Answers to the reviewers

Dear Editor and reviewers, we first want to thank you for carefully evaluating the manuscript and giving us the opportunity to revise it accordingly. We carefully addressed each comment made by both reviewers. You will find below our point-by-point responses to each of these comments. Please find attached a clean and also a tracking changes versions of the manuscript. Note that for some unknown reason related to the editing tool we are using, the tracked version does not contain the changes made in the abstract. We hope that this version will be satisfactory and thank you for your time in this matter.

Yours sincerely,

Philippe Massicotte, Ph.D.

Research Associate

Takuvik Joint International Laboratory (UMI 3376)

Université Laval (Canada) & Centre National de la Recherche Scientifique (France)

Québec-Océan / Pavillon Alexandre-Vachon

1045, Ave de la Médecine, local 2064

Université Laval

Québec (Québec)

G1V 0A6 Canada

c.c. all the authors of the paper.

Reviewer #1

Comment C1

The paper presents useful and complete data about two ice-camp sampling campaigns in the Arctic. The quality checks are appropriate and the process of reviewing the data is up-to-date and grants for usefulness of the data to other potential scientists. The data and methods are sufficiently described and well presented, excpet than for the productivity section (line 197-200), where the method and the protocol used are not well delineated. The presentation is of high quality and I don't see any inconsistencies that could raise suspects that the data are erroneous. As such, in my opinion, the data presented hold potential for being reused in the future for comparison and further elaboration.

Answer A1

Thank you for the comments. We agree that the paper was missing information on the methods used to measure primary production. The following paragraph has been added to the paper (see the section entitled Phytoplankton).

Briefly, rates of carbon fixation (primary production), were measured using a dual ^{13}C-^{15}N isotopic technique (Raimbault1999). Water samples and ice melted was collected into three 600 ml polycarbonate bottles, previously rinsed with 10 % HCl, then with ultrapure Milli-Q water. Labelled ^{13}C sodium bicarbonate ($NaH^{13}CO_3$ – 6 g, 250 mL-1 deionized water – 99 at % ^{13}C, EURISOTOP) was added to each bottle in order to obtain ≈ 9.7% final enrichment (0.5 mL/580 mL-1 seawater). After the addition of ^{13}C-tracer ($H^{13}CO_3$), samples were spiked with inorganic nitrogen labelled with ^{15}N. Immediately after tracers addition, samples were fixed on an array placed under the ice. Incubation was stopped after 24 hours and samples were immediately filtered on Whatman GF/F filters (25 mm diameter) pre combusted at 500°C. These filters were used to determine the final $^{15}N/^{13}C$ enrichment ratio in the particulate organic matter and the concentrations of particulate carbon and particulate nitrogen.

Reviewer #2

Comment C2

The authors produced an impressive, integrated data set. All the procedures are well explained and are supportive of their quality. I believe that any significant data set, in terms of representativeness and relevance of variables, complemented by clear description of procedures, is worth to be made accessible acknowledging the data generators for their willingness to share their data. This also when no intercalibration with other teams has been performed. I have only one question for the authors. Why they use the units of g kg-1 instead of PSU?

Answer A2

Thank you for the comments. We have decided to use the "new" TEOS salinity definition. We have specified everywhere in the text and updated the figure legend to replace *salinity* with *absolute salinity* (S_A) which is the new standard.

In the next paragraph, we are giving precisions on this new salinity standard.

http://www.teos-10.org/

"A significant change compared with past practice is that TEOS-10 uses Absolute

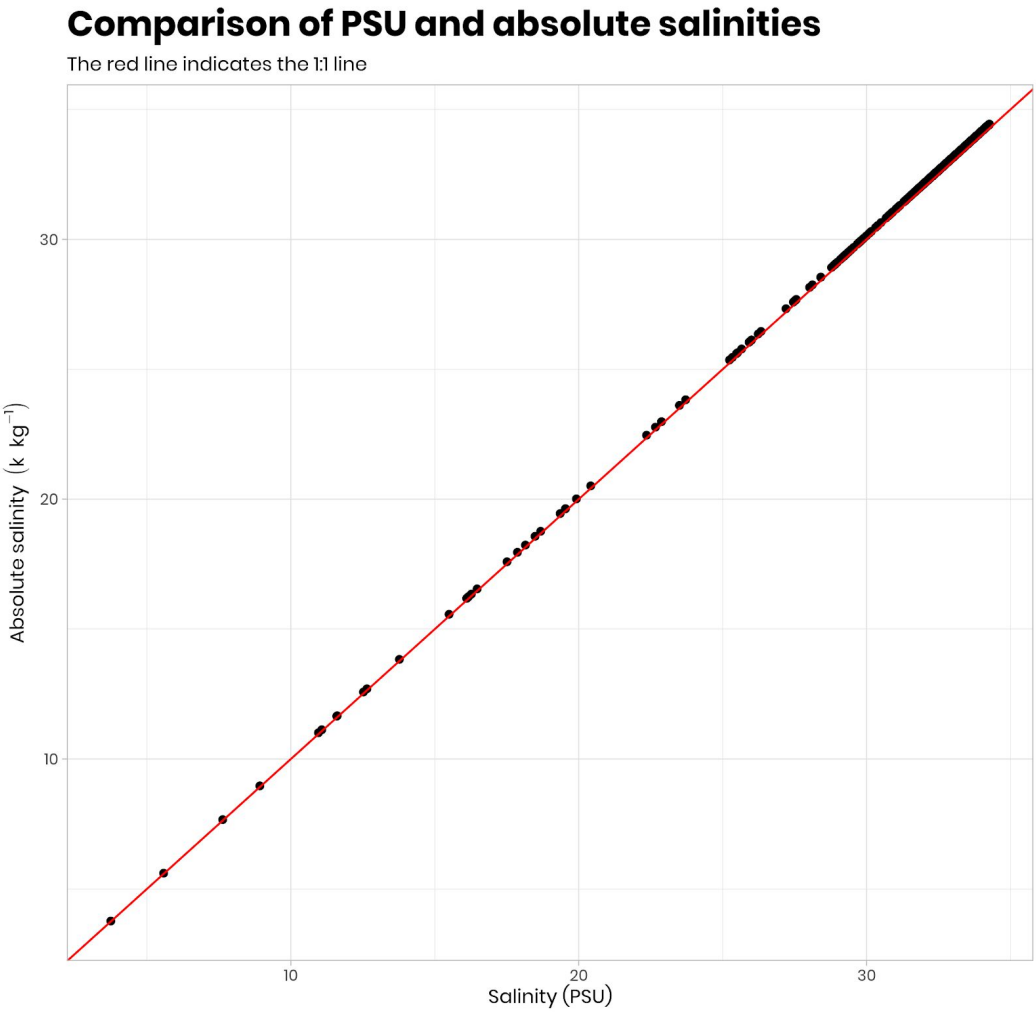
Salinity SA (mass fraction of salt in seawater) as opposed to Practical Salinity SP

