DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE **RAPPORT 2021/70**

ICAROS 2021 Cruise Report

Ice-ocean interactions and marine ecosystem dynamics in Northwest Greenland

Sofia Ribeiro, Steffen M. Olsen, Andreas Münchow, Katrine J. Andresen, Christof Pearce, Sara Harðardóttir, Heike Zimmermann & Alice Stuart-Lee

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GEUS

Cruise report

ICAROS 2021

Ice-ocean interactions and marine ecosystem dynamics in Northwest Greenland

Aasiaat-Pituffik-Nuuk
(22nd Aug-3rd Sep 2021)

Sofia Ribeiro, Steffen M. Olsen, Andreas Münchow, Katrine Juul Andresen, Christof Pearce, Sara Harðardóttir, Heike Zimmermann, Alice Stuart-Lee

Dansk Center for Havforskning GEUS DMI AARHUS UNIVERSITY

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1. Foreword

The ICAROS 2021 cruise was planned as a 3-week marine research expedition on board *HDMS Lauge Koch* including two complementary legs, from Aasiaat-Qaanaaq and Qaanaaq-Nuuk from 22th Aug-13th Sep. The expedition was however terminated on the 31st Aug at Pituffik (Thule Air Base) by Arctic Command due to unforeseen operational issues. This was followed by transit to Nuuk, where demobilization of equipment and disembarkment of the team took place on the 3rd Sep. This report gives an account of the research activities performed from the 22nd Aug-31st Aug, including an overview of the samples and data collected during the expedition. We note that the unexpected termination of our research activities compromises the objectives we set out to pursue.

2. Participants

Science crew

Figure 1- Science crew minutes before onboarding HDMS Lauge Koch in Aasiaat, 22nd Aug 2021. From left to right: S.M. Olsen, S. Ribeiro, E. Brischt, H. Zimmermann, K. J. Andresen, A. Münchow, C. Pearce, S. Harðardóttir, A. Stuart-Lee. Photo by F.W. Teglhus

Name	Affiliation	Main role
Sofia Ribeiro	GEUS	Cruise leader, Paleoclimate/Paleoceanography
Steffen M. Olsen	DMI	Cruise co-lead, Oceanography
Andreas Muenchow	DMI/UDEL	Oceanography, Ice-ocean interactions
Katrine Juul Andresen	AU	Geophysics, sub-bottom profiling, multibeam echosounding
Christof Pearce	AU	Paleoclimate, sediment coring
Sara Harðardóttir	GEUS	Marine ecology and eDNA
Heike Zimmermann	GEUS	Sedimentary ancient DNA
Alice Stuart-Lee	GINR/NIOZ	Ecosystem dynamics, Biogeochemistry
Eik Brischt	DTU	DCH-certified technician
Frederik Wolff Teglhus	Underground Channel	Filmmaker, science communication
Anna Bang Kvorning	GEUS	PhD student (onshore support, planned leg2 participant)

Royal Danish Navy crew

Name	Position
Steen Kempf-Amkær	Commanding Officer
Christian Aa. Rothly	Executive Officer
Ditte R. Olesen	Navigational Officer
Rene Olsson	Chief Engineer
Erik Johannes Schmidt	Quartermaster
Jimmi Søren Vestergaard	Supply
Henrik Borum Pedersen	Radio
Jens T. Konge	Weapon
Henrik N. Andersen	Cook
Anders S. Godiksen	Food and Bakery
Morten Grysbæk Jensen	Deckhand
Jon Evers	Deckhand
Mikkel Diederichsen	Deckhand

Name	Position
Daniel Jensen	Deckhand
Torben Bjørn	Deckhand
Jais Thuge Andersen	Deckhand
Allan Berg	Technician
Morten M. Møller	Technician
Lars Peter Nielsen	Technician
Peter Ravn Mikkelsen	Technician

3. Cruise motivation and objectives

Sea ice loss, increasing glacier discharge, and ocean warming will continue to affect the Arctic region in the coming decades under all future climate scenarios (IPCC SROCC 2019). Such changes, at the interface between the cryosphere and the ocean, raise concerns about the downstream effects in marine ecosystems. These include ecosystem services of societal relevance such as fisheries and carbon sequestration, as well as potential hazards such as the introduction of pollutants and invasive/toxic marine species (AMAP 2017). In order to understand the impacts of a rapidly-changing cryosphere on the Arctic marine environment, knowledge concerning the physical and biochemical perturbations occurring at the ice-ocean interface and the structure, function, and resilience of affected ecosystems must be integrated in time and space.

The Northwest Greenland region and in particular its marine environment is sensitive to climate forcing from both the Arctic (Münchow et al., 2015) and subpolar regions (e.g. Rysgaard et al., 2020). Several marine-terminating glaciers in this region have been retreating and accelerating over the past decades, and the mass loss from the Northwest sector of the Greenland Ice Sheet alone is estimated to contribute to 1-3 cm of sea-level rise by 2100 (Morlighem et al., 2019). Some of these glaciers are located in deep fjords and are vulnerable both to sea ice retreat and to the inflow of warm and saline subsurface Atlantic waters carried by the West Greenland Current (Rignot et al. 2016). Also, subglacial meltwater discharge at the calving front of marine-terminating glaciers leads to enhanced melting and upwelling of bottom waters strongly affecting the structure and properties of the water column and promoting upwelling of nutrient-replete bottom waters that may enhance primary production during summer (Meire et al., 2017, Hopwood et al., 2018).

While future climate change is expected to drive habitat and biome shifts, with associated changes in the ranges and abundance of keystone as well as potentially harmful/toxic species, very little is known about the long-term response of primary producers to climate change. This is an important concern when it comes to assessing the vulnerability of hotspot productivity areas such as the North Water polynya or Pikialasorsuaq, a unique and vulnerable sea ice ecosystem and an important area for ocean heat transport (Ribeiro et al. 2021, Jackson et al. 2021). Marine sediments contain a wealth of signatures from primary producers including microfossils, source-specific biomarkers, as well as genetic material that, over time, build up sedimentary archives from which past environmental conditions can be inferred.

The Holocene Epoch (last 11 700 years) offers a suitable time frame for inferring long-term changes, as it encompasses both periods of relatively warmer and cooler conditions than present. Ice core and lake records from Northwest Greenland indicate that summer air temperatures were warmer than modern during the Holocene Thermal Maximum (McFarlin et al. 2018). This period can thus provide a unique "window" into projected future conditions and interlinked cryosphere-ocean-biosphere responses to climate forcing. However, only very few marine records have been recovered from the Northwest Greenland shelf to date that cover the Holocene at high-resolution. Furthermore, new methods are now emerging, such as sedimentary ancient DNA analyses that are particularly sensitive to degradation and contamination and require careful processing of samples and minimal storage time for optimal results (Armbrecht et al., 2019).

This research expedition was motivated by previous and ongoing collaborative work among the consortium partners. It directly addresses the knowledge gap identified by the IPCC calling for new long-term datasets on cryosphere-ocean-biosphere dynamics in the context of climate change (see also Smith et al., 2019, Straneo et al., 2019). The overarching goal of the expedition was to obtain new data on modern ocean conditions, influence of glacier runoff and links to sea-ice retreat along the Northwest Greenland shelf, Melville Bay and the North Water polynya. Biogeochemical, plankton and environmental DNA (eDNA) investigations were also planned, to provide new information on ecosystem structure and functioning while paleo-studies were aimed at tracking long-term changes in ocean conditions, sea-ice cover, productivity, and biodiversity throughout the Holocene. One of the main goals of the cruise was to retrieve new marine records for sedimentary ancient DNA studies. The cruise was designed including 3 interlinked work packages with specific objectives (O).

WP1 – Modern oceanography
O 1.1 – Document summer water column properties along offshore-fjord and latitudinal transects
O 1.2 – Characterize the spatial variability of the West Greenland current system and its interaction with nearby fjords and marine-terminating glaciers

WP2 – Ecosystem dynamics
O 2.1 – Identify drivers of primary productivity and biogeochemical fluxes in the region
O 2.2 – Characterize spatial trends in the distribution of plankton species (including phyto- and zooplankton) with focus on keystone, toxic/harmful species, and taxa relevant to paleo studies
O 2.3 – Further explore biodiversity trends with eDNA and biomarker approaches

WP3 – Holocene paleoceanography and ecosystem changes
O 3.1 – Reconstruct changes at the sea surface (SST, sea ice cover) and at depth (WGC variability) over the Holocene for selected sites
O 3.2 – Reconstruct paleoproductivity changes, including sea ice vs. pelagic productivity
O 3.3 – Explore the potential of sedimentary ancient DNA to trace biodiversity trends and potential invasions/range expansion of harmful or toxic species

4. Deck configuration for scientific operations on Lauge Koch

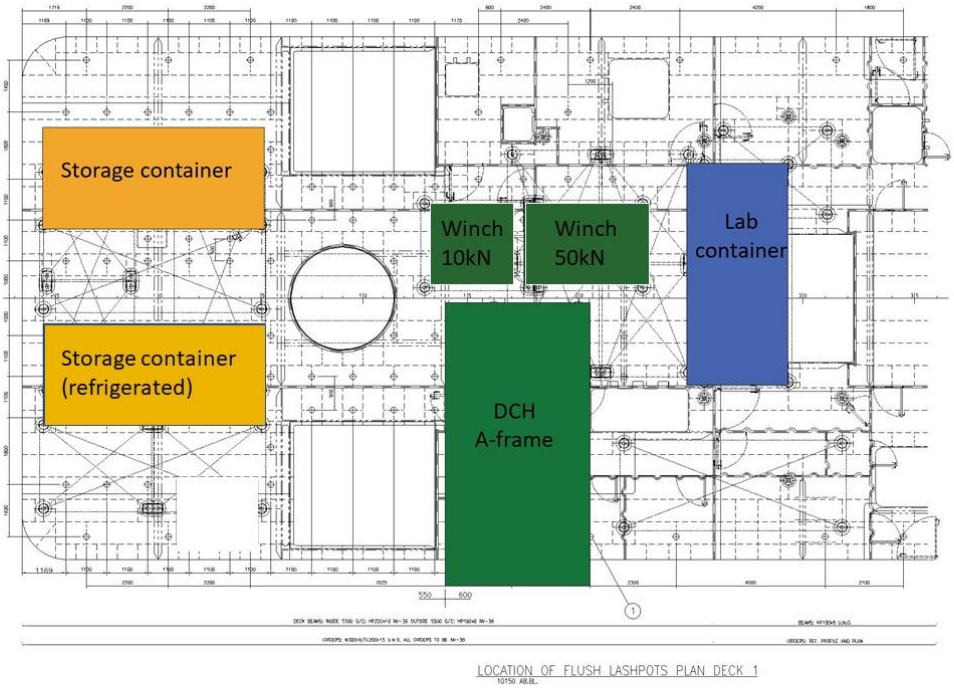

***Figure 2**- Aft deck configuration during ICAROS21.*

Two storage containers were placed on the aft deck (Fig. 2); one for storage of equipment at room temperature and the second one refrigerated (4℃) to keep the sediment cores at a stable temperature (to avoid DNA and biomarker degradation).
Deployment of the standalone CTD and standalone Rosette were done using the A-frame and the 10kN winch with a 3500m Rochester 8mm wire. Deployment of the sediment coring devices (HAPS, Rumohr lot and Gravity corer) were performed using the A-frame and the 50kN winch with a 4200m DynIce Warps (16mm) wire.

