PROMBIO – PROGRAMME FOR MONITORING GLACIER ICE ALGAE ON THE GREENLAND ICE SHEET

Notes and figures for the 2022 campaign

Technical Report from DCE – Danish Centre for Environment and Energy No. 314 2024

AARHUS UNIVERSITY
DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Preface

This report outlines figures and a preliminary analysis of biological and abiotic impurities around a selected number of PROMICE and GC-Net weather stations on the Greenland ice sheet (GrIS) for samples collected during the summer of 2023. This is the first year in which samples are collected as part of a monitoring programme of glacier ice algae on the GrIS. More samples over a number of years will be necessary in order to provide a more comprehensive overview of the distribution of biological and abiotic impurities on the GrIS. As such, those results in this report should be seen as indicative of the abundance range of glacier algae in specific locations of the GrIS. The report here includes an indication of the range and quantity of glacier ice algae in six different regions of the GrIS, four of which were collected around PROMICE (https://promice.org/weather-stations/) weather stations (UPE, NUK, QAS and TAS) and two are associated with sampling in the KAN-M and Qaanaaq region from other research projects. Ultimately, these results together with additional years and locations can be used as ground-truth data for validation of remote satellite and future modelling work on estimation of biological and abiotic impurities on the GrIS.

Sammenfatning

Denne rapport præsenterer den allerførste fase af et overvågningsprogram til demonstration af biologiske og abiotiske urenheder på den grønlandske indlandsis (GrIS). På dette stadie er antallet af prøver indsamlet i rum og tid stadig begrænset, og derfor bør absolutte tal anvendes med forsigtighed i enhver ground-truth valideringsøvelse. Ikke desto mindre er de data, der præsenteres her, stadig en god indikation af kompleksiteten forbundet med distributionen af biologiske og abiotiske urenheder på den grønlandske indlandsis og giver den første indikation af den relative betydning af biologiske versus abiotiske urenheder på isens mørkning. To konklusioner kan drages ud fra de foreløbige data: 1) Barisens varighed er en vigtig kontrol af mængden af gletsjerisalger, og 2) forskellige områder af GrIS kan have meget forskellige hovedmekanismer til mørkning.

Summary

This report represents the very first stage of a monitoring programme for the demonstration of biological and abiotic impurities on the Greenland ice sheet (GrIS). At this stage, the number of samples collected in space and time are still limited and thus, absolute numbers should be used with care in any ground-truth validation exercise. Nevertheless, the data presented here are still a good indication of the complexity related to the distribution of biological and abiotic impurities on the Greenland ice sheet and provide the first indication of the relative importance of biological vs abiotic impurities on the darkening of the ice. Two conclusions can be drawn from the preliminary data: 1) The bare ice duration is an important control of the abundance of glacier ice algae and 2) different areas of the GrIS can have very different main mechanisms for darkening.

1 Introduction and context

Loss of mass from the Greenland Ice Sheet (GrIS) poses a significant threat to coastal communities globally (IPCC 2023). Should it fully melt, the sea level would rise by 7.4 meters (Bamber et al. 2012). Albedo serves as the primary determinant of the surface melt within the ice sheet under a specific climate (He et al. 2013; Masson-Delmotte et al. 2018). Over the period since the commencement of satellite observations in 1981, there has been a consistent decline in the Greenland ice albedo (Feng et al. 2023). Currently, we know that a combination of physical, geochemical and biological factors contributes to ice surface darkening (Benning et al., 2014; Cook et al., 2017, 2020; Lutz et al., 2016, 2018; Williamson et al., 2018, 2020). However, the relative contributions of biological vs abiotic impurities to ice darkening are still under debate. In certain areas of the Greenland ice sheet, the surface ice is highly colonised by pigmented ice algae, in concentrations of 10^2 – 10^5 cells per ml (Lutz et al., 2018). The ice algae contain a unique deep purple pigment, which is used primarily as a photo-protectant, but which darkens the surface considerably (Stibal et al., 2017; Williamson et al., 2020; Yallop et al., 2012). Understanding the trends in algal growth on the Greenland ice sheet is massively compromised by the fact that there are no long-term data associated with the collection of biological data. Thus, a full picture of whether the glacial algae is growing in extension is purely based on information of the darkening measured with remote satellite imagery across time. Yet, such correlation is not yet fully proven, since other impurities (e.g., dust and black carbon) are also correlated with the darkening of the ice. Therefore, it is paramount to both establish and to maintain a long-term monitoring program that takes into consideration the algal growth on the ice sheet and its relations with other light absorbing impurities.

