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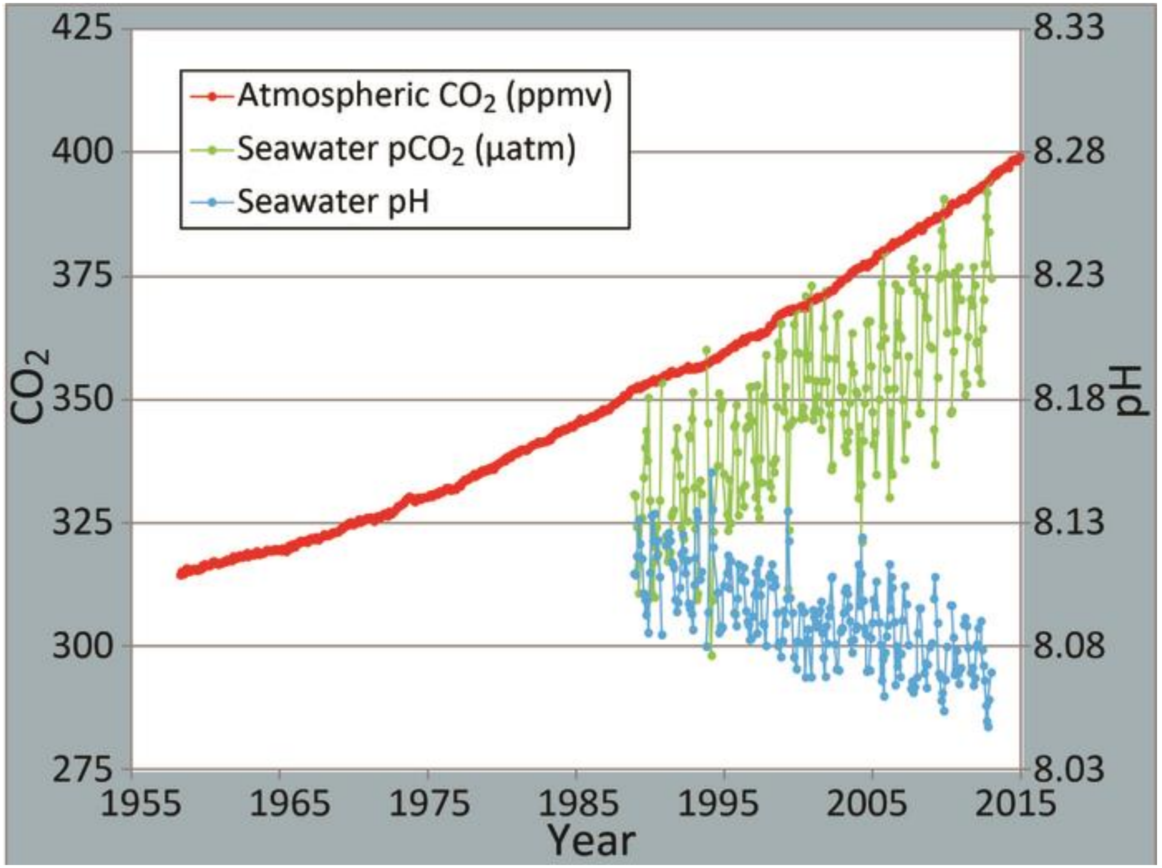
Carbon cycle in perspective of glacier recession - marine or terrestrial control?

Łukasz Stachnik

Photo credits to D. Ignatiuk (right), A. Kies (left)

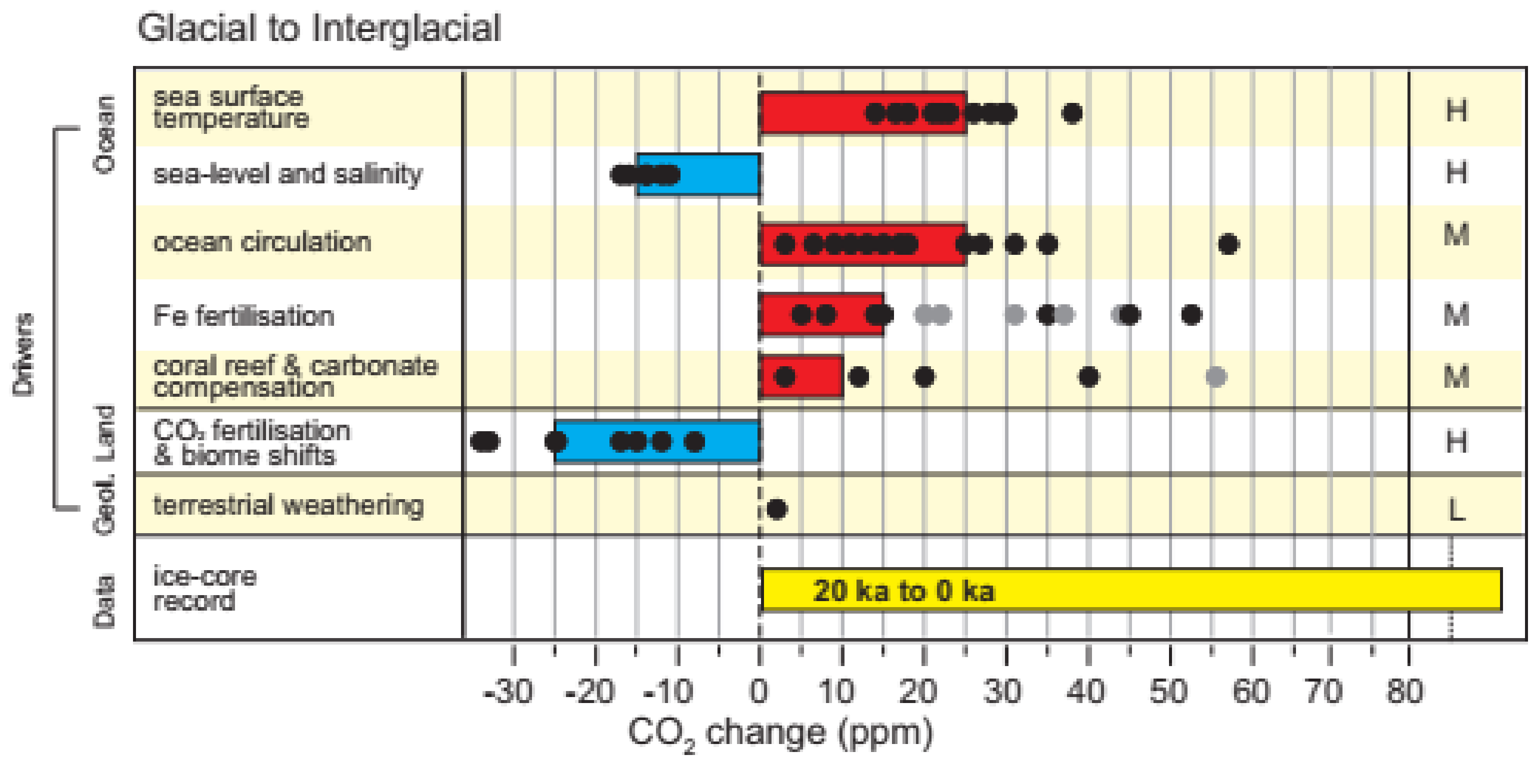
Strong relationship between atmospheric and seawater CO_2



- Increase of atmospheric CO_2 causes increase of CO_2 in seawater and consenquent drop in pH
- The inverse processes can be also observed – lower CO_2 concentration in seawater causes decrease in atmospheric CO_2

http://www.fondriest.com/environmental-measurements/parameters/water-quality/ph/

Iron fertilisation causes lower atmospheric CO_2 during LGM



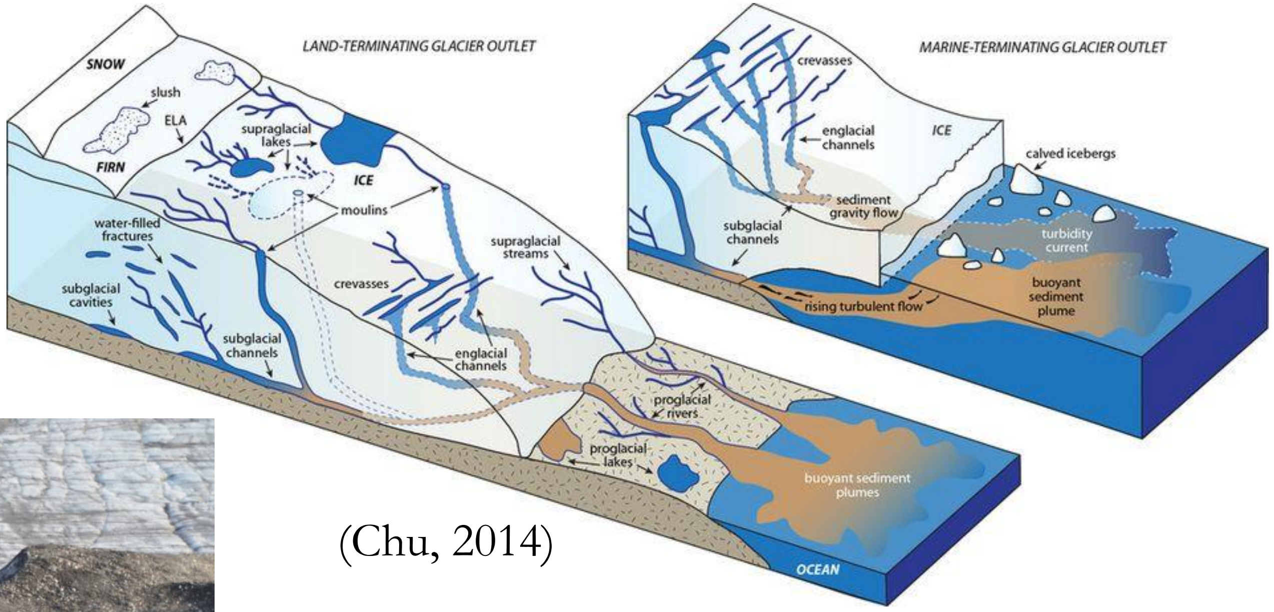
Atmospheric CO_2 concentration during glacial intervals was 180-200 ppm CO_2

- After LGM, inhibition of ocean fertilization via lower Fe-rich dust deposition caused an increase in CO_2 by 15 ppm, corresponding to 10% of atmospheric CO_2

(Ciais et al., 2013)

Aim

What are processes controlling carbon cycle during glacier recession – tidewater and land-based glacier?



(Chu, 2014)

Photo credits to D. Ignatiuk (right), A. Kies (left)

Earlier approach in carbon cycle associated with glaciers

Glaciers and Nutrients in Arctic Seas

Abstract. *Significantly higher concentrations of nitrate and silicate were found in glaciated South Cape Fiord than in unglaciated Grise Fiord, in the Canadian Arctic, or in adjacent Jones Sound. No significant differences in phosphate concentrations were found. Glacial activity apparently enriches the concentrations of those nutrients most critically limiting for arctic phytoplankton requirements.*

The effects of active, moving glaciers discharging into the sea on the nutrient content of adjacent waters have been the subject of some limited speculation. Vibe (*1*), for example, discussing conditions in northwest Greenland, remarked " . . . I hold the view that the glaciers far surpass precipitation as an erosive factor in procuring the inorganic material . . . which renders all organic life possible." Similarly, Sverdrup ". . . suggested that Antarctic waters should also receive much dispersed silica formed by comminution of rock beneath the very large glaciers of the Antarctic continent" (*2*). Hartley and Dunbar (*3*) discussed upwelling and enriching hydrodynamic processes associated with "brown zones" adjacent to glaciers terminating in the sea.

The hypothesis that active coastal glaciers enrich nutrient concentrations in the sea was tested in May 1969 in two of the numerous fiords that indent the southern shore (latitude 76°30′N) of Ellesmere Island, Northwest Territories, Canada. Glaciated and unglaciated fiords provide experimental and control areas, respectively, in which hypothetical effects of glaciation may be isolated and examined without undue external dilution, which might obscure glacial influence. Grise Fiord, the control area, extends inland approximately 38 km and does not have any glaciers reaching its shores. South Cape Fiord, the experimental area, is approximately 25 km long and has three glaciers reaching its shores (see cover photograph). The largest of these, unnamed, is approximately 32 km long and about 3.2 km wide where it reaches the fiord. This glacier evidently is active, calving small icebergs into South Cape Fiord. The cover photograph shows one such berg recently calved from the glacier front. In May 1969, at least 15 icebergs were frozen into the fiord.

At the time of this survey, air temperatures were in the range of −15° to −1°C and the entire area was snow-covered with no signs of spring thaw or melt. There were no effects on the sea of runoff from the land. Throughout the area of this study, Jones Sound and the adjacent waters were completely covered with intact, snow-covered sea ice averaging 0.75 to 1.0 m in thickness.

Grise Fiord has a maximum depth of about 365 m inside a sill depth of

(Apollonio, 1973)

REVUE BELGE DE GEOGRAPHIE
88e année — 1964 — Fascicules un et deux

Les karsts des régions polaires

par J. CORBEL
Lyon.

Les calcaires dans l'Arctique.