The lab container was insulated (temperature controlled), and equipped with a fume hood, several storage cabinets, and both an under-bench freezer (-20℃) and fridge. One of the benches was dedicated to processing of samples for eDNA analyses and a filtering station was set-up with 2 filtering units for eDNA (with individual sterile units used for each sample) and 6 filtering units for biogeochemical analyses run separately (Fig. 3).

Figure 3 - Processing of water samples (water filtering for biogeochemistry and eDNA) was performed in the dedicated lab container installed on deck during ICAROS21.

5. Cruise track and stations

Our research activities were carried out on the Northwest Greenland shelf, Upernavik fjord and Melville Bay, ranging 68-76° North and 50-70° West. Our research cruise track (Fig. 4) covered 1279nm (2368Km). Seismo-acoustic data were acquired along most of these track kilometers (see section 6.3.1). From the total of 41 stations, we carried out CTD casts and water collection for biogeochemistry at 39 unique stations, collection of water samples for eDNA at 15 stations and surface sediments at 14 stations and obtained Gravity cores and Rumohr lot cores from 8 and 4 stations, respectively. Plankton net samples were collected at 10 stations for phytoplankton and 6 stations for zooplankton analyses.

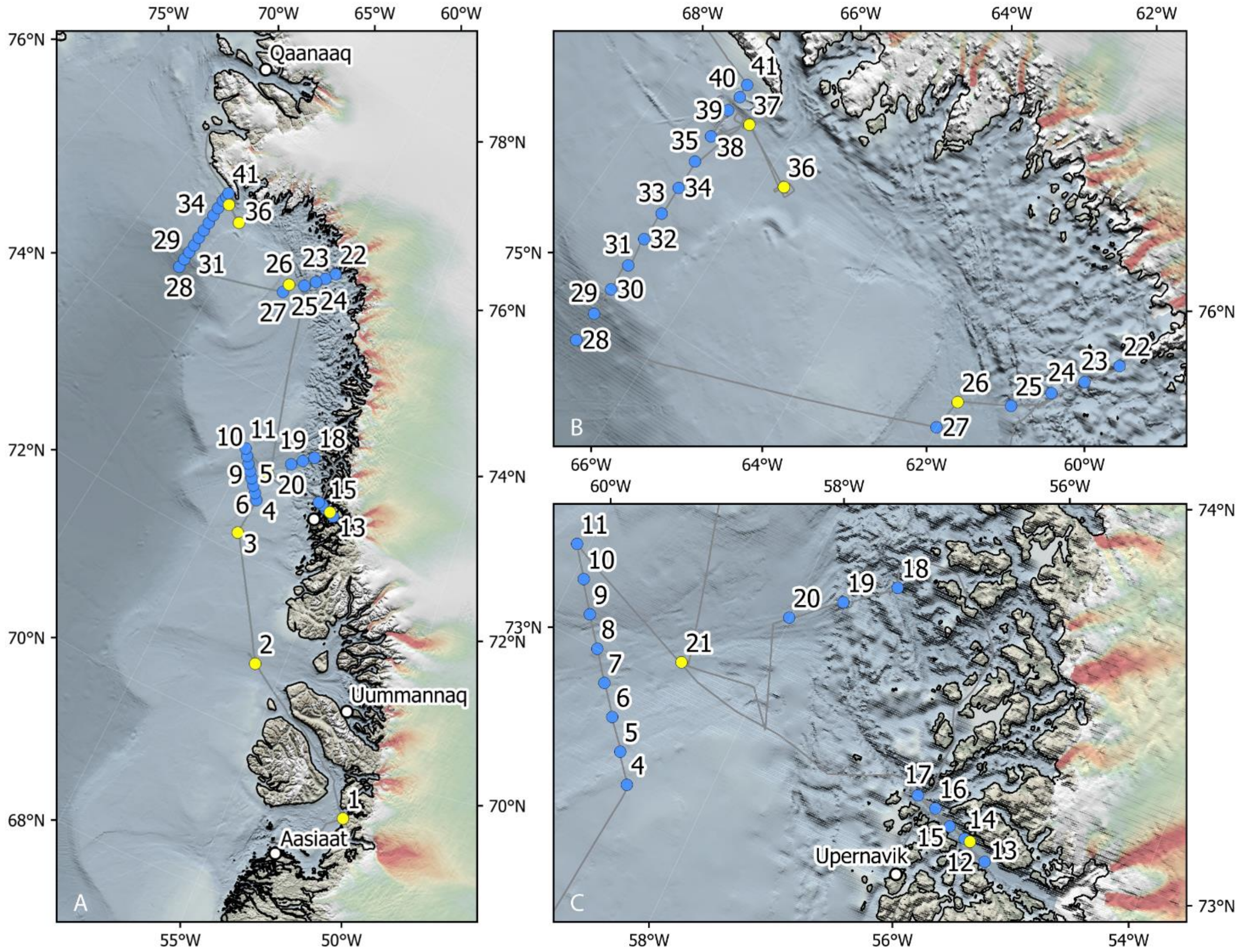

*Figure 4 - Overview of stations along the ICAROS21 cruise track. Yellow dots indicate stations were gravity cores were collected (see text for details) Bathymetry data from GEBCO 2020 Grid (*doi:10.5285/a29c5465-b138-234d-e053-6c86abc040b9*) and ice velocity data from https://doi.org/10.24381/cds.0b96b838). The full station log is given in Appendix 1.*

6. Scientific operations

<u>6.1 Modern oceanography (WP1)</u>

Equipment and operational procedures

The ICAROS CTD and water sampling was planned with an SBE911plus integrated CTD and rosette system with 12, 5-liter Niskin bottles. The system would be supplied from DCH together with the hydrographic winch and frame as part of the grant and project support. This system was not mobilized, only the winch. Attempts to assemble a backup system failed in the days prior to departure after heroic efforts from DCH staff. In the last minute, a simple, less capable (depth rating, bottles) and non-integrated CTD and Rosette system was kindly supplied by the Greenland Institute of Natural Resources, a system operated from R/V *Sanna*. Other backup CTD's considered included systems available from ICAROS partners but placed in Thule and Qaanaaq. These would not allow water sampling and left in place for pickup if needed.

The available CTD for ICAROS and used throughout the cruise was an autonomous, internally recording SBE19plusV2 fitted with several auxiliary sensors. This includes oxygen, fluorescence, PAR and turbidity. The sensor package makes the system well suited for characterizing both ocean-glacier and bio-physical interactions in the region. The depth rating of the system is 2000m, just adequate for the planned sections with maximum depths close to 1800m. The low sampling frequency of the SBE19 system (4 Hz) and sensor response times put strong constraints on the lowering speed and add significant time to deep CTD stations as compared to SBE911 systems. The SBE19 system also needed to be operated with additional care and safety margin in order to avoid bottom contact. Bottom depth is known with about 1% uncertainty from the ship navigational system or multibeam, but the only way to estimate the actual depth of the system during deployment is via the wire payout counter and considering wire angles during strong drift. This is another disadvantage of the SBE19 system compared to the SBE911. For ICAROS this was specifically critical as measurements in the near bottom layer is required along with water sampling.

Serial numbers and calibration dates

<u>SBE 19plus V 2.5.2 SERIAL NO. 7090</u>

- Pressure, SN 7090, 21-Dec-20
- Temperature, SN 7090, 02-Feb-21
- Conductivity, SN 7090, 02-Feb-21
- Oxygen SBE 43, SN 3056, 01-Jan-21
- Fluorometer, Seapoint, SN 3694, 20-Jan-21
- Turbidity meter, Seapoint, SN 10629, 20-Jan-2021
- PAR/Irradiance, Biospherical/Licor, SN 70578, 21-Jan-2021

An operational procedure that optimized instrument safety, ship-time and data quality was decided. This included a payout speed during downcast of 0.5 m/s for the depth range 0-300m, increasing to 1.0 m/s below 300m and during the full up-cast (backup data). Prior to the downcast, the system was dwelling for 3 min while the pumps activated (1min) and sensors equilibrated (2-3 min). In general, it was intended to keep 20-50 m above the bottom (despite scientific interests in the near bottom layer) depending on water depth, but this was not always possible.

Data quality was generally good, exceptions include one casts where bottom contact and mud clutched the pump and intake. Here the upcast was visibly affected. As only downcast are kept and all with superior data quality relative to the upcast (due to instrument design), this is not a critical issue. Also, the system was re-deployed at the same station after cleaning showing no biases, no degrading of sensors. Noise (leakage) from the PAR voltage channel is also observed in most profiles below 150m. Attempts to correct this by cleaning and reassembling cables had a minor, non-lasting positive effect. PAR/Irradiance data above 150m are considered good. Below these depths there is little or no interests in this parameter. It is noted that shadow effects from the ship may hamper the data quality and usability, no consistent positioning to overcome this has been attempted.