In 2021, PROMBIO devised a methodology for gathering various impurities, including biological samples, from the surface ice (Anesio et al 2022). Subsequently, in 2023, this method is now implemented across 10 weather stations spanning 4 different regions on the GrIS. The resulting data is presented here and will be integrated into the publicly accessible database on the PROMICE website.

2 Procedures and observations about the data presented in this report

Samples were collected during 2023 by GEUS personnel during the campaign for maintenance of PROMICE and GC-Net weather stations. For most of the locations, three samples were collected using an ice screw to collect the top 2 cm of the ice surface. One sample was collected under the radiometer of the weather station, which can then be directly associated to albedo measurements by the weather station. One sample represented the "average" ice in the area of the weather station, while another sample was collected for dark ice. The samples were preserved with paraformaldehyde before transport back to a laboratory at Aarhus University (Risø campus). Preservation with paraformaldehyde results in loss of pigmentation in glacier ice algae, but the cells are still visible under the microscope. Therefore, pictures of glacier ice algae presented here do not always show their true dark coloration.

Samples were collected from the following weather stations (Figure 2.1): QAS-U, QAS-M, QAS-L (representing a transect in the south), UPE-U, UPE-L (representing a northwest transect), TAS-A, TAS-L, MIT (representing a transect on the east), NUK-U and NUK-L (representing a transect on the southwest). Samples were also collected on the KAN transect, but they were not deemed of good quality enough to be considered in the analyses. Additional data from Qaanaaq and KAN region are presented as part of research data collection by the Department of Environmental Science at Aarhus University.

Each sample was counted twice using a hemocytometer under an Olympus microscope, alternating between 200 and 400x magnification, depending on the size of the cells. A total of 2 µl were counted per sample. Therefore, the limit of detection of biological impurities is considered to be 1000 cells per ml in this study. Abiotic loading (presence of minerals) was qualitatively classified between low, medium and high.

