

# Impacts of the 2012 Jakobshavn Isbræ melting season on turbidity and primary production

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## Abstract

In the summer of 2012, Jakobshavn Isbræ glacier surged, producing the highest ever recorded glacial velocity while retreating (Joughin *et al.*, 2014). Glacial melt water in Greenland has been associated with both increases in turbidity and increases in local and off-shore primary production, most likely due to increases in nutrient concentrations. In this study, we use daily satellite-derived particulate and chlorophyll a concentrations during the summer of 2012 to determine how this extraordinary summer melt season impacted primary production and turbidity in the region. We found that the area near Jakobshavn had chlorophyll a concentrations on average two times higher than the region as a whole, and that increases in chlorophyll a were correlated with increases in particulate in both Jakobshavn and the region as a whole. Particulate had no correlation to lagged chlorophyll a concentrations. These findings may support the idea that melt water provides phytoplankton with nutrients necessary to support a bloom and indicate the need for more research in the Jakobshavn area to see how primary production is influenced by the high melt water output of the glacier.

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## Introduction

Air and water temperature changes in the polar regions are occurring at an accelerated pace (Chapman and Walsh, 1993; Serreze *et al.*, 2000), most likely due to the positive feedback cycle of ice loss and diminished albedo (Holland and Bitz, 2003; Screen and Simmonds, 2010). Changes in summer air temperature have had dramatic impacts on the region, causing increases in river discharge into the Arctic Ocean (Peterson *et al.*, 2002) and leading to increases in glacial melt rate (Gardner *et al.*, 2011). The Greenland ice sheet, the largest ice sheet in the Northern Hemisphere, has experienced accelerated melting and mass sheet loss since at least the early 2000s (Chen *et al.*, 2006). In the summer of 2012, 95% of the surface of the Greenland ice sheet melted for 2 or more days, making the year the most extensive melting year on record (Hall *et al.*, 2013).

One particular glacier to the west of Greenland, Jakobshavn Isbræ, is currently considered the most rapidly retreating glacier in the world (Joughin *et al.*, 2014). The glacier serves as an outlet glacier for 7% of the mass of the Greenland ice sheet (Rignot and Kanagaratnam, 2006; Csatho *et al.*, 2008) and contributed 1mm towards changes in global sea level between 2000 and 2010 (Joughin *et al.*, 2012). Through the early and mid-1990s, the

glacier slowly thickened (Holland *et al.*, 2008). In 1997, an incursion of warm subsurface water due to changes in the North Atlantic Oscillation, paired with the bathymetry under Jakobshavn, led to rapid retreat (Holland *et al.*, 2008). Critical to this increase in melt rate was the thinning and disintegration of the 15 km floating ice tongue in the early 2000s, which had previously slowed up-stream glacial velocity (Holland *et al.*, 2008). In the summer of 2012, Jakobshavn's mean annual retreat was recorded at rates 3 times higher than in the mid-1990s, and its peak summer speed was a factor of 4 greater (Joughin *et al.*, 2014). Over the course of 2012, the Jakobshavn glacial velocity surged at a rate of  $18 \text{ km yr}^{-1}$ , retreating by 1 km and thinning by 20 m (Joughin *et al.*, 2014).

As warming ocean and air temperatures increase the rate of glacial melting, they also affect the amount of suspended sediment in the water column, greatly influencing regional primary production. At McBride Glacier in Alaska, rapid retreat ( $0.25 \text{ km yr}^{-1}$ , 1984-86) led to the deposition of  $6.6 \times 10^6 \text{ m}^3$  of sediment over a two-year period, with sediment accumulation rates as high as  $13 \text{ m yr}^{-1}$  over 300m from the glacier (Cowan and Powell 1991). Approximately 2/3 of the total volume of sediment was emitted by meltwater plumes originating at the base of the tidewater glacier and was subsequently deposited by suspension settling (Cowan and Powell 1991). Despite sediment flocculation close to the glacier, fine particles stay suspended even several kilometers from the meltwater plumes (Cowan and Powell 1991). While no surveys have been conducted on the sediment output of Jakobshavn in particular, research in the nearby Kangerlussuaq fjord reveals that satellite observations of sediment plumes were an effective proxy for determining the onset, duration and volume of melt water runoff (McGrath *et al.*, 2010).