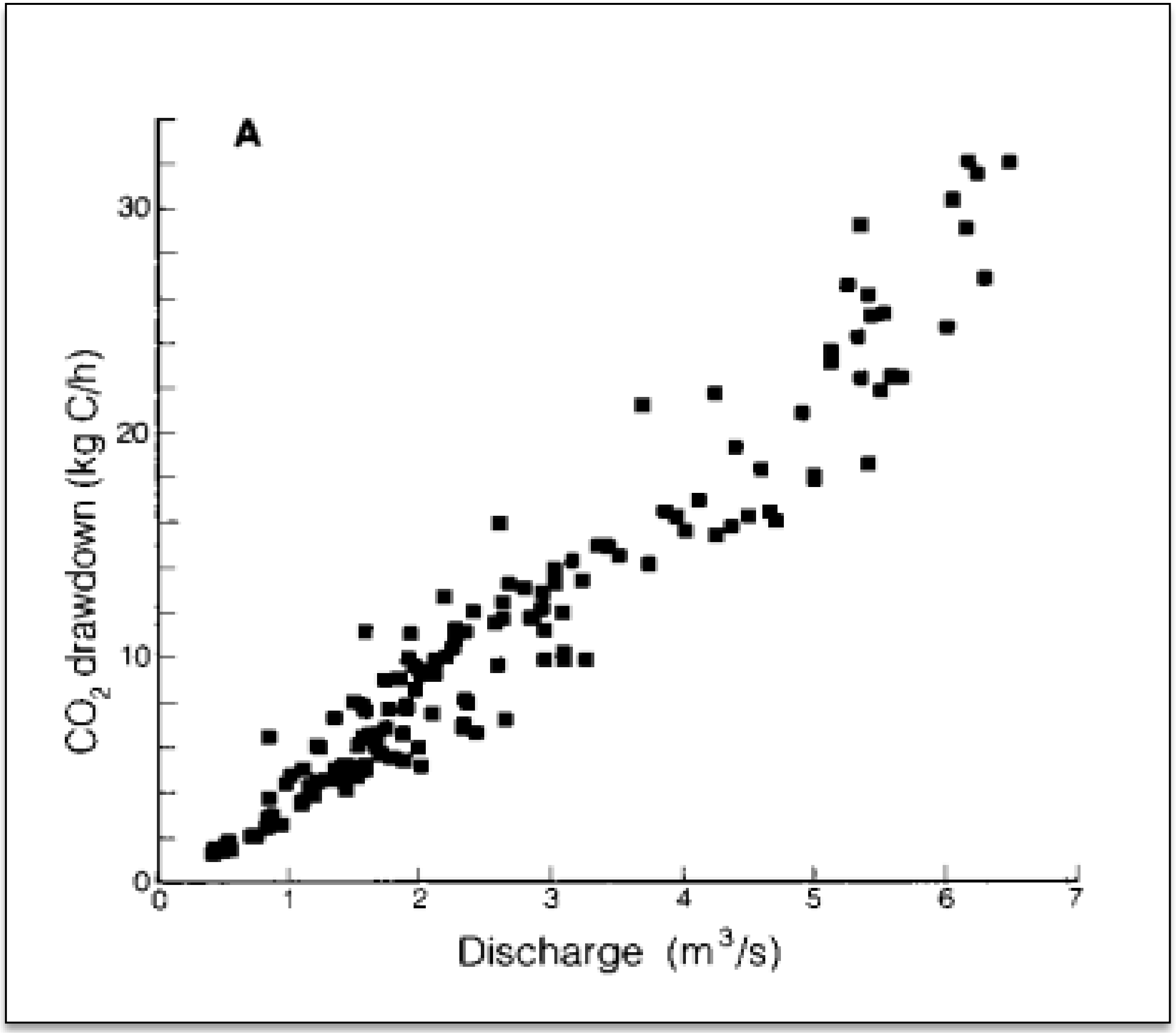
Si l'on appelle « régions polaires » uniquement les zones situées au-delà du Cercle Polaire (66° 32 lat.), on couvre un ensemble de 43.000.000 km². L'Antarctique, autour du Pôle Sud, est enseveli sous une énorme calotte glaciaire ne laissant que quelques mers bordières et des nunataks (îlots rocheux émergeant des glaces). L'Arctique, au contraire, est largement dégagée. La surface émergée est de 7.700.000 km², dont 1.700.000 km² seulement couverts de glace, ce qui laisse 6.000.000 km² pour les zones de toundra périglaciaire, plaines et montagnes.

Sur ces 6 millions de km² les formations géologiques à faciès marins sont assez larges, alors que dans l'Antarctique les rares régions déglacées montrent à peu près uniquement des formations d'origines continentales ou volcaniques sans calcaire.

Dans l'Arctique les calcaires sont loin d'être rares; d'après une première estimation faite suivant ce que nous savons actuellement de la géologie de ces régions, ils couvrent environ 1 à 200.000 km², répartis entre les diverses grandes régions Nord-Alaska, Nord-Canada, Nord-Groënland, Spitsberg et Norvège septentrionale, Taïmyr, îles arctiques russes et diverses petites régions du Nord-Sibérie). Au total une centaine d'affleurements notables de 100 à 1000 km² dispersés dans tout l'Arctique.

(Corbel, 1964)

Earlier approach in CO_2 comsumption – silicate weathering



(Sharp et al. 1995)

- During glacial/interglacial transition, enhanced chemical weathering of silicates caused high CO_2 consumption in tectonically active mountain ranges (e.g. Himalayas)
- Net consumption of CO_2

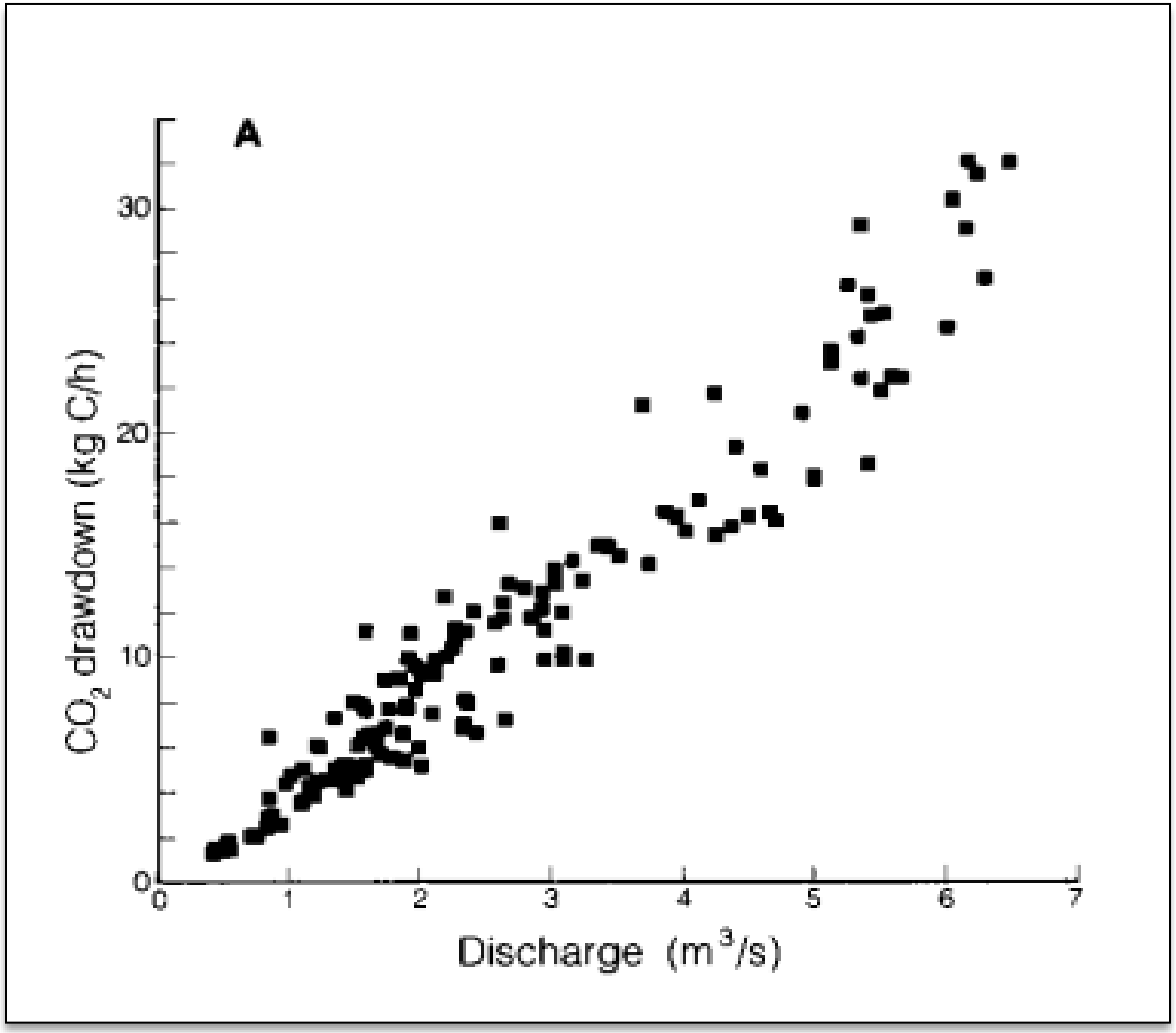
$$CaAl_2Si_2O_8 + 2\ CO_2 + 3\ H_2O = Ca^{2+} + Al_2Si_2O_5(OH)_5 + 2\ HCO_3$$

terrestrial environment

$$Ca^{2+} + 2HCO_3^- = CaCO_3 + CO_2 + H_2O$$

marine environment

Historical perspective: CO_2 comsumption via silicate weathering



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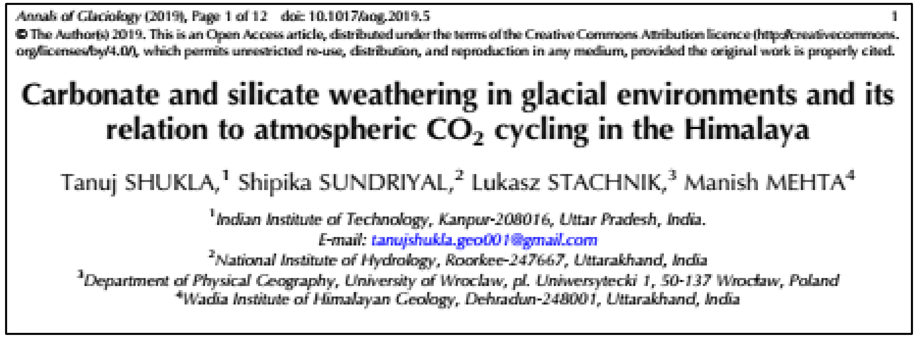
Annals of Glaciology (2019), Page 1 of 12 doi: 10.1017/aog.2019.5 1

Carbonate and silicate weathering in glacial environments and its relation to atmospheric CO_2 cycling in the Himalaya

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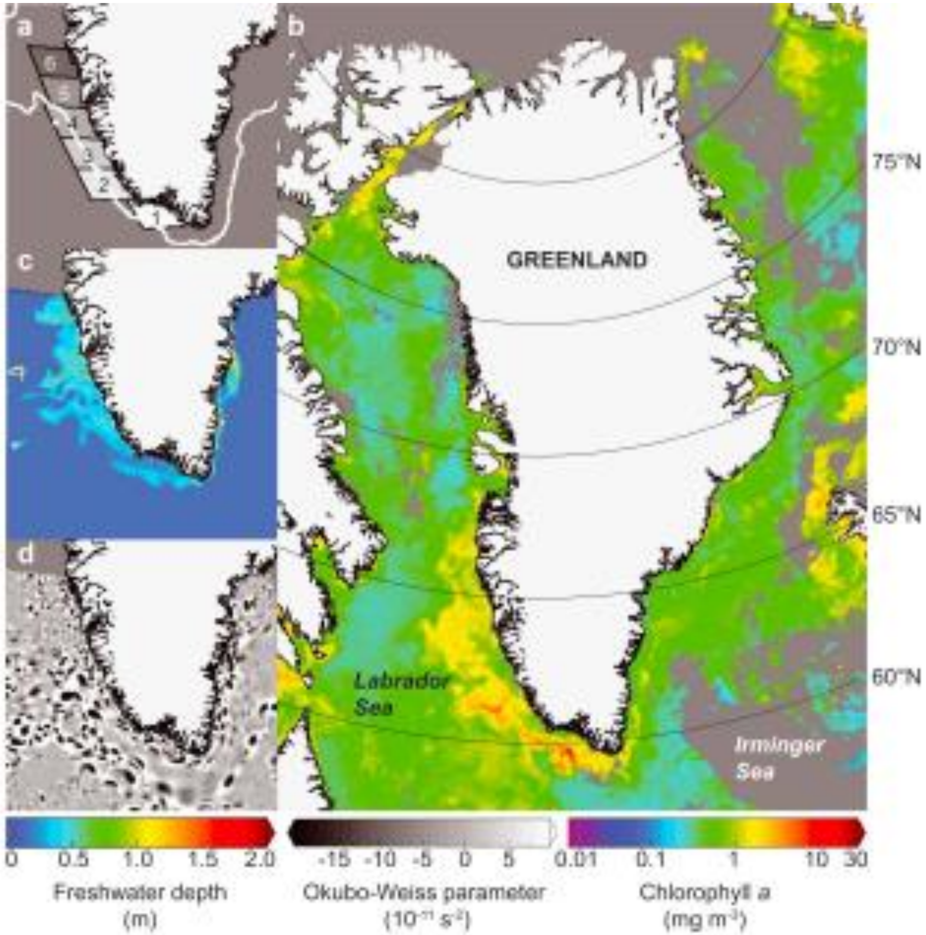
E-mail: tanujshukla.geo001@gmail.com
[2]National Institute of Hydrology, Roorkee-247667, Uttarakhand, India
[3]Department of Physical Geography, University of Wrocław, pl. Uniwersytecki 1, 50-137 Wrocław, Poland
[4]Wadia Institute of Himalayan Geology, Dehradun-248001, Uttarakhand, India