For water sampling we made use of programmable autonomous Rosette water sampling system from General Oceanics (Owner: GINR, model number M10180605, Serial NO H18/23473/1735, firmware version 14003), fitted with 6x5l Niskin bottles. Programming the system for preset depths was achieved via the General Oceanics Rosette Sampling System software release 4.019 dated 10/31/2014. The GO rosette system was calibrated in the range 0-400db July 2009 (depth rated to 6000m) and potentially not adequate for sampling of bottom and deep waters as planned. Even though the rosette has been deployed 80+ times, we never experienced reliability of both software/communication and hardware. The rosette system almost consistently failed below 200m. Charging of the internal battery was also not predictable. The manufacturer has been consulted with the conclusion that the system suffers from known bugs and need to be sent to service and upgrades at GO facilities.

In order to collect at least some bottom water, a single 5L Niskin bottle was attached to the CTD wire above the rosette and triggered by a drop-messenger. The success rate of this well-proven system was 100%.

The complete CTD operations log is given in Appendix 2.

Figure 5- Complete Niskin-Rosette-CTD rack assembled for ICAROS 2021 in replacement for the planned SBE911 system.

CTD data processing

The raw CTD hex files are processed with standard Seabird software and routines. Steps includes the following routines with settings incorporated in the header file of processed data:

1. <u>Data Conversion</u> converts raw data to engineering units from
2. <u>Filter</u> runs a low-pass filter on one or more columns of data. A low-pass filter smooths high frequency (rapidly changing) data. To produce zero phase (no time shift), the filter is first run forward through the data and then run backward through the forward-filtered data. This removes any delays caused by the filter.

3. Align CTD aligns parameter data in time, relative to pressure. This ensures that calculations of salinity, dissolved oxygen concentration, and other parameters are made using measurements from the same parcel of water. Typically, Align CTD is used to align temperature, conductivity, and oxygen measurements relative to pressure.
4. Cell Thermal Mass uses a recursive filter to remove conductivity cell thermal mass effects from the measured conductivity
5. Loop Edit marks scans bad by setting the flag value associated with the scan to badflag in input files that have pressure slowdowns or reversals (typically caused by ship heave).
6. Derive uses pressure, temperature, and conductivity from the input file to compute oceanographic parameters
7. Bin Average averages data, using averaging intervals based on depth range

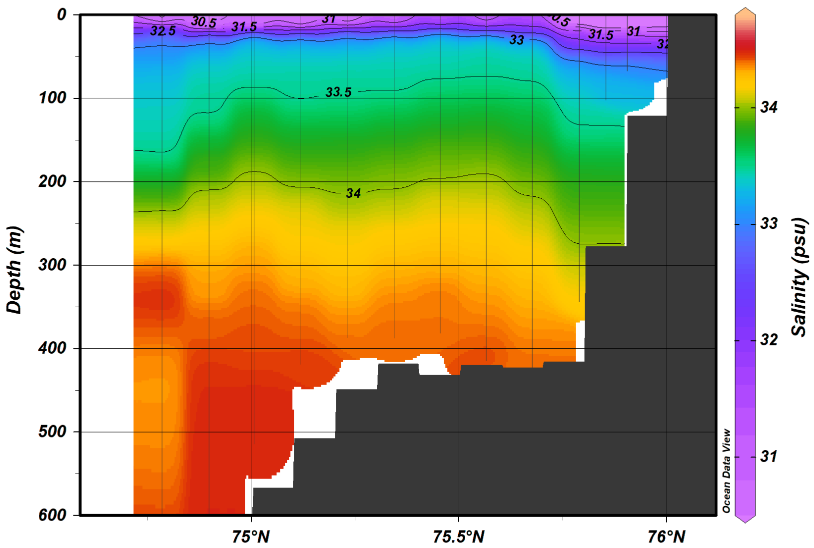

Figure 6 - Cape York section ICAROS2021, Salinity distribution in the upper 600m of the water column.

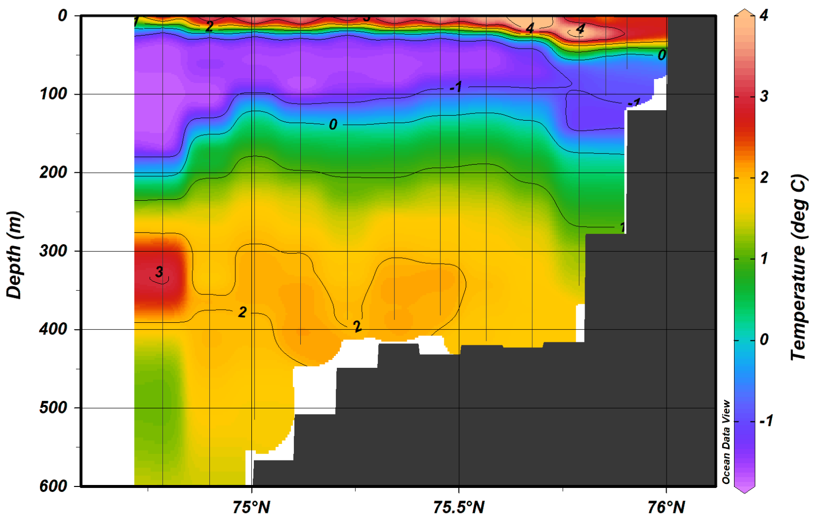

Figure 7- Cape York section ICAROS2021, Temperature distribution in the upper 600m of the water column.

Ferry Box

HDMS Lauge Koch is fitted with a SBE21 Seacat Thermosalinograph or 'Ferry Box', measuring underway salinity and temperature from a 5m intake. Data are logged continuously for scientific use with position and time. The system has been running during ICAROS cruise and data presented below. Apparent calibration information indicates that accuracy may be affected by sensor drift since 2017. Temperature SN 3443, 19-Nov-17, Conductivity SN 3443, 19-Nov-17, Temperature SBE38, SN 0989, 22-Nov-17.

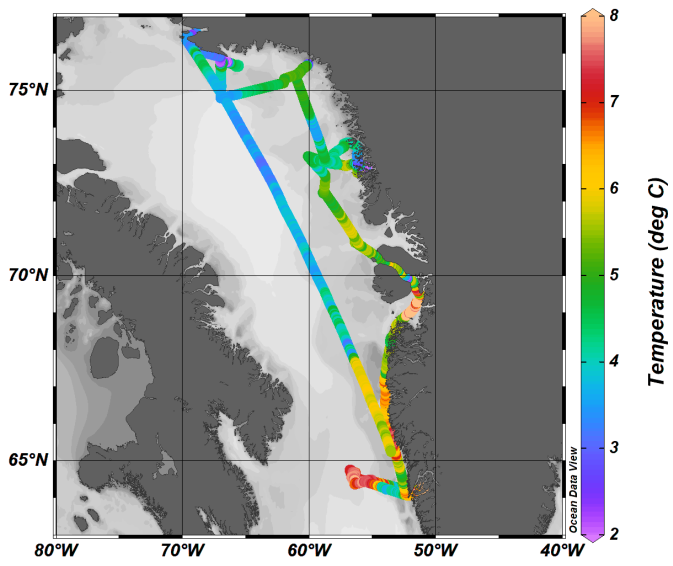

Figure 8 - Surface 5m temperature along the ICAROS cruise track from the ship mounted Ferry Box (Seabird)

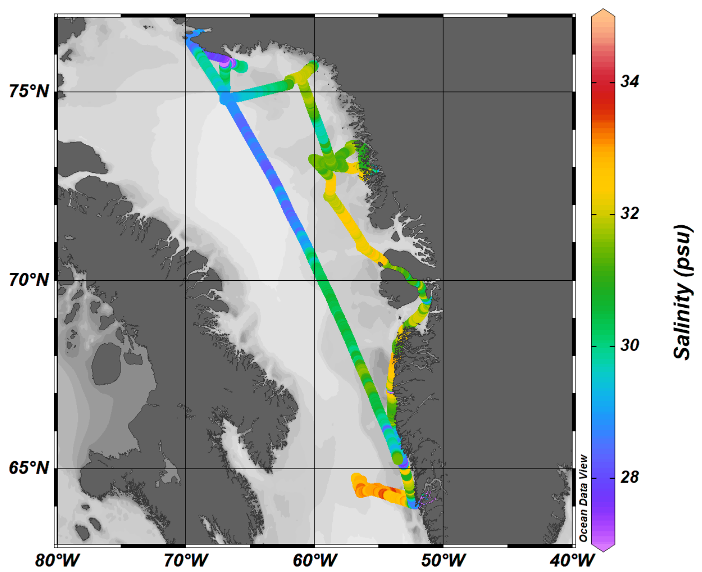

Figure 9 - Surface 5m salinity along the ICAROS21 Cruise track from the ship mounted Ferry Box (Seabird)

Infrared Sea surface temperature Autonomous Radiometer (ISAR)

An ISAR has been installed on port side at level 3 looking at the sea surface. The ISAR provides accurate and reliable measurements of the radiative sea surface temperature (skin SST) to an accuracy of ±0.1 K. Infrared emission from the sea surface and atmosphere are measured in the spectral waveband 9.8-11 µm. The ISAR system is specifically designed to address the problem of sea-water spray or rain, which without adequate environmental protection of delicate infrared radiometer fore-optics, could introduce significant errors in the skin SST measurement. Furthermore, it provides a self-calibrating infrared radiometer system that can operate autonomously for extended periods. During ICAROS, performance of the system had been monitored daily including the automatic shutter system protecting the delicate infrared radiometer fore-optics. Data will be used for match-up and calibration of satellite-based sea-surface temperature maps.

Figure 10 - ISAR installation, Lauge Koch, during ICAROS 2021 (Installed on the 23rd Aug and unmounted on the 3rd Sep).