(which is essentially a measure of the conductivity of seawater) to describe the salt content of seawater. Ocean salinities now have units of g/kg. Absolute Salinity (g/kg) is an SI unit of concentration. The thermodynamic properties of seawater, such as density and enthalpy, are now correctly expressed as functions of Absolute Salinity rather than being functions of the conductivity of seawater. Spatial variations of the composition of seawater mean that Absolute Salinity is not simply proportional to Practical Salinity; TEOS-10 contains procedures to correct for these effects.

Importantly, while Absolute Salinity (g/kg) is the salinity variable that is needed in order to calculate density and other seawater properties, the salinity which should be

archived in national data bases continues to be the measured salinity variable, Practical Salinity (PSS-78)."

Furthermore, the following graph shows that the PSU and absolute salinities are tightly correlated and that there are only very few differences between these two ways of measuring salinity.



Green Edge ice camp campaigns: understanding the processes controlling the under-ice Arctic phytoplankton spring bloom

Note: there is one new author to the list:

Catherine	Schmechtig	schmechtig@obs-vlfr.fr	Sorbonne Université, CNRS, Laboratoire d'Océanographie de Villefranche, LOV, F-06230 Villefranche-sur-Mer, France

Abstract

The Green Edge initiative was developed to investigate the processes controlling the primary productivity and the fate of organic matter produced during the Arctic phytoplankton spring bloom (PSB) and to determine its role in the ecosystem. Two field campaigns were conducted in 2015 and 2016 at an ice camp located on landfast sea ice southeast of Qikiqtarjuaq Island in Baffin Bay (67.4797N, 63.7895W). During both expeditions, a large suite of physical, chemical and biological variables was measured beneath a consolidated sea ice cover from the surface to the bottom at 360 m depth to better understand the factors driving the PSB. Key variables such as conservative temperature, absolute salinity, radiance, irradiance, nutrient concentrations, chlorophyll-a concentration, bacteria, phytoplankton and zooplankton abundance and taxonomy, carbon stocks and fluxes were routinely measured at the ice camp. Meteorological and snow-relevant variables were also monitored. Here, we present the results of a joint effort to tidy and standardize the collected data sets that will facilitate their reuse in other Arctic studies. The dataset is available at https://doi.org/10.17882/59892 (Massicotte2019b).

Introduction

In the Arctic Ocean, the phytoplankton spring bloom (PSB) initiates the period of highest biomass primary production of the year (Sakshaug2004, Perrette2011, Ardyna2013). Although it was discovered that the PSB may occur more extensively and more frequently beneath a consolidated ice-pack (Arrigo2012, Arrigo2014, Assmy2017), only a small number of research initiatives (e.g., Fortier2002, Galindo2014, Mundy2009, Mundy2014, Wassmann1999, Gosselin1997) have been investigating the processes controlling the Arctic PSB in the ice-covered water column. Additionally, ice algal communities play an important role within the Arctic food web and for the carbon export to the benthos during the winter-spring transition (Leu2015). However, primary production within the Arctic ice-pack is still poorly understood. The Green Edge project was conceived in an effort to better understand the Arctic PSB from the level of fundamental physical, chemical and biological processes to that of their interactions within the ecosystem, and at spatial scales ranging from local to pan-Arctic. Besides studying each major component of the processes controlling Arctic PSB, another objective of Green Edge was to investigate its impact on the nutrient and carbon dynamics within the ecosystem. A total of three Green Edge campaigns were conducted: two ice camp campaigns on landfast sea ice in 2015 and 2016, and an oceanographic cruise aboard the *CCGS Amundsen* in Baffin Bay in 2016. In this article, we present an overview of an extensive and comprehensive data set acquired during two surveys conducted at the Green Edge ice camp.