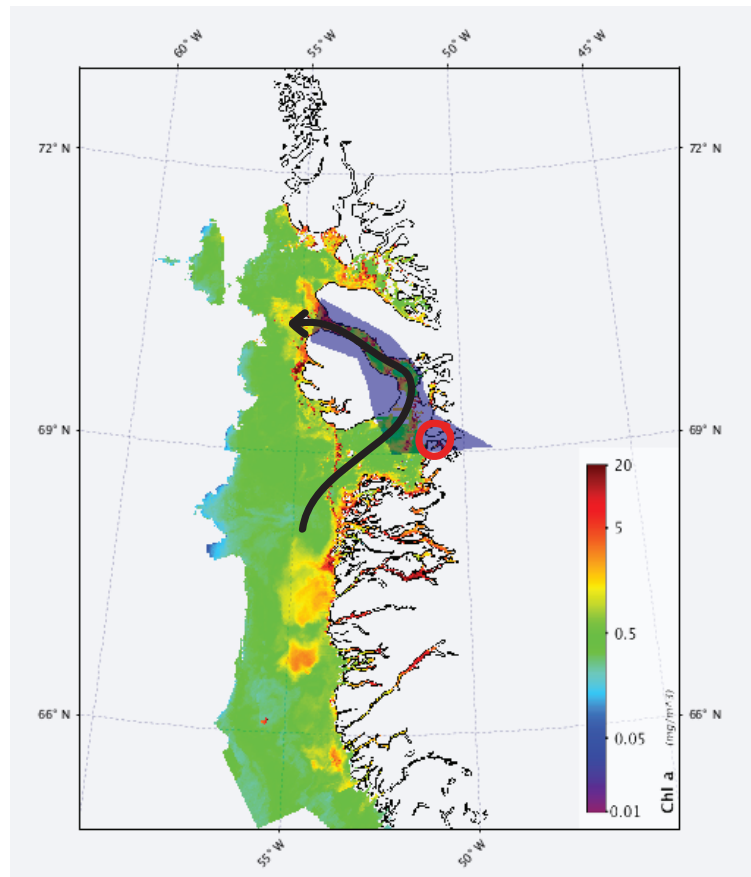
In addition to being correlated with increased sediment concentrations, glacial runoff may be associated with higher primary production. In various fjords along western Greenland, the arrival of melt water in the fjord has been associated with increases in bioavailable nutrients, particularly iron and phosphorus (Hawkings *et al.*, 2014; 2015; 2016) and silicate (Meire *et al.*, 2016). Additionally, a study by Arrigo *et al.* (2017) found that the variance in satellite-derived summer phytoplankton blooms off the west coast of Greenland was correlated to the modeled arrival of melt water from the Greenland ice sheet, and lagged behind the melt water by about 1 week. Together, these studies indicate that glacial melt water may provide nutrients to phytoplankton both in fjords and in areas off-shore.

Here, we present an analysis of satellite data from the summer of 2012 in the region surrounding Jakobshavn Isbræ. We aim to address how the rapid retreat of Jakobshavn that summer affected suspended particulate and chlorophyll a both close to Jakobshavn and in the surrounding region. We also evaluate if changes in turbidity and chlorophyll a near the Jakobshavn glacier are correlated, and if there is any lagged correlation between changes in suspended particulate and in chlorophyll a.

## Methods

Daily maps for this region were produced from satellite derived chlorophyll a (Chl a; NASA's OCI algorithm) and Rrs-667 (which approximates particulate in surface water) measurement by processing Modis Aqua level 2 images from the NASA Ocean Color website and using the mosaic tool on SeaDAS (NASA) to compute daily averages for each pixel. A daily composite map was made for each date between June 1<sup>st</sup> and August 15<sup>th</sup> of 2012 between 66°N and 72°N and between 50°W and 60°W. A mask (shown in Figure XX) was used to distinguish the near-Jakobshavn area from the larger region.

Excluding pixels for which there were no data due to ice or cloud cover, mean, median, and sigma chlorophyll a and Rrs-667 measurements for both the region and the Jakobshavn mask were computed using SeaDAS statistical software. Daily maps with less than 1000 pixels were discarded from analysis. Because mean and median values for particulate and chlorophyll were comparable, only median values were used for the statistical analysis in this project.