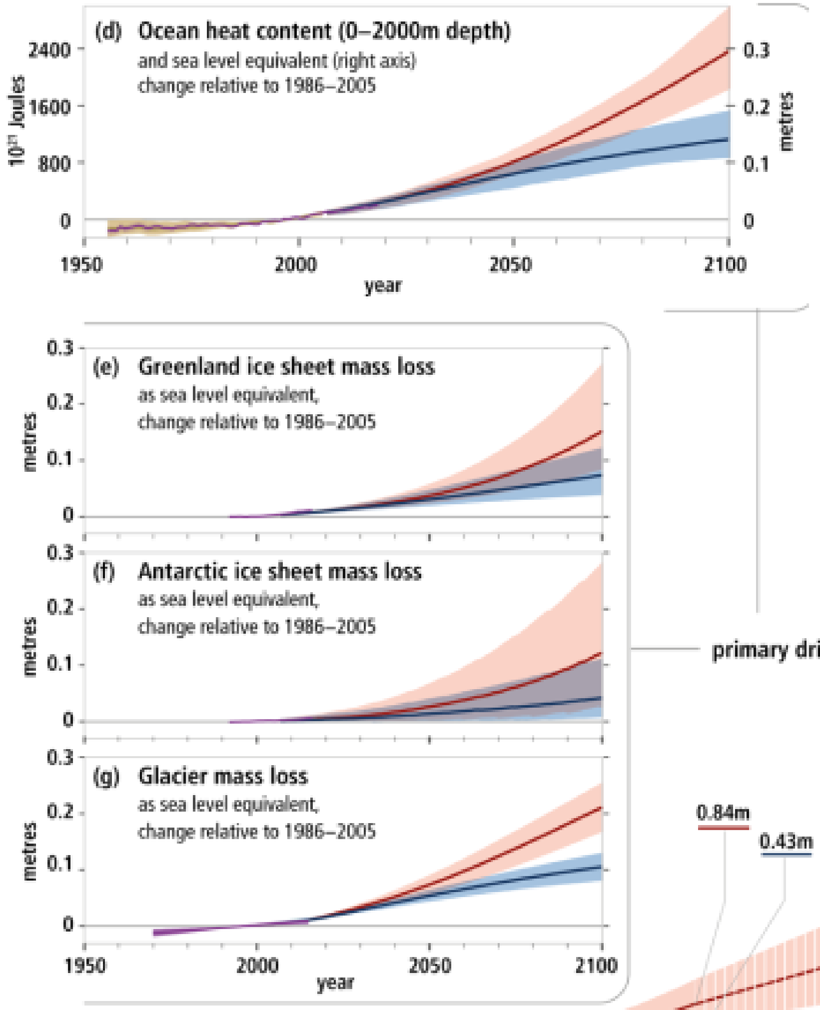
Increase of ocean primary production in vicinity of glaciers



- In sector of sea under an influence of glacier meltwater, primary production increases leading to consumption of atmospheric CO_2 but factors controlling this process are poorly known

(Arrigo et al., 2017)

Enhancement of meltwater runoff via glacier ablation



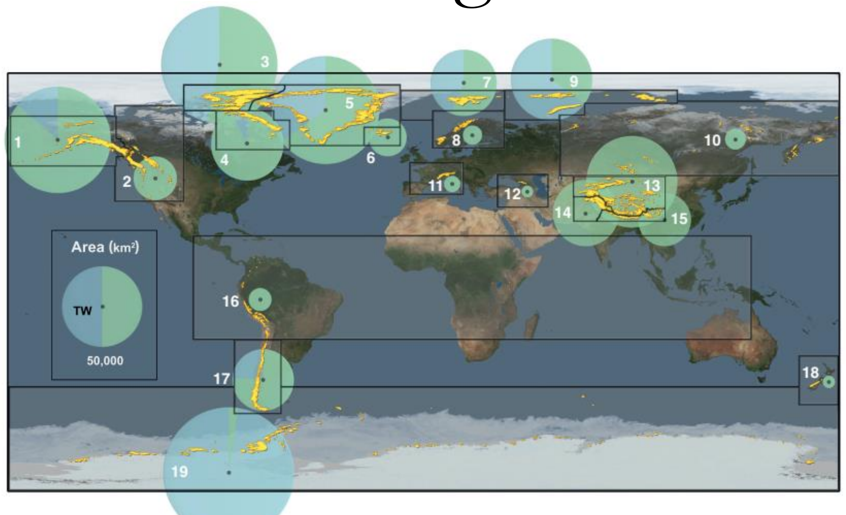
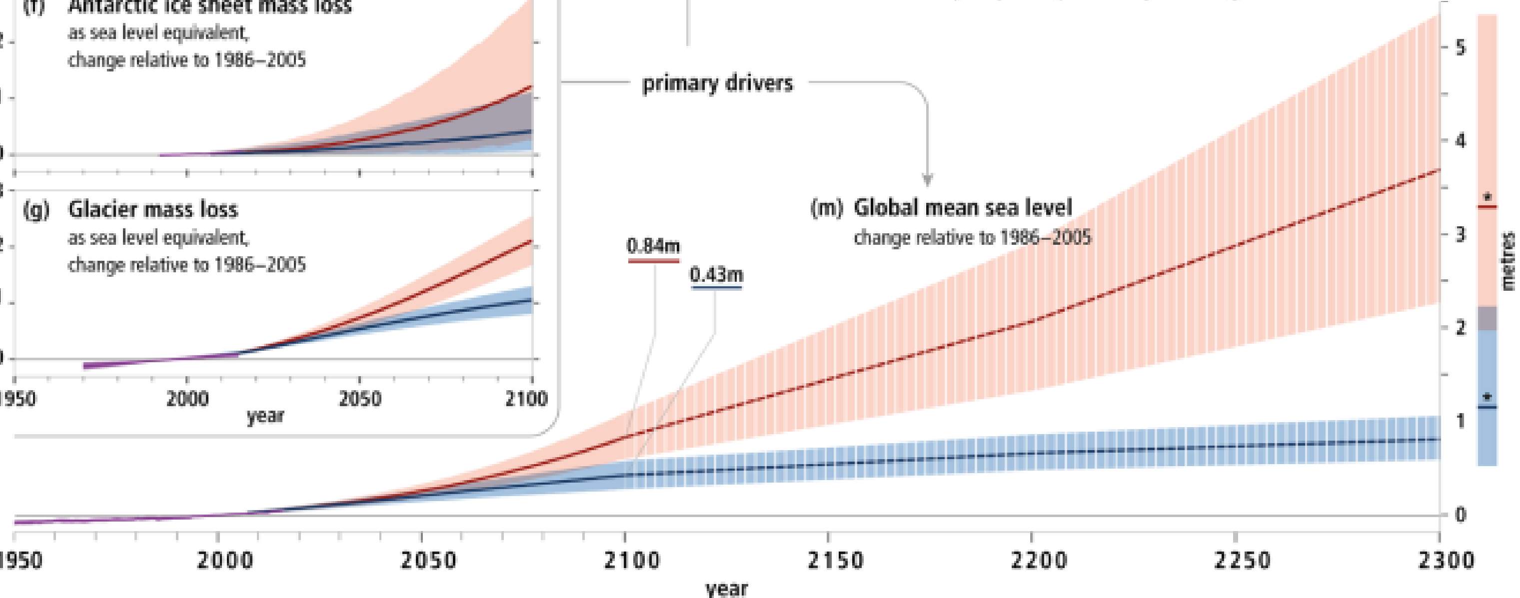


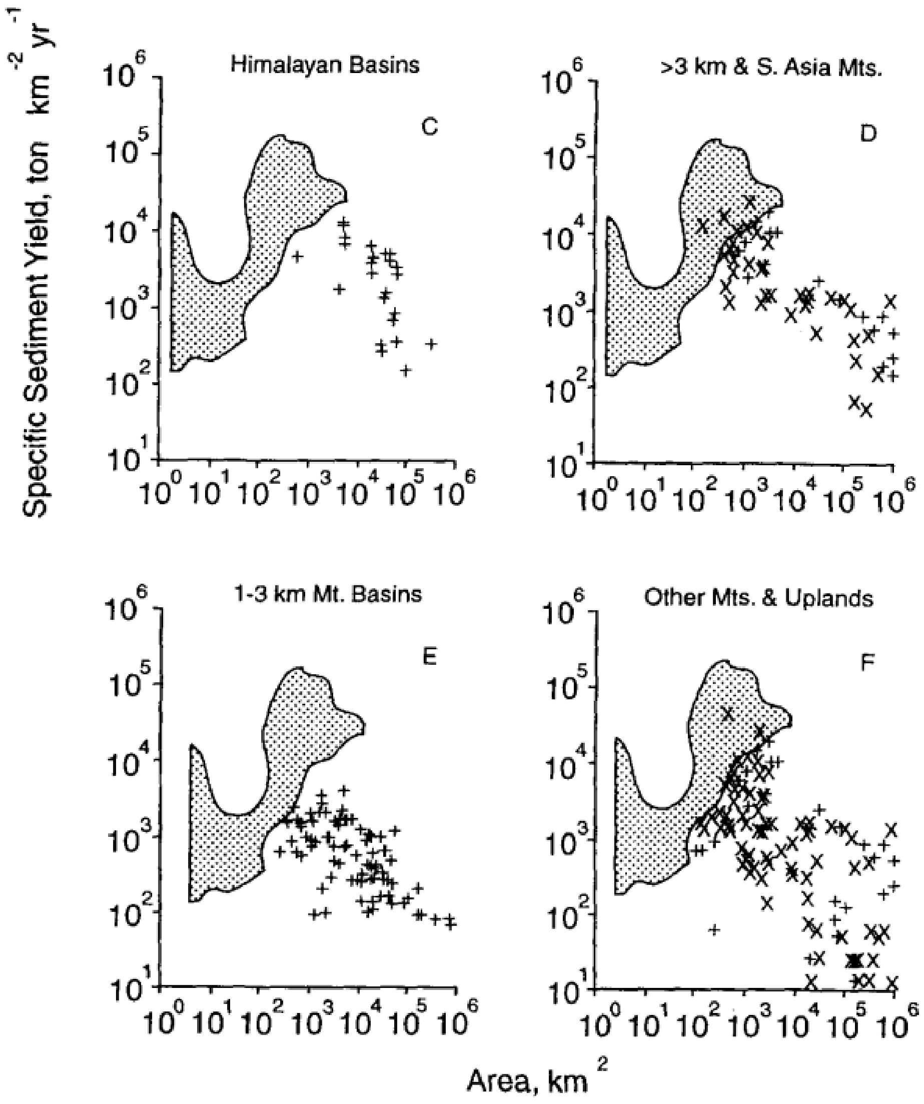
Figure 4.8 | Global distribution of glaciers (yellow, area increased for visibility) and area covered (diameter of the circle), sub-divided into the 19 RGI regions (white number) referenced in Table 4.2. The area percentage covered by tidewater (TW) glaciers in each region is shown in blue. Data from Arendt et al. (2012) and Gardner et al. (2013).



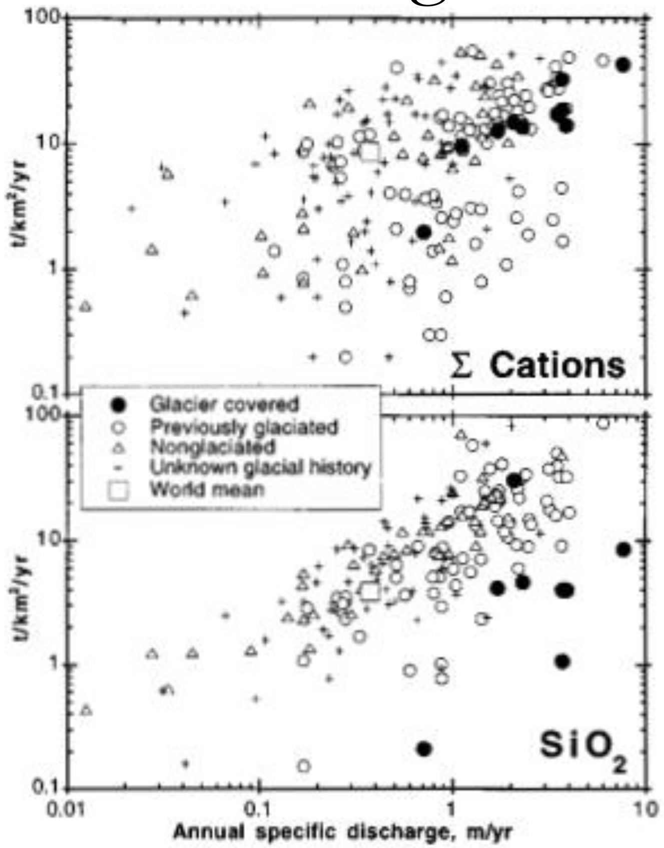
- Glacier ablation also leads to a higher yield of weathering products (suspended sediment and dissolved solids)

(IPCC SR OCCC, 2019; Vaughan et al., 2013)

Elevated yield of suspended sediment in glacierised basins



(Hallet et al., 1996)



(Anderson et al., 1997)

- Unlike to solute yield, suspended sediments load from glaciers is higher as compared with non-glacierised basins

