# Multidisciplinary Arctic Program (MAP) – Last Ice: Expedition Report, Spring 2018 Field Campaign

Joannie Charette, Benjamin A. Lange, Karley Campbell, Cody Carlyle, Pierre Coupel, Steve Duerksen, Steve Ferguson, Geoff Stupple, Hauke Flores, Christian Katlein, Andrew Platt, Kevin Rawlings, Alexandra Steffen , Pascal Tremblay, Brent Young and Christine Michel

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CANADIAN MANUSCRIPT REPORT OF
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2023

# MULTIDISCIPLINARY ARCTIC PROGRAM (MAP) – LAST ICE: EXPEDITION REPORT, SPRING 2018 FIELD CAMPAIGN

by

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Charette, J., Lange, B. A., Campbell, K., Carlyle, C., Coupel, P., Duerksen, S., Ferguson, S., Stupple, G., Flores, H., Katlein, C., Platt, A., Rawlings, K., Steffen, A., Tremblay, P., Young, B., Michel, C. 2023. Multidisciplinary Arctic Program (MAP) – Last Ice: Expedition Report, Spring 2018 Field Campaign. Can. Manuscr. Rep. Fish. Aquat. Sci. 3238: vii + 36 p.

This report presents a review of the scientific activities that occurred during the first Multidisciplinary Arctic Program (MAP) – Last Ice field campaign which took place from April 25$^{th}$ to June 7$^{th}$, 2018, in the Lincoln Sea, North of Ellesmere Island. An ice camp was set up at 9 km away from CFS Alert in a region of mixed first-year and multi-year ice cover. The camp was accessed every day from CFS Alert, between April 26$^{th}$ and May 26$^{th}$. Sampling of the sea ice and water column, as well as processing of these samples were conducted at the camp. Moreover, six continuous recording instruments were deployed to characterize atmospheric and oceanographic conditions as well as sea ice properties. An Unmanned Aerial Vehicle (UAV) was used to describe snow and sea ice surface variability. Aerial surveys were also carried out to characterize marine mammal abundance and habitats. These surveys were conducted by Twin Otter between June 2$^{nd}$ and June 5$^{th}$ 2018. This document details the sampling, observational systems, and biogeochemical measurements during the MAP-Last Ice 2018 spring field campaign, a first-ever ice camp investigation and ecosystem study of the Lincoln Sea. We also present a logistical overview of the field campaign.

## RÉSUMÉ

Charette, J., Lange, B. A., Campbell, K., Carlyle, C., Coupel, P., Duerksen, S., Ferguson, S., Stupple, G., Flores, H., Katlein, C., Platt, A., Rawlings, K., Steffen, A., Tremblay, P., Young, B., Michel, C. 2023. Multidisciplinary Arctic Program (MAP) – Last Ice: Expedition Report, Spring 2018 Field Campaign. Can. Manuscr. Rep. Fish. Aquat. Sci. 3238: vii + 36 p.

Ce rapport présente une revue des activités scientifiques qui se sont déroulées lors de la première campagne de terrain du Programme multidisciplinaire arctique (PMA) – Glace séculaire, qui a eu lieu entre le 25 avril et le 7 juin 2018, dans la mer de Lincoln, au nord de l'île d'Ellesmere. Un camp de glace fut aménagé à 9 km de la SFC Alert, dans une région de couvert de glace mixte, composée de glace de première année et de glace pluriannuelle. L'accès au camp de glace s'est fait depuis SFC Alert, tous les jours entre le 26 avril et le 26 mai. L'échantillonnage de la glace de mer et de la colonne d'eau, ainsi que le traitement de ces échantillons se déroulaient au camp. De plus, six instruments à enregistrement en continu ont été déployés pour caractériser les conditions atmosphériques et océanographiques en plus des propriétés de la glace de mer. Un véhicule aérien sans pilote fut utilisé pour décrire la variabilité de la neige et de la glace de mer. Des survols aériens furent également réalisés afin de caractériser les populations de mammifères marins et leurs habitats. Ces survols furent réalisés du 2 au 5 juin 2018 à l'aide d'un Twin Otter. Ce document présente l'échantillonnage, les mouillages et les mesures biogéochimiques effectués lors de la campagne de terrain 2018 du PMA – Glace séculaire, la première étude écosystémique à partir d'un camp de glace dans la mer de Lincoln. Un aperçu logistique de la campagne de terrain est également présenté.

# 1.0 INTRODUCTION

As Arctic temperatures continue to increase, the rapid declines in sea ice call for urgent efforts to better characterize the role of sea ice in the Arctic marine ecosystem (e.g., AMAP 2017; IPCC 2019). With model projections forecasting a summer ice-free Arctic over the next decades, the region north of Ellesmere Island along with northern Greenland, are the only Arctic regions where summer sea ice is projected to be retained by mid-century (Pfirman 2009; DFO 2011; WWF 2013). This area, the so-called Last Ice Area (LIA), may then provide the last summer sea ice habitat, critical for ice-dependent and ice-associated flora and fauna (Pfirman 2009; Speer and Laughlin 2011; AMAP 2017). This region is also of critical importance to communities that rely on ice-dependent species for food and cultural use as a region of enduring sea ice in the context of the continuing decline of the Arctic sea ice cover.

The LIA, at the northernmost boundary of the Canadian Arctic Archipelago, is one of the most remote regions in the world, largely due to difficulty of access, leading to an exceptionally sparse ecological knowledge base. The Government of Canada has committed to work in collaboration with northern partners and national and international stakeholders to better understand the ecology of this region and of its unique multi-year ice (MYI) ecosystem, supporting Arctic conservation and sustainable development. Further to this commitment, the Tuvaijuittuq Marine Protected Area was established by Ministerial Order in August 2019, while a feasibility assessment evaluates long-term protection tools (DFO 2020). The Fisheries and Oceans Canada (DFO) Multidisciplinary Arctic Program (MAP) - Last Ice is the first ecological assessment of a region of Tuvaijuittuq where multi-year sea ice still resides, providing insights into the role of this unique ecosystem in the Arctic Ocean. This knowledge is essential to understand the structure, function and role of the sea ice associated ecosystem in the Arctic Ocean and to inform long-term protection for Tuvaijuittuq.

## 1.1 PROGRAM OBJECTIVES

The Arctic cryosphere is experiencing fundamental changes, with already observed and anticipated far-reaching impacts from sea ice loss and the transition from multi-year to first-year ice (FYI) (e.g., Underwood et al. 2019; Ardyna and Arrigo 2020). Tuvaijuittuq constitutes a refuge for the enduring Arctic multi-year ice, offering a window into a unique ecosystem threatened by climate change. The overarching objective of MAP-Last Ice is to assess the role of multi-year ice in the ecosystem of Tuvaijuittuq and in the Arctic marine ecosystem. In partnership with Canadian and International partners, the program provides an integrated study of the atmosphere-sea ice-ocean connected system, characterizing key physical, chemical and biological processes including sea ice biodiversity, habitat and habitat usage in Tuvaijuittuq. The proximity of multi-year and first-

year ice in the study area further provides an opportunity to compare ice types. Specific objectives are detailed in the Science Plan (Michel and Lange 2018) and include characterizing ocean and sea ice physical, chemical and biological properties, biological assemblages within and under sea ice, carbon constituents and their cycling, and marine mammal distribution and habitat usage. Novel scientific findings on multi-year ice characteristics and communities (Campbell et al. 2022; Lange et al. 2019), food web interactions (Kohlbach et al. 2020), and marine mammal studies from the MAP-Last Ice field campaigns (Yukowski et al. 2019) already offer insights into this poorly known ecosystem.

In this report, we present a summary of the sampling program undertaken during the 2018 spring field campaign, as four interconnected program components were successfully accomplished, namely:

- Spatially-distributed sea ice habitat and productivity analysis;
- Seasonal characterization of the ice and under-ice ecosystems;
- Continuous atmospheric, oceanographic and sea ice observations;
- Marine mammals survey.

## 2.0 PROGRAM PARTICIPANTS

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## 3.0 DESCRIPTION OF THE ICE CAMP

An ice camp was set up in the coastal region of the Lincoln Sea, North of Ellesmere Island (Fig. 1), 9 km from Canadian Forces Station (CFS) Alert and was accessed by snowmobile every day. The camp was set up on a FYI floe, directly adjacent to a MYI floe to allow for a comparison between both ice types. The site was carefully selected based on the following considerations: i) the presence of floes of adequate size, ii) the proximity of multi-year and first-year ice, iii) the stability of the ice and yet in a region where mobile ice abounds, and iv) accessibility from the

CFS Alert base. Two WeatherHaven tents were installed to accommodate scientific activities at camp (Fig. 2). One tent was used for CTD (Conductivity, Temperature, Depth) profiling and water sampling, and as a laboratory for the processing of biogeochemical samples, and the second tent was used as the Remotely Operated Vehicle (ROV) command center. Three smaller tents were installed and used for storage. Sampling and observational sites on FYI and MYI were at walking distance from the WeatherHaven tents.

Field work included a water column as well as a first-year and multi-year ice component, and was conducted between April 28th and May 26th, 2018. The spring aerial survey to document marine mammals was conducted between June 2nd and 5th, 2018. All activities were conducted following the Safety Plan described in Michel and Lange (2018).