Study area, environmental conditions and sampling strategy

The field campaigns were conducted on landfast sea ice southeast of the Qikiqtarjuaq Island in Baffin Bay (67.4797N, 63.7895W, Fig. 1) in 2015 (April 24~~March 15~~ - July 17) and in 2016 (April 20 to July 27). These periods were chosen in order to capture the dynamics of the sea-ice algae and phytoplankton spring blooms, from bloom initiation to termination. The field operations took place at a location (the "ice camp") south of the Qikiqtarjuaq Island where the water depth is 360 m. Continuous records of wind speed and air temperature were made with a meteorological station (Automated Meteo Mat equipped with temperature (HC2S3) and wind (05305-L) sensors (Campbell Scientific) positioned near (< 100 m) the tent (Polarhaven, Weatherhaven) in which water sampling was carried out. During the sampling periods, the study site experienced changes in snow cover and ice thickness (Fig. 2). In 2015, the snow and ice thickness at the monitoring spot varied between 2-40 cm (mean = 21 cm) and 103-136 cm (mean = 121) respectively. In 2016, the snow and ice thickness varied between 0.3-49 cm (mean = 19 cm) and 106-149 cm (mean = 128 cm) respectively. For both years, snowmelt began at the beginning of June and lasted for approximately two to three weeks (Oziel2019). Water sampling was usually carried out every two days through a 1x1 m hole in the ice pack shielded by the tent. For the analysis of nutrient concentration, photosynthetic parameters, primary production, chlorophyll *a* (chl *a*), phytoplankton taxonomy and carbon stocks such as dissolved organic carbon (DOC), particulate organic carbon (POC), water samples were collected at 1.5, 5, 10, 20, 40 and 60 m using 10 or 20-L Niskin bottles. Details about specific measurements such as zooplankton and bacteria abundances are provided in the following sections.

Data quality control and data processing

Different quality control procedures were adopted to ensure the integrity of the data. First, the raw data were visually screened to eliminate errors originating from the measurement devices, including sensors (systematic or random) and errors inherent from measurement procedures and methods. Statistical summaries such as average, standard deviation and range were computed to detect and remove anomalous values in the data. Then, data were checked for duplicates and remaining outliers. Once raw measurements were cleaned, data were structured and regrouped into plain text comma-separated (CSV) files. Each of these files was constructed to gather variables of the same nature (ex.: nutrients). In each of these files, a minimum number of variables (columns) were always included so the different data sets can be easily merged together (Table 1). More than 120 different variables have been measured during the Green Edge landfast-ice expeditions. The complete list of variables is presented in Table 2 and detailed metadata information can be found on the LEFE-CYBER online repository (http://www.obs-vlfr.fr/proof/php/GREENEDGE/greenedge.php). The processed and tidied version of the data is hosted at SEANOE (SEA scieNtific Open data Edition) under the CC-BY license (https://www.seanoe.org/data/00487/59892/, Massicotte201b). In the following sections, we present a subset of these variables along with the methods used to collect and measure them. For each of these variables, time series or vertical profiles are used to describe the data. Data cleaning and visualization were performed with R 3.6.1 (RCoreTeam2019). The code used to produce the figures and the analysis presented in this paper is available under the GNU GPLv3 licence (https://github.com/PMassicotte/greenedge-icecamp-data-paper). The code used to process and tidy the data provided by each

researcher is also publicly available (https://gitlab.com/Takuvik/greenedge-database) under the GNU GPLv3 licence.

Data description: an overview

Physical data

Some meteorological variables were measured during both campaigns. Starting on 27 March 2015, air temperature and relative humidity, wind speed and snow depth were measured. Data were recorded using a CR1000 Campbell data logger. Field measurements were performed most days to obtain snow physical variables. These included vertical profiles of snow density and specific surface area with 1 cm vertical resolution, and visual determination of snow stratigraphy. Snow spectral albedo in the 400-1100 nm spectral range was also measured during these field measurements. Snow measurements are detailed in Verin et al. (2019) doi:10.5194/tc-2019-113~~Verin2019~~.

Underwater, ~~C~~conductivity, conservative temperature and depth (CTD) vertical profiles were measured using a Sea-Bird SBE19plusV2 CTD system (factory calibrated prior to the expedition) deployed from inside the Polarhaven tent between the surface and a 350 m depth. The data were post-processed according to the standard procedures recommended by the manufacturer and averaged into 1-m vertical bins. During the sampling periods, absolute salinity (SA) was generally greater than 31.5 g kg^{-1} (range: 4-34.4 g kg^{-1}). Flushes of freshwater at the ocean surface due to snow/ice melt started slowly at the beginning of June with the largest peaks/pulses taking place late June when absolute salinity decreased to approximately 4 g kg^{-1} (Fig. 3). Note that the new standard of absolute salinity is used in the remaining of the paper (Oziel2019, Randelhoff2019).

Ocean current profiles in the water column were measured using a downward-looking 300 kHz Sentinel Workhorse Acoustic Doppler Current Profiler (ADCP, RDI Teledyne) mounted directly beneath the sea ice bottom. The study site was

dominated by seawater originating from the Arctic Ocean modulated by spring-neap tidal cycles (14 days) and semidiurnal M2 periods (~12.4 hours). Vertical profiles of water column turbulence were measured on June 23 of 2016 during a spring tidal cycle (~12.4) using a self-contained autonomous microprofiler (SCAMP, Precision Measurement Engineering, California, U.S.A.). The turbulence profile (i.e. a median profile of the rate of dissipation of turbulent kinetic energy, ε) showed a mixing layer depth of about 20–25 m characterized by an elevated dissipation rate with values above 10^{-8} W kg^{-1}. The reader is referred to the paper by Oziel2019 for detailed methods, visualization and discussion of the CTD, SCAMP and ADCP data.