6.2 Ecosystem dynamics (WP2)

Environmental DNA (eDNA) – precautionary notes

In preparation of sampling for DNA (seawater and surface sediments) we wore synthetic aprons, face masks and gloves, which we cleaned with 1% bleach followed by a rinse with 70% ethanol. To monitor contamination from rain or sea spray, we attached open 1.5 mL microcentrifuge tubes as air blanks during the sampling procedures. Lanolin was used as a lubricant for the CTD and Rosette wire (10kN winch). The amount was substantial, and we consider this to be a contamination risk to the DNA samples. We took a sample of the Lanolin as control for the eDNA analyses. To avoid contamination, the Niskin bottles were washed with strong detergent, followed by a 1% bleach and 70% ethanol wash at least one time per day. The messenger was cleaned before every deployment as above.

Figure 11 - Use of protective gear during sampling for eDNA on board

Water sampling and filtering for eDNA

To assess spatial trend in species composition (with focus on protists) along the NW Greenland coats via DNA metabarcoding, a water sampling program was carried out with the Rosette, which was mounted with 6x 5L Niskin bottles and deployed together with the CTD. The setup was cast twice to 1) collect deep water (bottom) and locate the depth of chlorophyll maximum (DCM) 2) collect water at DCM and at surface, which was programed at 1 m until station 15, and from station 16 onwards at 2 m. From station 4 onwards, the bottles 4-6 did not close at the deeper water depths. As described in section 6.1, a separate 5L Niskin bottle was placed above the Rosette and triggered with a drop messenger which was custom-made for us on the ship. We are therefore very grateful to the crew of LAKO to have made it possible for us to collect the deeper water samples (> 100 m) from station 26 onwards.

To prevent contamination during the collection of water, we cleaned the nip (outlet) of the Niskin bottle and around the nip with 1% bleach, which was rinsed off with 70% ethanol. We then attached a short hose (soaked in 1% bleach followed by 70% ethanol) onto the nip and flushed it with the collected seawater. Subsequently, we collected the seawater into 1.6 L sterile Whirl-Pak bags through a sterile 200 µm mesh size cell strainer to remove larger zooplankton. The water samples were immediately placed at 4°C in the dark, and filtered as soon as possible onto sterile 0.45 µM CN filtration units (Thermo Fisher Scientific) with a vacuum not exceeding 0.47 mbar. Each filter was folded with tweezers five times and placed into a sterile 1.5 mL Eppendorf tube to which 1.3 mL RNAlater were added. Between each sample, the tweezers were soaked in 1% bleach (min. 10min, max. overnight) and rinsed with ethanol 70% and finally with DNA away. The DNA samples (40 filtered water samples) plus air blanks from each water sampling event were stored at -20°C until further analysis.

Table 1 - List of water samples collected for eDNA analyses

#	Station	Region	Sample ID	Water depth (m)	Volume filtered (L)
1	1	Rodebay	LK21ICst.1_bottom	400	1.5
2	1	Rodebay	LK21ICst.1_DCM	20	1.5
3	1	Rodebay	LK21ICst.1_surface	1	1.5
4	2	Uummannaq	LK21ICst.2_surface	1	1.5
5	2	Uummannaq	LK21ICst.2_DCM	35	3
6	2	Uummannaq	LK21ICst.2_bottom	600	3.2
7	3	PS26 area	LK21ICst.3_surface	1	2.65
8	3	PS26 area	LK21ICst.3_DCM	42	2.8
9	3	PS26 area	LK21ICst.3_bottom	340	1.6
10	12	Uper1 (fjord)	LK21ICst.12_surface	1	1.25
11	12	Uper1 (fjord)	LK21ICst.12_DCM	10	1.5
12	13	Up4 (fjord)	LK21ICst.13_surface	1	1.215
13	13	Up4 (fjord)	LK21ICst.13_DCM	3	1.275
14	15	Up7 (fjord)	LK21ICst.15_surface	2	1.5
15	15	Up7 (fjord)	LK21ICst.15_DCM	7	1.58
16	17	Up9 (fjord outer)	LK21ICst.17_surface	2	1.5
17	17	Up9 (fjord outer)	LK21ICst.17_DCM	10	1.5
18	18	T1#12	LK21ICst.18_surface	2	1.4
19	18	T1#12	LK21ICst.18_DCM	13	1.65
20	21	PS25	LK21ICst.21_surface	2	1.45
21	21	PS25	LK21ICst.21_DCM	32	1.37
22	21	PS25	LK21ICst.21_bottom	350	2.5
23	24	T2#3	LK21ICst.24_surface	2	1.6
24	24	T2#3	LK21ICst.24_DCM	35	1.62
25	24	T2#3	LK21ICst.24_bottom	275	2.28

#	Station	Region	Sample ID	Water depth (m)	Volume filtered (L)
26	26	Melville1	LK21ICst.26_surface	2	1.5
27	26	Melville1	LK21ICst.26_DCM	40	1.39
28	26	Melville1	LK21ICst.26_bottom	868	2.9
29	28	T3#12	LK21ICst.28_surface	2	1.375
30	28	T3#12	LK21ICst.28_DCM	33	1.35
31	28	T3#12	LK21ICst.28_bottom	1700	2.175
32	32	T3#8	LK21ICst.32_surface	2	1.4
33	32	T3#8	LK21ICst.32_DCM	36	1.5
34	32	T3#8	LK21ICst.32_bottom	385	1.95
35	35	T3#5	LK21ICst.35_surface	2	1.73
36	35	T3#5	LK21ICst.35_DCM	32	1.6
37	35	T3#5	LK21ICst.35_bottom	417	1.45
38	39	Melville3	LK21ICst.39_surface	2	1.5
39	39	Melville3	LK21ICst.39_DCM	15	1.65
40	39	Melville3	LK21ICst.39_bottom	343	1.75

Water sampling for biogeochemistry (nutrients, chlorophyll a, SPM)

To assess the impact of glaciers on the biogeochemical properties of water and on marine ecosystems we conducted a water program using a 'Mini Rosette' water sampling system equipped with 6 individual 5 L Niskin bottles that could be programmed to close at selected depths. At 30 stations we collected 10-15ml water from depths in the upper 50 m of the water column for analysis of dissolved nutrients (nitrate, phosphate, and silicate). For nutrient samples, water was filtered through 0.45 µm Millipore filters and stored frozen at -20 °C. For chlorophyll a, 500 ml water was filtered onto 25 mm GFF filters and frozen at -20 °C.

At a subset of 14 of these stations we also sampled deeper water for nutrient analysis (as above), bacterial abundance and suspended particulate matter (SPM). Approximately 4 ml water at each sampled depth was collected for bacterial abundance analysis via flow cytometry. These were fixed with 20 µl 2% glutaraldehyde and frozen at -20 °C. For SPM, between 1000 and 2000 ml of water from selected depths was filtered onto pre-weighed and pre-combusted 25 mm GFF filters and frozen at -20 °C.

A complete list of samples taken for water biogeochemistry is given in Appendix 3.

Zooplankton

Zooplankton were collected at 6 stations using a Hydrobios Multinet equipped with nets of 50 µm mesh. This could be programmed to open and close the nets across five depth ranges that varied depending on the seafloor depth, for example at 0 - 100 m, 100 - 200 m, 200 - 300 m, 300 - 400 m and 400 - 550 m. The nets were rinsed thoroughly with seawater and their contents were preserved with 25 ml 4 % buffered formalin and stored dry.

Individuals in samples will be identified, counted, and measured for prosome length, and this data will be used to calculate zooplankton biomass using known length to weight regression values from literature.

Figure 12 - Deployment and recovery of the multinet for zooplankton sampling

Table 2 – List of samples collected for zooplankton investigations

			Programmed depth ranges				
Date	**Station**	**Stn depth**	**Net 5**	**Net 4**	**Net 3**	**Net 2**	**Net 1**
23-08-2021	2	600	100	200	300	400	530
24-08-2021	3	380	50	100	150	200	310
26-08-2021	15	1000	150	300	450	600	800
27-08-2021	21	747	100	200	300	400	500
28-08-2021	24	370	50	100	150	200	250
30-08-2021	39	367	50	100	150	200	250

			Sample numbers				
Date	**Station**	**Stn depth**	**Net 1**	**Net 2**	**Net 3**	**Net 4**	**Net 5**
23-08-2021	2	600	1	2	3	4	5
24-08-2021	3	380	6	7	8	9	10
26-08-2021	15	1000	11	12	13	14	15
27-08-2021	21	747	16	17	18	19	20
28-08-2021	24	370	21	22	23	24	25
30-08-2021	39	367	26	27	28	29	30

Phytoplankton sample collection, onboard microscope observations and culturing

At selected stations, water samples collected with Niskin bottles ranging 0-50m water-depth (and 200m-bottom for two stations) were gathered into 25L containers and filtered through a 20-µm mesh for phytoplankton work. Sub-samples of 100-200 ml were fixed with Lugol's solution (4%) and stored at 4°C in amber glass bottles for further taxonomic investigations. Live material from a few stations was both observed under an upright light microscope on board and placed into replicate culture flasks with growth medium (TL and L1). Mixed phytoplankton cultures were kept alive under cool white light at constant temperature in the ship's walk-in cold room (5°C). Microscope observations on board revealed diverse phytoplankton assemblages. The assemblages from station 3 included the diatom taxa *Chaetoceros* spp. (e.g. *C. affinis, C. willie and C. decipiens*), *Leptocylindrus* spp. and *Rhizosolenia* spp. and dinoflagellates of the genus *Protoperidinium* as well as *Ceratium arcticum*. Station 12 was largely dominated by diatoms, mainly *Thalassiosira* and *Chaetoceros* species. *Coscinodiscus* species were detected at low abundance. At station 39, the assemblages were dominated by diatoms, including *Chaetoceros* spp., *Thalassiosira* spp., *Pseudo-nitzschia* spp. and dinoflagellates *Alexandrium tamarense*, *Protoperidinium* sp. and *Ceratium* spp. Single-cell isolations of target species, namely *Pseudo-nitzschia* spp. and *Alexandrium tamarense* were performed at GEUS upon arrival to establish clonal cultures and investigate the potential toxicity of these species.