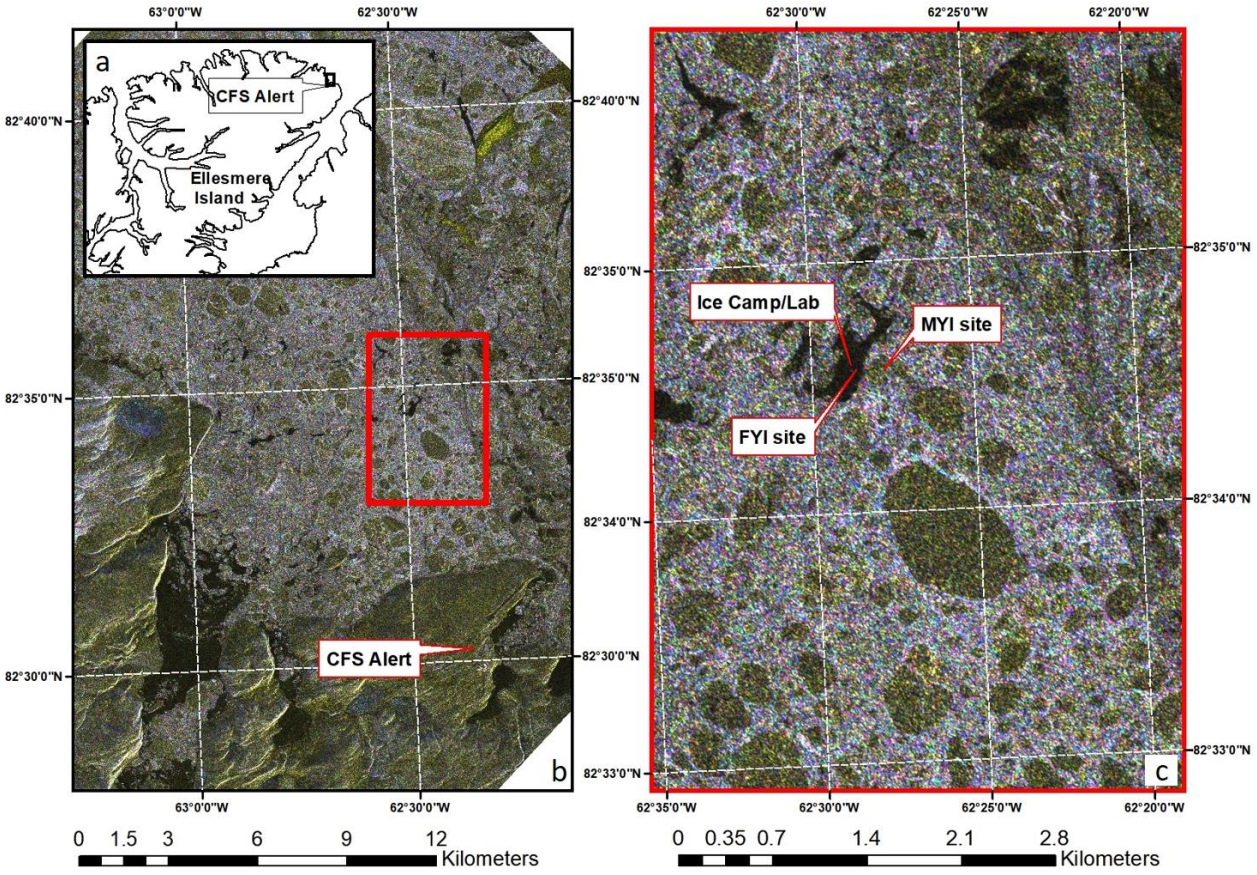


**Figure 1.** RADARSAT-2 (RS-2) imagery of the Multidisciplinary Arctic Program (MAP) – Last Ice 2018 spring field campaign study area. a) general location of the study area, b) SAR Fine Quad-Pol overview image of the landfast sea ice north of Ellesmere Island, c) zoomed image of the section outlined in red in panel b). MacDonald, Dettwiler and Associates Ltd. 2018, All Rights Reserved.


**Figure 2.** Aerial photo of the ice camp during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. The photo was taken with the Unmanned Aerial Vehicle (UAV).

## 4.0 SAMPLING

### 4.1 SEA ICE SAMPLING

A total of 15 FYI and 14 MYI sites were sampled between May 3rd and 23rd, 2018. At each site, sea ice was collected using an ice corer (Mark II coring system, 9 cm internal diameter, Kovacs Enterprises). For FYI, cores were collected using either a Bosch drill or Honda coring motor installed on the ice corer, whereas MYI cores were collected using a Honda coring motor (Fig. 3e). At each sampling site, snow and ice thickness as well as freeboard height were measured for each coring hole.


**Figure 3.** Sampling during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. a) ADCP mooring, b) Preparation for primary production incubations, c) Under-ice arm deployment for under-ice light measurement, d) CTD cast, e) MYI coring, f) Measurement of an ice core for core sectioning. Credits: a) C. Katlein, AWI; b to d) DFO, S. Duerksen; e to f) DFO, P. Coupel.

A total of 258 ice cores were collected during the sampling season (Table 1). Among these cores, 127 were FYI with an ice thickness ranging between 1.37 and 1.76 m and 131 were MYI, with an ice thickness ranging between 2.08 and 4.58 m. The cores collected were measured and sectioned on site, immediately after collection (Fig. 3f). Several core sections were pooled together in order to obtain sufficient material to perform a series of biogeochemical analyses. The sea ice sampling strategy was structured to follow temporal changes in FYI and MYI (T sites) as well as characterize the spatial heterogeneity of sea ice (S sites) and the diversity of ice habitats (V sites). In total, 14 or 15 cores were collected at each of the FYI and MYI temporal (T) sites. Three 10 cm core sections (top, middle and bottom horizons; Fig. 4) were collected on seven of the extracted cores. Once melted, the sections from six cores were pooled by horizon whereas the core sections from the 7$^{th}$ core were kept separate for chemical analyses. For the remaining seven to eight cores, only the bottom 10 cm were collected. These bottom core sections were combined and used for photosynthesis-irradiance (P-E) curves, as detailed in Campbell et al. (2022). At spatially-

distributed sites (S), four cores were extracted, and the bottom 10 cm were collected (Fig. 4). After melting, these four bottom core sections were pooled together for analyses. Vertical characterization of cores (V sites) was carried out twice during the field season, with three different habitats sampled each time. A single core was extracted and 10 cm sections were collected every 40 cm for the vertical characterization (Fig. 4). Consequently, during the sampling season a total of 636 different core sections were analyzed, 307 from FYI and 329 from MYI. Additionally, three MYI cores were collected and kept frozen for future analyses.

At most coring sites, one core was extracted to measure temperature and for sea ice texture analysis. A Testo 720 RTD Thermometer was used to measure temperature in a 2 mm diameter hole drilled to the center of the core with a Bosh drill. Temperature measurements were acquired every 10 cm along the total core length. This core was bagged and brought back to a shore laboratory at CFS Alert, where ice texture was analyzed.

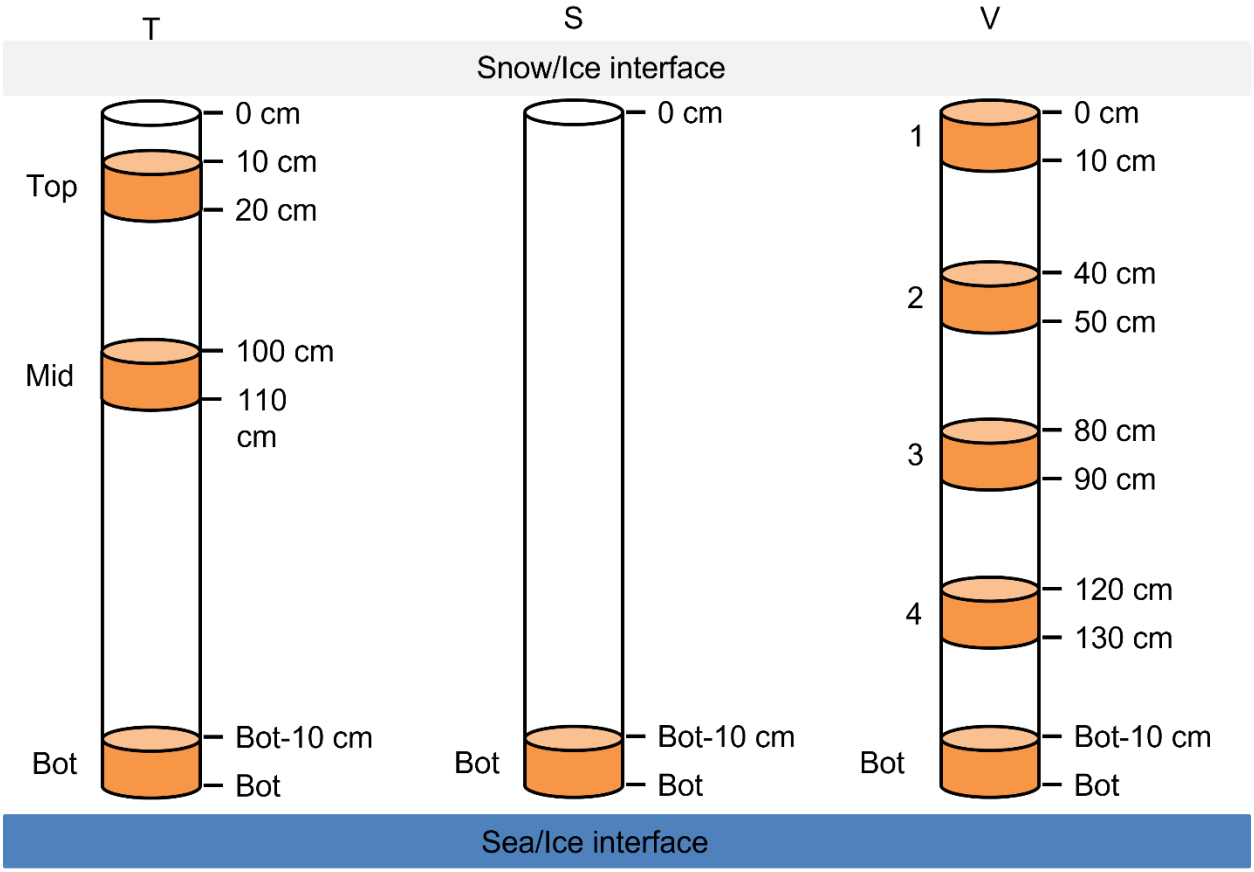


**Figure 4.** Schematic representation of sampled sea ice sections at temporal (T), spatial (S) and vertical (V) sites during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. Orange shading represents the sampled sections.

**Table 1.** Summary of first-year (FYI) and multi-year (MYI) ice sampling during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. N/A: not applicable. Geocores were brought back frozen to Winnipeg. Top: 10-20 cm from the snow-ice interface, Mid: 100-110 cm from the snow-ice interface, Bot: last 10 cm of the core.