Vertical profiles (surface to 200 m) of CTD and bio-optical properties were measured every hour during a M2 tidal cycle measured on June 9, 2016 (an example of modelled surface tidal height versus time is shown in supplementary Fig. A1). These observations (Fig. 4) illustrate that internal tidal waves caused large vertical isopycnal displacements (20-30 m) of all observed physical and biogeochemical properties below 50 m depth across the semi-diurnal M2 period. Hence, as vertical profiles of physical and bio-optical variables were measured at approximately the same time each day, properties (assuming they follow a conservative mixing behaviour) will appear to be vertically displaced. Therefore, when comparing properties from vertical profiles taken at the ice camp, we suggest that comparisons of profile variables should be made on isopycnal (constant density) coordinates, rather than depth coordinates (Fig. 4).

Underwater bio-optical data

Radiance and irradiance measurements with ICE-Pro

A total of 173 and 89 vertical radiometric~~light~~ profiles were measured in 2015 and 2016, respectively, using a factory-calibrated ICE-Pro (an ice-floe version of the C-

OPS, or Compact-Optical Profiling System, from Biospherical Instruments Inc.). The ICE-Pro was equipped with radiometers for both downward plane irradiance (E_d, W m^{-2} nm^{-1}) and either upward irradiance (E_u, W m^{-2} nm^{-1}) in 2015 or upward radiance (L_u, W m^{-2} sr^{-1} nm^{-1}) in 2016. The profiles were taken at two sites, separated by approximately 40 m. In order to perform the profiles, the ICE-Pro was deployed through auger holes that had been drilled at distances of 82 and 113 m from the tent and cleaned of ice chunks. Once the ICE-Pro was underneath the ice layer, fresh clean snow was shovelled back into the hole to avoid, as much as possible, having a bright spot above the sensors (see supplementary Fig. B1 and Table B1). The frame was then manually lowered at a rate of approximately 0.3 m s^{-1}. The above-surface reference sensor was fixed on a steady tripod installed approximately 2 m above the ice surface and above all neighbouring camp features. Data processing and validation were performed using a protocol inspired by that of Smith1984, which is now used by several space agencies for their Ocean Colour algorithms validation activities. Measurements were taken between 380 and 875 nm at 19 discrete spectral wavebands. Vertical profiles were usually performed~~measured~~ in duplicates or triplicates. Time series of daily photosynthetically active radiation (PAR, computed from the 19 spectral irradiance values~~wavelengths~~) at the sea-ice/water interface (1.3 m depth) are shown in Fig. 5. In 2016, PAR started to increase rapidly in the second week of May, compared to early June in 2015. Overall, PAR at 1.3 m in the water column was also greater in 2016 than in 2015 and reached the threshold of 0.415 mol of photons m^{-2} d^{-1}, above which light is sufficient for net growth (Letelier2004), a few days earlier. Further information about *in situ* underwater irradiance and radiance measurements can be found in Massicotte2018.

Underwater photos and videos of ice bottom

Several vertical profiles to 30 m were performed using a GoPro Hero 4 camera mounted on the ICE-Pro and pointing up, towards the ice bottom (see Fig. B1 and Table B1). Still images were captured every five seconds during descent, as well as a video was taken of the complete descent. These photos and videos were used for a qualitative assessment of the pronounced spatial and temporal heterogeneity of the under-ice environment and the associated water column nekton community between the two profiling locations.

Irradiance measurements with TriOS

To quantify the impact of the heterogeneous radiation field under sea ice on irradiance measurements, replicated spectral irradiance profiles were collected beneath landfast sea ice from 5 May to 8 June 2015 and from 14 June to 4 July 2016. The replicates were made on each sampling day, under different surface conditions. In 2015, measurements were performed prior to melt onset, under different snow depths. In 2016, measurements began after the onset of snowmelt and were performed beneath sea ice with a wet snow cover, shallow melt ponds and white ice. The deployed sensor array consisted of a surface reference radiometer, which recorded incident downwelling planar irradiance, $E_d(0,\lambda)$, and three radiometers attached to a custom-built double-hinged aluminum pole (under-ice L-arm) to measure downwelling planar irradiance, $E_d(z,\lambda)$, downwelling scalar irradiance, $E_{0d}(z,\lambda)$, and upwelling scalar irradiance, $E_{0u}(z,\lambda)$. These four hyperspectral radiometers (two planar RAMSES-ACC and two scalars RAMSES-ASC, TriOS GmbH, Germany) measured pressure and tilt internally and recorded irradiance spectra in the wavelength range from 320 to 950 nm at a resolution of 3.3 nm (190 channels). Transmitted irradiance was recorded along with vertical profiles by lowering the L-arm manually through a 20-inches auger hole with a

winch and 1.5-m aluminum poles extensions. In 2015, 17 vertical profiles were collected in 0.4 - 0.5-m depth steps from the ice bottom to a water depth of 18 m. In 2016, 11 profiles were recorded to a depth of 20 m under different sea ice surface conditions. Differences between planar and scalar PAR measurements were used to derive the downwelling average cosine, μ_d, an index of the angular structure of the downwelling under-ice radiation field which, in practice, can be used to convert between downwelling scalar, E_{0d}, and planar, E_d, irradiance. The average cosine was smaller prior to snowmelt in 2015 compared to after snowmelt (~0.6 vs. 0.7), when melt ponds covered the ice surface in 2016 (Fig. 6). Further details about the sampling procedure, data processing and results can be found in Matthes2019.