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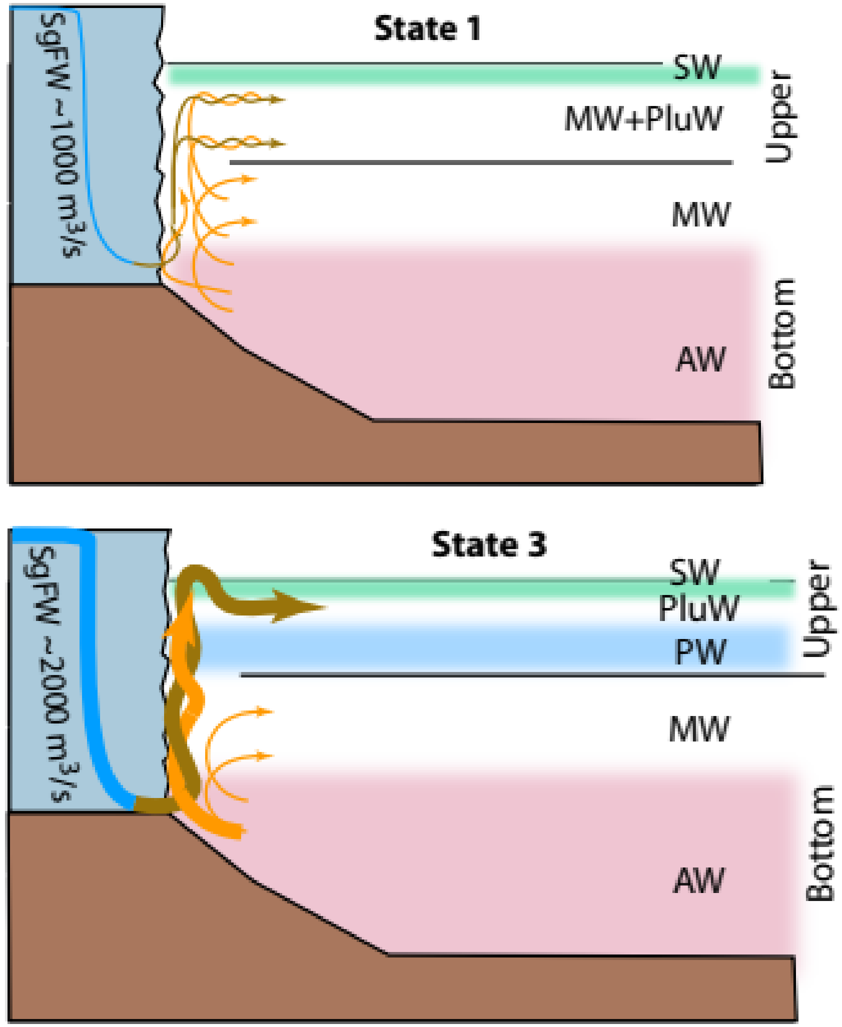
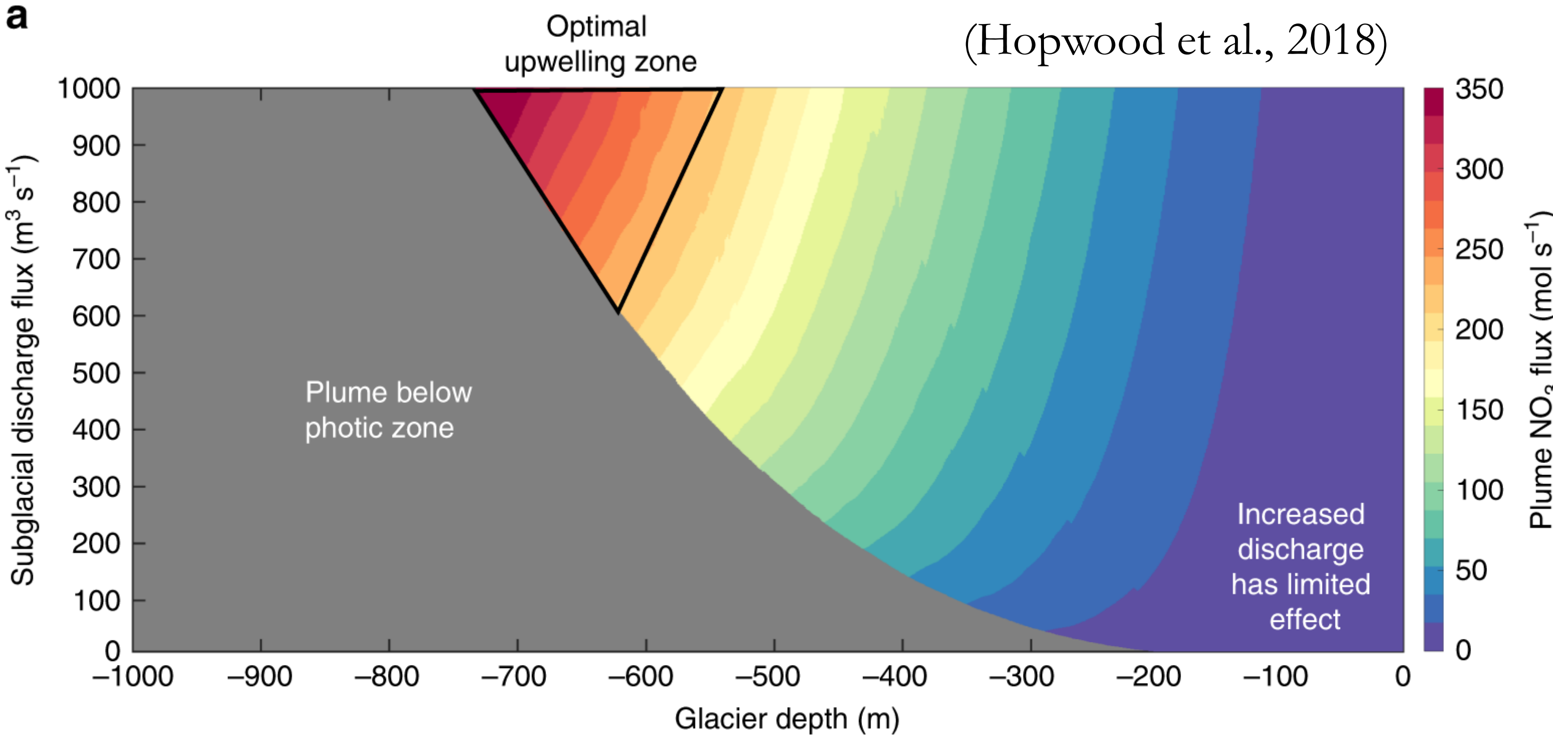
Deep water upwelling is observed at the tidewater glaciers



(Chuche et al., 2014)



(Hopwood et al., 2018)

- Higher subglacial runoff in tidewater glacier causes upwelling of deep waters
- Upwelling waters should get to photic zone to cause an increase in primary production

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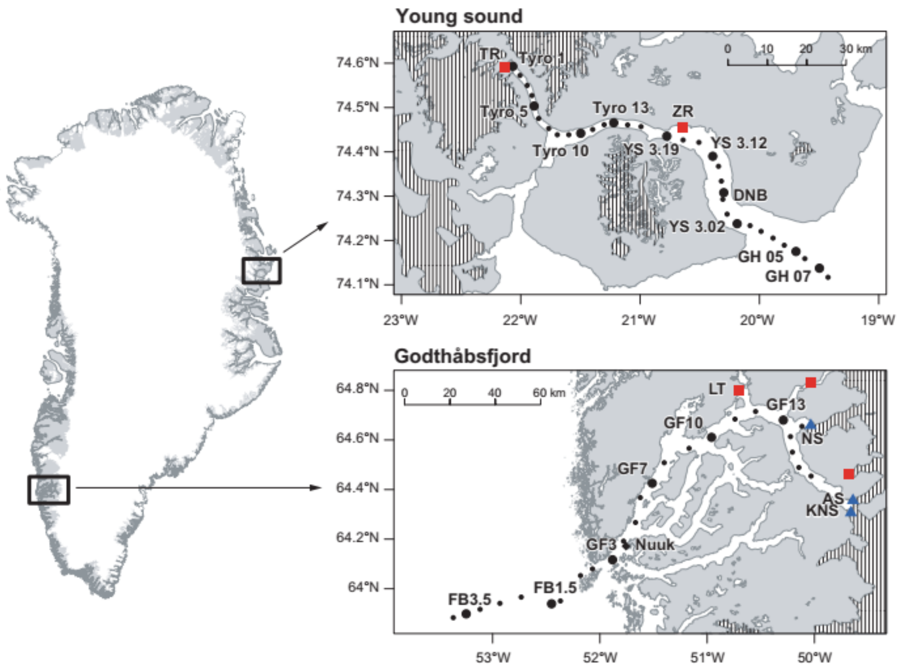
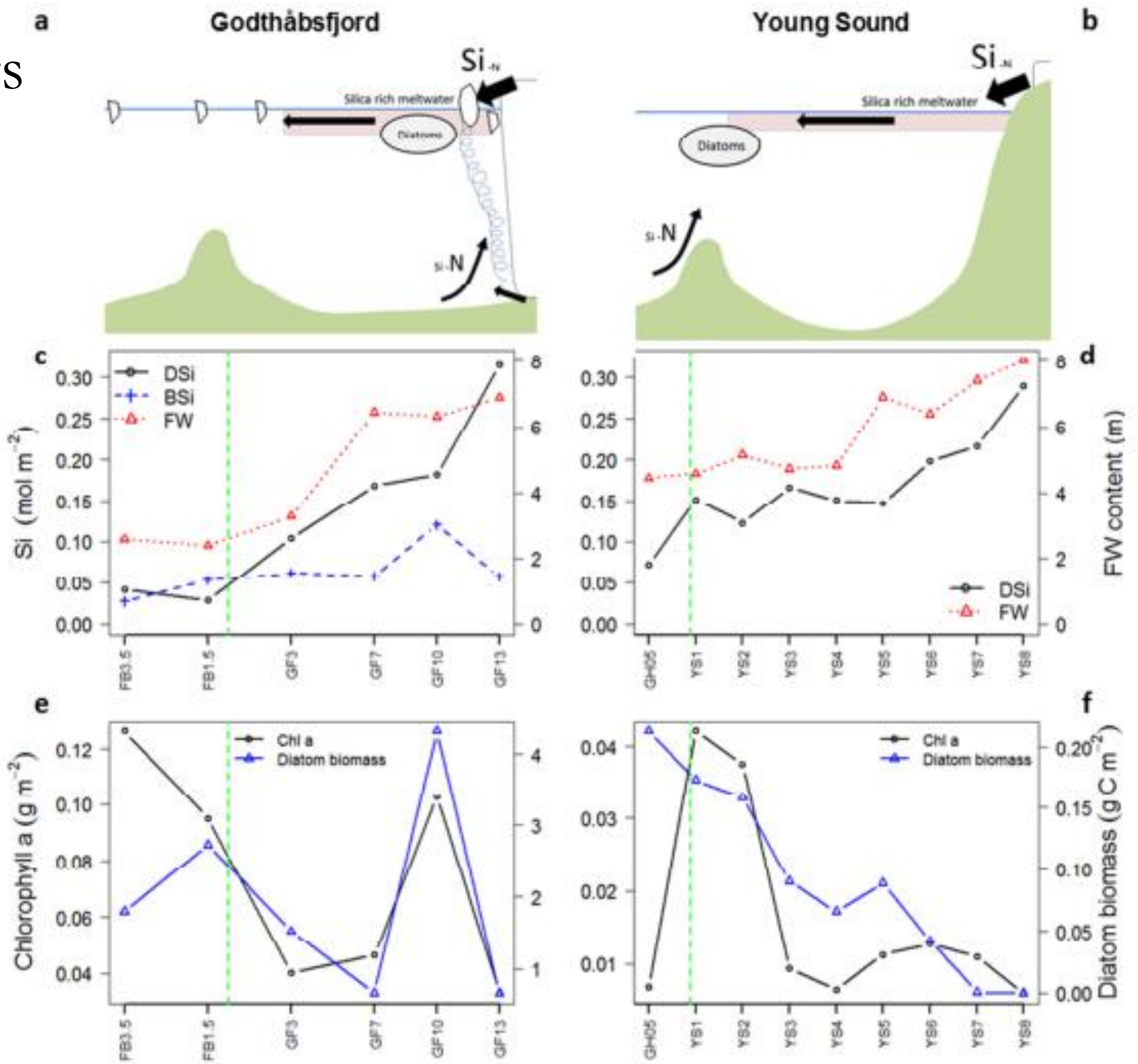
Nutrients upwelling at tidewater glaciers front

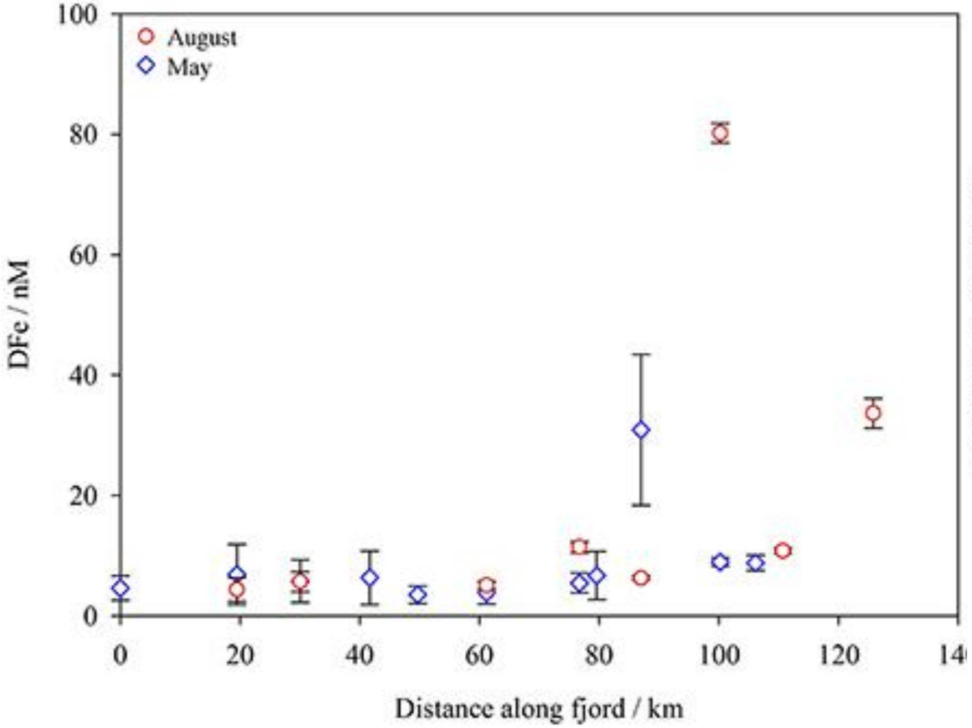


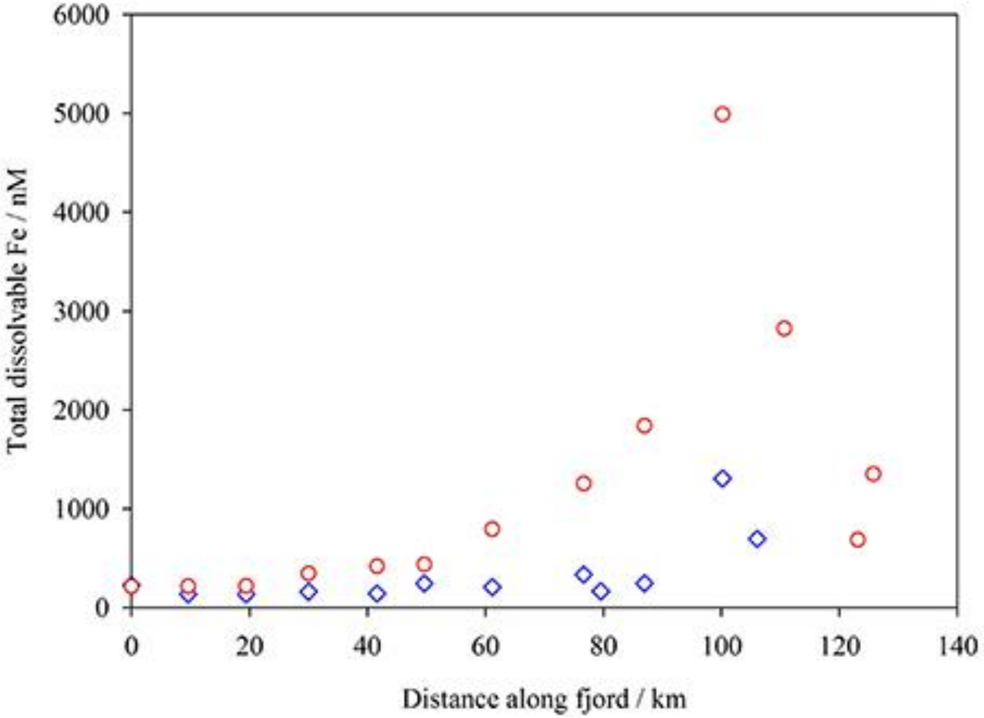
- In tidewater glaciers, upwelling of deep nitrogen rich water causes an increase in the primary production, leading to CO_2 consumption

