions and the physical and chemical environment with implication for circulation patterns (Mortensen et al., 2011) and pelagic (Arendt et al., 2010) and benthic (Sejr et al., 2010) community structure. Changes in climate are increasing the supply of freshwater in the Arctic region. This affects the hydrographic conditions, leading to increased stratification and, in areas without upwelling, reducing the vertical transport of nutrients (McLaughlin and Carmack, 2010; Tremblay et al., 2012). Work in the Antarctic shows that meltwater is associated with increased phytoplankton biomass (Dierssen et al., 2002). Increased freshwater supply may also affect the loading of coloured dissolved organic matter (CDOM), particles and nutrients.

Freshwater inflow is a characteristic feature of estuaries and fjords and in temperate estuaries freshwater sources contribute with significant amounts of nutrients, CDOM and particles to the inner parts of these systems. Inputs of nutrients, CDOM and particles often control the productivity of the systems (Timmermann et al., 2012) in that the nutrients stimulate primary production whilst CDOM and particles increase light attenuation, which to some degree counter-acts the positive effect of riverine inputs on primary production (Markager et al., 2011). In this study, we examine two Greenlandic fjord systems, Young Sound on the north-east coast and Godthåbsfjord on the south-west coast. Nutrient concentrations in the freshwater supplied to these fjords are much lower than in freshwater supplied to typical temperate estuarine systems (Rasch et al., 2000; Telling et al., 2012), where nutrient concentration greatly exceeds that in the recipient. In Young Sound the nutrient concentration in streams running into the sound (Mernild et al., 2007) is of the same order of magnitude as that seen in the fjord itself. However, glacial meltwater has high concentrations of mineral particles (glacial flour) (Dierssen et al., 2002; Davies-Colley and Nagels, 2008). Thus, in these Greenlandic fjord systems the freshwater does not contribute with nutrients but has a negative effect on the availability of light for primary production due to large numbers of particles which increase scattering. Although vertical mixing replenishes surface water nutrient concentrations, new nutrients originate mainly from the adjacent seas, as does CDOM. Thus, the systems can be regarded as ‘reversed’ in comparison with typical temperate estuarine systems with respect to the distribution and sources of CDOM and nutrients. In both fjords, freshwater from summer runoff enters at the surface but there are differences between the two systems. In Godthåbsfjord, a number of fjord-terminating glaciers release meltwater at depths up to 200 m generating upwelling and vertical mixing (Mortensen et al., 2011). A relatively large tidal amplitude of up to 5.5 m (Richter et al., 2011) contributes further to vertical mixing. In Young Sound, the tidal amplitude is about 1 m (Bendtsen et al., 2007). Godthåbsfjord has sea-ice cover limited to the innermost parts and smaller fjord branches whilst Young Sound has 9 months of sea-ice cover. Primary production in Godthåbsfjord is of the order of 100 g C m^{-2} yr^{-1} (Mikkelsen et al., 2008; Juul-Pedersen et al., 2015) but only 10 g C m^{-2} yr^{-1} (Rysgaard et al., 1999) in Young Sound.

The hydrographical conditions observed in the Godthåbsfjord system during the present study do not stand out from the conditions observed in other similar periods (Rysgaard et al., 2008; Mortensen et al., 2013). The conditions observed in Young Sound can also be considered representative for the situation during July and August (Rysgaard et al., 2003; Sejr et al., 2012). It should be noted that sampling in Young Sound took place during the height of glacial discharge whilst Godthåbsfjord was sampled in May, several months before peak discharge, which occurs in September.

Greenlandic coastal waters are experiencing the effects of recent climate change, with increased melting of the Greenland Ice Sheet (Gregory et al., 2004; Chu, 2013) and reduced sea-ice coverage (Perovich and Richter-Menge, 2009; Wang and Overland, 2012). These factors will cause changes in the structure and productivity of coastal marine ecosystems, of which the Greenlandic society is economically and culturally dependent (Calbet et al., 2011). However, the bio-optical implication of glacial discharge in Greenland fjords and coastal water has not been quantified. We hypothesise that the ecological and hence socio-economic consequences of global change for Greenland will in part be driven by alteration in the optical environment of the fjord systems. Characterizing the optical properties of two contrasting Greenlandic fjord systems allows us to examine how changes in light attenuation may affect light available for primary production. The aim of this study is to compare the bio-optical properties of waters in these two fjords and determine which components control light attenuation. Thus, we can contribute to better understanding of climate change impact on coastal ecosystems due to the combined effects of changes in runoff and loadings on light attenuation.

2. Materials and methods

2.1. Study sites

Godthåbsfjord (Greenlandic: Nûp Kangerdlua) is a sub-arctic fjord located in SW Greenland (64°15′N, 51°40′W) (Fig. 1a). The fjord has a number of branches with a total surface area of ca. 2013 km^2, but the main part of the fjord is 170 km long (Mortensen et al., 2011). This fjord system has an estimated mean depth of 260 m, with a main sill at the entrance (ca. 170 m) and a deeper basin (>600 m). Terrestrial freshwater sources are 6 glaciers from the Greenlandic Ice Sheet, of which 3 terminate on land and 3 in the fjord (Van As et al., 2014). Mortensen et al. (2011) estimate an annual ice discharge of 8 km^3 from the largest single source, the Kangiata Nunâta Sermia calving front. The majority of this ice has melted before leaving the fjord. Total runoff to the fjord in 2011 was of the order of 20 km^3 (Van As et al., 2014). The fjord system also experiences seasonal intermittent inflows of coastal water during 1–3 months in winter. Sampling here was carried along a route from the inner fjord to the open sea at Fyllas Bank from 5 to 11 May.

Young Sound is a high-arctic fjord on the NE coast of Greenland (74°15′N, 20°20′W) (Fig. 1b). The 90 km long Young Sound/Tyroler fjord system consists of the narrower inner Tyroler Fjord with a