Inherent optical properties (IOP)

IOPs measurements were made using an optical frame equipped with the physical and bio-optical sensors that were factory calibrated before each field campaign. A Seabird SBE-9 CTD measured temperature, absolute salinity, and pressure. A WetLabs AC-S was used for spectral beam attenuation (c, m^{-1}) and total absorption (a, m^{-1}) between 405 and 740 nm, and a BB9 (WetLabs) and a BB3 (WetLabs) were utilized for backscattering coefficients (b_b, m^{-1}) between 440 and 870 nm. During both campaigns, pure water calibration was performed for the AC-S sensor on each sampling day and linear regression of these calibration values as a function of time was computed for each wavelength of absorption and attenuation signals. Then, the offset applied during the data processing was taken on this linear regression at the exact date of the measurement. Figure 7 shows two vertical profiles of attenuation coefficients at different wavelengths acquired during pre-bloom and bloom conditions in 2016. One can see that during the bloom, attenuation

increased markedly in the 0-50 m surface layer due to higher phytoplankton biomass.

Other optical measurements

Other optical variables measured during both field campaigns included absorbance of particulate matter, absorbance of dissolved organic matter, snow and sea-ice transmittance, snow/ice hyperspectral and hyperangular hemispherical-directional-reflectance (Goyens2018) and surface spectral albedo (Verin et al., 2019, doi:10.5194/tc-2019-113~~Verin2019~~) (Table 2). Downwelling spectral irradiance above the surface (1°x1° spatial resolution, daily temporal resolution, interpolated hourly) was also computed based on the radiative transfer model SBDART (Ricchiazzi1998) as described in Laliberte2016 and Randelhoff2019.

Nutrients

Nitrate, nitrite, phosphate and silicate concentrations were measured from water filtered through 0.7 µm Whatman GF/F filters and through 0.2 µm cellulose acetate membranes. Filtrates were collected into sterile 20 mL polyethylene vials, poisoned with 100 µL of mercuric chloride (60mg L^{-1}) and subsequently stored in the dark prior to analysis. Nutrient concentrations were determined using an automated colorimetric procedure described in Aminot2007. Figure 8 shows an overview of the dynamics of nitrate which is often the limiting nutrient for phytoplankton growth in the ocean (Tremblay2009). It can be seen that the depletion of the nitrates started approximately mid-June for both years, coinciding with the initiation of the phytoplankton bloom. However, the depletion was observed deeper in the water column in 2016 compared to 2015 due to stronger currents and a longer sampling period in 2016 (Oziel2019). Other nutrients such as dissolved organic and inorganic carbon (DOC/DIC), particulate organic and inorganic carbon (POC/PIC), total organic

carbon (TOC), phosphate (PO4), orthosilicic acid ($Si(OH)_4$), and ammonium (NH_4), were also measured during both campaigns (Table 2)**.** Detailed information about analytical procedures can be found in the LEFE-CYBER online repository. A comprehensive discussion about nutrient dynamics during the Green Edge missions can be found in Grondin2019.

Bacteria and Phytoplankton

Flow cytometry

The abundances of pico-phytoplankton, nano-phytoplankton and bacteria were measured by flow cytometry. Samples (1.5 mL) were preserved with a mix of glutaraldehyde and Pluronic (Marie2014) and frozen at -80°C. Samples were analyzed on a FACS Canto flow cytometer (Becton Dickinson) in the laboratory at the Station Biologique de Roscoff. The abundance (cells mL^{-1}) of phytoplankton populations was determined on unstained samples and cells were discriminated by their red chlorophyll autofluorescence. Bacterial abundance was determined based on the fluorescence of SYBR Green-stained DNA (Marie1997). In both 2015 and 2016, bacteria concentrations were initially low, of the order of 100 000 cells mL^{-1}, and quite uniform throughout the water column. During the bloom, bacterial abundance increased continuously, reaching values of one million cells mL^{-1} (Fig. 9). Simultaneously, the distribution of highest abundance became stratified with a higher concentration found near the surface in early July before it moved down to the subsurface (between 10 and 20 m) later in July (Fig. 9). In 2015, the sampling period did not extend long enough to capture the full progression of bacterial community development.

Phytoplankton

Chlorophyll a

Chl *a* and accessory pigments concentrations were determined by high-performance liquid chromatography (HPLC) following Ras2008. Concentrations were measured using volumes between 0.1 and 1 L of melted ice and volumes between 1 and 2.5 L of seawater. Water was filtered onto Whatman GF/F 25 mm filters and stored at -80 ℃ until analysis. Filters were extracted in 100% methanol, disrupted by sonication and clarified by filtration. Pigments were analyzed using an Agilent Technologies 1200 Series system with a narrow reversed-phase C8 Zorbax Eclipse XDB column (150 × 3 mm, 3.5 µm particle size) which was maintained at 60°C. Figure 10 shows the temporal evolution of surface integrated chl *a* in the bottom 10 cm of the ice cover and the water column for both years. At the beginning of the sampling periods in 2015 and 2016, total chl *a* concentrations in the bottom of the ice and the water column were of approximately the same magnitude (~5 mg m^{-2}). Later in the season, when the snowpack and the ice sheet started to melt (between June and July), and at the onset of the PSB, chl *a* in the water column increased rapidly to reach concentrations of 145 mg m^{-2} in 2015 and 113 mg m^{-2} in 2016. At the same time, or slightly before, chl *a* in the ice bottom started to decrease rapidly to concentrations varying between 0.1 and 0.3 mg m^{-2}.