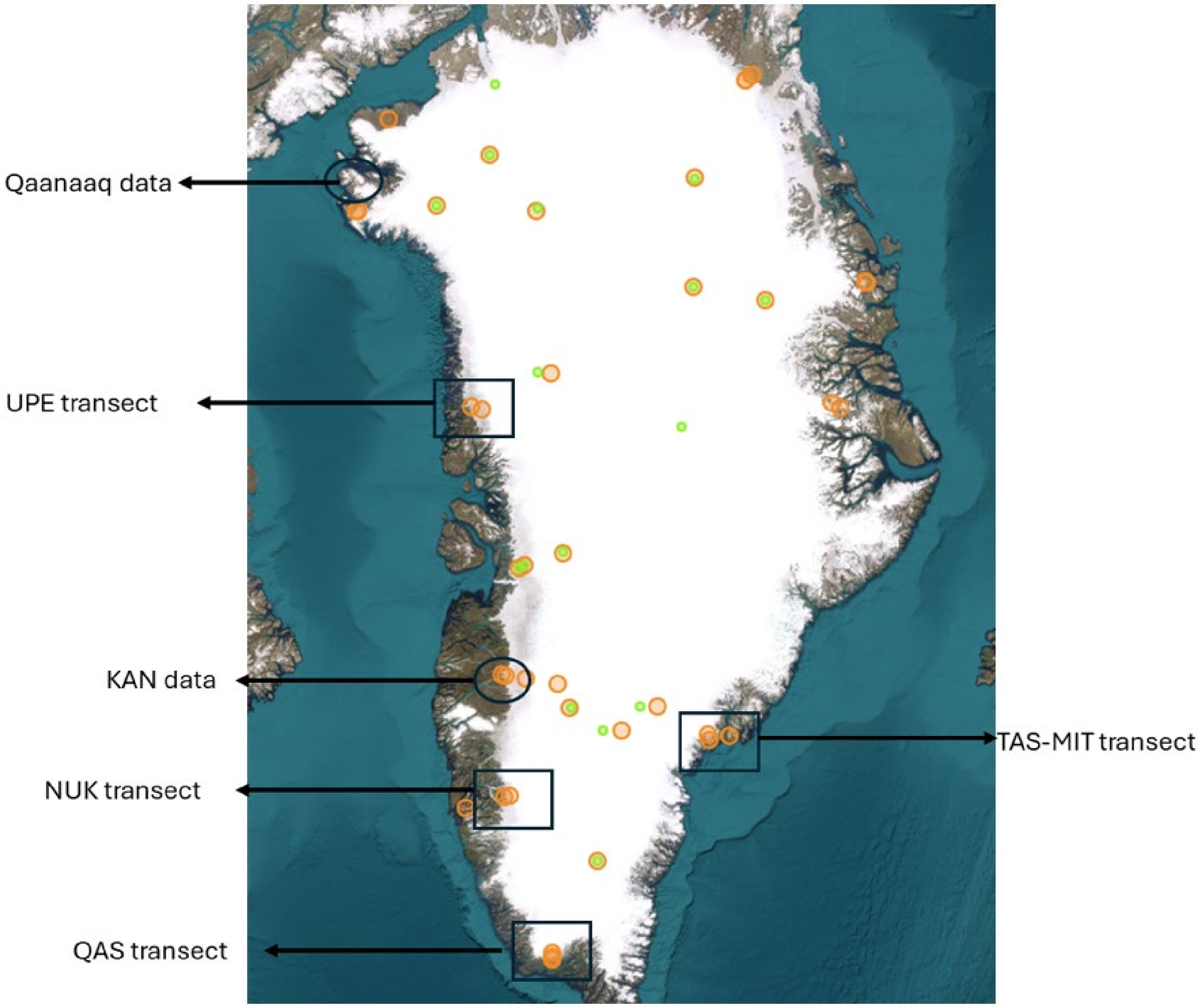

Figure 2.1. Locations where samples were taken by PROMICE-GC-Net during the 2023 summer season (circles within the squares) and locations where data from previous/current research projects are also added to PROMBIO (circles within the circles).

3 Results

Table 3.1 presents the main results for the PROMBIO 2023 sampling, including data from PROMBIO 2021. A more complete version of the table, containing notes, is also submitted as a Dataverse file for uploading at the PROMICE portal, containing links to photos when available (Box and Anesio, 2024). The version below shows the ranges and averages of biological impurities in cells/ml and a qualitative indication of the abiotic loading on samples collected at different regions on the Greenland ice sheet.

Table 3.1. Cell abundances and abiotic loading at different locations on the Greenland ice sheet.

	Location	radiometer (a)		representative (b)		dark (c)		range*				position		
date		cells/ml	approx. abiotic load**	cells/ml	approx. abiotic load**	cells/ml	approx. abiotic load**	min	max	average	abiotic load**	Sampling	latitude	longitude
02-09-2021	QAS-U	<1000	high	NA	high	NA	high	NA	NA	NA	high	PROMBIO 2021	61,172265	-46,822545
31-08-2021	QAS-M	2430	high	31100	high	189000	high	<1000	202000	24100	high	PROMBIO 2021	61,109911	-46,808667
01-09-2021	QAS-L	116000	high	NA	high	NA	high	NA	NA	NA	high	PROMBIO 2021	61,030653	-46,849501
31-08-2023	QAS-U	2000	high	1500	high	<1000	high	<1000	4000	1750	high	PROMBIO 2023	61,172265	-46,822545
31-08-2023	QAS-M	17000	high	54500	high	9500	high	6000	68000	27000	high	PROMBIO 2023	61,109911	-46,808667
01-09-2023	QAS-L	213000	high	489000	high	28000	high	25000	636000	243333	high	PROMBIO 2023	61,030653	-46,849501
07-08-2023	UPE-U	<1000	low	NA	NA	NA	NA	NA	NA	<1000	low	PROMBIO 2023	72,885081	-53,619149
07-08-2023	UPE-L	1500	low	<1000	low	10500	low	<1000	15000	4167	low	PROMBIO 2023	72,893392	-54,295809
10-08-2023	TAS-A	9000	low	NA	NA	NA	NA	NA	NA	9000	low	PROMBIO 2023	65,774442	-38,890758
10-08-2023	TAS-L	52000	low-medium	46000	medium	91000	medium-high	25000	122000	71500	medium	PROMBIO 2023	65,639166	-38,899180
11-08-2023	MIT	27000	high	19500	high		high	18000	21000	23250	high	PROMBIO 2023	65,691955	-37,829808
19-08-2023	NUK-U	2500	low	19500	medium	35500	medium-high	19000	39000	19167	low-medium	PROMBIO 2023	64,509001	-49,285930
19-08-2023	NUK-L	149000	medium	3500	low	328000	medium	3000	338000	160166	medium	PROMBIO 2023	64,484214	-49,553779
24-08-2023	KAN-M	<1000	low	<1000	low	31500	medium	NA	NA	NA	medium	PROMBIO 2023	67,068214	-48,852638
24-08-2023	KAN-L	<1000	low	<1000	low	24000	low	NA	NA	NA	low	PROMBIO 2023	67,104996	-49,931426