Table 3 – List of samples collected for phytoplankton investigations

Sample #	Station	Mesh size (µm)	Water depth (m)	Volume filtered (L)	Live sample
1	2	20	200-439	10	
2	2	20	0-50	20	
3	3	20	200-340	10	
4	3	20	0-50	20	x
5	12	20	0-50	20	x
6	13	20	0-50	15	
7	17	20	0-50	15	
8	18	20	0-50	15	x
9	21	20	0-50	15	
10	26	20	0-50	15	x
11	35	20	0-50	15	x
12	39	20	0-50	15	x

6.3 Holocene Paleoceanography (WP3)

6.3.1 Seismo-acoustic investigations

The seismo-acoustic investigations (sub-bottom profiling (SBP) and multibeam echosounding (MBSE) on the ICAROS-2021 expedition served two purposes:

1. To investigate the geology of the surveyed area, primarily focusing on the configurations of (smaller or larger) sediment basins and expected thickness of soft sediment successions, but also on identification and mapping of morphological features on the seafloor (e.g. glacial landforms), substrate structures such as faults and folds, and re-depositional sediment structures such as contourites or mass transport deposits
2. To identify suitable locations for the sediment sampling program with the gravity and Rumohr Lot corers based on the investigations of the geology and in particular the surveying for soft sediment (mud) packages (preferable > 4 m in thickness)

During the first leg (Aasiaat to Pituffik), SBP and MBES data were acquired almost continuously (e.g. both during transit and at stations), as much as the surveyor capacity allowed (only one geophysicist onboard LAKO to do the surveying). At some nights, the ship was anchored and surveying could therefore not be performed.

All stations (both CTD and sediment coring stations) were preplanned prior to the cruise. While some of these were well-constrained in terms of information on the substrate and sediment compositions (e.g. by use of existing seismo-acoustic data or information from the literature), others were planned with no prior knowledge of the substrate conditions and no existing seismo-acoustic data control. Hence, for all coring stations seismo-acoustic surveying were carried out prior to deploying the coring devices in order to check the substrate conditions. Depending on the amount of shiptime set aside for surveying these site investigations ranged in duration from only a couple of crossings at the coring sites, to several hours when surveying was planned during the night time and a proper survey could be done. For many of the planned sites, the surveying showed good conditions for coring, while for others, new locations had to be found based on a more extensive survey – typically in an area of ca. 10 km x 10 km around the originally planned site.

Suitable coring sites were identified as areas with a relatively flat or smooth seafloor and where at least 3 m of subparallel (stratified) low-amplitude reflections could be observed on the SBP data immediately below the seafloor. Furthermore, the area of stratified reflections should preferably have a certain lateral extent (>100 m) to allow for some drifting during the coring operations. When drifting exceeded ca. 500 m, the ship typically repositioned back to the planned site.

The seismo-acoustic investigations were carried out from the Flexroom at LAKO via remote desktop connections to the SBP (Fig. 13), MBES and NaviPac/NaviScan computers. Communication to the bridge and the aft deck relied on radios or telephone. It would have been of benefit, with a screen link to the cameras on the aft deck from the Flexroom, so that the geophysical surveyor placed in the Flexroom could follow the deck operations more easily.

Sub-bottom profiler

<u>Instrument and method</u>

The sub-bottom profiler instrument used for the shallow seismic surveying onboard LAKO is an Innomar SES-2000 Deep, Narrow-Beam Parametric Sub-Bottom Profiler. The instrument is hull-mounted on the ship (placed centrally in the front half of the ship), next to the multibeam echosounder, and associated with a motion sensor (IMU) for recording the heave, pitch and roll variations and a GPS (Applanix PosMV5) for navigation. The cruise track was logged via the Ethernet Logging option in the POSMV module and also via the NaviPac Custom Logging Module.

The parametric sub-bottom profiler works by transmitting a primary fixed high-frequency (HF) (35 kHz) sound pulse (formed as an electrical signal from a transducer) and a secondary pulse that interferes with the primary pulse to form a final lower frequency (LF) sound pulse with frequencies between 2 and 7 kHz. The sound travels through the water column to the seafloor and subsurface layers where it is reflected from the seafloor and the layer interfaces and then travels back to the receiver where it is recorded (Fig. 13). By utilizing the time it takes for the pulse to travel to the seafloor and back again (the two-way-travel time, TWT) as well as the differences in arrival time from different layer interfaces at varying depths (Fig. 13), vertical profiles of the subsurface can be constructed. From these, the geophysicist can interpret the subsurface.

The SBP instrument records data in SES and RAW formats (Fig. 14), which are converted to SEG-Y format using the SES-convert software. No processing of the raw data was carried out onboard LAKO. After conversion, the SEG-Y files were loaded into IHS Markit Kingdom Suite (seismic interpretation software) (Fig. 15) for preliminary interpretation.

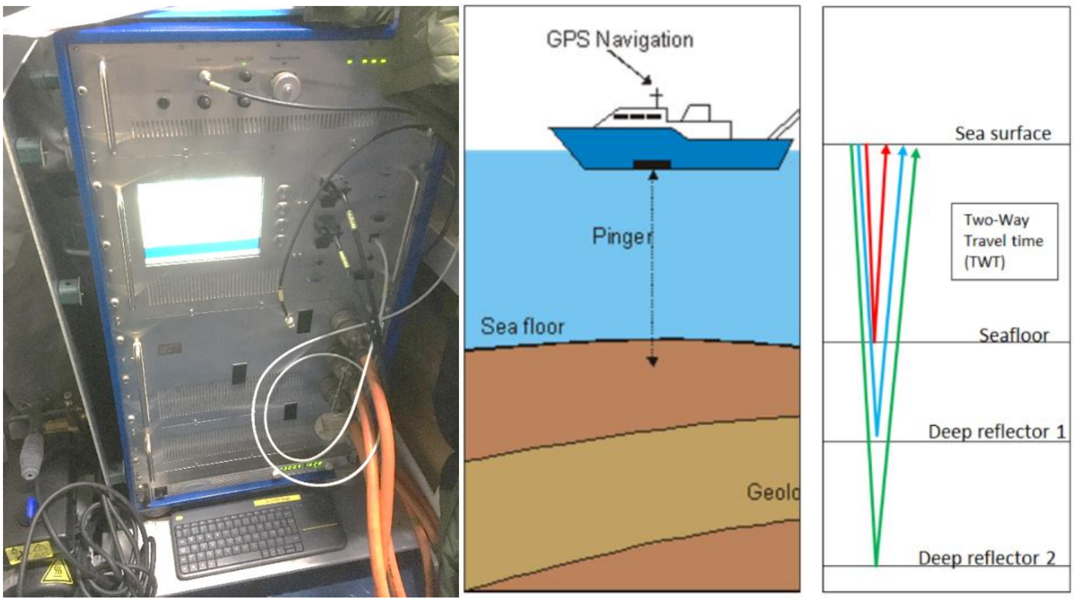

Figure 13 - Sub-bottom profiler. Left: Control computer for the permanently installed Innomar SES-2000 Deep sub-bottom profiler at LAKO. Middle and Right: Principle of seismic reflection used in sub-bottom profiling. Reflections from the deeper geological layers will arrive later (i.e. longer two-way travel times (TWT)) than reflections from the shallower layers. The difference in arrival time can be processed into images (vertical sections/profiles) of the subsurface.

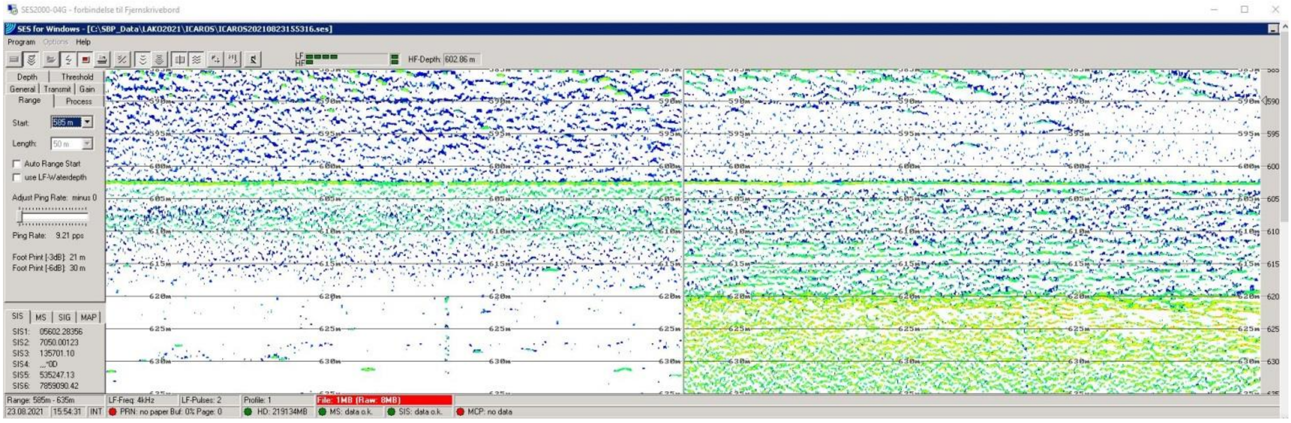

Figure 14 - Example of a raw data recording display from the SES-win software at Station 2 (Ummanaq) showing a thick sedimentary drape above basement rocks. Settings for the data recording are adjusted in the left-side grey panels. Left color display shows the HF signal (which is mainly used for seafloor detection) while the colour display to the right shows the LF signal (where the substrate is visible). Vertical scale is meters (depth converted from TWT using a constant velocity of 1500 m/s).