Primary production during the phytoplankton bloom was incompletely sampled in 2015, while in 2016 it was monitored from the onset under melting sea ice in May to its termination in July (Fig. 11). Briefly, rates of carbon fixation (primary production), were measured using a dual 13C-15N isotopic technique (Raimbault1999). Water samples and ice melted was collected into three 600 ml polycarbonate bottles, previously rinsed with 10 % HCl, then with ultrapure Milli-Q water. Labelled 13C sodium bicarbonate (NaH13CO3 – 6 g, 250 mL-1 deionized

water – 99 at % 13C, EURISOTOP) was added to each bottle in order to obtain ≈ 9.7% final enrichment (0.5 mL/580 mL-1 seawater). After the addition of 13C-tracer (H13CO3), samples were spiked with inorganic nitrogen labelled with 15N. Immediately after tracers addition, samples were fixed on an array placed under the ice. Incubation was stopped after 24 hours and samples were immediately filtered on Whatman GF/F filters (25 mm diameter) pre combusted at 500°C. These filters were used to determine the final 15N/13C enrichment ratio in the particulate organic matter and the concentrations of particulate carbon and particulate nitrogen. During the ice-covered period in 2015, primary production, as well as nitrate assimilation (rNO3), occurred at very low but detectable rates reaching 8 and 0.4 mmol m^{-2} d^{-1}, respectively. Phytoplankton production rates were higher in the ice than in the water column, representing approximately 80% and 40% for primary production and rNO_3, respectively. Estimated assimilated concentrations of total carbon and nitrate within the ice cover were 30-96 and 1.4–4.6 mmol m^{-2} during this period. The break-up of the sea ice cover was characterized by a rapid increase in primary production and rNO_3. During this period of high light transmission through the melting ice cover (day 169 to 190), concentrations of assimilated total carbon and rNO_3 reached 60 and 8 mmol m^{-2}, respectively, leading to a complete nitrate depletion. The quantities of total carbon and nitrate assimilated during the 2016 PSB in the water column were 562 and 97 mmol m^{-2}, respectively.

Phytoplankton taxonomy

The phytoplankton community species composition was determined using an *Imaging FlowCytobot* (IFCB, Woods Hole Oceanographic Institute, Sosik2007, Olson2007). The size range targeted was between 1 and 150 µm, while the image

resolution of approximately 3.4 pixels μm^{-1} limited the identification of cell < 10 µm to broad functional groups. A 150 µm Nitex mesh was used to avoid clogging of the fluidics system by large particles, although this might have induced a bias in the results by preventing large cells to be sampled. For each melted ice and seawater sample, 5 mL were analyzed and Milli-Q water was run between samples with high biomass in order to prevent contamination between samples. Image acquisition was triggered by chl *a* *in vivo* fluorescence, with excitation and emission wavelengths of 635 and 680 nm, respectively. Grayscale images were processed to extract regions of interest (ROIs) and their associated features (e.g.: geometry, shape, symmetry, texture, etc.), using a custom made MATLAB (2013b) code (Sosik2007, Olson2007; processing codes are available at *https://github.com/hsosik/ifcb-analysis*). A total of 231 features (see the full list and description at *https://github.com/ hsosik/ifcb-analysis/wiki/feature-file-documentation*) were derived on the resulting ROIs and were used for automatic classification using random forest algorithms with the EcoTaxa application (Picheral2017). A learning set was manually prepared for each year, with *ca.* 20 000 images annotated and used for automatic prediction. Each automatically annotated image was further validated by visual examination and corrected when necessary. The final 2015 and 2016 datasets consist of 124 247 and 57 397 annotated images and their associated features in 39 and 35 taxonomic categories, respectively (Fig. 12). As it was impossible to count the number of cells in each image, we assumed one cell per image. To account for potential underestimations of cell abundance when colonies or chains were imaged, the biovolume of each living protist on images was computed during image processing according to Moberg2012. Using carbon to volume ratios from Menden-Deuer2000, biovolume was converted into carbon

estimates, as described in Laney2014. Detailed information about sea ice algae and phytoplankton community composition can be found in Grondin2019 (in prep).

Physiology of the phytoplankton community

The photosynthetic potential of microalgae was assessed by measuring Fv/Fm, namely the maximum photochemical efficiency of Photosystem II (PSII), via dynamic chl *a* fluorescence:

$$Fv/Fm = (Fm - F0) / Fm$$

where Fm and F0 are the maximum and minimum PSII chl *a* fluorescence yields, respectively. Chl *a* fluorescence was recorded with a Water-PAM fluorometer (Walz, Germany) on melted sea-ice (last centimeter of the cores) and water samples collected at different depths (i.e. 1.5 m, 10 m, 40 m, 60 m). Measurements were performed after storing samples in 50 mL dark Falcon tubes (Corning Life Sciences, USA) on ice for at least 1 h. For further technical details, see Galindo2017. Fv/Fm is often used as an index for evaluating the physiological condition of microalgal communities. For algae that are growing optimally, the Fv/Fm ratio ranges between 0.50 and 0.75 in the absence of cyanobacteria. Below 0.50, algal growth is considered to be limited by nutrient availability and/or light stress (Suggett2010). Figure 13 shows the temporal evolution of Fv/Fm for ice algae and phytoplankton for the ice camp in 2016. At the beginning of the sampling period, all samples showed Fv/Fm above 0.55. While in ice Fv/Fm ranged between 0.60 and 0.75 until the beginning of June, it decreased to ca. 0.20-0.35 in water. This decrease of Fv/Fm (Fig. 13A) is coincident with a sharp increase in PAR under the ice sheet (Fig. 5), which may have induced light stress in phytoplankton and ice algae communities. After approximately 1 month, phytoplankton became acclimated to this new light environment and Fv/Fm increased back to 0.60-0.75 by the beginning of June. From

that time on (corresponding to higher irradiance transmittance through ice, see Fig. 5), Fv/Fm in ice decreased dramatically to an approximate value of 0.20 while Fv/Fm in the water column generally remained between 0.60 and 0.75 for depths between 10 and 60 m (note however the large decrease at 40 m on June 13). In contrast, Fv/Fm at 1.5 m was lower and noisier with values varying between 0.45 and 0.60.