* range means cell concentartions between average and dark ice
** abiotic load - semi-quantitative indication whether abiotic impurities (minerals) loading are low, medium or high
a - sample collected under the radiometer
b - sample collected to represent the average ice in the area
c - sample collected to represent dark ice in the area
NA - information not available

Generally, the concentration range and averages of biological impurities on the ice surface are higher at low elevations compared to higher elevations within the same transect. There is also a large spatial variability within the data. In certain locations, biological impurities have a significant importance on the darkening of the ice (e.g., Qaanaaq, KAN-M, TAS-L) while other locations, observed darkening may be mostly associated with mineral/abiotic particulates (e.g., QAS-U) (Figure 3.1).

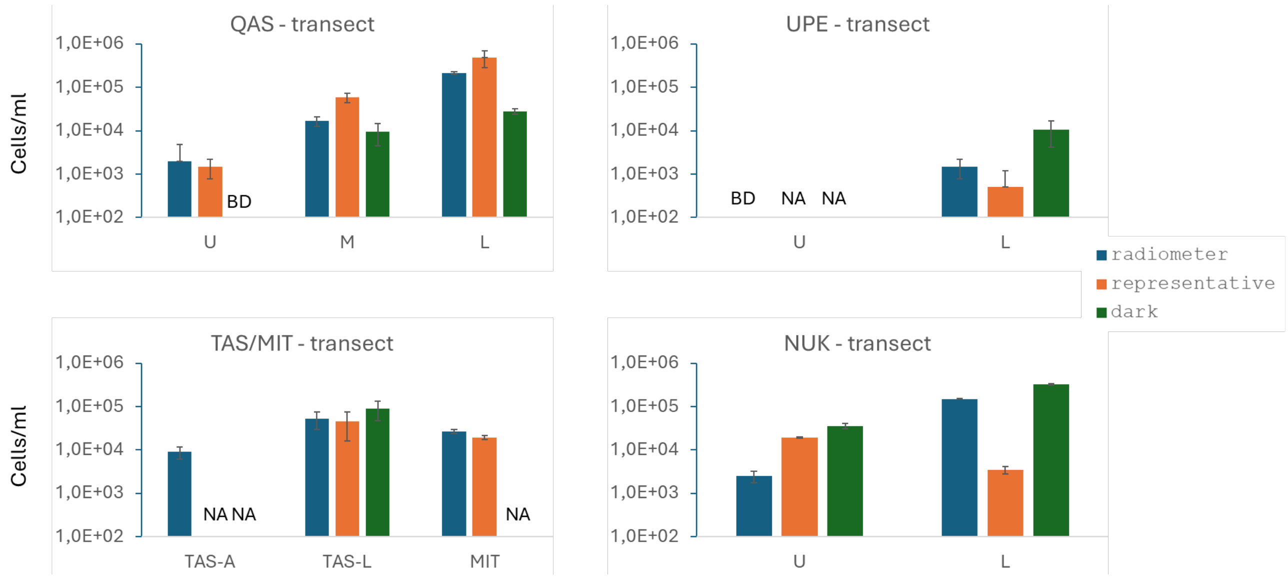

Figure 3.1. Summary of algal cell counts for the different samples collected during the PROMICE and GC-Net weather station mantainance in 2023. For most of locations, three types of samples were collected: under the radiometer, a representative ice of the region and dark ice. U, M and L are upper, mid and lower elevations, respectivelly. NA = information not available. BD = below detection limit.