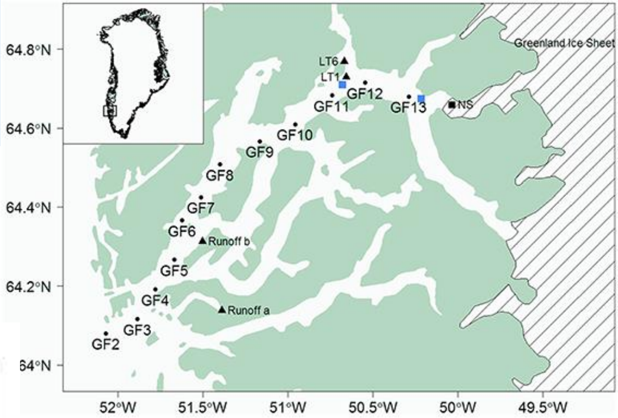


(Meire et al., 2016)

Nutrients upwelling – iron in fjord system







- There is lack of clear signal of iron release from glacier derived meltwater and sediments, as concentration of dissolved iron (left image) and sediment-bound (right image) are low at the glacier front

(Hopwood et al., 2016)

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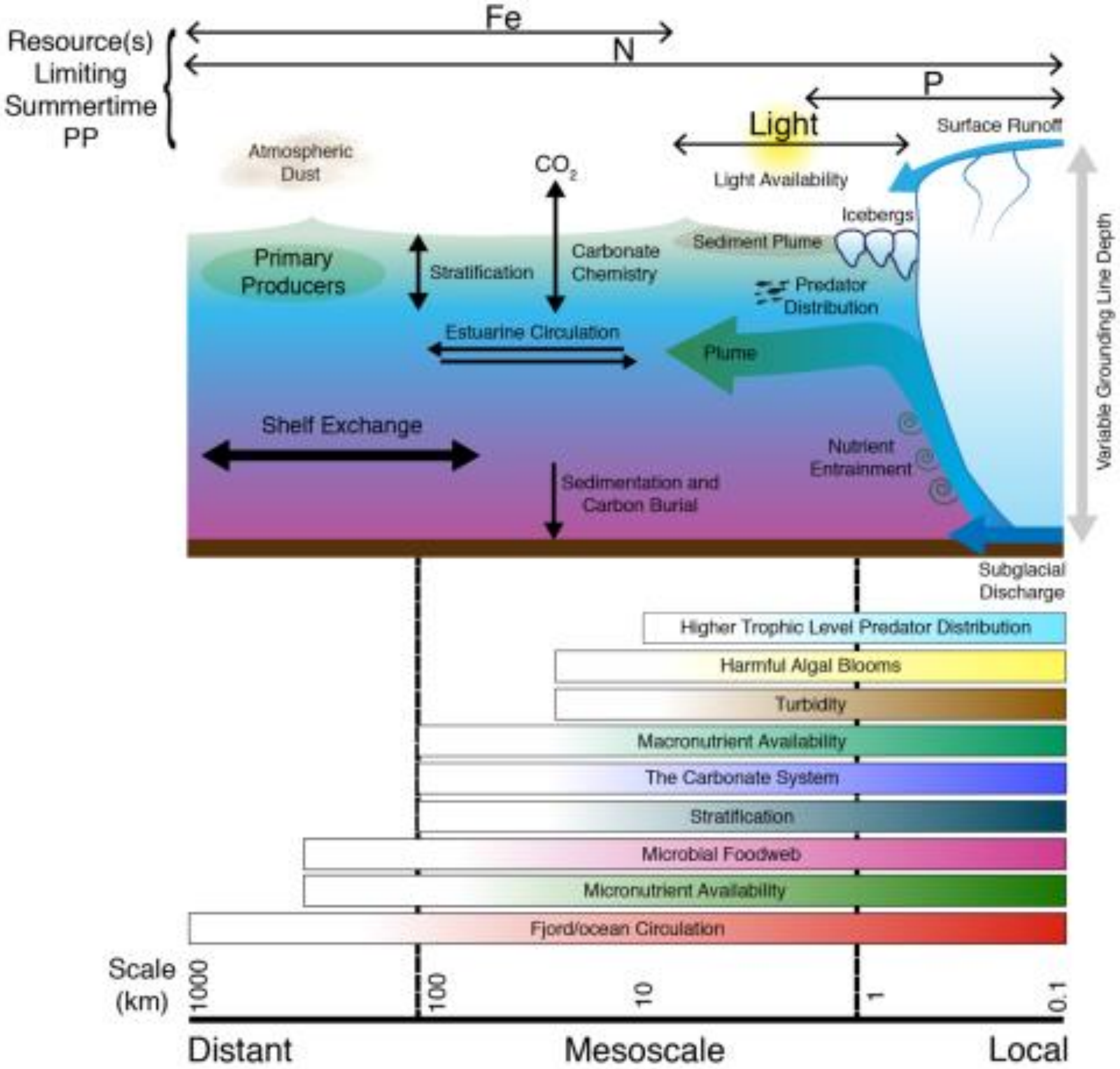
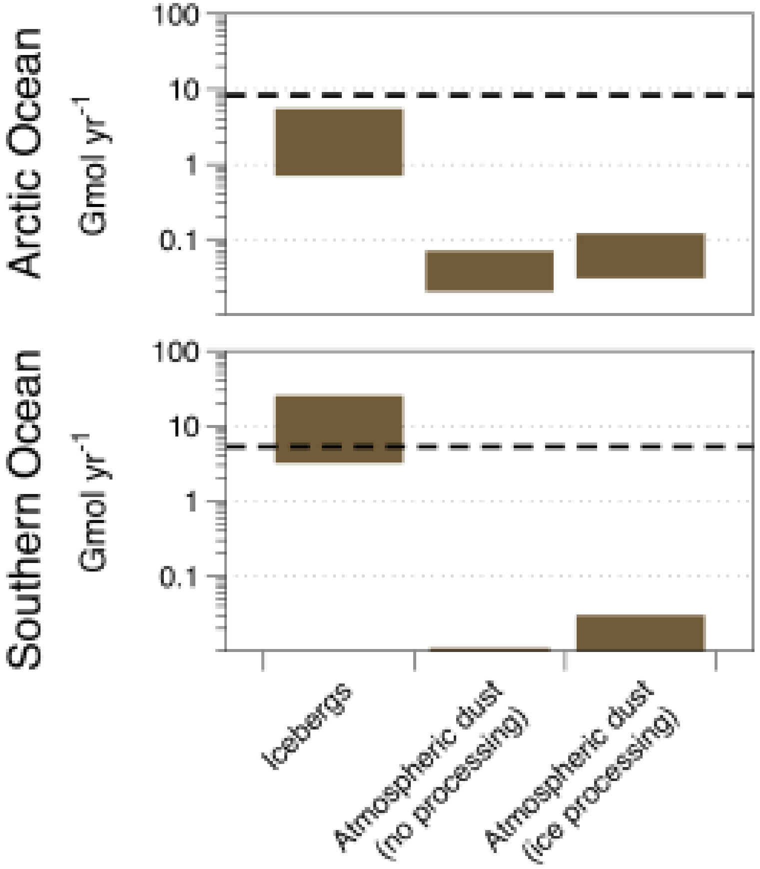
Nutrients upwelling – tidewater glacier impact

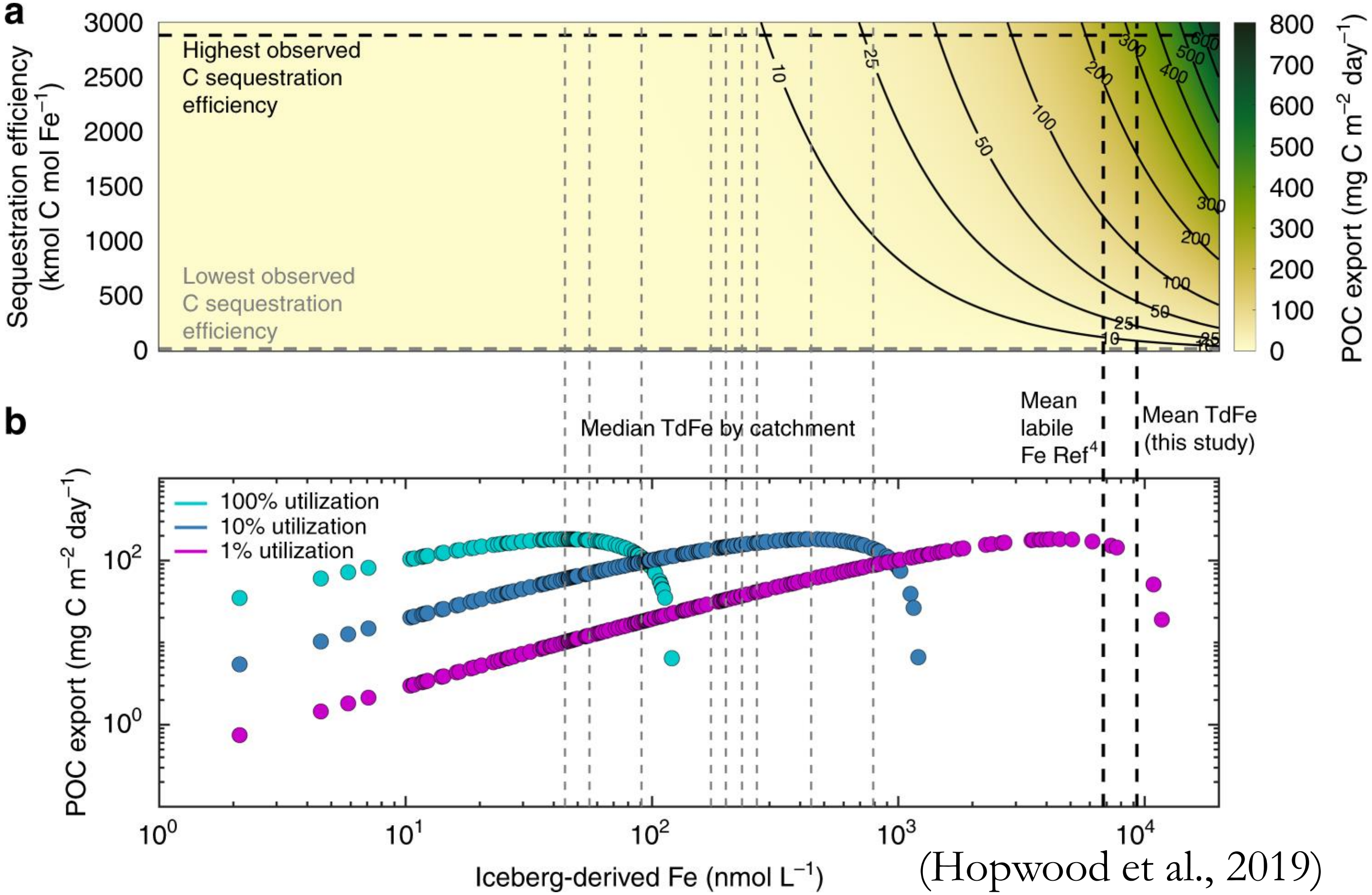


(Hopwood et al., 2019)

Photo credits to M. Kondracka

Ice bergs release iron





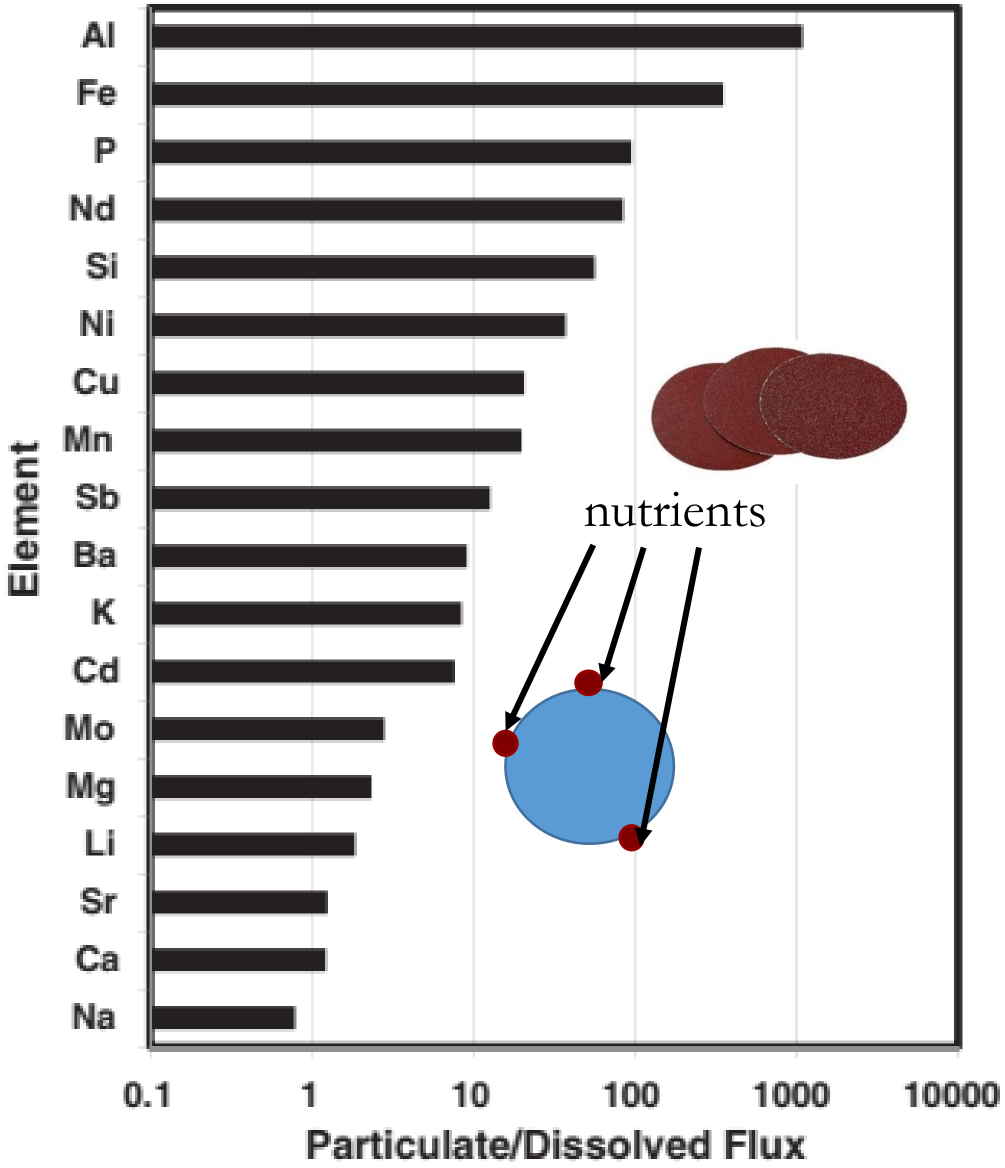
(Hopwood et al., 2019)