In addition to the photosynthetic potential of microalgae, photosynthetic parameters were measured from seawater incubated at different irradiance levels in the presence of ^{14}C labelled sodium bicarbonate. The light saturation parameter, E_k, is an indication of the physiological state of the phytoplankton community. Figure 13B shows the increase of E_k as the phytoplankton community grows between May and July of 2016 at 1.5 m, 5 m and 10 m depth. Between 1.5 m and 10 m depth, E_k varied between 15 and 194 µmol m^{-2} s^{-1} (61 ± 37 µmol m^{-2} s^{-1}, *n* = 69) which fall in range within values reported in other marine studies conducted at high-latitudes (Bouman2018, Massicotte2019). The observed increase in E_k over the growing season suggests that the phytoplankton community became more photo-adapted to increasing available irradiance (Fig. 5).

Zooplankton

Zooplankton was collected from a ring net deployed under the ice at the ice camp between April 22 and June 10 in 2015 and between May 16 and July 18 in 2016. This sampler, composed of a 1 m diameter circular frame mounted with a 4 m long 200 µm mesh size conical plankton net was lowered cod-end first to avoid filtration during the descent, using an electric winch. An additional 50 µm net with an aperture of 10 cm in diameter was attached to the side of the metal ring to sample eggs and small zooplankton larvae while the main net collected the mesozooplankton fraction. This sampling device was hauled vertically from a depth

of 100 m (2015 and 2016) or 350 m (only in 2016), 10 m above the seafloor to the surface at a speed of about 30m min^{-1}. The filtered volume was estimated by a KC Denmark flowmeter placed in the mouth of the 200 µm mesh net. Samples were preserved in 10% buffered formalin seawater solution for further taxonomic analyses. Classification and count of the 200 µm mesh net samples from both campaigns were performed using the zooscan by the PIQv team at l'Observatoire Océanographique de Villefranche-sur-Mer, France, following their protocol. Figure 14 shows the time series of the abundance of copepods (the dominant group of zooplankton in the Arctic) for the first 100 m and 350 m of the water column in 2016.

Highest copepod abundance was observed in late May and early June in both the top 100 m and over 350 m hauling depths. At the beginning of the sampling period, abundance was approximately 10 times higher in the first 100 m of the water column than over 350 m, suggesting that copepods were agglomerating near the surface to exploit the ice algae production before the start of phytoplankton production. Abundance started to decrease during the first week of June. The family of Oithonidae and the order of Calanoida were the two most abundant groups over the 2 sampling depths. Oithonidae was more abundant over the top 100m layer as this group is probably mainly composed of small epipelagic *Oithona similis* one of the most numerous copepods in the Arctic. Calanoida, the most common copepod order, which includes the families Calanidae (including species such as *Calanus spp.*) and Acartiidae, was the dominant group over the 350m depth haul.

Other data

An exhaustive list of all measured variables is presented in Table 2 along with contact information of principal investigators associated with each measured parameter.

Data availability

The raw data provided by all the researchers, as well as metadata, are available on the LEFE-CYBER repository (http://www.obs-vlfr.fr/proof/php/GREENEDGE/greenedge.php). The data presented in this paper and in Table 2 are hosted at SEANOE (SEA scieNtific Open data Edition) under the CC-BY license (https://www.seanoe.org/data/00487/59892/, Massicotte201b). Detailed metadata are associated with each file including the principal investigator's contact information. For specific questions, please contact the principal investigator associated with the data (see Table 2).

Recommendations and lessons learned

As with any Arctic surveys, a large number of measurements were acquired during the Green Edge project. Although initial recommendations on good practices about collection, processing and storage of collected data were communicated to all scientists, extensive efforts, such as data standardization, had to be performed to assemble the data. It is important for reducing possible errors, that a uniformized data management plan should be prepared and distributed prior to each mission. Furthermore, dedicated data management specialists should be involved from the beginning of the project to ensure the data are adequately collected, tidied, stored, backed up and archived.

Conclusions

The comprehensive data set assembled during both Green Edge ice-camp campaigns allowed us to study the fundamental physical, chemical and biological processes controlling the Arctic PSB. In this paper, only a handful of variables have been presented. The reader can find the complete list of measured variables in Table 2, all of which are also fully available in the data repository. Furthermore, a collection of scientific research papers is currently being submitted to a special issue of the Elementa journal entitled *Green Edge -The phytoplankton spring bloom in the Arctic Ocean: past, present and future response to climate variations, and impact on carbon fluxes and the marine food web*. The uniqueness and comprehensiveness of this data set offer more opportunities to reuse it for other applications.

Author contribution

- Ghislain Picard and Laurent Arnaud designed the snow optical measurements. Ghislain Picard ~~and~~ participated in the 2015 campaign along with Gauthier Verin who performed~~sampled~~ the 2015 and 2016 snow-related measurements.
- Anda Vladoiu, Caroline Sevigny and Dany Dumont deployed and Marie-Noëlle Houssais added her contribution to the analysis of the Self-Contained Autonomous MicroProfiler (SCAMP) on 23 June 2016 and quality-controlled, processed, analyzed and interpreted the data.
- Guislain Becu, Claudie Marec performed the setup and deployment of the CTD inside the tent in 2015. CTD setup and deployment was performed by José Lagunas, Christiane Dufresne, in 2016.
- Guislain Becu, Griet Neukermans, Eric Rehm, Simon Lambert-Girard and Laurent Oziel, Jade Larivière, Joannie Ferland, Julien Laliberté, performed the

setup, calibration, and deployments of the ICE-Pro optical profiler outside the tent and the IOP frame inside the tent. Eric Rehm performed the 13-h tidal cycle measurements in 2015. Griet Neukermans and Eric Rehm deployed the GoPro Hero on the ICE-Pro.