4 Considerations on the use of PROMBIO data and implications

This report represents the very first stage of a monitoring programme for the demonstration of biological and abiotic impurities on the GrIS. At this stage, the number of samples collected in space and time are still limited and thus, absolute numbers should be used with care in any ground-truth validation exercise. Nevertheless, the data presented here are still a good indication of the complexity related to the distribution of biological and abiotic impurities on the Greenland ice sheet and provide the first indication of the relative importance of biological vs abiotic impurities on the darkening of the ice. Two aspects are briefly presented below that will need further validation and additional data:

a) The bare ice duration is an important control of the abundance of glacier ice algae

Recent research has demonstrated that topographical aspects are well correlated to darkening of the ice surface (Feng et al. 2024). Specifically, the bare ice duration over the melt season is the main factor associated with dark ice. From a biological perspective, it is hypothesized that the growth of algal cells is dependent on a certain amount of time for growth and longer bare ice duration during the melt season provides the longer season for biological darkening of the ice. Bare-ice duration is related to elevation and data presented here confirms that algal abundances are generally higher at the lower elevations, where bare ice duration is longer. However, the importance for outcropping of ancient dust at the margins of the ice should not be ignored as a potential additional source of darkening (Wientjes et al. 2012), which links with the following conclusion below.

b) Different areas of the GrIS can have very different main mechanisms for darkening

Previous studies suggest that biological impurities are a main driver of ice darkening (e.g., Cook et al. 2020). However, this assertion should not be indiscriminately applied for the whole ice sheet. Results in this report demonstrate that ground-truth data are fundamentally important to determine which factors are the main responsible for the ice albedo decline in the past years. Two extremes illustrate this important issue (Figure 4.1). In Qaanaaq, glacial ice algae abundance is among one of the highest on the Greenland ice sheet. Very few minerals are observed, and most of those minerals have a translucent aspect. Therefore, we can establish with high degree of certainty that darkening of the ice in the Qaanaaq region is mostly caused by biological growth of ice algae. On the other hand, QAS-U has a low glacial algal abundance, while the mineral load is very high. Satellite observations show that the QAS-U region is among one with the lowest albedo measurements. Results in this report suggest with high degree of certainty that darkening in the QAS-U region is mostly associated with the presence of abiotic minerals.

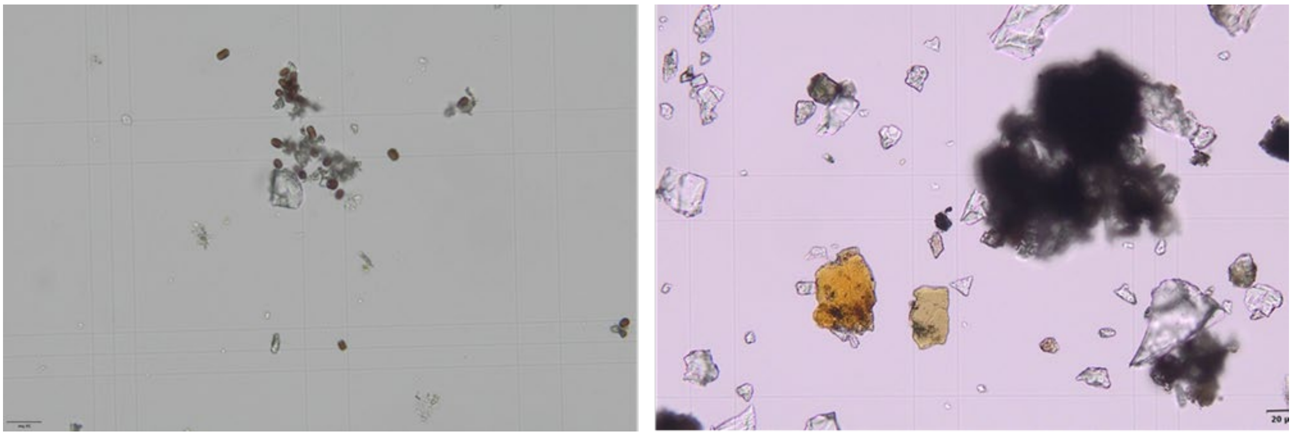

Figure 4.1. Representative microscopic picture (same magnification) from two different locations on the GrIS. Photo on the left is from surface ice in the Qaanaaq region, where most of the darkening is associated with glacier ice algae. Photo on the right is from QAS-U, where most of the impurities are associated with abiotic impurities.

5 Recommendations for future sampling

Additional photos with a ruler in the field of view of the sampling locations would greatly aid to the differentiation and understanding of the relative importance between abiotic and biological impurities, as well as the conditions of the weathering crust at the time of the sampling collection.