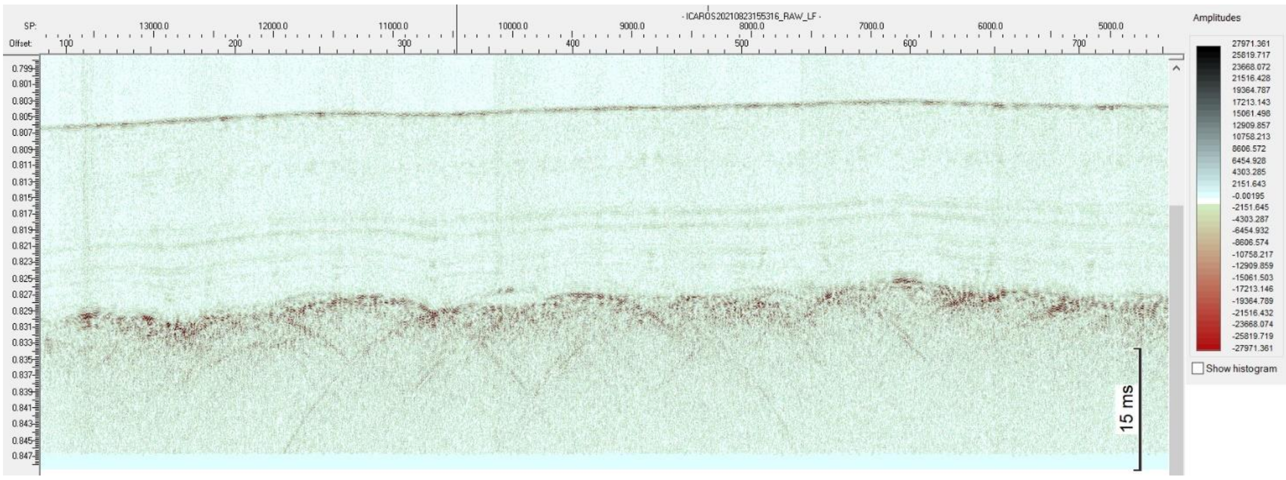

Figure 15 - Corresponding image of the data from Fig. 14, converted to segy-format and loaded in Kingdom Suite. Vertical scale in TWT.

Data quality and resolution

As the target area for the ICAROS expedition extended across Disco Bay, Uummannaq and Upernavik Troughs and fjord systems, and Melville Bay, a wide range of water depths from 50-1800 m were encountered. In the beginning of the cruise, settings were tested in order to find the best settings for a good data quality. These settings were then generally kept throughout the cruise (Fig. 16). In summary, we used a 4 kHz LF pulse, with 2 LF pulses emitted, and a range length of either 50 m, 100 m or 200 m. The Deep Water Pulse Mode was activated, which allowed for higher ping rates up to 11 pps for the 50 m range length. The 50 m range length was preferably used at the coring sites in order to get higher resolution images of the substrate, while we often used 100 m or 200 m range during the transits. For the coastal areas, use of the larger range lengths were particularly necessary due to great variations in water depths over small distances.

Acquisition speed varied as surveying was done both during transit and at stations. Transit speed was 12 knots, while dedicated survey speed was 5 knots or 8 knots. All speeds produced usable data although for detailed mapping, the 5 knots was clearly best. Interference with propeller noise appeared to be reduced below 5 knots, while it was most severe at around 7 knots. Other tests for eliminating noise were also performed such as checking the interference with the other acoustic systems on LAKO, in particular the MBES as well as the single beam echosounder (SBES) and forward-looking sonar used by the bridge. None of these appeared to have any negative effects on the quality of the SBP data. The main factor for SBP data quality was therefore related to survey speed.

The SES-2000 Deep is designed to deliver ultra-high-resolution reflection seismic data optimized for mapping the shallowest subsurface. Depending on the geology of the areas investigated and the water depths, the subsurface penetration depth on the ICAROS 2021 expedition varied from no penetration in areas with a 'hard' seafloor, such as on the ice ploughmarked platforms on the shelf, to over 50 m penetration in areas with thick soft sediment successions – typically within the fjords. The average penetration was around 15-20 m. Concerning resolution, an average velocity of 1500 m/s for the sediments gives a dominant wavelength of 0.4 m (using a dominant frequency of 4 kHz) which in turn gives a vertical resolution around 10 cm (estimated here as a quarter of the dominating wavelength). Hence, the instrument should be able to fully resolve layers that are above 10 cm in thickness.

INNOMAR SETTINGS ICAROS 2021			
Range		**Threshold**	
Auto Range Start	OFF	LF Mode	LOG
Use LF-waterdepth	OFF	LF Min level	5
Ping Rate	Maximum, ranges from 1-11 pps ca, depends on water depth, lenght of range window and transmit mode	LF SRange	10
Length	50-200 m, depending on expected topography	HF Mode	LOG
General		HF Min Level	1
Ship	LAKO	HF SRange	10
Travel	ICAROS 2021	**Gain**	
Area	NW Greenland	LF Gain	60-70 dB
Depth		HF Gain	46-60 dB
LF detection sesibility	40 %	LF Auto Gain control	OFF
HF detection sensibility	40 %	HF Auto Gain Control	OFF
Detection offset	10 %	Deep Water Amplifier	OFF
Bottom Averaging	5	**Transmit**	
Process		LF frequency	4 kHz
Stacking	2	LF Pulses	2
Smoothing	3	High Energy Mode	OFF
soft TVG	0 to 0.5	Multi Frequency Mode	OFF
LF Depth for TVG	OFF	Dual Range Mode	OFF
Normalize Gain	OFF	Beam Steering Mode	OFF
Reduce Noise	ON	Deep Sea Pulse Mode	ON
Median Filter	ON	Burst Mode	OFF
Swell Filter	OFF	Chirp Mode	OFF

Figure 16: Overview of SBP settings used during the ICAROS2021 expedition.

Encountered operational problems

Based on experience from the LAKO research cruise in 2019 (BIOS2019), trigger cables from the SBP and the MBES had been installed on LAKO. Using a trigger box unit from Aarhus University, these cables should allow for trigger synchronization of the two systems (and a third sparker system used during the DaSSap cruise) so that interference could be avoided. While the trigger box connection to the SBP worked without problems, the connection to the MBES did not come through. The trigger cable itself was tested for errors, but none were found. This led us to conclude that the trigger cable most likely had been connected to the wrong port on the MBES computer in Apparatrum 3. Since the connection is placed on the back side of the MBES computer, we could not immediately check whether this was in fact the case. Rather, we needed assistance from the ships technician to dismantle the MBES computer for performing this check-up. Due to a tight research program, where the DCH technician onboard was needed for CTD winch and A-frame operations full-time, we did not investigate the problem any further.

We also did not have the possibility of using the built-in synchronization options in the user interfaces for the SBP and MBES because the two instruments were not connected. Hence, surveying was done throughout the cruise with no synchronization between the MBES and the SBP. The lack of synchronization caused a slightly lower quality of the recorded MBES data – particularly for water depths above 550 m (see more in section on MBES). However, it did not, as described earlier, induce any negative effects on the SBP, but rather allowed for the highest possible ping rates for the SBP to be used (via the Deep Sea Pulse Mode) since the SBP did not have to ‘wait’ for the slower pinging MBES.

Other issues to be mentioned are instances of drop-out of the POSMV GPS (twice). It occurred two evenings in a row (26-27 august 2021, while the ship was in the Upernavik Trough) at around 19.30 (ship time) and lasted for about 20 min. During this time interval the POSMV did not receive reliable GPS input impacting both the navigation/positioning in NaviPac and Helmsmann Display as well as the IMU sensor data and the roll, pitch and heave logging for the SBP (in the SES-2000 software) and MBES (in NaviScan). During the drop-out time, the SBP seafloor and trackline in Helmsmann Display ‘jumped’ (see Fig. 17). Restarting NaviPac online did not fix the problem, so it was likely isolated to the POSMV. After approximately 20 min, the POSMV received normal data again and the problem was over. This only occurred twice during the cruise.

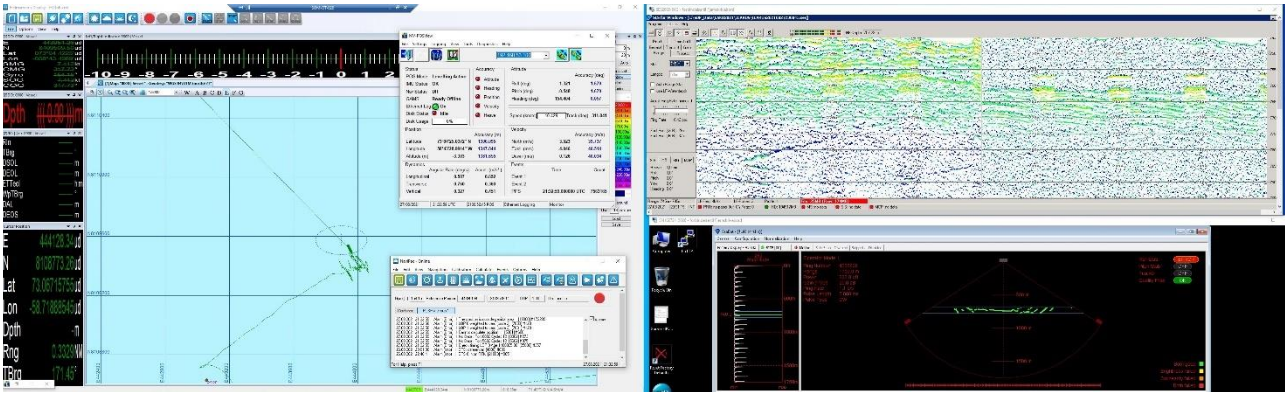

Figure 17: Screen-dump showing data during drop-out of POSMV on the 27 august 2021. All instruments and navigation data were affected.

Multibeam echosounding

The multibeam echosounder (MBES) acquisition on the ICAROS-2021 cruise served to acquire bathymetry data along the planned transects, at stations and during transit between stations. This data provide information on the seafloor morphology, which allow for interpretations of glacial and sediment dynamics in the surveyed areas and can further be used as additional information in the selection of good coring sites (e.g. Fig. 18).