- Claudie Marec performed the setup and installation of IFCB in the lab in 2015. Joannie Ferland performed the setup and installation of the IFCB in the lab in 2016. Joannie Ferland, Erin Reimer, Atsushi Matsuoka, Marie-Hélène Forget and Pierre-Luc Grondin performed the measurements. Pierre-Luc Grondin analyzed the data.
- Claudie Marec and José Lagunas performed the setup and deployment of an In-water profiler for particle size distribution and zooplankton vertical distribution (UVP Underwater Visio Profiler).
- Claudie Marec and José Lagunas performed setup and water sampling in both 2015 and 2016 campaigns.
- Claudie Marec was involved in the design and deployment of the ADCP in 2015, José Lagunas deployed the instrument in 2016.
- Atsushi Matsuoka coordinated the sampling strategy of discrete waters in terms of examining the linkages between optical and organic matter properties.
- Atsushi Matsuoka and Annick Bricaud wrote the protocols for both CDOM and particulate absorption~~s~~. For aCDOM, Atsushi Matsuoka, Joannie Ferland, Marie-Hélène Forget, Erin Reimer, and Pierre-Luc Grondin contributed to the measurements. For ap, Atsushi Matsuoka, Céline Dimier, Léo Lacour, Joséphine Ras, Mathieu Ardyna, Henry Bittig, Blanche St-Béat and Thomas Lacour contributed to the measurements. In 2015, particulate spectral absorption was also measured ~~done~~ by Lisa Matthes, Christine Quiring and

Jens Ehn. Nicole Pogorzelec (who also did snow and ice salinity and overall chl-a filtrations in the field lab).

- Marie-Pier Amyot worked on tidying and uniformizing the data.
- Martí Galí ran the radiative transfer calculations and compared them to irradiance measurements taken on the ice camps.
- Lisa Matthes, Simon Lambert-Girard, Bob Hodgson, Jens Ehn, Nicole Pogorzelec and CJ Mundy designed and/or carried out the TriOS and ROV under-ice irradiance measurements
- Christos Panagiotopoulos and Richard Sempéré coordinated the sampling strategy for sugars/DOC and the analyses. Remi Amiraux collected the samples.
- Between October 2014 and July 2016, Éric Brossier and France Pinczon du Sel conducted measurements, collected clams, maintained equipment, kept a time-lapse photography record and represented the Greenedge team in Qikiqtarjuaq outside of the sampling season. Debra Christiansen Stowe coordinated logistics in Qikiqtarjuaq, in support of the 2016 ice camp.
- Makoto Sampei designed and curried copepods incubations to collect fecal pellets out at the ice camp in 2016. Makoto Sampei made microscopic observations on the collected fecal pellets in the laboratory.
- Sea ice and snow hemispherical directional reflectance were measured on the ice camp in 2015 by Sabine Marty and Clémence Goyens. The set-up was designed by Sabine Marty, Edouard Leymarie, Simon Bélanger and Clémence Goyens. They also processed and analyzed the data.

- Catherine Schmechtig, the LEFE-CYBER database manager is warmly thank for her efficient~~acknowledged for her~~ help in gathering the data presented.

- Florent Domine designed the snow specific surface area measurements and participated in the 2015 campaign along with Gauthier Verin who performed~~sampled~~ the 2015 and 2016 snow-related measurements.

- Daniel Vaulot, Adriana Lopes dos Santos, Ian Probert and Priscillia Gourvil sampled at the ice camp for flow cytometry, phytoplankton cultures and molecular biology. Catherine Gérikas, Adriana Lopes dos Santos, Priscillia Gourvil and Florence Le Gall established phytoplankton culture isolates. Dominique Marie and Margot Tragin performed flow cytometry measurements ~~and cytogram analyses of~~ for the 2015 and 2016 ice camp samples. David Mah analyzed and plotted the flow cytometry data.

- Fabien Joux and Virginie Galindo measured the bacterial production during the 2016 ice camp.

Acknowledgments

The GreenEdge project is funded by the following French and Canadian programs and agencies: ANR (Contract #111112), CNES (project #131425), IPEV (project #1164), CSA, Fondation Total, ArcticNet, LEFE and the French Arctic Initiative (GreenEdge project). This project would not have been possible without the support of the Hamlet of Qikiqtarjuaq and the members of the community as well as the Inuksuit School and its Principal Jacqueline Arsenault. The project was conducted under the scientific coordination of the Canada Excellence Research Chair in Remote Sensing of Canada's new Arctic frontier and the CNRS & Université Laval Takuvik Joint International laboratory (UMI3376). The field campaign was successful

thanks to the contribution of A. Wells, M. Benoît-Gagné, and E. Devred from the Takuvik laboratory as well as R. Hodgson from the University of Manitoba. Pascale Bouruet-Aubertot and Yannis Cuypers who provided the SCAMP and contributed to the processing, quality control, analysis and interpretation of the data. We also thank Michel Gosselin, Québec-Océan, the CCGS Amundsen and the Polar Continental Shelf Program for their in-kind contribution to the logistic and scientific equipment. Thanks to Etienne Ouellet for IT support and data infrastructure management. Scientific research licenses for both 2015 (NRI licence 01 010 15-N-M) and 2016 (NRI licence 01 001 15-R-M) were kindly accorded by the Nunavut Research Institute.