**Figure 1.** Map of regional Chl a distribution from June 5th, 2012, with Jakobshavn area highlighted in blue, predominant current in black, and Jakobshavn glacier circled in red.

## Results

*How does particulate vary across the region?*

Particulate is highly variable on a daily timescale in both the Jakobshavn Isbræ area and in the region as a whole (Figure 2). Mean particulate in the Jakobshavn area over the entire period was  $0.00092 \text{ mg m}^{-3}$ , as compared to  $0.00074 \text{ mg m}^{-3}$  for the region as a whole.

Particulate for Jakobshavn and the region are positively correlated (Figure 3). Variation in Jakobshavn particulate concentrations explains 24.4% of the variance in regional particulate concentrations over this period ( $p = 0.012$ , Figure 3).

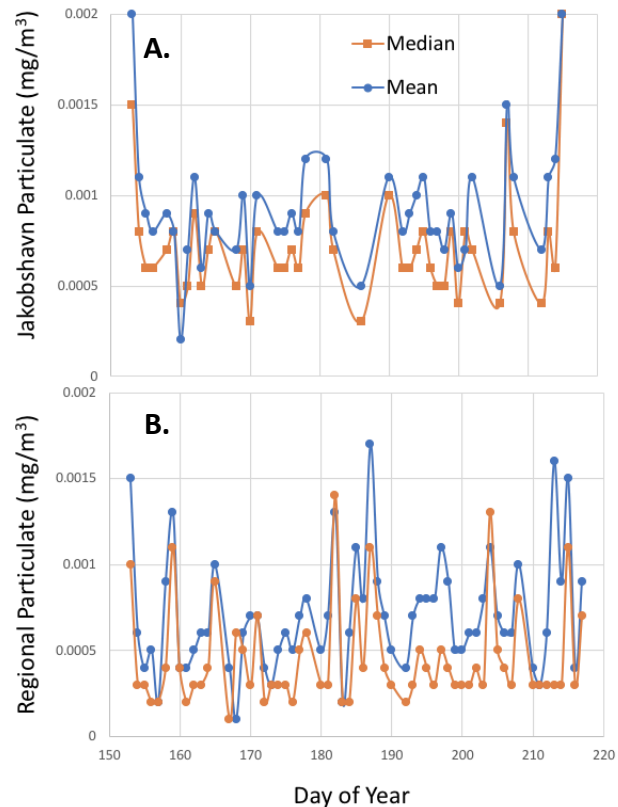
*How does Chlorophyll a vary across the region?*

Chlorophyll is highly variable on a daily timescale in both the Jakobshavn area and in the region as a whole (Figure 4). Mean chlorophyll in the Jakobshavn area over the entire period was  $3.06 \text{ mg m}^{-3}$ , as compared to  $1.50 \text{ mg m}^{-3}$  for the region as a whole. The last day in the timeseries, with an outlier chlorophyll a concentration of over  $20 \text{ mg m}^{-3}$ , was omitted from the remainder of the analysis.

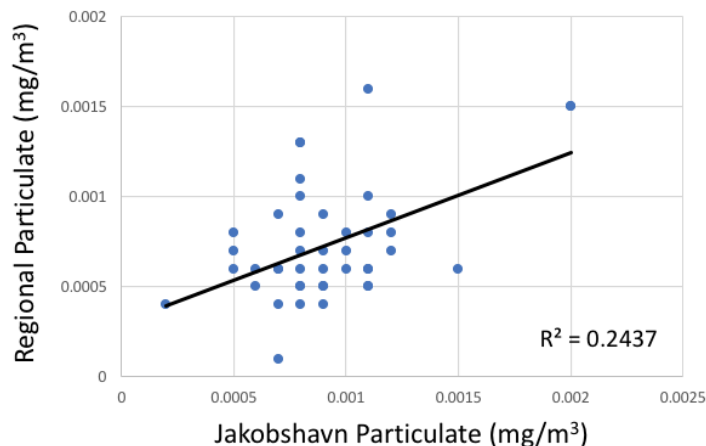
Chlorophyll a for Jakobshavn and the region are positively correlated (Figure 5). Variation in Jakobshavn Chlorophyll a concentrations explains 37.7% of the variance in regional particulate concentrations over this period ( $p < 0.001$ , Figure 5).