| Site ID | Ice type | Sampling Date | Number of cores per site | Number of horizons per site | Number of core sections per site | Core horizons sampled |
|---|---|---|---|---|---|---|
| T1 | FYI | 3-May | 7 | 3 | 21 | Top, Mid, Bot |
| T1 | FYI | 4-May | 7 | 1 | 7 | Bot |
| T2 | FYI | 7-May | 15 | 3 | 45 | Top, Mid, Bot |
| T2 | MYI | 7-May | 15 | 3 | 45 | Top, Mid, Bot |
| Geocore 1 | MYI | 8-May | 1 | N/A | N/A | Full core |
| Geocore 2 | MYI | 8-May | 1 | N/A | N/A | Full core |
| T3 | FYI | 11-May | 15 | 3 | 45 | Top, Mid, Bot |
| T3 | MYI | 11-May | 15 | 3 | 45 | Top, Mid, Bot |
| T3 | FYI | 12-May | 4 | 3 | 12 | Top, Mid, Bot |
| T3 | MYI | 12-May | 3 | 3 | 9 | Top, Mid, Bot |
| Geocore 3 | MYI | 12-May | 1 | N/A | N/A | Full core |
| S1 | MYI | 14-May | 5 | 1 | 5 | Bot |
| V1 | MYI | 14-May | 1 | 6 | 6 | Every 40 cm |
| S2 | MYI | 14-May | 5 | 1 | 5 | Bot |
| V2 | MYI | 14-May | 1 | 8 | 8 | Every 40 cm |
| T4 | FYI | 15-May | 16 | 3 | 48 | Top, Mid, Bot |
| T4 | MYI | 15-May | 15 | 3 | 45 | Top, Mid, Bot |
| S3 | MYI | 15-May | 4 | 1 | 4 | Bot |
| V3 | MYI | 15-May | 1 | 11 | 11 | Every 40 cm |
| FA | FYI | 17-May | 3 | 1 | 3 | Bot |
| FA | MYI | 17-May | 3 | 1 | 3 | Bot |
| S4 | MYI | 18-May | 5 | 1 | 5 | Bot |
| V4 | MYI | 18-May | 1 | 7 | 7 | Every 40 cm |
| S5 | MYI | 18-May | 5 | 1 | 5 | Bot |
| V5 | MYI | 18-May | 1 | 7 | 7 | Every 40 cm |
| T5 | FYI | 19-May | 16 | 3 | 48 | Top, Mid, Bot |
| T5 | MYI | 19-May | 15 | 3 | 45 | Top, Mid, Bot |
| T5 | FYI | 20-May | 3 | 3 | 9 | Top, Mid, Bot |
| T5 | MYI | 20-May | 3 | 3 | 9 | Top, Mid, Bot |
| S6 | MYI | 19-May | 4 | 1 | 4 | Bot |
| V6 | MYI | 19-May | 1 | 10 | 10 | Every 40 cm |
| M0 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M1 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M2 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M3 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M4 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M5 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M6 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M7 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M8 | FYI | 22-May | 3 | 1 | 3 | Bot |
| M15 | MYI | 22-May | 3 | 1 | 3 | Bot |
| M16 | MYI | 22-May | 3 | 1 | 3 | Bot |
| M19 | MYI | 22-May | 3 | 1 | 3 | Bot |
| M23 | MYI | 22-May | 3 | 1 | 3 | Bot |
| T6 | FYI | 23-May | 14 | 3 | 42 | Top, Mid, Bot |
| T6 | MYI | 23-May | 13 | 3 | 39 | Top, Mid, Bot |
| **Total** | | | **258** | **116** | **636** | |
| **Total FYI** | | | **127** | **35** | **307** | |
| **Total MYI** | | | **131** | **81** | **329** | |

## 4.2 WATER COLUMN SAMPLING

The water depth at the ice camp was measured with a *Furuno* LCD Sounder FCV-620 sounder on May 1st. Water depth at the station was 217 m. Water sampling and CTD profiles were conducted in a 1 m × 1 m ice hole located in the Laboratory tent (Fig. 3d). A CTD cast was performed down to 200 m, at an approximate speed of 0.5 m $s^{-1}$, every day between May 4th and 24th at ca. 9:30 AM local time. Water column temperature, salinity, pressure and fluorescence were recorded with a *Sea-Bird* SBE 19plus CTD. The downcast measurements were used for profiles.

Water samples were collected at 4-d intervals between May 2nd and 22nd, for a total of 6 sampling events (Table 2). Seven depths were sampled (2, 10, 25, 50, 100, 150 and 200 m) for biochemical analyses using 5 L *Niskin* bottles and a *KC Denmark* portable winch, model 30.100 equipped with a *EWC-6* Electronic Wire Counter Module.

**Table 2.** Summary of water column sampling during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. N/A: not applicable.

| Type of sampling | Sample ID | Sampling Date | Number of *Niskins* collected | *Niskin* depths (m) | Number of zooplankton net tows | Depth of zooplankton net tows (m) |
|---|---|---|---|---|---|---|
| Biogeo-chemical variables | T1 | 02-May | 9 | 2, 10, 25, 50, 100, 150, 200 | 1 | 0-200 |
| | T2 | 06-May | 9 | 2, 10, 25, 50, 100, 150, 200 | 2 | 0-100; 0-200 |
| | T3 | 10-May | 9 | 2, 10, 25, 50, 100, 150, 200 | 2 | 0-200 |
| | T4 | 14-May | 9 | 2, 10, 25, 50, 100, 150, 200 | 2 | 0-200 |
| | T5 | 18-May | 10 | 2, 10, 25, 50, 100, 150, 200 | 2 | 0-200 |
| | T6 | 22-May | 10 | 2, 10, 25, 50, 100, 150, 200 | 2 | 0-200 |
| Mercury | | 02-May | 5 | 2, 10, 50, 100, 200 | 1 | 0-100 |
| | | 08-May | 5 | 2, 10, 50, 100, 200 | 1 | 0-200 |
| | | 17-May | 5 | 2, 10, 50, 100, 200 | N/A | N/A |
| | | 22-May | 5 | 2, 10, 50, 100, 200 | 1 | 0-200 |
| **Total:** | | | **76** | | **14** | |

Water column samples were also collected for measurement of total, methyl and particulate mercury concentrations. For these analyses, five depths were sampled (2, 10 50, 100 and 200 m) with a 2.5 L *Niskin* bottle on four occasions (May 2nd, 8th, 17th and 22nd; see Table 2). On three of the four mercury sampling days, one zooplankton net tow was performed as described below and the bulk samples were kept at either at 4 ºC or -20 ºC for subsequent mercury analyses (Table 2).

Zooplankton collection took place immediately following water column sampling. One or two vertical zooplankton tows were performed from surface to 100 or 200 m at a speed of ca. 0.5 m $s^{-1}$ using a 153 µm mesh zooplankton net (50 cm diameter). The first tow was used for zooplankton abundance and species composition (taxonomy) and the second tow was used for zooplankton fatty acid biomarkers characterization. Samples for zooplankton abundance and taxonomy were preserved in buffered formalin (4% final concentration). For fatty acid biomarkers, individuals from target groups were immediately sorted and frozen at -80 ºC.

An ROV from the Alfred Wegener Institute (AWI) was used to collect zooplankton and under-ice fauna at discrete depth layers. A newly designed under-ice net mounted on the AWI-ROV was used for collection of these samples. This "ROVnet" consisted of a polycarbonate frame (60 × 40 cm) mounted on top of the ROV, with a zooplankton net (5 m length, 150 µm mesh) attached to it. At the end of the net, the catch was collected in a cod-end bottle (10 cm diameter). On the top bar of the frame, a street broom was mounted upside-down in order to efficiently sweep the ice underside (Fig. 5). During ROVnet tows, current speed and physical data, i.e., water temperature, salinity, fluorescence, ice draft and multi-spectral light transmission, were recorded. During each sampling event, we aimed to sample 3 depth layers: the under-ice surface, 5 m and 10 m, which were trawled horizontally at a speed of 0.3 to 0.4 m $s^{-1}$.

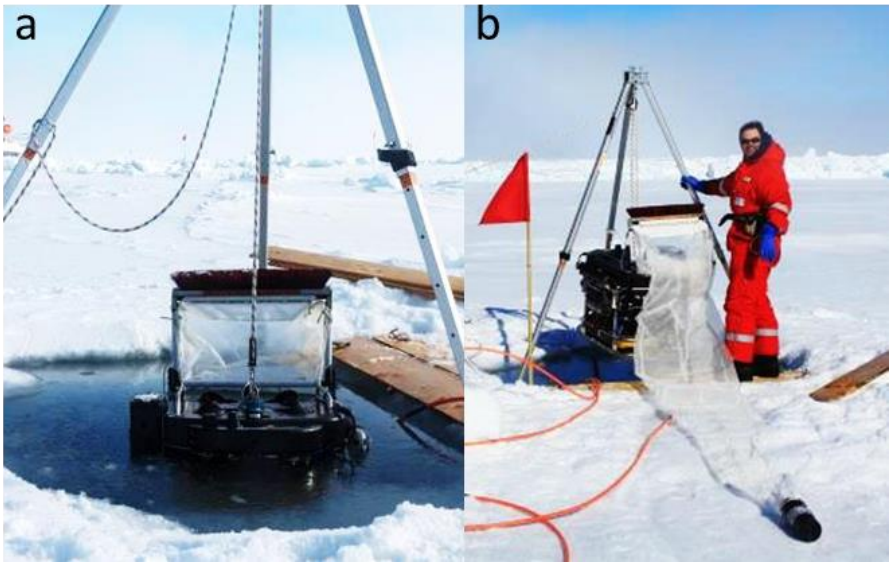


**Figure 5.** The ROVnet in front view during deployment (A), and in rear view (B). Photos: Marcel Nicolaus (during Polarstern expedition PS106, 2017)

Altogether, 30 ROVnet stations were completed during the MAP-Last Ice spring field campaign (Table 3). On May 14th, 15th, 18th and 19th, 2018, we conducted two diurnal vertical distribution studies to evaluate whether the presence of zooplankton and under-ice fauna in the surface layer responded to the diurnal cycle of light. To achieve this, three consecutive sampling events were accomplished at noontime, midnight, and the following noontime, respectively. In addition, 0-50 m double-oblique tows were conducted to evaluate the comparability of ROVnet catches with vertical net tows of the top 50 m. An overview of the sampling stations is given in Table 3. Samples of macrofauna were either preserved in 4 % formaldehyde/seawater solution, in 100% ethanol, or were frozen (-20°C / -80°C). The samples will be used for a variety of analyses, including fatty acid composition, stable isotope analysis and genetics.

In total, 76 *Niskin* bottles were sampled and 44 zooplankton net tows were performed during the spring field season.

**Table 3.** Summary of Remotely Operated Vehicle net tow sampling during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018.

| Station ID | Date | Number of habitats sampled | Habitat/Variable sampled |
|---|---|---|---|
| 1 | 08-May | 1 | FYI |
| 2 | 11-May | 4 | FYI, MYI, Deformed Ice, Comparative tows |
| 3 | 14-May | 5 | MYI, Deformed Ice, Comparative tows, Diel Vertical Migrations, Biomarkers |
| 4 | 15-May | 5 | MYI, Deformed Ice, Comparative tows, Diel Vertical Migrations (x2) |
| 6 | 18-May | 5 | MYI, Deformed Ice, Transition zone (FYI Edge), Comparative tows, Diel Vertical migration |
| 7 | 19-May | 6 | MYI, Deformed Ice, 50 meter horizontal tow, Comparative tows, Diel Vertical Migrations (x2) |
| 8 | 23-May | 4 | FYI, MYI, Deformed Ice, Biomarkers |

## 4.3 CONTINUOUS ATMOSPHERIC, OCEANOGRAPHIC AND SEA ICE OBSERVATIONS

Six continuously recording systems/instruments were deployed during MAP-Last Ice 2018 spring field season, as listed in Table 4. A solar powered weather station equipped with a *Campbell Scientific* HMP45CF temperature and relative humidity probe, a *Young* wind monitor model 05103, a *Vaisala* CS106 barometric pressure sensor, a *LI-COR* LI-190 cosine irradiance air sensor and a *LI-COR* LI-192 cosine underwater irradiance sensor was installed on May 2nd and recorded data until May 25th. A *Campbell Scientific* CR10X measurement and control module was used for data logging. Records of under-ice and downwelling irradiance, temperature, relative humidity, wind speed and direction and barometric pressure were collected every 60 seconds for the duration of the field season. Both under-ice and downwelling irradiance sensors malfunctioned at the

beginning of the field season so no data are available for these variables prior to May 9th. An additional *LI-COR* LI-190 cosine irradiance air sensor was installed at the top of the Laboratory tent on May 9th, providing continuous measurements of downwelling irradiance at 15 min intervals until May 25th.