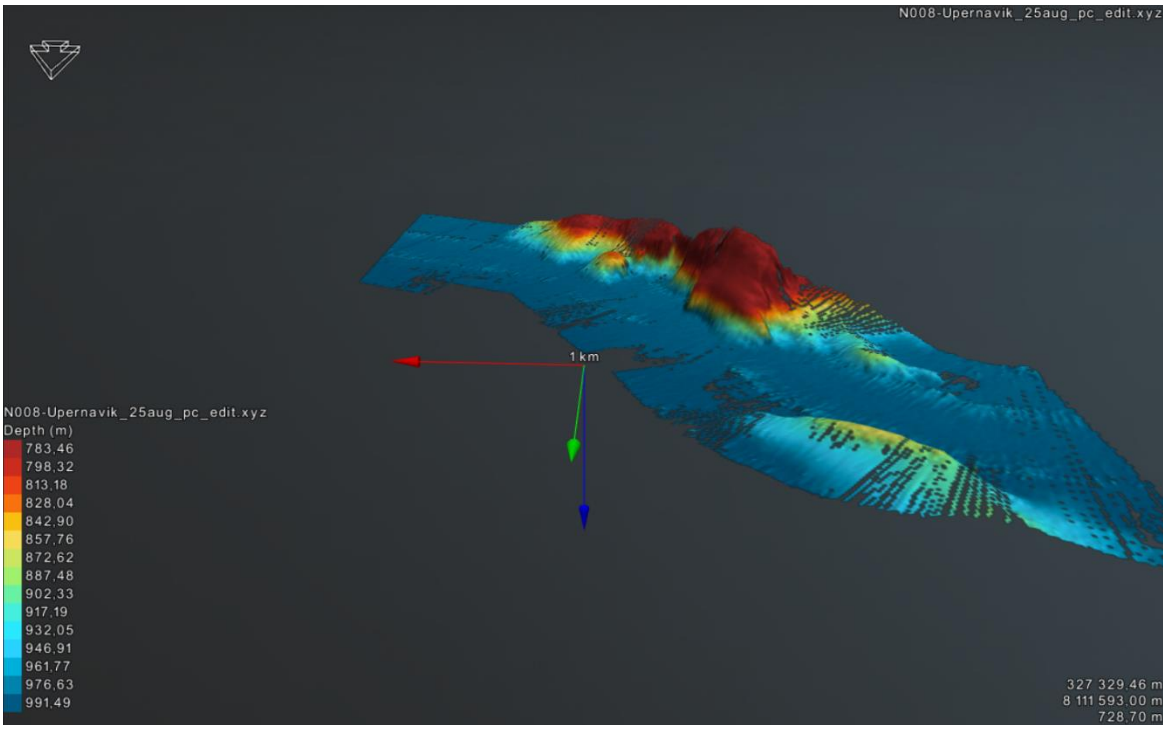

Figure 18: Example of recorded MBES data as they appear in NaviModel. The data is from the Upernavik Fjord (view towards south) showing a flat fjord bottom with soft stratified sediments and steep rocky sides.

LAKO is routinely used by the Danish Hydrographic Service (Søopmålingen) and the infrastructure for acquisition of bathymetry was passed on in an informal handover with the hydrographers before they departed the ship. This was done in Nuuk on the 12. August 2021 in relation to the previous research cruise with LAKO, DaSSap (the week prior to ICAROS). The handover included discussions on software setup, acquisition parameters and post-processing workflows related to the Seabat 7160 and the RapidCast system. The RapidCast system was used during the DaSSap cruise but not deployed during the ICAROS cruise because CTD measurements were carried out with other instruments at the stations.

In general, MBES bathymetry was acquired continuously as far as possible. Survey time was limited by the capacity of only one geophysicist onboard the ship responsible for all of the surveying. At stations, the MBES was typically turned off during the winching operations. MBES data was logged to NaviScan Online where a point cloud and preliminary DTM could be viewed together with heave, roll and pitch measurements to quality check the data. Data was logged in .SBD format together with the online sound velocity profile data. Water column data or backscatter data (side scan and snippets) (.s7k format) were not acquired or recorded during this expedition.

Instrument and method

LAKO has two hull-mounted MBES systems. A Teledyne Reson Seabat T50 and 7160. Because we acquired data in both deep and shallow water settings, we used the Seabat 7160 during the entire expedition. This MBES emits up to 512 beams in a swath that produces "3D-scannings" of the seafloor. Navigation and altitude data is derived from the Applanix PosMV5. Online sound velocity used in the beamforming process is obtained from two SV70 sensors mounted and run in a tandem configuration. Multibeam parameter settings used during the cruise are shown in Fig. 19.

MBES SETTINGS ICAROS 2021

Instrument type	**Reson Seabat 7160**
Primary high frequncy	44kHz
Range	varies with water depth
Power	full power (223 dB)
Beam Mode	Best coverage (512ED) (equi-distant)
Ping rate	Max
Actual ping rate	around 1.0-1.3 pps
Beam width	1.5 degree (minimum)
Puse length	4.5 ms (ok for water dephts up to 500 m), deeper 8.0 ms
Pulse Type	CW (constant wavelength at 41.5 kHz), not used FM (Frequency modulated)
Horizontal steering	0 degrees as default but sometime steering was used in the fjords
Coverage angle	80-130 degrees, varies depending on noise from innomar and water depth
Absolute depth gates	varies, depending on water depth
online sound velocity probe	varies typically around 1470-1480 m/s
Absorption	0.0 dB/km
Spreading	3.0 dB
Tracker	OFF

Figure 19: Settings for the 7160 used during MBES surveying on ICAROS 2021.

Data quality

The quality of the MBES data was generally very good (Figs. 20 and 21) except for water depths where there was a high interference with the SBP (Fig. 22).

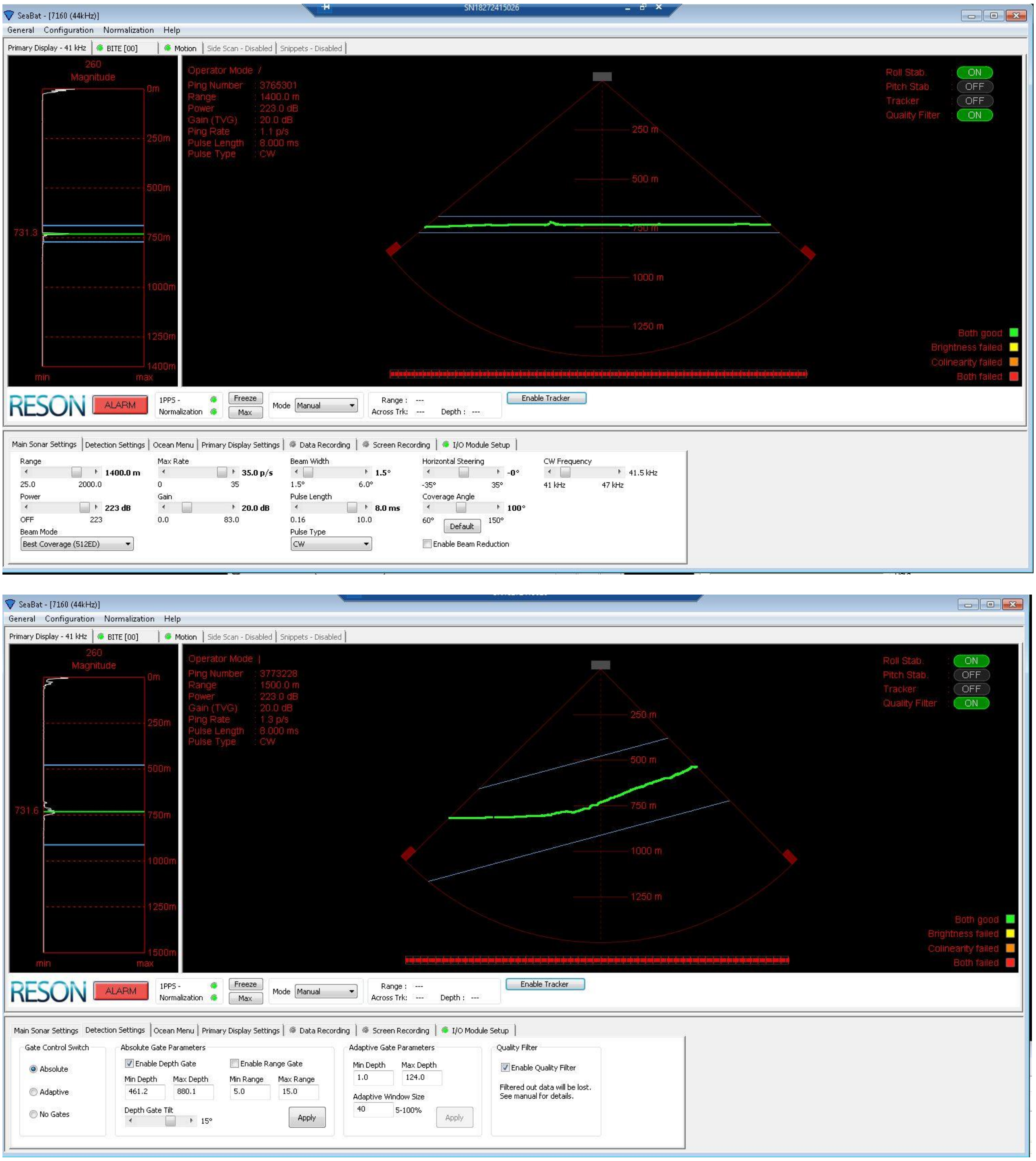

Figure 20: Examples of good MBES data from the SeaBat 7160 User Interface, with no interference from the SBP (turned off). There is a strong clear detection of the seafloor in both examples. Top: water depths of 731 m showing an area with a generally flat seafloor. The minor curvature is due to the actual seafloor topography). Bottom: MBES from one of the fjords where tilting of the depth gates was applied.