*How does particulate concentration influence Chlorophyll a?*

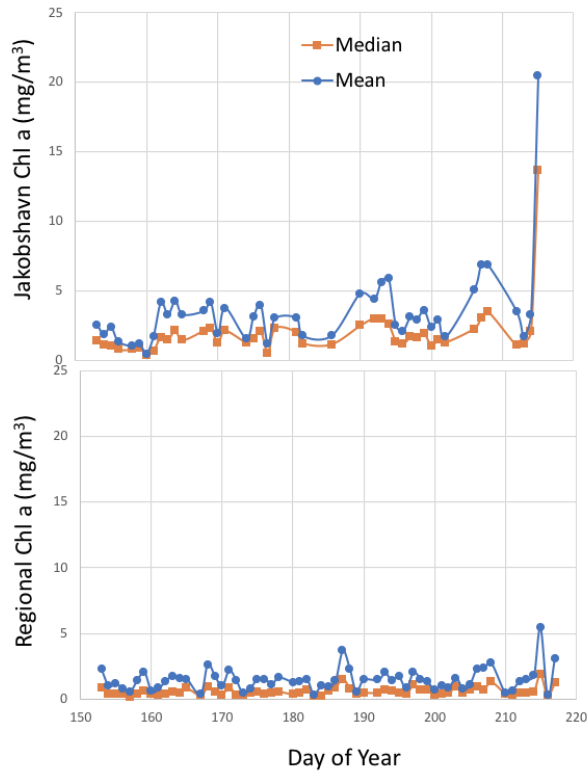
In both the Jakobshavn area and in the region as a whole, particulate concentrations are positively correlated with Chlorophyll a concentrations (Figure 6). In the Jakobshavn area, variation in particulate concentration explains 31.8% of the variance in Chlorophyll a



**Figure 2.** Summer 2022 timeseries of mean (blue line) and median (orange line) particulate concentrations for A) Jakobshavn area and B) the region as a whole.



**Figure 3.** Scatterplot (blue dots) of Jakobshavn (x axis) vs. regional (y axis) mean particulate concentration in the summer of 2022. Linear regression (black line) has an  $R^2$  value of 0.2437 and a  $p$ -value of 0.012.

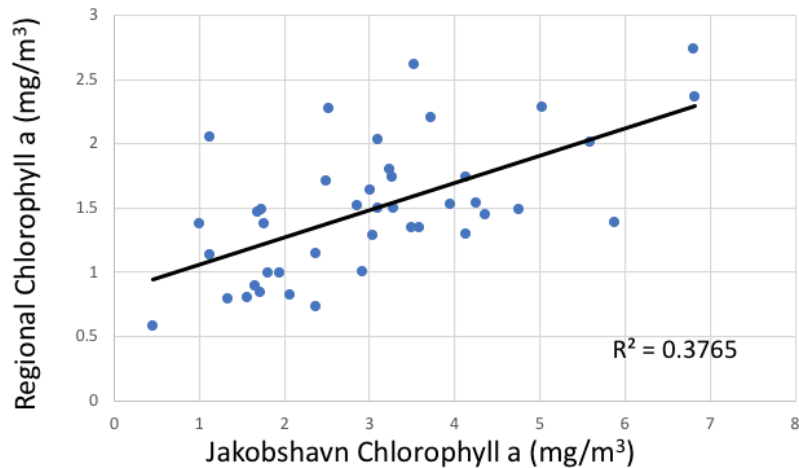


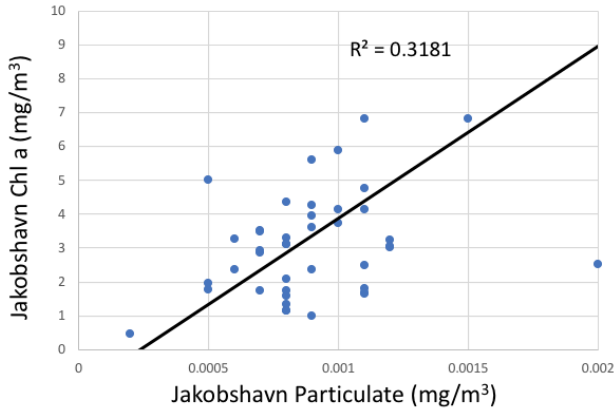
**Figure 4.** Summer 2012 timeseries of mean (blue line) and median (orange line) Chlorophyll a concentrations for A) the Jakobshavn area and B) the region as a whole.

concentration ( $p < 0.001$ , Figure 6a). In the region as a whole, variation in particulate concentration explains 38.4% of the variance in Chlorophyll a concentration ( $p < 0.001$ , Figure 6b).