**Table 4.** Summary of continuously recording systems/instruments during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. PAR: Photosynthetic Active Radiation; CDOM: Colored Dissolved Organic Matter.

| System / Instrument | Deployment date | Recovery date | Sampling incidence | Deployment depth | Measurement | Model |
|---|---|---|---|---|---|---|
| Acoustic Doppler Current Profiler (ADCP) | 01-May | 24-May | 3 minutes | 3m | Under-ice current velocity and direction | *Teledyne* Sentinel V100 |
| Acoustic Zooplankton and Fish Profiler (AZFP) | 01-May | 24-May | | 3m | Zooplankton and fish presence and abundance in water column | *ASL Environmental Science* |
| Conductivity, Temperature, Depth profiler (CTD) (2x) | 05-May | 22-May | 1 minute | 2m, 60m | Conductivity, Temperature , depth | *Sea-Bird* SBE 16plus |
| | | | | | PAR | *Wet-labs* ECO-PAR sensor |
| | | | | | Fluorescence, CDOM | *Wet Labs* Eco-Triplets FL3w |
| Meteorological Station | 02-May | 25-May | 1 minute | 2.5m | Downwelling PAR | *LI-COR*, LI-190 |
| | | | | 3.5m | Under-ice PAR | *LI-COR*, LI-192 |
| | | | | 2.5m | Air temperature | *Campbell Scientific*, HMP45CF |
| | | | | 2.5m | Relative humidity | *Campbell Scientific* HMP45CF |
| | | | | 3m | Wind speed and direction | *Young* 05103 |
| | | | | 1m | Barometric pressure | *Vaisala* CS106 |
| *LI-COR* Downwelling Recorder | 09-May | 25-May | 15 minutes | 3m | Downwelling PAR | *LI-COR*, LI-190 |
| Time Lapse Camera | 28-Apr | 26-May | 5 minutes | 1.5m | Pictures of the site every 5 minutes | *Canon* Rebel EOS T6i |

Two *Sea-Bird* SBE 16plus CTDs, equipped with Wet-labs ECO-PARs PAR sensor and Wet Labs Eco-Triplets FL3w sensor were moored on the same line, tethered to first-year ice, one deployed at 2 m and the other at 60 m. The CTD deployed at 60 m malfunctioned and the temperature data is therefore considered unreliable. Some of the conductivity data may be useable, but there appears to be a gap in the data collected by the CTD moored at 60 m and more analysis is required to determine the validity of these data.

An Acoustic Doppler Current Profiler (ADCP, *Teledyne* Sentinel V100) was deployed downward facing, under MYI, at a depth of 3 m on April 30$^{th}$ and collected data until May 24$^{th}$ (Fig. 3a). The ADCP used 1 m cells with a total depth of 90 m and a frequency of 300 kHz. Every 3 minutes, 30 pings were emitted for 15 seconds.

An Acoustic Zooplankton Fish Profiler (AZFP, *ASL Environmental Science*) with a multi-frequency transducer (125, 200 and 455 kHz) and a 38 kHz transducer was deployed downward facing, under MYI, at a depth of 3 m, from May 1$^{st}$ to May 24$^{th}$.

A time-lapse camera, *Canon* Rebel EOS T6i, set at a shooting interval of 5 minutes, was installed on April 28$^{th}$ and recovered on May 26$^{th}$. The camera was installed with *Harbortronics* Solar Charger and a solar panel for batteries autonomy. The time-lapse camera took more than 8000 pictures of the study site during 29 days.

### 4.4 UAV SURVEYS

Unmanned Aerial Vehicle (UAV) surveys were performed using an *InDRO Robotics* M210C RTK quadcopter UAV. Operations were conducted under the Exemption from sections 602.41 and 603.66 of the *Canadian Aviation Regulations* (Transport Canada). The UAV was flown in systematic overlapping grids (ca. 400 × 400 m), with visible (*DJI* Zenmuse X5S 15 mm model: FC6520), multi-spectral (*MicaSense* RedEdge) and thermal infrared (*DJI* Zenmuse XT Flir Model: ZXT01) cameras. All surveys were planned and implemented using the flight planning software *DJI* GS Pro v. 2.0. Surveys were conducted on May 10$^{th}$, 13$^{th}$ and 24$^{th}$, 2018. The visible camera was used on every flight day, whereas the multi-spectral camera was used during the two first surveys and the infrared camera was used only on May 13$^{th}$. All images were processed using the Pix4DMapper software. The visible imagery data are used to create orthorectified georeferenced images and 3-dimensional digital surface maps (DSM) of the snow and sea ice surface. Figure 6 shows preliminary results from one of the surveys conducted on May 10$^{th}$, 2018.

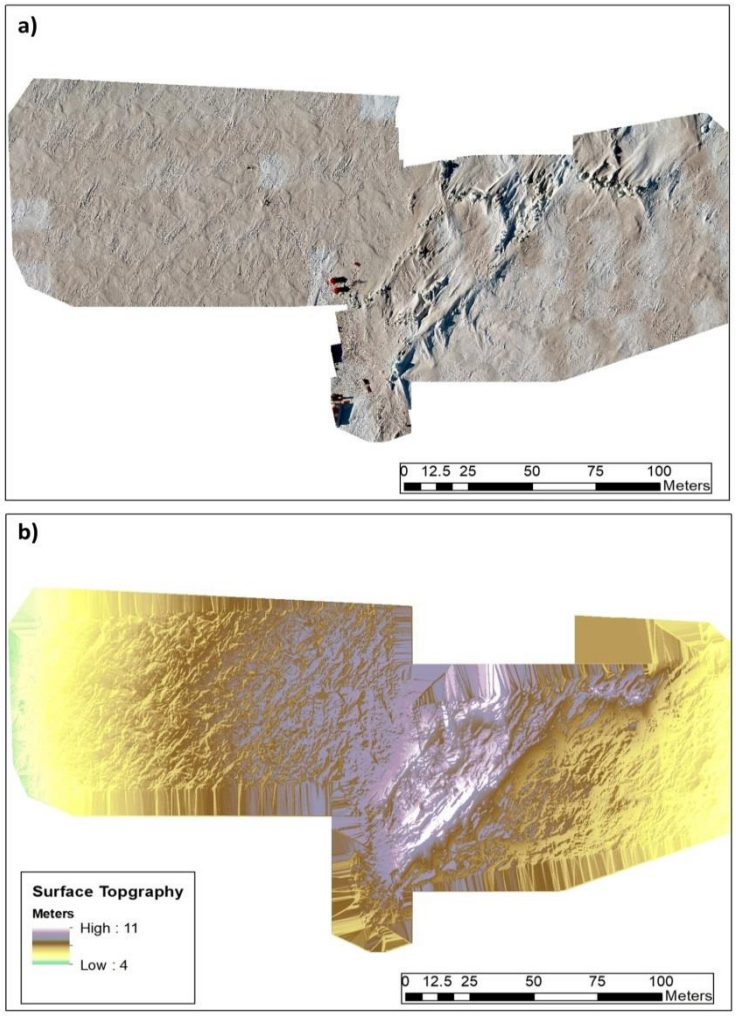


**Figure 6.** Unmanned Aerial Vehicle (UAV) survey with the visible camera on May 10th 2018 showing: a) orthorectified mosaic; and b) digital surface model (DSM) derived from the visible images.

## 4.5 MARINE MAMMAL SURVEY

A marine mammal aerial survey was carried out with a Twin Otter aircraft mobilized from Polar Continental Shelf Program in Resolute Bay. A total of 51 survey lines were completed between June 2nd and June 5th, 2018, in Nares Strait and the Lincoln Sea, east and north of Ellesmere Island, respectively (Fig. 7). The survey was conducted with a Twin Otter aircraft travelling at a target speed of 110 knots and a target altitude of 1000 feet (ca. 300 m). The Twin Otter was equipped with a Nikon D810 DSLR camera with a 35 mm lens and a FLIR T1030sc infrared camera with a 45° lens via a custom hole and mounting bracket on the belly of the plane. This allowed continuous collection of digital and infrared images of the area beneath the plane with a strip width of 312 m for the digital images and a strip width of 250 m for infrared imagery (Table 5). With our lines spaced 5 km apart, we obtained 5% coverage of the area surveyed. A GPS unit mounted in the plane and Bluetooth linked to the cameras also allowed for geo-referencing of all images collected

along the transect line. Through these lines, more than 35 000 pictures were taken and 29.25 hours of flight have been performed to complete the sampling plan.

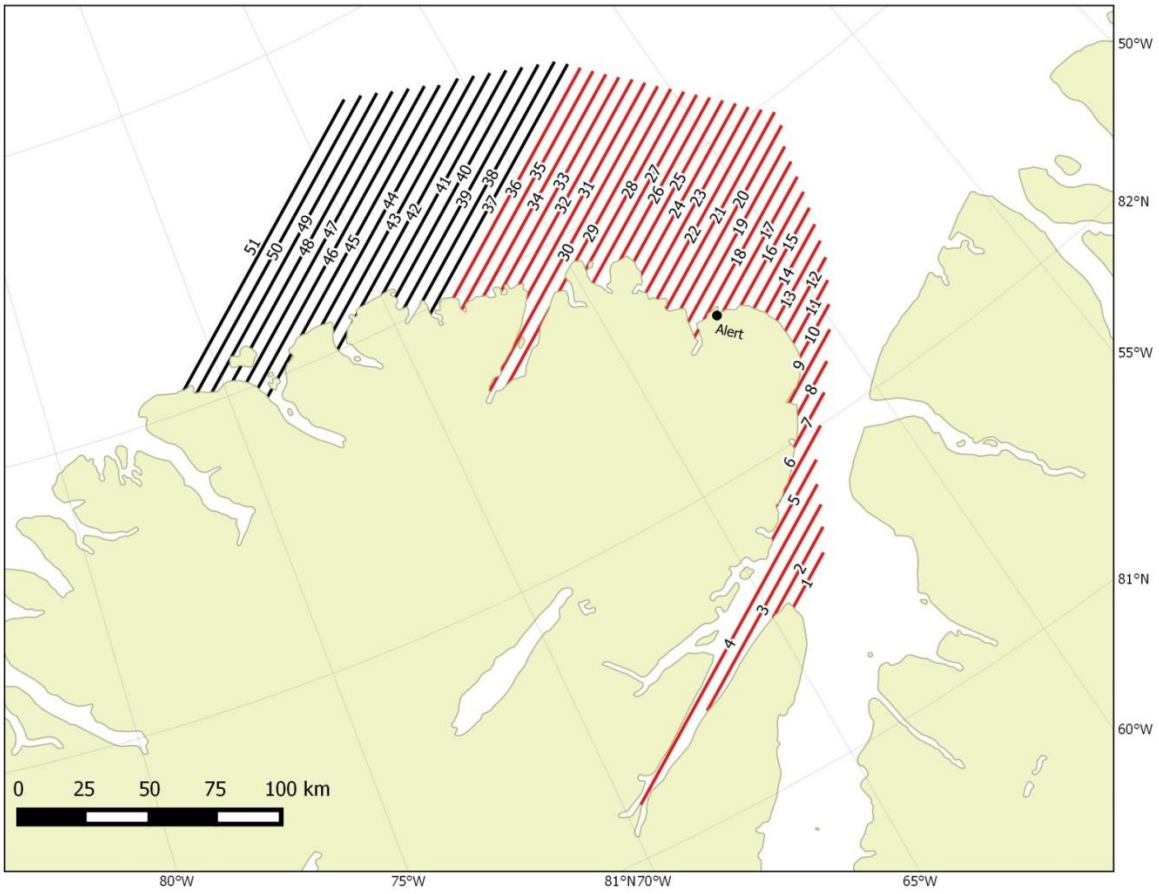


**Figure 7.** Location of the marine mammal aerial survey lines in Nares Strait and the Lincoln Sea, during the Multidisciplinary Arctic Program (MAP) – Last Ice, spring 2018.