(Raiswell et al., 2016)

Photo credits to T. Smagacz

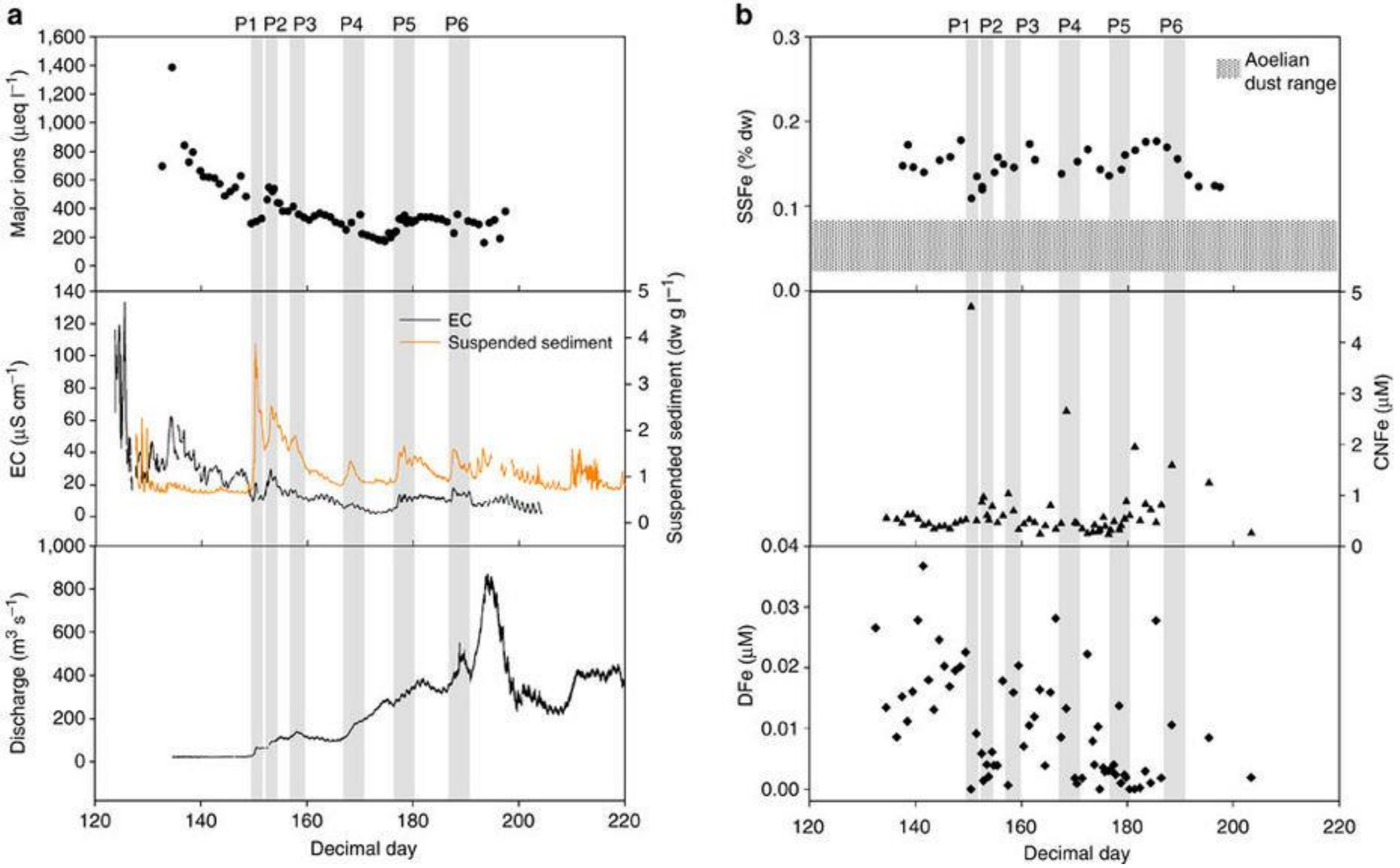
Sediment-bound nutrients from land-based glaciers

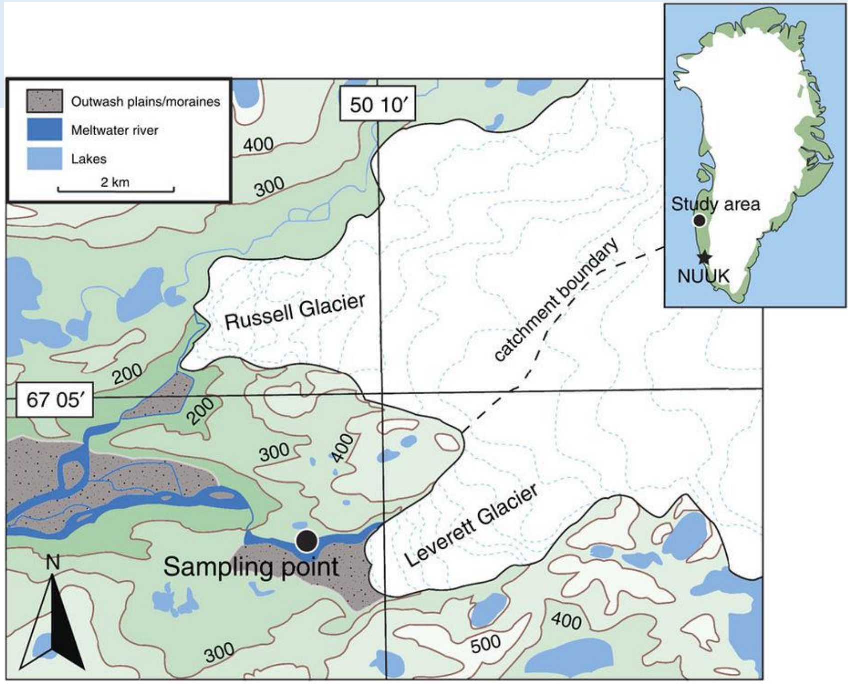
- Nutrients are transported in sediment-bound form
- High rate of physical erosion under glacier may faciliate transport of geochemically active suspended sediment



(Jeandel et al., 2015)

Sediment-bound nutrients

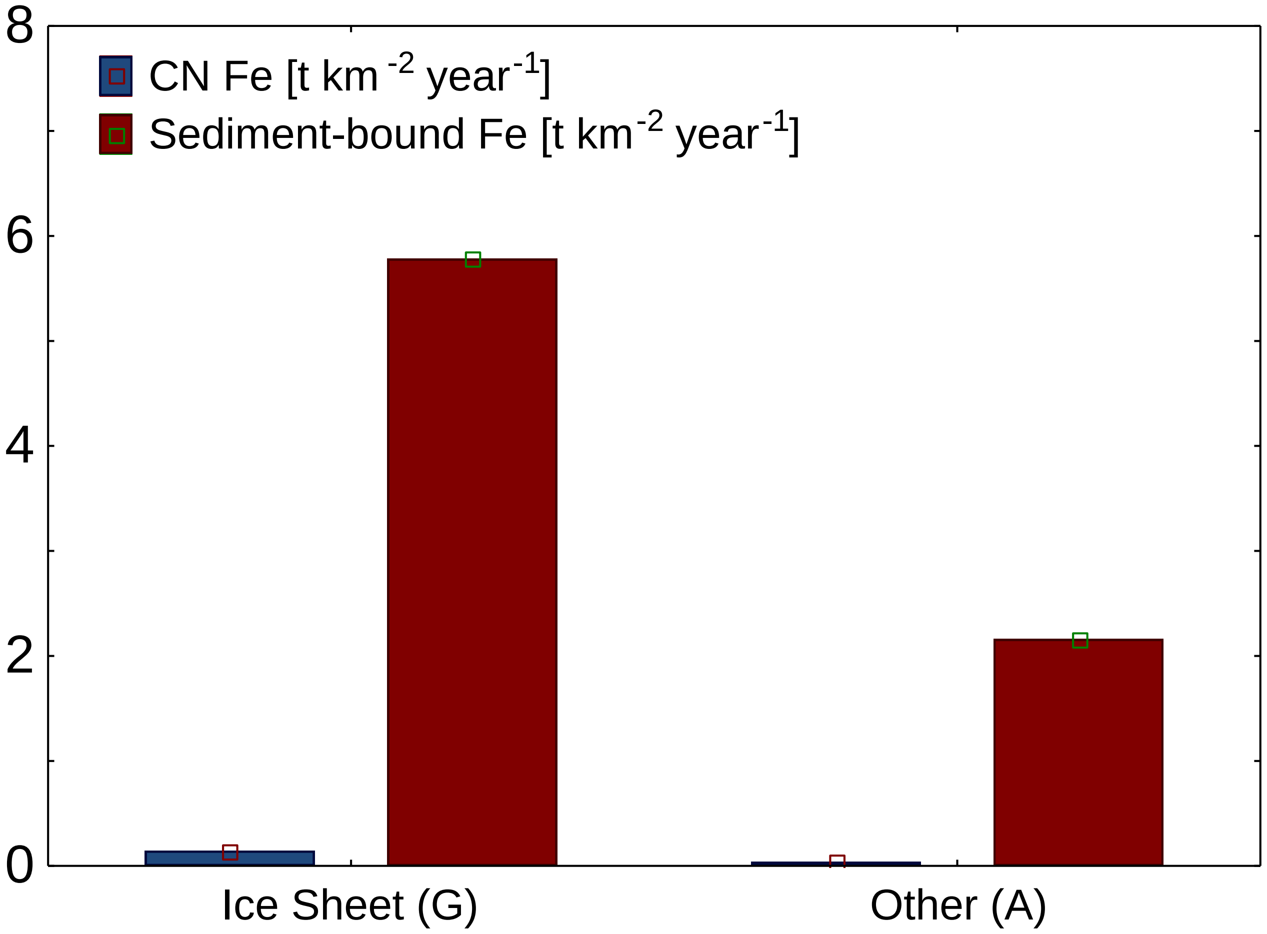


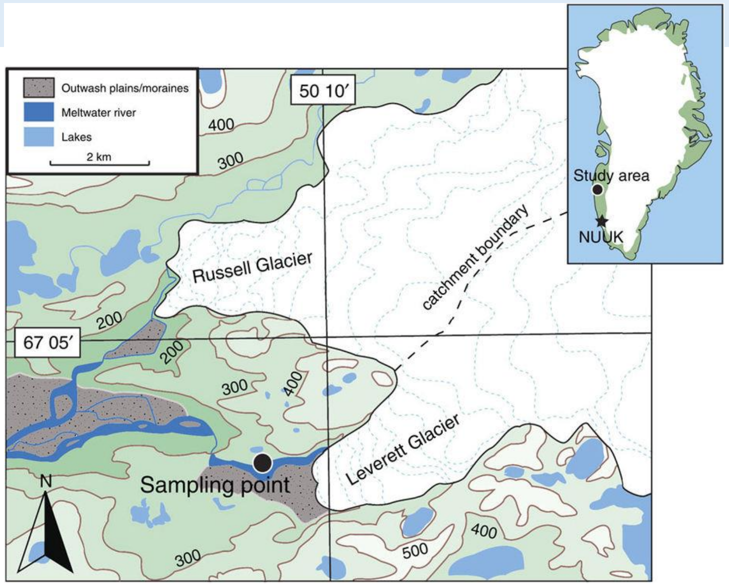


(Hawkings et al., 2014)

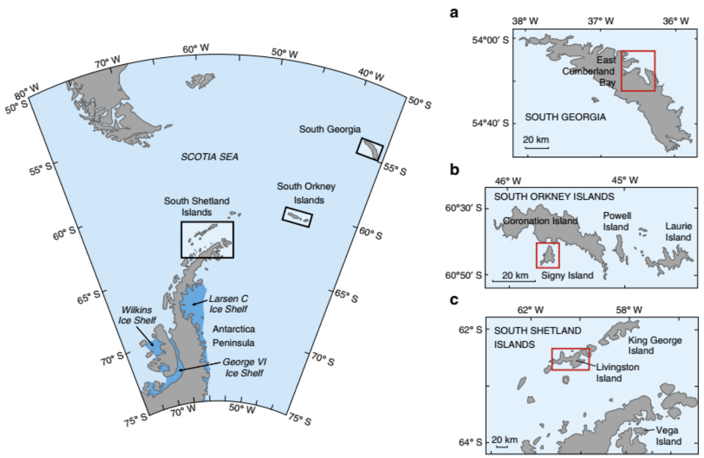
- High suspended sediment load and sediment-bound iron content during the ablation season

Sediment-bound glacier-derived iron





(Hawkings et al., 2014)



(Hodson et al., 2017)

- Iron yield in sediment-bound form appears to be two orders of magnitude higher than dissolved and colloidal iron yields