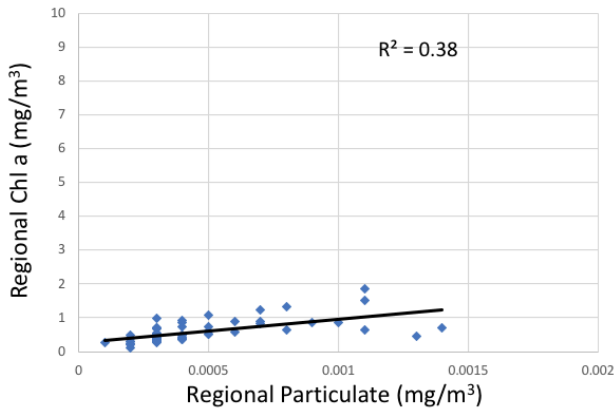
Chlorophyll a data were lagged behind particulate data for 1-9 days to see if particulate data from might predict future Chlorophyll a values. Particulate concentrations explained 0 to 1.9% of the variance in lagged Chlorophyll a values (Figure 7), indicating that there was no lagged correlation between particulate and Chlorophyll a.

**Figure 5.** Scatterplot (blue dots) of Jakobshavn (x axis) vs. regional (y axis) mean Chlorophyll a concentration in the summer of 2012. Linear regression (black line) has an  $R^2$  value of 0.3765 and a  $p$ -value of  $< 0.001$ .

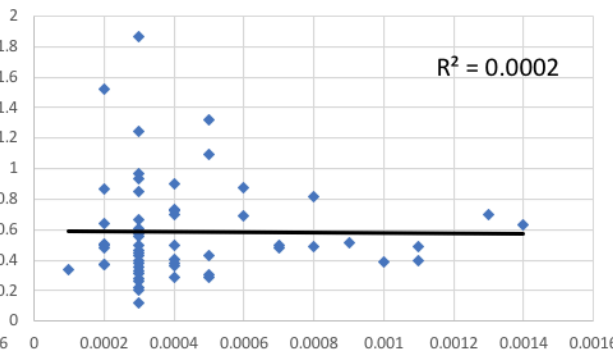
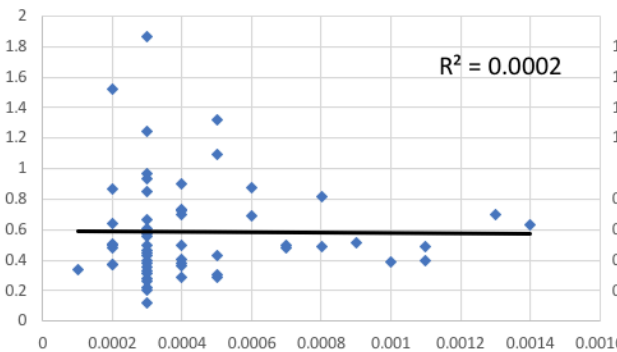
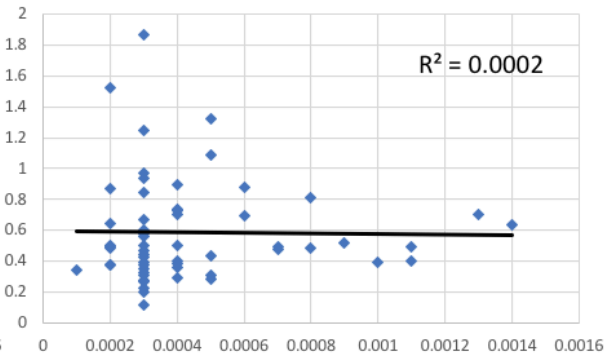
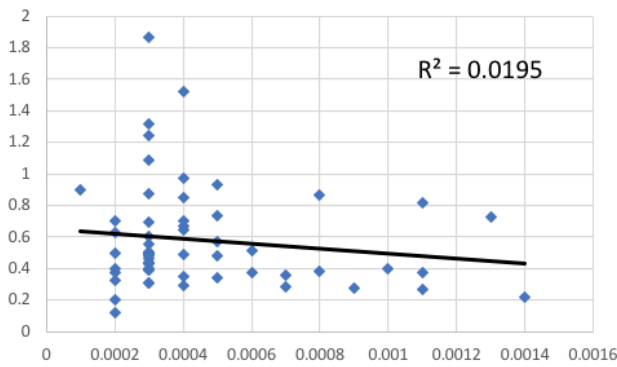