Whenever possible, scrapping of the upper 2-5 cm of the weathering crust with an ice axe should take place to verify whether dark ice can be found. If dark ice is found below the upper 2-10 cm, this layer should also be collected, as it could be indicative of biological and abiotic impurities at the peak of the summer.

Whenever possible, additional samples should be collected to increase statistical robustness and understanding of the spatial variability at the sampling location.

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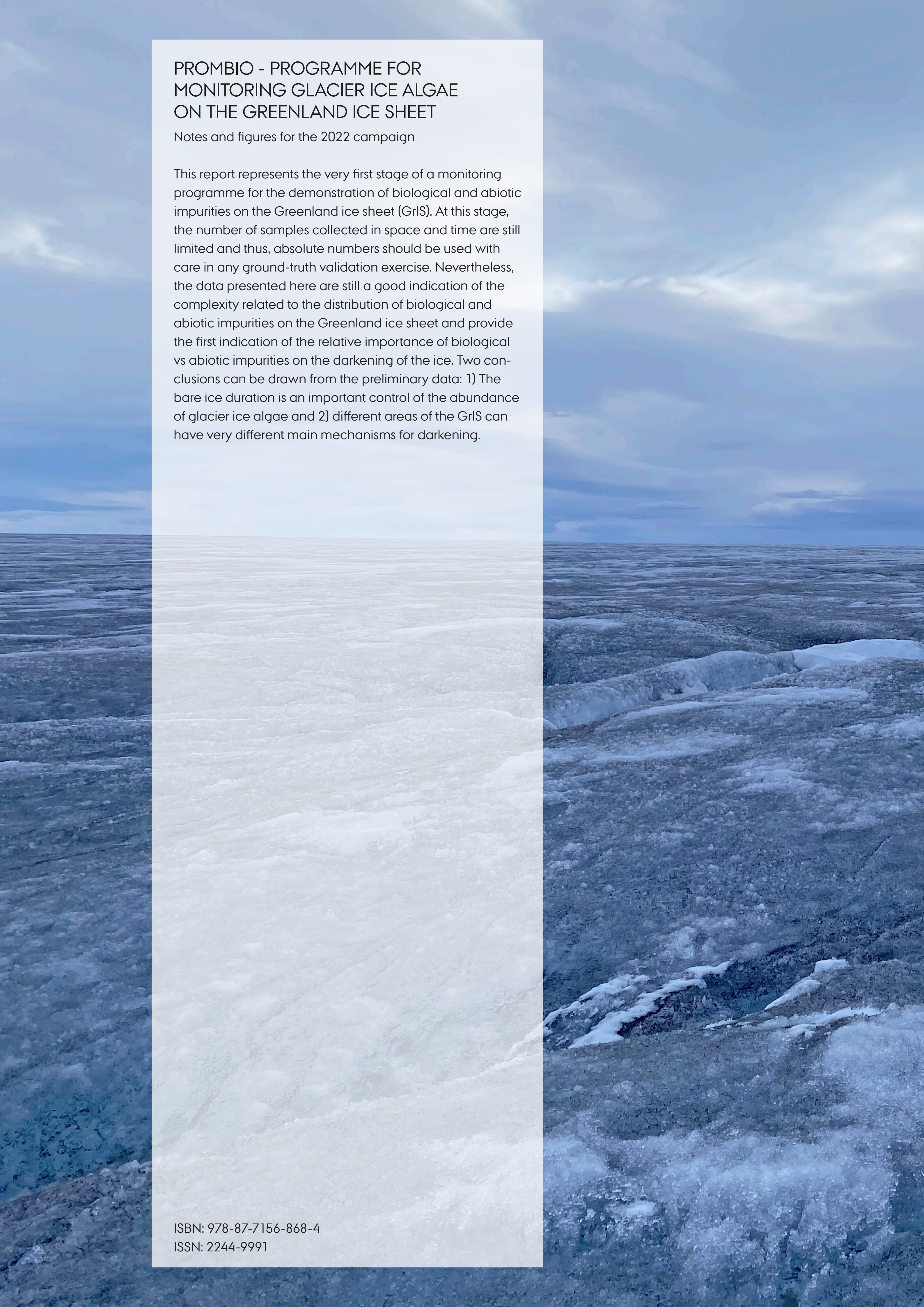

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