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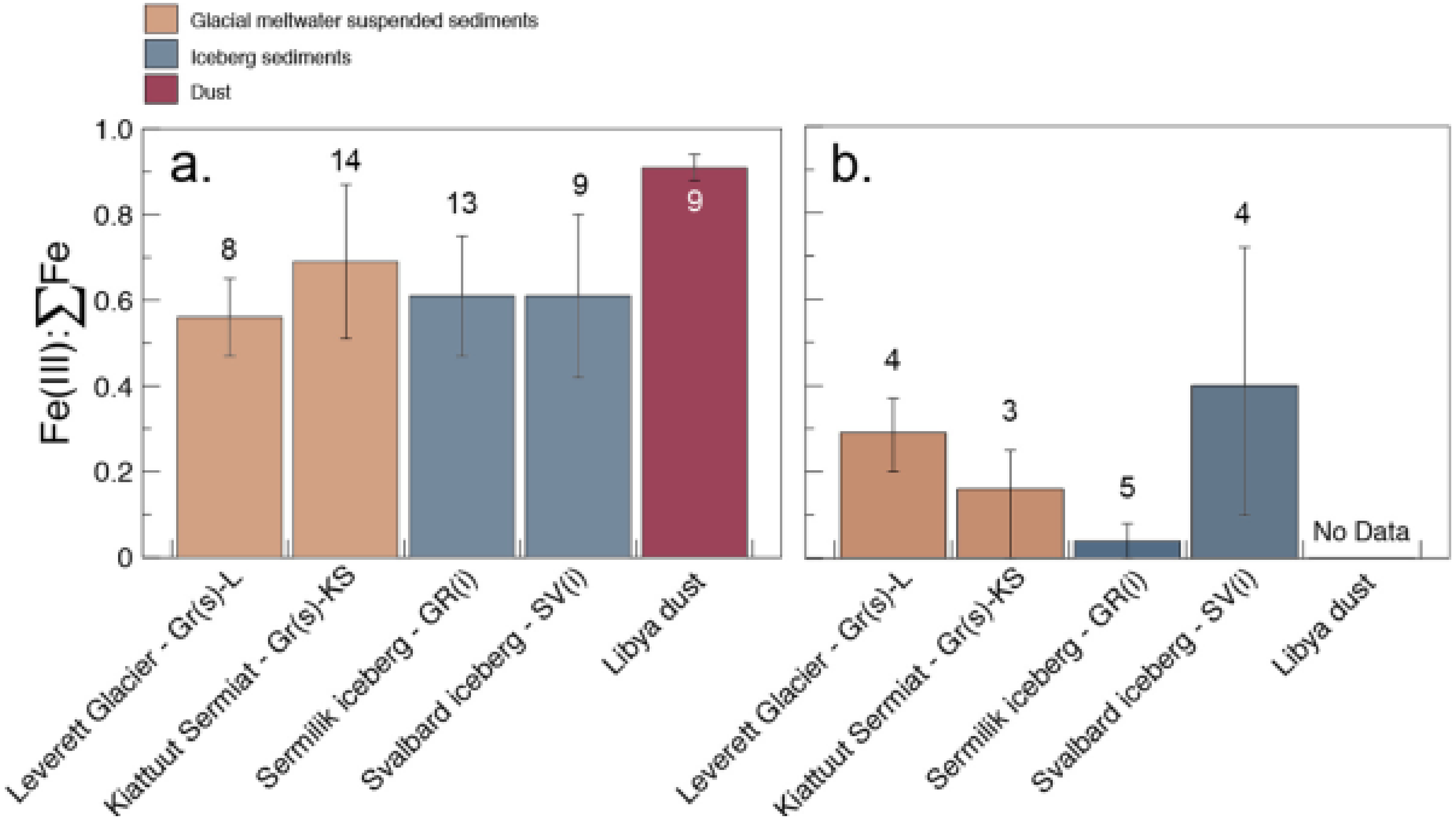
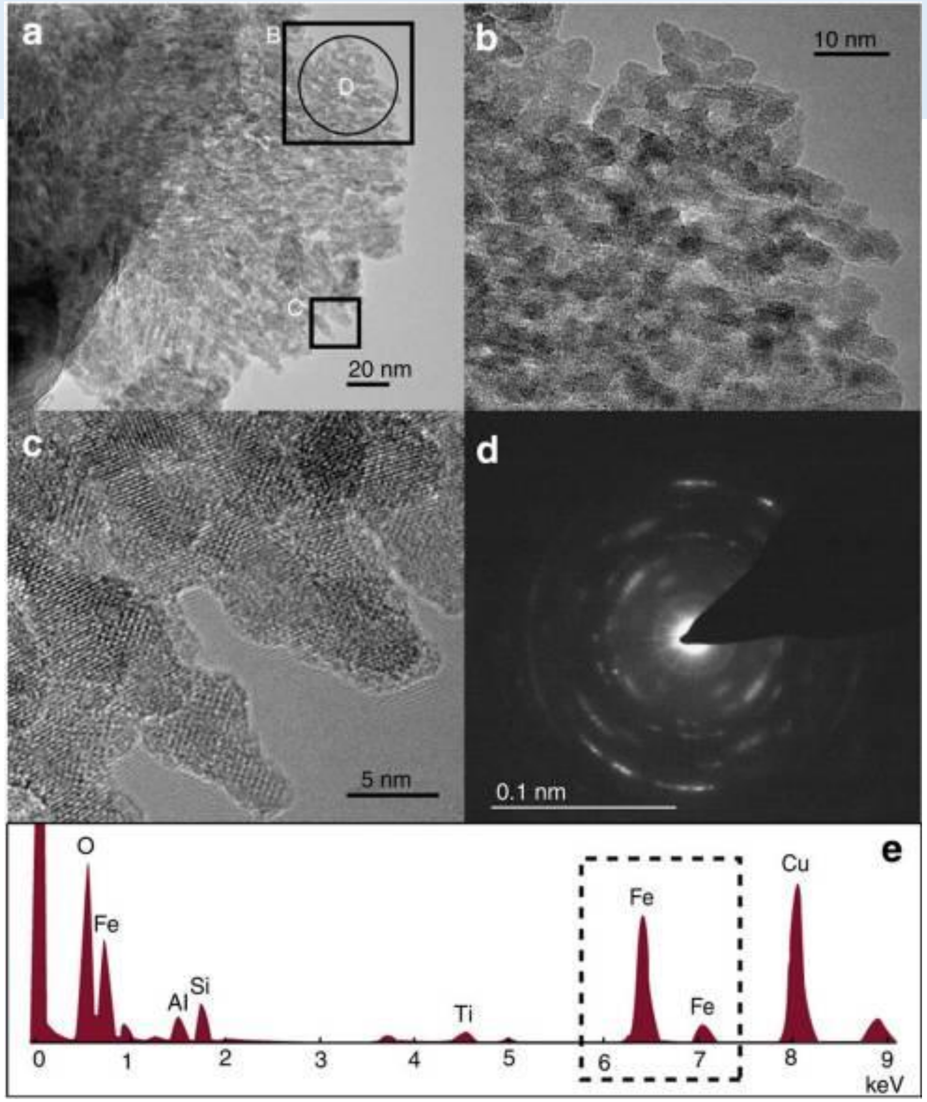
Sediment-bound nutrients hypothesis





- Sediment-bound iron appears to be in highly bioavailable form (Fe^{2+}) potentially affecting an increase in ocean primary production

(Hawkings et al., 2014, 2018)

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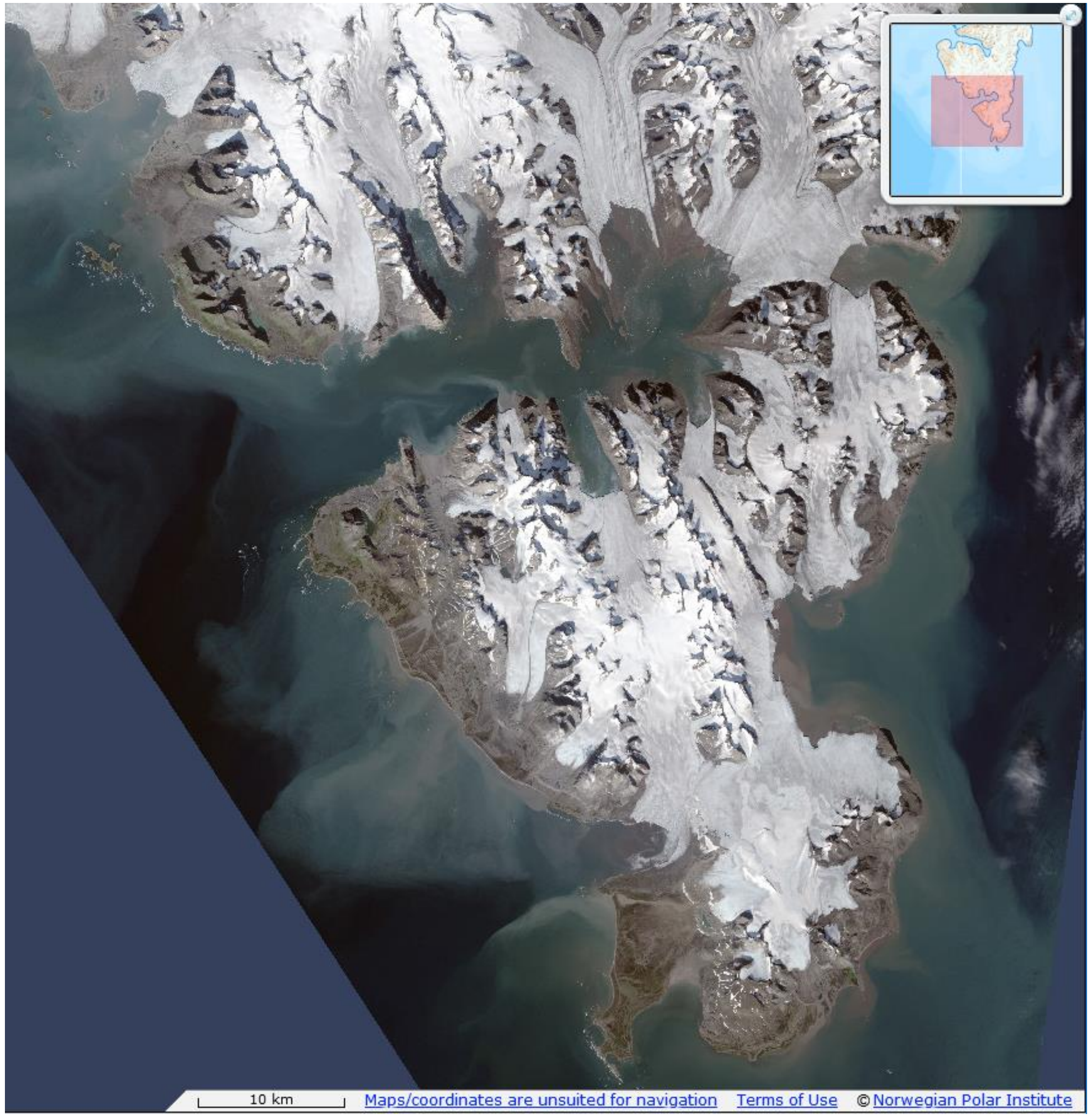
Svalbard research



Research papers

Marine CO_2 system variability in a high arctic tidewater-glacier fjord system, Tempelfjorden, Svalbard

Ylva Ericson[a,b,*], Eva Falck[a,b], Melissa Chierici[a,c], Agneta Fransson[d], Svein Kristiansen[e]

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[b] *Geophysical Institute, University of Bergen, Allégaten 70, 5007, Bergen, Norway*
[c] *Institute of Marine Research, Fram Centre, Hjalmar Johansens Gate 14, 9007, Tromsø, Norway*
[d] *Norwegian Polar Institute, Fram Centre, 9296, Tromsø, Norway*
[e] *Department of Arctic and Marine Biology, UiT the Arctic University of Norway, PO Box 6050 Langnes, 9037, Tromsø, Norway*

Effect of glacial drainage water on the CO_2 system and ocean acidification state in an Arctic tidewater-glacier fjord during two contrasting years

Agneta Fransson[1], Melissa Chierici[2,3], Daiki Nomura[1,4], Mats A. Granskog[1], Svein Kristiansen[5], Tõnu Martma[6], and Gernot Nehrke[7]

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HYDROLOGICAL PROCESSES
Hydrol. Process. **30**, 1219–1229 (2016)
Published online 21 November 2015 in Wiley Online Library
(wileyonlinelibrary.com) DOI: 10.1002/hyp.10701

Glacial and periglacial floodplain sediments regulate hydrologic transfer of reactive iron to a high arctic fjord

Andrew Hodson,[1,2*] Aga Nowak[1] and Hanne Christiansen[2]

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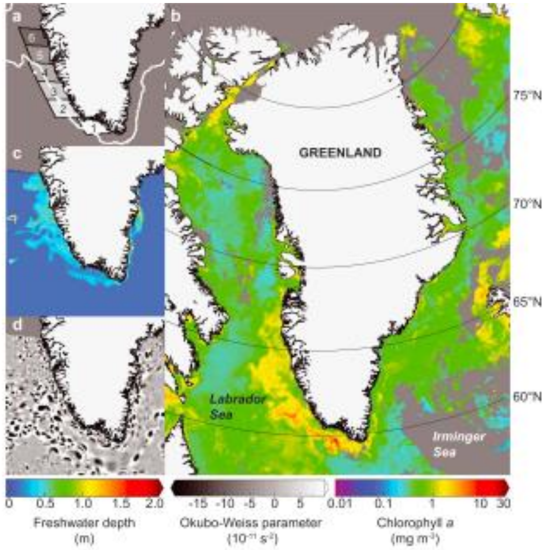
[2] *Arctic Geology, University Centre in Svalbard (UNIS), P.O. Box 156N-9171 Longyearbyen, Norway*

Negative feedback effect enhances CO_2 consumption



(Arrigo et al.., 2017)