**Table 5.** Summary of flights completed during the aerial survey component of the Multidisciplinary Arctic Program (MAP) – Last Ice aerial survey, spring 2018.

| Date | Start | End | Length | Transects |
|---|---|---|---|---|
| 02-June-18 | 09:00 | 12:30 | 3.5 | AL01 – AL08 |
| 02-June-18 | 12:45 | 16:00 | 3.25 | AL09 – AL19 |
| 03-June-18 | 08:45 | 12:30 | 3.75 | AL20 – AL27 |
| 03-June-18 | 12:45 | 16:00 | 3.25 | AL28 – AL32 |
| 04-June-18 | 08:15 | 13:00 | 4.75 | AL33 – AL39 |
| 04-June-18 | 13:15 | 15:45 | 2.5 | AL40 – AL42 |
| 05-June-18 | 08:15 | 13:15 | 5.0 | AL43 – AL48 |
| 05-June-18 | 13:30 | 16:45 | 3.25 | AL49 – AL51 |

Images collected were analyzed for seals hauled out on the ice. Additionally, images will be used to evaluate polar bear abundance and activity including tracks, predation attempts and seal kill sites. Notably, the GPS data allows a geographic location to be applied to all occurrences. This will be accomplished by analyzing the infrared imagery for hotspots corresponding to potential animals and validated on the digital image that covers the same area (Fig. 8). Analysis is in progress and thus far, several seals and at least one polar bear has been confirmed in the imagery (Fig. 9).

**Figure 8.** Example of seal detection using survey footage during the Multidisciplinary Arctic Program (MAP) – Last Ice aerial survey, spring 2018. First, a hotspot is detected on an infrared image and then the corresponding digital image is inspected to validate the presence of a seal.

**Figure 9.** A polar bear, along with tracks and a seal kill site, detected during the Multidisciplinary Arctic Program (MAP) – Last Ice aerial surveys, spring 2018.

# 5.0 PROCESSING

## 5.1 SEA ICE SAMPLES

Tables 6 & 7 summarize the list of variables measured for sea ice and water samples, respectively. Samples for biochemical analyses were immediately processed upon collection in the Laboratory tent at the ice camp.

Sea ice samples were individually melted in a sterile Whirl-pak bag, in the dark, at room temperature and without addition of filtered sea water (FSW), with the exception of the FSW addition experiments conducted twice during the field season. The melted ice samples were processed 36 to 48 hours after collection, as soon as they were completely melted. The sample volume was measured for each core prior to prefiltration through 350 µm nitex. Samples were pooled together in an isothermal container for subsequent analyses (listed in Table 6) except for one core sample kept separately in its sterile Whirl-pak bag subsampled for nutrients, dissolved organic carbon (DOC), flow cytometry, salinity and carbohydrate analyses. Samples for bacterial enumeration were also collected for inter-calibration with flow cytometry counts.

A shore laboratory within the ECCC facilities at CFS Alert was used for the fluorometric measurements of chlorophyll *a* (chl *a*) as well as for rinsing and drying ice coring equipment. The remaining biogeochemical and mercury samples were stored for later analysis at the Freshwater Institute in Winnipeg or other laboratories (see section 5.3 for sampling method specific to each analysis).

**Table 6.** Analyses performed for sea ice samples collected during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. X represents a replicate. DIC: Dissolved inorganic carbon, TA: Total alkalinity, DOC: Dissolved organic carbon, DN: Dissolved nitrogen, Sal: Salinity, $\delta^{18}O$: Ratio of Oxygen-18 isotope and Oxygen-16 isotope, FC: Flow cytometry, chl *a*: chlorophyll *a*, POC: Particulate organic carbon, PN: Particulate nitrogen, PP: Primary production, P-E curves: Photosynthesis-irradiance curves. Nutrients are nitrate plus nitrite ($NO_3 + NO_2$), phosphate ($PO_4$) and silicate ($Si(OH)_4$).

| Analyses | Stations T1 to T6 | | | Stations | Stations | Stations |
|---|---|---|---|---|---|---|
| | Top | Mid | Bot | S1 to S6 | V1 to V6 | M0 to M23 |
| **Biochemistry** | | | | | | |
| Nutrients | XX | XX | XX | | XX | XX |
| DOC/DN | XX | XX | XX | | XX | XX |
| Sal/$^{18}O$ | X | X | X | | X | X |
| Carbohydrates | X | X | X | X | | |
| **Community structure** | | | | | | |
| FC - Bacteria | XX | XX | XX | XX | XX | XX |
| FC - Protists | XX | XX | XX | XX | XX | XX |
| FC - Viruses | XX | XX | XX | XX | XX | XX |
| **Biomass** | | | | | | |
| Chl *a* total | XX | XX | XX | XX | XX | XX |
| POC/PN | | | | | | X |
| **Diversity** | | | | | | |
| DNA | X | X | X | X | X | X |
| Taxonomy | X | X | X | X | X | X |
| **Food web biomarkers** | | | | | | |
| Fatty acids | | | | | | X |
| Stable isotopes | | | | | | X |
| **Incubations*** | | | | | | |
| PP $^{13}C/^{15}N$ | | XX | XX | | | |
| PP oxygen | XX | XX | XX | | | |
| P-E curves | | | X | | | |

*See Table 8 for detailed Incubation sampling

## 5.2 WATER SAMPLES

Dissolved inorganic carbon (DIC) samples were collected first, directly from the *Niskin* bottle following the protocol from Dickson et al. (2007). Nutrients, DOC and flow cytometry samples were then collected from the *Niskin* with a 60 ml acid-washed syringe, after rinsing three times with sample water. The rest of the water from the *Niskin* bottle was pre-filtered through a 350 µm nitex mesh, transferred to a clean carboy and kept cool in the dark. All sample processing, described in Table 7, was done within four hours of collection.

Samples for mercury analysis were processed in one of the two small storage tents and at the ECCC facilities at CFS Alert. Filtration for particulate mercury was achieved at the shore laboratory, at the end of the day. Zooplankton, total mercury, methyl mercury and particulate filter samples were sent to Dr. Lars-Eric Heimbürger at the Mediterranean Institute of Oceanography for analysis. A duplicate of total mercury samples will be analyzed at Canada Centre for Inland Waters in Burlington, ON.

**Table 7.** Analyses performed for water samples during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. X represents a replicate. DIC: Dissolved inorganic carbon, TA: Total alkalinity, DOC: Dissolved organic carbon, DN: Dissolved nitrogen, Sal: Salinity, $\delta^{18}O$: Ratio of Oxygen-18 isotope and Oxygen-16 isotope, FC: Flow cytometry, chl *a*: chlorophyll *a*, POC: Particulate organic carbon, PN: Particulate nitrogen. Nutrients are nitrate plus nitrite ($NO_3 + NO_2$), phosphate ($PO_4$) and silicate ($Si(OH)_4$).

| Analyses | Depth (m) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **2** | **10** | **25** | **50** | **100** | **150** | **200** |
| **Biochemistry** | | | | | | | |
| DIC/TA | XXX | X | X | X | X | X | X |
| Nutrients | XX | XX | XX | XX | XX | XX | XX |
| DOC/DN | XX | XX | XX | XX | XX | | |
| Sal/$\delta^{18}O$ | X | X | X | X | X | X | X |
| **Community structure** | | | | | | | |
| FC - Bacteria | XX | XX | XX | XX | XX | XX | XX |
| FC - Protist | XX | XX | XX | XX | XX | XX | XX |
| FC - Virus | XX | | | | | | |
| **Biomass** | | | | | | | |
| Chl *a* total | XX | XX | XX | XX | XX | | |
| Chl *a* >5 µm | XX | XX | XX | XX | XX | | |
| POC/PN | XX | | | | | | |
| **Diversity** | | | | | | | |
| DNA | XX | | | | | | |
| Taxonomy | XX | | | | | | |
| **Food web biomarkers** | | | | | | | |
| Fatty acids | XX | | | | | | |
| Stable isotopes | XX | | | | | | |

## 5.3 LABORATORY ANALYSES

DIC samples were collected directly from the *Niskin* bottles in clean 250 ml borosilicate glass reagent bottles with a tapered stopper, after abundant overflow. Precautions were taken to minimize air bubbles during filling. To allow for thermal expansion, a headspace of 1 % of the bottle's volume was removed using a calibrated spacer. The samples were preserved with 50 µl of mercury chloride and tightly sealed with Apiezon M grease upon return to the field laboratory. The glass stopper was secured with an elastic band and clamp and the samples were stored at 4 °C in the dark until analysis. Samples were analyzed using a SOMMA sample handling system and a

coulometer (UIC Inc.) Certified reference material seawater (CRMs; Scripps Oceanographic Institution) were used for calibration every 20 samples.

Duplicate subsamples were filtered through pre-combusted 25 mm Whatman GF/F filters (450°C for 12 h) using an acid-washed syringe holder for macro-nutrient analysis. Samples were kept in 15 ml acid washed (12-24 h soak in 10 % HCl and rinsed with ultrapure water) Falcon polypropylene tubes, immediately frozen at -80°C and stored until analysis using an Autoanalyzer 3 (Seal Analytical) following a method adapted from Grasshoff et al. (1999).

