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ORIGINAL RESEARCH ARTICLE

Spatiotemporal changes in the concentration and composition of suspended particulate matter in front of Hansbreen, a tidewater glacier in Svalbard

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Summary Tidewater glaciers supply large amounts of suspended particulate matter (*SPM*) and freshwater to fjords and affect oceanographic, sedimentological and biological processes. Our understanding of these processes, is usually limited to the short summer season. Here, we present the results of a one-year-long monitoring of the spatial variability in *SPM* characteristics in a context of oceanographic and meteorological conditions of a glacial bay next to Hansbreen, a tidewater glacier in Hornsund (southern Spitsbergen). The observed range of *SPM* concentrations was similar to ranges measured in other sub-polar glaciated fjords, especially in Svalbard. The major source of SPM is the meltwater discharge from the glacier. The maximum water column-averaged *SPM* concentrations did not correlate with peaks in freshwater discharge and were observed at the beginning of the autumn season, when the fjord water transitioned from stratified to fully mixed. The observed spatiotemporal variations in the total *SPM*, particulate organic matter (*POM*) and particulate inorganic matter (*PIM*) are likely controlled by a combination of factors including freshwater supply, water stratification and circulation, bathymetry, the presence of sea ice, biological productivity and sediment resuspension. During the ablation season, the *SPM* maximum concentrations were located within the upper water layer, whereas during the winter and spring, the greatest amounts of *SPM* were concentrated in deeper part.

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Thus, typical remote sensing-based studies that focus on *SPM* distributions may not reflect the real *SPM* levels. *POM* and *PIM* concentrations were correlated with each other, during most of the time suggesting that they may have a common source.

1. Introduction

Glaciers are one of the most sensitive indicators of ongoing climate changes that have commonly resulted in their recent very rapid retreat since the end of the Little Ice Age (e.g., Carr et al., 2017; Radić and Hock, 2011; Solomina et al., 2016). Due to the retreat of marine-terminating tidewater glaciers, at a rate of several tens of metres per year, as in Svalbard (e.g., Błaszczyk et al., 2013), or several hundreds of metres per year, as in Alaska (e.g., Molnia, 2007), new glacial bays have formed and host immature coastal ecosystems. Melting glaciers affect coastal waters in many ways, the most important of which is the delivery of freshwater and suspended particulate matter (*SPM*), which is often called suspended sediment. They are among the key driving factors for coastal glaciomarine ecosystems, as well as oceanographic and sedimentary regimes (e.g., Bennett and Glasser, 2009; Chauche et al., 2014; Motyka et al., 2003; Szczuciński and Zajączkowski, 2012). Their influence can also extend far beyond the coastal zone into the open ocean and affect larger scale circulation and biological processes. For example, *SPM*-rich glacial meltwater can provide critical limiting micronutrients (e.g., Fe) to the ocean and thereby influence its primary production (e.g., Bhatia et al., 2013; Markussen et al., 2016).

Many of the existing records of sediment accumulation rates in fjords suggest that climate warming has enhanced sediment production and export to the fjords (Boldt et al., 2013; Koppes and Hallet, 2002; Szczuciński et al., 2009; Zajączkowski et al., 2004). In addition, the combination of historical data and modelling experiments suggests that present-day sediment fluxes to the polar zone of the coastal ocean have increased. For instance, the suspended sediment supply from Greenland to the ocean is currently approximately 56% higher than it was during the 1961—1990 period (Overeem et al., 2017). Moreover, one may expect that the seasonality of *SPM* delivery, distribution and sedimentation processes will also change. However, this issue is still open to research because present-day seasonal changes in *SPM* distributions are poorly known.

SPM is mainly delivered to fjords by ice-contact processes, including meltwater discharge, rafting by icebergs and sea ice, riverine inputs and exchanges with external water masses (Syvitski, 1989; Winters and Syvitski, 1992). The general model of *SPM* delivery shows the driving role of freshwater and sediment-laden outflows from tidewater glaciers, which, due to density differences, form surface brackish water plumes covering most of the glacial bays during the summer season (Syvitski, 1989). However, a growing number of observations, indicate that other factors are also significant. For example, a study on a large dataset from Greenland found that the delivery of *SPM* is likely mainly a function of the regional glacial dynamics and the resulting intensity of erosion, not freshwater flux (Overeem et al., 2017). Furthermore, oceanographic circulation is important not only in terms of the sediment transport and circulation patterns in glacial bays but also as a driving factor of tidewater glacier stability (e.g., Straneo and Heimbach, 2013). Because field observations on seasonal cycles are sparse, the driving forces that control the *SPM* input and distribution in fjords are still subject to ongoing debate.

The fjords of Svalbard are particularly suitable for studies on climate warming impacts on the supply and fate of *SPM* since they are affected by the northward flowing West Spitsbergen Current (WSC) that transports warm Atlantic Water (AW), resulting in accelerated warming (e.g., Cisek et al., 2017; Osuch and Wawrzyniak, 2016; Promińska et al., 2017). Moreover, these fjords are among the best studied subpolar fjords in the world, and many supplementary data are available (e.g., Drewnik et al., 2016; Forwick et al., 2010; Svendsen et al., 2002). The *SPM* concentrations in the fjords of Svalbard are commonly documented during the summer season in central parts of fjords (e.g., Sagan and Darecki, 2018; Svendsen et al., 2002), in meltwater river-fed bays (e.g., Dowdeswell and Cromack, 1991; Zajączkowski and Włodarska-Kowalczuk, 2007) and in the glacial bays near tidewater glaciers (e.g., Elverhøi et al., 1983; Görlich et al., 1987; Schildt et al., 2017; Szczuciński and Zajączkowski, 2012; Trusel et al., 2010; Urbanski et al., 2017; Zajączkowski, 2002, 2008).

However, observations on the seasonal *SPM* concentration changes and their major controlling factors in the fronts of tidewater glaciers in Spitsbergen are very limited. Szczuciński and Zajączkowski (2012) studied sedimentary processes in the summer and autumn in Adolfbukta next to the calving front of Nordenskiöldbreen. These authors found that in the autumn, the vertical particulate matter fluxes (sedimentation) decrease much more than the *SPM* concentrations and that residence time of the *SPM* in the water increases likely due to less effective flocculation. These authors also suggested a list of factors that affect the sedimentation of *SPM*, such as the positions of freshwater inlets (surface/subsurface), meltwater discharge, *SPM* concentrations in the meltwater, local wind damming effects, tides and resuspension. Moreover, studies conducted in glacier-distal settings revealed that phytoplankton blooms are important factors in the increase of *SPM* concentrations in the spring (Pawłowska et al., 2011; Węsławski et al., 1988).

The goal of the paper is to present a unique time series of the seasonal changes of the *SPM* delivery, distribution and composition in a glacial bay next to the calving front of Hansbreen in Hornsund. This paper presents a complementary dataset, including supporting meteorological and ocea-