Glacier ablation and recession

Higher nutrients yield

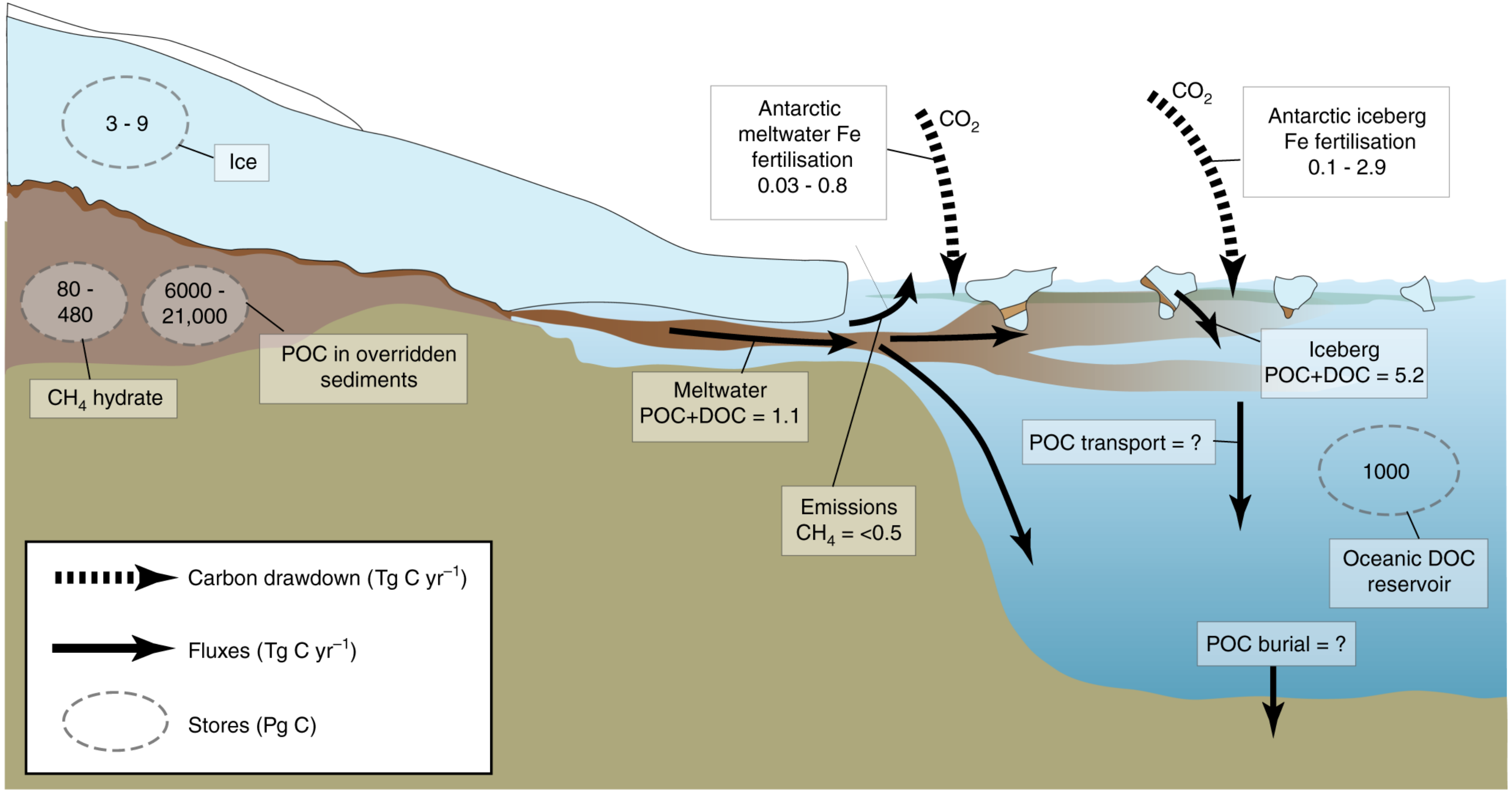
Release of nutrients to the ocean

Higher CO_2 consumption

Decrease of CO_2 in seawater and atmosphere

Photo credits to D. Ignatiuk (upper), A. Kies (lower)

What is global contribution of glaciers to CO_2 consumption?

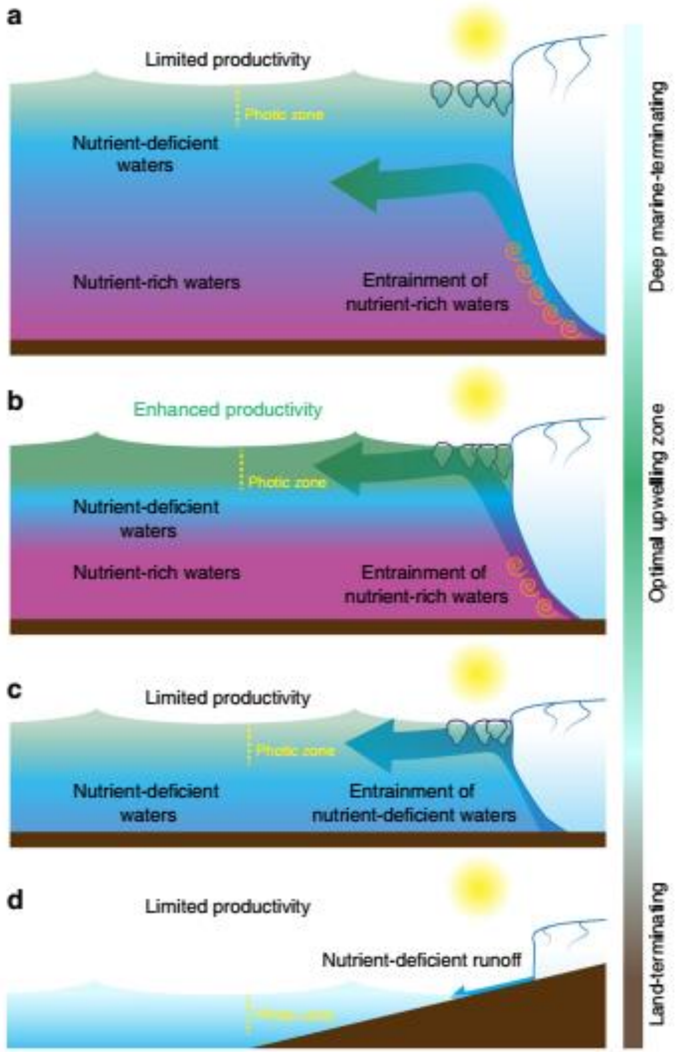


(Wadham et al., 2019)

- Relatively small contribution to CO_2 consumed from weathering globally (300 Tg, Ciais et al., 2013), but further research are required.

- Upscalling using remote sensing?
- Glaciers?
- Upwelling in front of tidewater glaciers?
- Dust from glacier-free parts of basins?

Carbon cycle in catchment with receding glacier – solvig puzzles

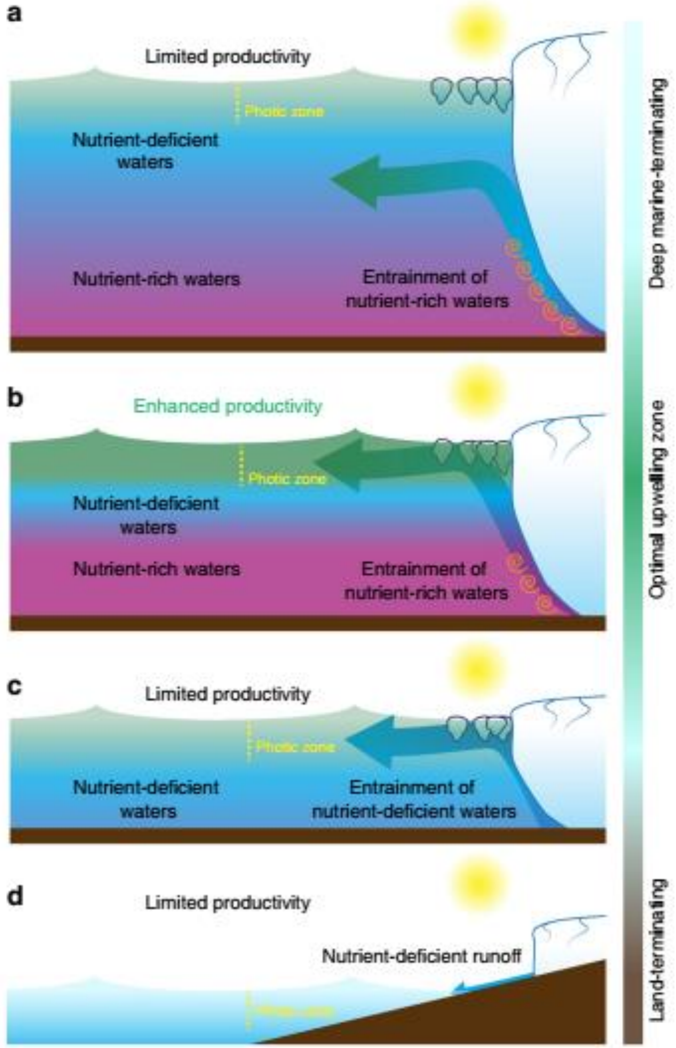


https://pl.pinterest.com/pin/518406607103509152/

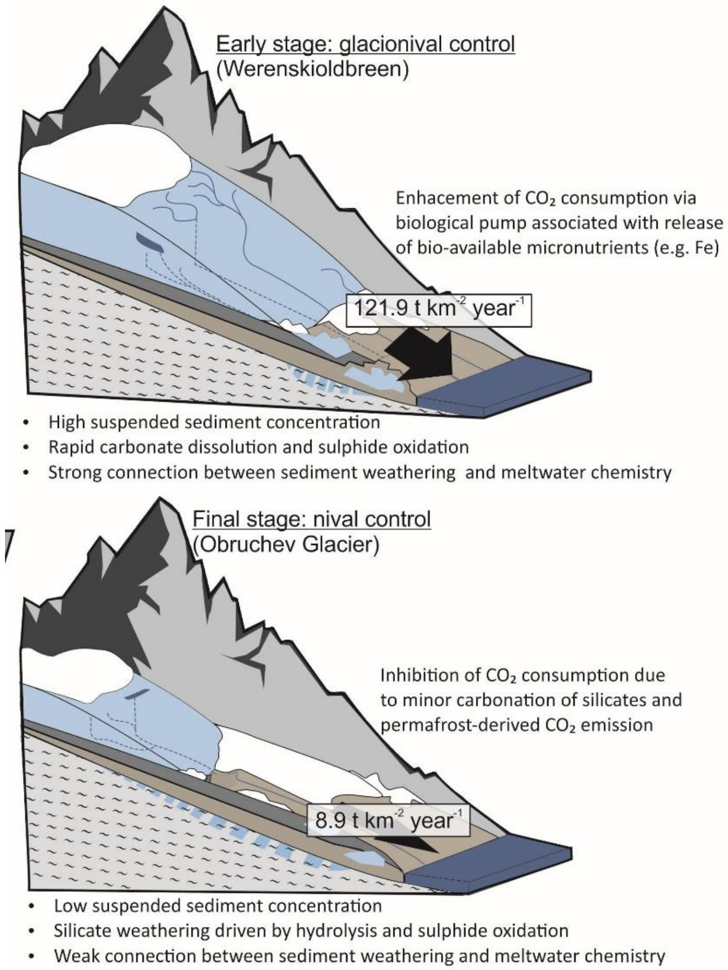
(Hopwood et al., 2018)

Carbon cycle in catchment with receding glacier – solvig puzzles

https://pl.pinterest.com/pin/518406607103509152/



(Hopwood et al., 2018)



(Stachnik et al., in review)

Thank you!
Questions?

The Research Council of Norway

NARODOWE CENTRUM NAUKI

Received: 10 July 2018 | Accepted: 19 February 2019
DOI: 10.1002/hyp.13426

RESEARCH ARTICLE

Lukasz_Arctic

WILEY

Aluminium in glacial meltwater demonstrates an association with nutrient export (Werenskiöldbreen, Svalbard)

Łukasz Stachnik[1,2,3] | Jacob C. Yde[2] | Adam Nawrot[4,5] | Łukasz Uzarowicz[6] | Elżbieta Łepkowska[7] | Katarzyna Kozak[8]

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[2] Department of Environmental Sciences, Western Norway University of Applied Sciences, Sogndal, Norway
[3] Institute of Geography and Spatial Management, Jagiellonian University, Kraków, Poland
[4] Institute of Geophysics, Polish Academy of Sciences, Warszawa, Poland
[5] forScience Foundation, Przeźmierowo, Poland
[6] Faculty of Agriculture and Biology, Warsaw University of Life Sciences – SGGW, Warszawa, Poland
[7] Faculty of Earth Sciences, University of Silesia (Centre for Polar Studies KNOW (Leading National Research Centre), Sosnowiec, Poland
[8] Department of Analytical Chemistry, The Chemical Faculty, Gdańsk University of Technology, Gdańsk, Poland

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The aluminium (Al) cycle in glacierised basins has not received a great deal of attention in studies of biogeochemical cycles. As Al may be toxic for biota, it is important to investigate the processes leading to its release into the environment. It has not yet been ascertained whether filterable Al (passing through a pore size of 0.45 μm) is incorporated into biogeochemical cycles in glacierised basins. Our study aims to determine the relationship between the processes bringing filterable Al and glacier-derived filterable nutrients (particularly Fe and Si) into glacierised basins. We investigated the Werenskiöldbreen basin (44.1 km^2, 60% glacierised) situated in SW Spitsbergen, Svalbard. In 2011, we collected meltwater from a subglacial portal at the glacier front and at a downstream hydrometric station throughout the ablation season. The Al concentration, unchanged between the subglacial system and proglacial zone, reveals that aluminosilicate weathering is a dominant source of filterable Al under subglacial conditions. By examining the Al:Fe ratio compared with pH and the sulphate mass fraction index, we found that the proton source for subglacial aluminosilicate weathering is mainly associated with sulphide oxidation and, to a lesser degree, with hydrolysis and carbonation. In subglacial outflows and in the glacial river, Al and Fe are primarily in the forms of $Al(OH)_4^-$ and $Fe(OH)_3$. The annual filterable Al yield (2.7 mmol m^{-2}) was of a magnitude similar to that of nutrients such as filterable Fe (3.0 mmol m^{-2}) and lower than that of dissolved Si (18.5 mmol m^{-2}). Our results show that filterable Al concentrations in meltwater are significantly correlated to filterable and dissolved glacier-derived nutrients (Fe and Si, respectively) concentrations in glaciers worldwide. We conclude that a potential bioavailable Al pool derived from glacierised basins may be incorporated in biogeochemical cycles, as it is strongly related to the concentrations and yields of glacier-derived nutrients.

KEYWORDS
aluminium, biogeochemical cycles, dissolved silica, glacier, iron, meltwater, nutrients, subglacial drainage