Duplicate subsamples for DOC/Dissolved Nitrogen (DN) analysis were collected using the same method as macro-nutrients, and were kept in 20 ml Amber EPA glass vials with polypropylene open-top caps and PTFE silicone septas. The vials, caps and septas were previously acid washed (12-24 h soak in 10 % HCl and rinsed with ultrapure water) and the vials were also combusted overnight at 500°C. Samples were acidified with 100 µl of 50 % $H_3PO_4$ and stored at 4 °C in the dark until analysis using a Shimadzu TOC-VCPN analyzer calibrated with potassium hydrogen phthalate in Milli-Q water. Results are consistently checked against low-carbon water and deep seawater reference water from the Hansell's CRM.

Salinity and δ18O samples were collected in clean 125 ml clear and 30 ml amber HDPE bottles, respectively. Samples were tightly sealed with tape to avoid evaporation and stored at 4 °C in the dark until analysis. Salinity was determined with an Portasal (model 8410A) analyzer. Ratio of Oxygen-18 isotope and Oxygen-16 isotope were determined in a certified laboratory using the $CO_2$ equilibration method described by Epstein and Mayeda (1953). The detailed method is described in Lange et al. (2021).

Photosynthetic eukaryote (picoalgae: < 2 µm and nanoalgae: 2–20 µm), bacterial and viral abundances were determined by flow cytometry. Duplicate 4 ml samples were fixed with 25 % glutaraldehyde Grade I (0.1 % final v/v concentration for photosynthetic eukaryote and bacterial abundance and 0.5 % final v/v concentration for viral abundance; Sigma-Aldrich G5882), stored and kept frozen at -80 °C until analysis by flow cytometry with a CytoFLEX Flow Cytometer (Beckman Coulter Inc.) (Belzile et al. 2008).

Duplicate subsamples for bacteria enumeration were preserved with buffered formaldehyde (1% final concentration). The samples were kept in the dark until they were stained with 4, 6-diamidino-2-phenylindole (DAPI; 1 µg ml-1 final concentration) and filtered onto 0.2 µm pore size black nucleopore membrane filters (Sherr et al. 1993), for further analysis using epifluorescent microscopy.

Duplicate sea ice and water subsamples (25-250 ml) were filtered onto 25 mm Whatman GF/F filters and 5 µm pore size Nucleopore membrane filters for determination of total chl *a* and 5 µm chl *a* concentrations, respectively. Fluorescence was measured in the field laboratory using a Turner Designs 10-AU fluorometer after 24 to 36 h extraction in 10 ml of 90 % acetone at 4°C in the dark, according to Parsons et al. (1984). The fluorometer was calibrated prior to and upon return from the field expedition using pure Anacystis nidulans extract (Sigma).

Subsamples for particulate organic carbon and particulate nitrogen (POC/PN) and stable isotopes analyses were filtered onto pre-combusted (450°C during 12 h) 21 mm Whatman GF/F filters, placed in acid-washed (12-24 h soak in 10 % HCl) cryovials, immediately frozen at -80°C and stored until analysis using a continuous-flow isotope ratio mass spectrometer (Thermo Electron Delta Advantage) in the continuous-flow mode (Thermo Electron ConFlo III) and an ECS 4010 Elemental Analyzer/ZeroBlank Autosampler (Costech Analytical Technologies). Blank filters were processed on each sampling day and stored as samples. Subsamples for DNA analysis were filtered onto sterile 47 mm 0.22 µm pore size cellulose (Mixed cellulose ester) filters, placed in sterile cryovials, immediately frozen at -80°C and stored until analysis.

Photosynthetic eukaryote abundance and taxonomy were determined on 250 ml subsamples from a water or pooled ice core sample, preserved with acidic Lugol's solution (final concentration of 0.4 %; Parsons et al. 1984), and kept in the dark at 4 °C until analysis. An additional 250 ml water subsample was preserved with formaldehyde (final concentration of 0.4 %), and kept in the dark at 4 °C until analysis. Identification is performed to the lowest taxonomic rank possible according to Lund et al. (1958) and a minimum of 400 cells is counted.

Subsamples for fatty acid analysis were filtered onto pre-combusted 47 mm Whatman GF/F filters (450°C during 12 h), placed in acid-washed (12-24 h soak in 10 % HCl) cryovials, immediately frozen at -80°C and stored until analysis. Blank filters were stored as samples. Filters were freeze-dried (-50 °C 0.2 mbar, 24 h) before extraction with chloroform/methanol (2:1, v/v). The detailed method is available in Kohlback et al. (2020).

Subsamples for carbohydrates were filtered through a pre-combusted 47 mm Whatman GF/F filter (450°C during 12 h) and collected into an acid washed (12-24 h soak in 10 % HCl) glass erlenmeyer. The sample was then transferred into an acid washed HDPE bottle, immediately frozen at -80°C and stored until analysis. The detailed analytical method can be found in Underwood et al. (2013, 2019).

## 5.4 INCUBATIONS

Ice algal primary production was estimated at every T site between May 3$^{rd}$ and 20$^{th}$, 2018, using four experimental approaches. These include *in situ* 24-h incubations with stable isotope and oxygen tracers, carried out under the ice using a mechanical arm or within the ice itself, and simulated 72-h oxygen-based photosynthesis-irradiance (PE) incubations (Table 8).

**Table 8.** Summary of methods used for primary production estimates carried out during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018. P-E: Photosynthesis-irradiance

| Sample ID | Sampling Date | *In situ* | | | Simulated |
|---|---|---|---|---|---|
| | | Stable isotopes | Oxygen (melted ice) | Oxygen (ice cores) | P-E curves |
| T1 | 03-May-18 | X | X | | |
| | 04-May-18 | | | | X |
| T2 | 07-May-18 | X | X | | X |
| T3 | 11-May-18 | X | | | X |
| | 12-May-18 | X | | X | |
| T4 | 15-May-18 | X | | | X |
| T5 | 19-May-18 | X | | | X |
| | 20-May-18 | X | | X | |
| T6 | 23-May-18 | | | | X |

## In situ incubations - Stable Isotopes

Stable isotope incubations were performed by filling three 500 ml clear polyethylene bottles with pooled ice samples of the mid and bottom ice sections and spiking each bottle with $^{15}NO_3$ solution (500 µM) and $^{13}C$ solution (20 g $l^{-1}$) to 10% of the *in situ* concentration. For every sample, one of the three bottle was filtered onto a 21 mm GF/F pre-combusted filter (450°C during 12 h) immediately after spiking. The other two samples were placed under their respective ice type using a mechanical arm (Fig. 3b). The samples were recovered after 24 h, kept in the dark until filtration onto 21 mm GF/F pre-combusted filters, typically within 1 h of sample recovery. All filters were frozen and stored at -80 ºC until analysis. Transmitted irradiance and albedo was measured at the incubation sites immediately prior to and after the incubation period using a Li-Cor LI-1500 data logger, a LI-192 underwater and a LI-190 air cosine sensors (Fig. 3c).

## *In situ incubations - Oxygen (melted ice)*

Duplicate 125 ml clear and black Winkler reagent bottles were filled with pooled samples of the mid and bottom ice sections. Bottles were tightly sealed using Hollow standard taper stoppers and cooled to *in situ* incubation temperatures, ca. -1.5ºC, in a darkened water bath. Once at temperature, the concentration of dissolved oxygen at time zero was measured in each bottle using a robust PreSens oxygen electrode, calibrated prior to experimental runs. Bottles were tightly sealed and deployed for 24 h at the *in situ* incubations sites. The dissolved oxygen concentration of samples was to be sequentially measured, as done for time zero, at the end of the incubation period. However, many of the samples refroze during the incubations, causing the gas-tight seals to break open. As a result, data were not retrieved for these incubations. We note that freezing may have been caused by the low salinity of the melted ice samples, between 1 and 9 psu, and the small bottle size.

***In situ incubations - Oxygen (ice cores)***

During sampling events T3 and T5, cores were collected for incubation of solid ice samples. For these experiments, a section of 10 cm of ice was collected from the top, mid and bottom of sea ice cores. The 10 cm sections were then cut in half vertically with the two resulting subsamples placed into individual polyethylene bags and vacuum sealed, using a *Foodsaver* vacuum sealer. Half of the vacuumed subsamples were immediately placed in a dark cooler for transportation to the shore laboratory for processing of dissolved oxygen at time zero. The remaining half of samples were deployed *in situ* for 24 h with the top and mid sections placed at their respective depths within a previously excavated core hole, then refilled with ice and snow. The bottom ice sections were attached to the mechanical incubation arm positioned underneath the sea ice. The light regimes of samples in the vertical ice profile were characterized during the incubations by ensuring the snow and ice conditions surrounding sensors were similar to natural conditions. For example, measurement of light in the mid-ice section was done by positioning a cosine sensor 1 m down a core hole and covering it with approximately 1 m core of sea ice and 10 cm of snow.

At the end of the incubation period, all sample bags were transported to the shore laboratory and melted at room temperature in the dark. The dissolved oxygen and salinity were measured in each bag using a calibrated PreSens oxygen electrode and a *WTW* 3300i conductivity probe, respectively. Samples for chl *a* and nutrients were also collected. Duplicate chl *a* samples were filtered onto a 25 mm Whatman GF/F filters and stored at -80 ºC until later analysis. Nutrient samples were filtered through pre-combusted 25 mm GF/F filters (450 ºC during 12 h), kept in acid washed polypropylene vials and stored at -80ºC for later analysis.

***P-E curves***

P-E curves were performed on pooled samples from seven bottom core sections collected at every T site. The melted samples were pre-filtered through 350 µm Nitex to remove large zooplankton grazers. Subsamples were processed for salinity, nutrients, chl *a* and taxonomic composition prior the start of the incubation. The methodology for the P-E curve incubations is detailed in Campbell et al. (2016, 2022). Briefly, the system consisted of six 700 ml gas-tight bottles (Winkler) equipped with calibrated oxygen optodes continuously measuring dissolved oxygen concentrations (measurement time interval: 2 seconds). The bottles were filled with the sample and incubated for 72 h over a range of light intensities, in a temperature-controlled chamber. The production or consumption of oxygen over time, at a given light intensity, is used to model photo-physiological responses of ice algae and extrapolate *in situ* production for different ice types and their respective light regimes. At the end of the incubation period, samples from the six bottles were re-pooled and duplicate samples were collected and processed for chl *a* and nutrients. The remaining sample volume was measured and filtered through a 40 µm Nitex mesh. The zooplankton collected onto the mesh was placed in a 50 ml Falcon tube and preserved in buffered formalin (4% final concentration) for post-field enumeration.

## 5.5 SEA ICE TEXTURE

Sea ice cores were cut into sections of ca. 20 cm long. The ice sections were cut in half longitudinally to create two half cylinders. A thin (ca. 4 mm) slice of ice was cut from the flat side of one half cylinder with a band saw for imaging in a cross-polarizing light box. The light box is composed of two perpendicular polarized filters and a 60 W incandescent light located at the bottom of the box. The box interior is designed to be completely opaque, thereby blocking any other source of light within the cross-polarizing compartment. A Panasonic DMC-FZ18 camera was used to photograph each piece of ice, using a small opening at the top of the box. The images are then analyzed to identify and classify the ice into various ice texture classes following Lange et al. (2015). Key features of the texture analyses include identification of annual layers apparent by an abrupt shift in ice crystal structure (Fig. 10).