**Figure 6.** Scatterplots (blue dots) of A) Jakobshavn and B) regional mean particulate concentration (x axis) vs. Chlorophyll a concentration (y axis) in the summer of 2012. Linear regressions (black line) have an  $R^2$  value of 0.3181 and 0.3849, respectively, and a p-value of  $< 0.001$  and  $< 0.001$ , respectively.



**Figure 7.** Scatterplots (blue dots) of particulate (x axis) vs. lagged [by 1 day (A), 3 days (B), 5 days (C), and 7 days (D)] Chlorophyll a concentration (y axis) for the Jakobshavn area in the summer of 2012. Linear regressions are in black, and  $R^2$  values indicate no significant correlation between data.



## Discussion

Particulate concentrations during the summer of 2012 were not significantly higher in the near-Jakobshavn area than in the region as a whole. This could indicate 1) that the Jakobshavn area is not a significant contributor to turbidity in the region, 2) that particulate contributions from other glaciers melting along the west coast of Greenland damped down the signal of the single glacier in our study, or 3) that the particulate flocculates out of the water column within a short distance, and thus that particulate is only an effective measure of melt water presence within a few kilometers of the glacier. In order to address the first and second possibilities, increased field work in the region is necessary to adequately determine how much particulate the Jakobshavn glacier is releasing into the water column, and to put its sediment production in context with the other glaciers along the west coast of Greenland. The third possibility can be evaluated remotely. Research by McGrath *et al.* (2010) in Kangerlussuaq fjord indicates that the sediment signal observed from meltwater runoff was constrained to about 50km from the glacial terminus. The mask we created for Jakobshavn particulate, however, extended 180km from the glacial terminus. By more tightly constraining the near-Jakobshavn area, the particulate signal might be significantly stronger.

Chlorophyll a concentrations were significantly higher near Jakobshavn than in the region as a whole. Mean Chl a concentrations were 2 times higher in Jakobshavn over the whole summer than they were in the larger region, and Jakobshavn Chl a levels appeared to partially drive Chl a in the region as a whole (explaining 38% of the variance in regional Chl a concentrations). This indicates that areas near Jakobshavn that have much higher levels of melt water also are more productive, further supporting the hypothesis advanced by Hawkings *et al.* (2014; 2015; 2016) and Arrigo *et al.* (2017) that glacial melt water is providing primary producers with limiting nutrients. However, further analysis is necessary to tease out whether proximity to Jakobshavn Isbræ specifically or to any glacial output is the critical factor in promoting primary production. In this current analysis, we are comparing Chl a production near Jakobshavn to a large regional box that includes off-shore areas. By comparing Jakobshavn Chl a concentration with the Chl a for other near-shore areas close to glaciers, we would be able to ensure that the heightened levels of Chl a observed within the Jakobshavn mask were in fact due to that glacier's melt water, rather than due to continental shelf or some other factor.

## Conclusion

Our results indicate that particulate concentrations are correlated to chlorophyll a concentrations, but that they are not correlated to lagged Chl a. Correlation of particulate and chlorophyll a provide further evidence that melt water may be an important source of nutrients to primary producers. However, one difficulty of using Rrs-667 to approximate turbidity in this region is that this wavelength may include phytoplankton concentrations in its estimates. This could give a falsely high correlation between measurements of particulate and Chlorophyll a. Assuming that our results indicate a true positive correlation between particulate and Chl a, further remote and field research would elucidate the importance of this correlation.

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