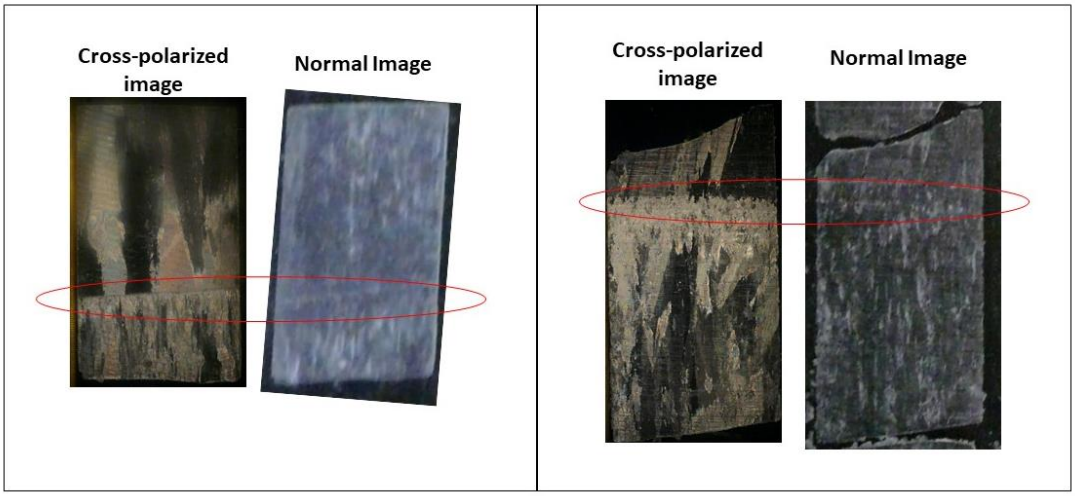


**Figure 10.** Cross-polarized and normal images of selected multi-year ice (MYI) sections showing annual layers, during the Multidisciplinary Arctic Program (MAP) – Last Ice field campaign, spring 2018.

We conducted cross-polarized texture analyses on one FYI (site T5 FYI) core and 8 MYI cores (sites: T2, T3, S1, S2, T4/S3/V3, S4, S5, T5/S6/V6). Partial texture analyses were conducted on one MYI core (site T6). For this core, cross-polarized images were obtained from the half cylinder ice sections, providing information on the structure of the ice albeit not with as much detail.

# 6.0 LOGISTICAL OVERVIEW

Sea ice conditions around CFS Alert were very good in April and May, 2018. Multiple snow falls in May allowed the snowmobile trail to remain in good condition. However, even with relatively smooth ice for the region, the rugged MYI topography limited travelling speed, therefore requiring ca. 45 minutes to reach the sampling site from CFS Alert. The presence of suitable first-year and a MYI floes beside each other made it possible to sample both ice types in close proximity to the ice camp. A larger distance between the comparative sites would have resulted in an important

increase of the ice sampling time. Remarkably, during the 2018 spring field season, no weather days prevented access to the ice camp, allowing for sampling every day. We would typically expect a few days of bad weather in the region at this time of the year.

Marine mammal aerial surveys could not be carried out between May 29th and June 1st, due to weather conditions. However, excellent conditions on June 2-5 made it possible to complete all planned transect lines. Late May and early June overlaps with the ice breakup period in the Canadian High Arctic often leading to significant and unpredictable periods of low visibility which can limit suitable flying days. This needs to be taken into consideration when planning aerial surveys.

We received outstanding logistical support from the Defense Research and Development Canada (DRDC) personnel at the base and at the ice camp. Notably, DRDC provided remarkable support for snowmobile maintenance and repairs, arranging after-hour meals, drilling large sampling and mooring holes, setting up the WeatherHaven tents, and acting as main communication link between CFS Alert and science personnel at camp. During the field season, the MAP – Last Ice personnel reached 17, with 15 science personnel and two DRDC employees. Accommodating so many people undoubtedly entailed significant challenges for snowmobile logistics and operations.

Partners at ECCC also provided invaluable support for the project, including help with trail safety (special thanks to A. Platt) and a variety of tasks at the ice camp, laboratory and sample storage space, and administrative aspects of life at CFS Alert.

This project would not have been possible without the support from the Polar Continental Shelf Program (PCSP) at Natural Resources Canada and the Department of National Defence at CFS Alert. PCSP organized transportation of ca. 24 000 L of Jet fuel for the marine mammal surveys, in addition to gasoline for snowmobiles, field sampling and safety equipment and transportation of personnel to/from CFS Alert. Twin Otter flights for the marine mammal surveys were mobilized from PCSP at Resolute where their personnel provided outstanding logistical support for the duration of the MAP-Last Ice program, and superior accommodations and meals for personnel in transit.

The support provided by CFS Alert and its personnel contributed to the successful execution of the MAP – Last Ice spring 2018 field campaign, especially the accommodations, meal arrangements, chemical storage and disposal and logistical support for aerial surveys.

## 7.0 ACKNOWLEDGEMENTS

The Multidisciplinary Arctic Program (MAP) – Last Ice program would not be possible without the support of northern communities and agencies, together with a government-wide partnering approach. The support from Defense Research and Development Canada (DRDC) was invaluable to the realization of this field program and we extend special thanks to Chris Brown, Jim Milne, Joel Higgins and Mike Simms. We would also like to thank Environment and Climate Change Canada (ECCC) for essential logistical support before and during the expedition. We thank Kenn

Borek Air Ltd and crew Phil, Alex and Mike for Twin Otter aircraft operation during the marine mammal aerial surveys. We would like to extend special thanks to the Polar Continental Shelf Program (PCSP) for their invaluable logistic support including transportation of fuel to CFS Alert for the MAP, and to the team in Resolute: Micheal Krisjanson, Jodi MacGregor, Tim McCagherty, Tom Platt, Glenn Parsons and Tanya Lemieux,. Last, but not least, we thank the Department of National Defense (DND) at CFS Alert and all CFS Alert personnel who contributed in various ways to the success of this sampling campaign, especially Major Caden Stiles, Commanding Officer (CO), Rene Hansen, Station Warrant Officer (SWO) and Rob Lutz, Alta SWO. This project was supported in Canada by DFO and the International Governance Strategy.

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## APPENDIX. LOGBOOK – MAIN ACTIVITIES

| Date | Approximate Time (local) | Activities |
|---|---|---|
| 4/25/2018 | 11:00 | Arrival at CFS Alert: K. Campbell (Bristol U.), J. Charette (DFO), S. Duerksen (DFO), B. Lange (DFO), P. Tremblay (DFO) |
| | 12:30 | Inventory of equipment |
| | 15:00 | Briefing by the Commanding Officer (CO) and Station Warrant Officer (SWO) on CFS Alert base operation |
| 4/26/2018 | 8:00 | Familiarization tour of CFS Alert (K. Campbell, J. Charette, S. Duerksen, B. Lange, P. Tremblay) |
| | 9:30 | Selection of camp location based on ice conditions, bathymetry and safety (access and ice stability) |
| 4/27/2018 | 8:30 | Mobilization of equipment to the ice camp |
| | 13:00 | Drilling sea ice: camp laboratory tent hole on first-year ice |
| | 13:00 | Time Lapse Camera: installation |
| 4/28/2018 | 8:30 | Mobilization of equipment to the ice camp |
| | 10:00 | Setup of two tents (WheaterHaven and storage) |
| | 10:00 | Time Lapse Camera: Maintenance |
| 4/29/2018 | 8:30 | Mobilization of equipment to the ice camp |
| | 10:00 | Drilling sea ice: 2 large MYI holes (AZFP and ACDP moorings) & 1 large FYI hole (PP incubations) |
| | 10:00 | Installation: Ice camp laboratory |
| 4/30/2018 | 8:30 | Mobilization of equipment to the ice camp |
| | 9:30 | Installation: Ice camp laboratory (continued) |
| | 13:00 | Setup of one additional tent (storage) |
| | 13:00 | ADCP: Deployment |
| 5/1/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Drilling sea ice: incubation hole on multi-year ice |
| | 13:00 | AZFP: Deployment |
| | 13:00 | Meteorological station: installation |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| | 14:00 | Niksin bottle deployment: test |
| 5/2/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Meteorological station: Installation (continued) |
| | 10:00 | Niskin bottles deployment for biochemical analyses: 9 (T1 WC; 3 x 2, 10, 25, 50, 100, 150, 200 m) |
| | 11:00 | Arrival at CFS Alert: Second science team: C. Michel (DFO), C. Haas (AWI), J. Hildebrandt (AWI), Philipp Anhaus (AWI), A. Jurtila (AWI), R. ten Boer (AWI). |
| | 12:00 | Niskin bottles deployment for mercury analyses: 5 (2, 10, 50, 100, 200 m) |
| | 12:30 | Processing: Water column (May 2nd) |
| | 13:00 | Zooplankton net tow for biochemical analyses: 1 (T1 Zoo; 0-200 m) |
| | 14:00 | Zooplankton net tow for mercury analyses: 1 (0-100 m) |
| 5/3/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Coring : 7 first-year ice cores (T1; top, mid, bot sections) |
| | 10:00 | Meteorological station: Installation (continued) |
| 5/4/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Coring : 7 first-year ice cores (T1; bot section, for P-E curves incubation) |
| | 13:00 | CTD moorings: preparation |
| 5/5/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Drilling sea ice: moored CTD's hole |
| | 13:00 | Moored CTDs: Deployment |
| | 13:00 | Meteorological station: Maintenance |
| 5/6/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Niskin bottles deployment for biochemical analyses: 9 (T2 WC ; 3 x 2, 10, 25, 50, 100, 150, 200 m) |
| | 11:00 | Arrival at CFS Alert: Third Science team: C. Carlyle (DFO), P. Coupel (DFO). |
| | 12:00 | Primary production incubation (stable isotope and oxygen (melted ice)): Start |
| | 12:30 | Processing: Water column (May 6th) and cores (May 3rd) |
| | 13:00 | Zooplankton net tow for biochemical analyses: 2 (T2 Zoo; 0-100, 0-200 m) |
| | 13:00 | Meteorological station: Maintenance |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| | 19:00 | P-E curves incubation: Start |
| 5/7/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Coring: 15 first-year ice (T2 FYI; top, mid, bot sections) and 15 multi-year ice cores (T2 MYI; top, mid, bot sections) |
| | 12:00 | Primary production incubation (stable isotope and oxygen (melted ice)): End |
| | 12:30 | Processing: primary production incubation (stable isotope and oxygen (melted ice)) |
| 5/8/2018 | 8:00 | Familiarization tour of CF S Alert (C. Carlyle, P. Coupel and C. Michel) |
| | 9:30 | Daily CTD profile |
| | 10:00 | Niskin bottles deployment for mercury analyses: 5 (2, 10, 50, 100, 200 m) |
| | 10:00 | Processing: Ice cores (May 7$^{th}$, first part) |
| | 13:00 | Zooplankton net tow for mercury analyses: 1 (0-200 m) |
| | 13:00 | Zooplankton net tow with the ROV net: 1 (FYI) |
| | 13:30 | Coring: 2 multi-year cores (Geocores 1 and 2) |
| | 19:00 | P-E curves incubation :End |
| 5/9/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Processing: Ice cores (May 7$^{th}$, second part) |
| | 12:00 | Primary production incubation (stable isotope and oxygen (melted ice)): Start |
| | 13:00 | Meteorological station: Maintenance |
| | 13:00 | Science Personnel leaving Alert: C. Michel (DFO) |
| | 14:00 | Li-COR sensor on the laboratory tent: Installation |
| 5/10/2018 | 19:00 | P-E curves incubation: Start |
| | 10:00 | Niskin bottles deployment for biochemical analyses: 9 (T3 WC; 3 x 2, 10, 25, 50, 100, 150, 200 m) |
| | 12:00 | Primary production incubation (stable isotope and oxygen (melted ice)): End |
| | 12:30 | Processing: water column & primary production incubation (stable isotope and oxygen (melted ice)) |
| | 13:00 | Zooplankton net tow for biochemical analyses: 2 (T3 Zoo; 0-200 m) |
| | 13:00 | AUV surveys: 4 (3x VIS and 1x multi-spectral, but did not work) |
| 5/11/2018 | 9:30 | Daily CTD profile |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| | 10:00 | Coring: 15 first-year ice (T3 FYI; top, mid, bot sections) & 15 multi-year ice cores (T3 MYI; top, mid, bot sections) |
| | 10:00 | Zooplankton net tow with the ROV net: 4 (FYI, MYI, Deformed Ice, Comparative tows) |
| 5/12/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Coring: 4 first-year ice (T3 FYI; top, mid, bot sections) and 4 multi-year ice cores (3x T3 MYI; top, mid, bot sections, Geocore 3) |
| | 12:00 | Primary production incubation (oxygen (ice cores)): Start |
| | 13:00 | Visit at the ice camp: CFS Alert Commanding Officer |
| 5/13/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Processing: Ice cores (May 11$^{th}$) |
| | 12:00 | Primary production incubation (Stable isotope): Start |
| | 12:00 | Primary production incubation (oxygen (ice cores)): End |
| | 13:00 | Meteorological station: Maintenance |
| | 13:00 | AUV surveys: 3 (VIS, multi spectral and thermal) |
| | 19:00 | P-E curves incubation: End & start of a new one |
| 5/14/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Niskin bottles deployment for biochemical analyses: 9 (T4 WC; 3 x 2, 10, 25, 50, 100, 150, 200 m) |
| | 10:00 | Zooplankton net tow with the ROV net: 5 (MYI, Deformed Ice, Comparative tows, Diel Vertical Migrations, Biomarker) |
| | 11:00 | Coring : 12 multi-year ice cores (5x S1; bot section, 1x V1; 6 sections, 5x S2; bot section, 1x V2; 8 sections) |
| | 12:00 | Primary production incubation (stable isotope) : End |
| | 12:30 | Processing: water column & primary production incubation (stable isotope) |
| | 13:00 | Zooplankton net tow for biochemical analyses: 2 (T4 Zoo; 0-200 m) |
| 5/15/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Zooplankton net tow with the ROV net: 5 (MYI, Deformed Ice, Comparative tows, 2x Diel Vertical Migrations) |
| | 10:00 | Coring: 16 first-year ice (T4 FYI; top, mid, bot sections) and 20 multi-year ice cores (15x T4 MYI; top, mid, bot sections, 4x S3; bot section, 1x V3; 11 sections) |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| 5/16/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Processing: ice cores (May 14th) |
| | 13:00 | Meteorological station: Maintenance |
| | 19:00 | P-E curves incubation: End & start of a new one |
| 5/17/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Niskin bottles deployment for mercury analyses: 5 (2, 10, 50, 100, 200 m) |
| | 10:00 | Processing: Ice cores (May 15th) |
| | 12:00 | Primary production incubation (stable isotope): Start |
| | 13:00 | Coring: 3 first-year ice (T4 FA FYI; bot section) & 3 multi-year ice cores (T4 FA MYI; bot section) |
| 5/18/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Niskin bottles deployment for biochemical analyses: 10 (T5 WC; 4 x 2, 10, 25, 50, 100, 150, 200 m) |
| | 10:00 | Zooplankton net tow with the ROV net: 5 (MYI, Deformed Ice, Transition zone (FYI Edge), Comparative tows, Diel Vertical migration) |
| | 12:00 | Primary production incubation (stable isotope): End |
| | 12:30 | Processing: water column & primary production incubation (stable isotope) |
| | 13:00 | Zooplankton net tow for biochemical analyses: 2 (T5 Zoo; 0-200 m) |
| | 13:00 | Coring : 12 multi-year ice cores (5x S4; bot section, 1x V4; 6 sections, 5x S5; bot section, 1x V5; 8 sections) |
| 5/19/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Zooplankton net tow with the ROV net: 6 (MYI, Deformed Ice, 50 meter horizontal tow, Comparative tows, 2x Diel Vertical Migrations) |
| | 10:00 | Coring : 16 first-year ice (T5 FYI; top, mid, bot sections) & 20 multi-year ice cores (15x T5 MYI; top, mid, bot sections, 4x S6; bot section, 1x V6; 11 sections) |
| | 19:00 | Processing: Texture core and salinity |
| 5/20/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Processing: Ice cores (May 18th) |
| | 10:30 | Coring : 3 first-year ice (T5 FYI; top, mid, bot sections) & 3 multi-year ice cores (T5 MYI; top, mid, bot sections) |
| | 12:00 | Primary production incubation (oxygen (ice cores)): Start |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| | 19:00 | P-E curves incubation: End |
| | 19:00 | Processing: Texture core and salinity |
| 5/21/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Processing: Ice cores (May 19th) |
| | 12:00 | Primary production incubation (stable isotope): Start |
| 5/21/2018 (continued) | 12:00 | Primary production incubation (oxygen (ice cores)): End |
| | 19:00 | P-E curves incubation: Start |
| | 19:00 | Processing: Texture core and salinity |
| 5/22/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Niskin bottles deployment for biochemical analyses: 10 (T6 WC; 4 x 2, 10, 25, 50, 100, 150, 200 m) |
| | 10:00 | Coring: 27 first-year ice (M0-M8; bot section) & 12 multi-year ice cores (M15, M16, M19, M23; bot section) |
| | 12:00 | Niskin bottles deployment for mercury analyses: 5 (2, 10, 50, 100, 200 m) |
| | 12:00 | Primary production incubation (stable isotope): End |
| | 12:30 | Processing: water column & primary production incubation (stable isotope) |
| | 13:30 | Zooplankton net tow for biochemical analyses: 2 (T6 Zoo; 0-200 m) |
| | 15:00 | Zooplankton net tow for mercury analyses: 1 (0-200 m) |
| 5/23/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Zooplankton net tow with the ROV net: 4 (FYI, MYI, Deformed Ice, Biomarker) |
| | 10:00 | Coring: 14 first-year ice (T6 FYI; 3 sections) & 13 multi-year ice cores (T6 MYI; 3 sections) |
| | 13:00 | Science Personnel leaving Alert: S. Duerksen (DFO) |
| 5/24/2018 | 9:30 | Daily CTD profile |
| | 10:00 | Processing: Ice cores (May 22nd) |
| | 10:00 | Recovery: ADCP, AZFP & CTDs |
| | 13:00 | Visit at the ice camp: CFS Alert Station Warrant Officer |
| | 14:00 | 3 AUV surveys (2x VIS, video) |
| | 19:00 | P-E curves incubation: End and start of new one |
| 5/25/2018 | 10:00 | Processing: Ice cores (May 23rd) |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| | 13:00 | Meteorological station & Li-COR sensor on the tent: takedown |
| | 14:00 | Ice camp laboratory demobilization |
| 5/26/2018 | 10:00 | Time lapse camera: Takedown |
| | 10:00 | Equipment cleaning and packing |
| | 13:00 | Final ice camp demobilization |
| 5/27/2018 | 8:30 | Equipment cleaning and packing |
| 5/28/2018 | 8:30 | Equipment cleaning and packing |
| | 10:00 | Processing: Texture core and salinity |
| | 11:00 | Arrival at CFS Alert: M. Galicia (DFO) and B. Young (DFO) |
| | 19:00 | P-E curves incubation: End |
| 5/29/2018 | 8:30 | Equipment packing |
| | 10:00 | Processing: Salinity |
| | | Weather day delaying aerial surveys |
| 5/30/2018 | 8:30 | Processing: Salinity |
| | 8:30 | Data compilation |
| | | Planned departure delayed (Philipp Anhaus (AWI), K. Campbell (Bristol U.), J. Charette (DFO), S. Duerksen (DFO), J. Hildebrandt (AWI), A. Jurtila (AWI), C. Katlein (AWI), B. Lange (DFO), R. ten Boer (AWI) , P. Tremblay (DFO), R. ten Boer (AWI)) |
| | | Weather day delaying aerial surveys |
| 5/31/2018 | 8:30 | Data compilation |
| | | Planned departure delayed (Philipp Anhaus (AWI), K. Campbell (Bristol U.), J. Charette (DFO), S. Duerksen (DFO), J. Hildebrandt (AWI), A. Jurtila (AWI), C. Katlein (AWI), B. Lange (DFO), R. ten Boer (AWI) , P. Tremblay (DFO), R. ten Boer (AWI)) |
| | | Weather day delaying aerial surveys |
| 6/1/2018 | 13:00 | Science Personnel leaving Alert: Philipp Anhaus (AWI), K. Campbell (Bristol U.), J. Charette (DFO), S. Duerksen (DFO), J. Hildebrandt (AWI), A. Jurtila (AWI), C. Katlein (AWI), B. Lange (DFO), R. ten Boer (AWI) , P. Tremblay (DFO), R. ten Boer (AWI) |
| | | Weather day delaying aerial surveys |

| Date | Approximate Time (local) | Activities |
|---|---|---|
| 6/2/2018 | 9:00 | Aerial surveys : lines AL01-AL19 |
| 6/3/2018 | 9:00 | Aerial surveys : lines AL20-AL32) |
| 6/4/2018 | 9:00 | Aerial surveys : lines AL33-AL42) |
| 6/5/2018 | 9:00 | Aerial surveys : (lines AL43-AL51) |
| 6/6/2018 | 9:00 | Demobilization: Aerial survey equipment |
| 6/7/2018 | 11:00 | Science Personnel leaving Alert: C. Carlyle (DFO), M. Galicia (DFO), B. Young (DFO) |