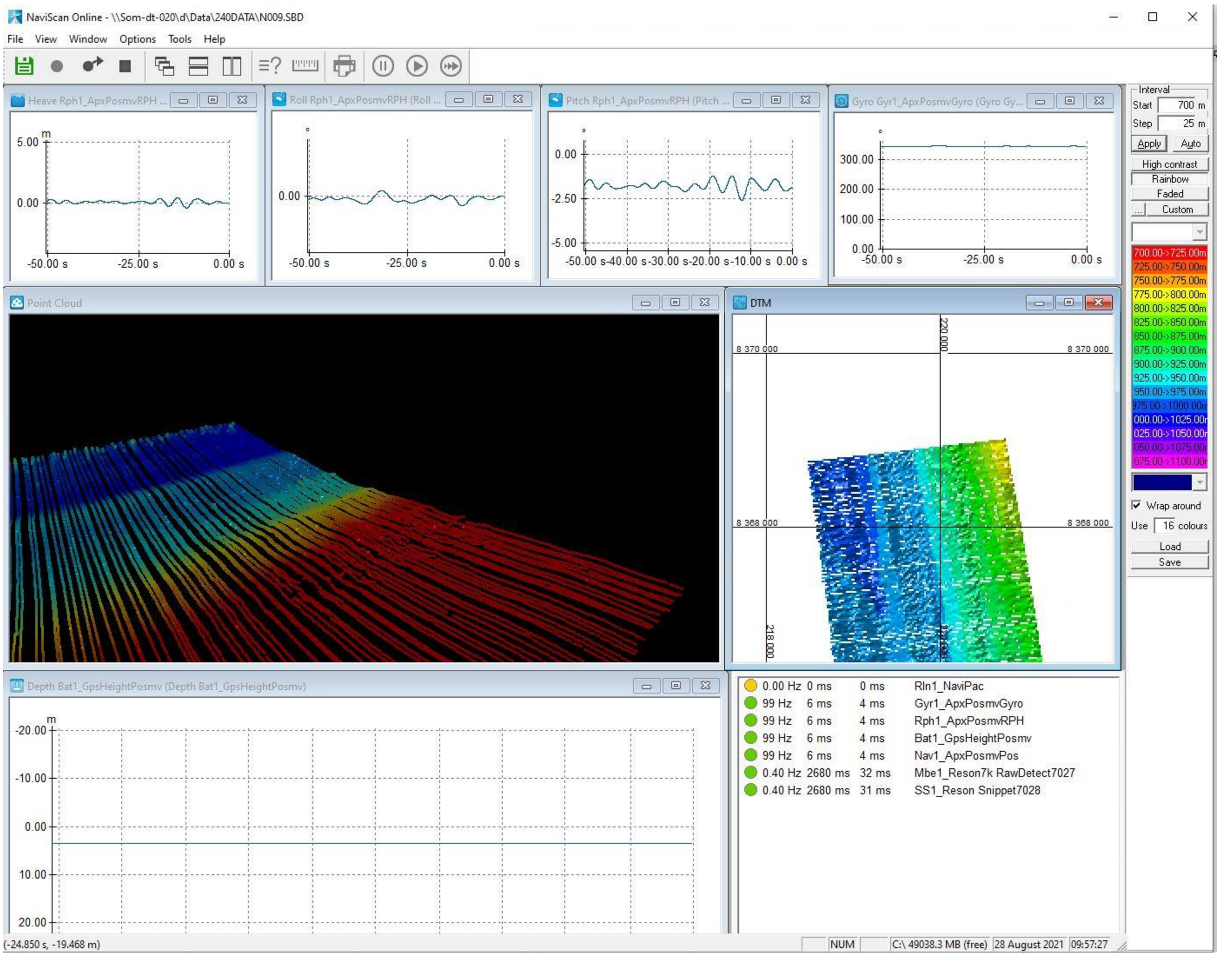

Figure 21: Example of good MBES data logged in NaviScan Online.

Poor data resulted from interference with the SBP due to the lack of synchronization between the two instruments as described earlier. Interference was most severe for depths > 550 m. Below 550 m water depth, the SBP did not disturb the MBES very much. MBES recording was typically paused when drifting at stations. For some of the transits across deep-water settings, we further decided to turn off the SBP recording to allow for good MBES.

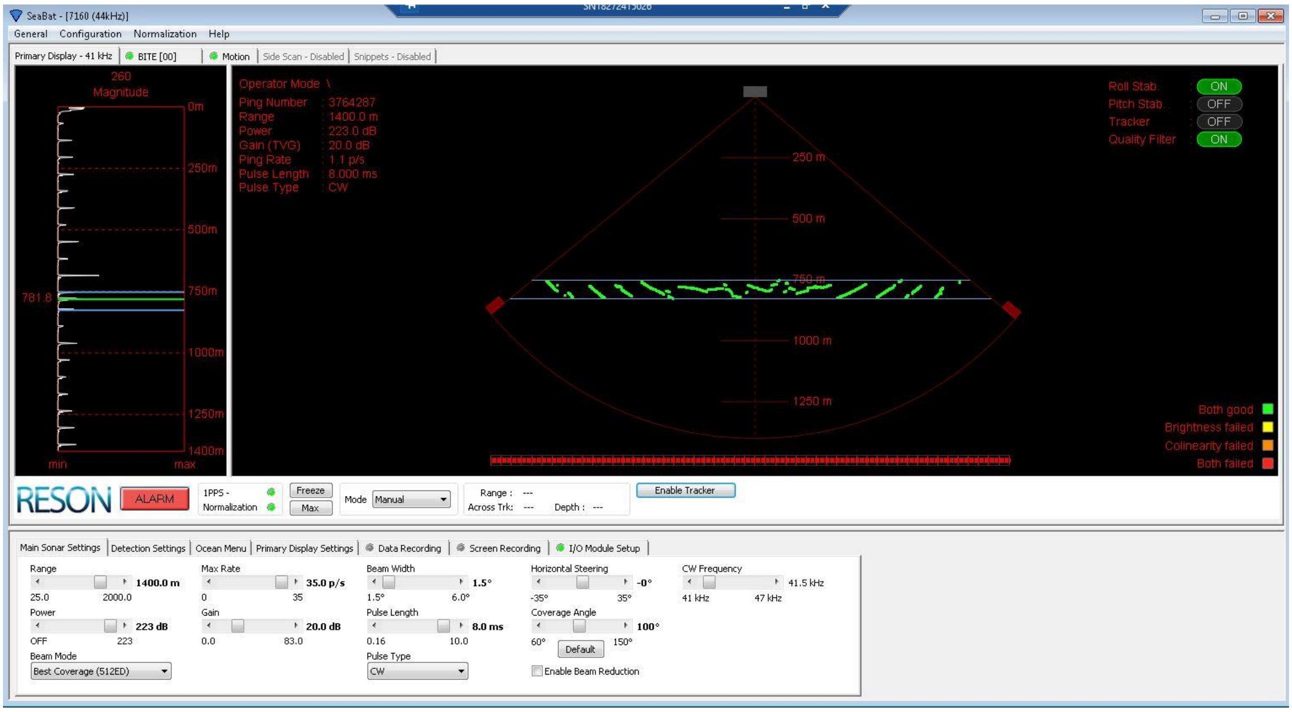

Figure 22: Example of poor MBES data at water depth of 750 m, due to interference with the SBP

For some of the recorded data, the MBES data showed a set of two parallel noise lines at approximately 30-40 degrees angle on either side ("Erik's horn" artefacts). We tested whether this noise was induced by the SBP, the SBES or the forward-looking sonar, but turning off all three instruments did not remove the noise. Hence, this is something that will have to be cleaned during the postprocessing of the data. No such processing was performed during the cruise due to limited surveyor capacity.

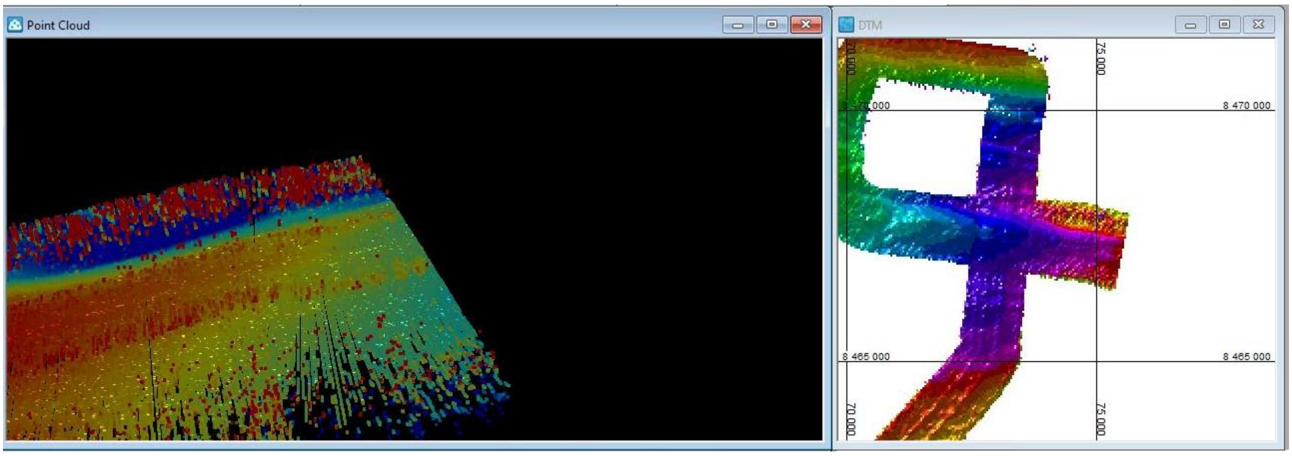

Figure 23: Point cloud and DTM from NaviScan showing the two parallel noise tracks at ca. 30-40 degree angles (from nadir) on both sides. The noise will be cleaned during processing of the data

6.3.2 Sediment sampling

We retrieved a total of 14 Haps, 8 Gravity cores and 4 Rumohr cores during the expedition, which amount to about 40m of marine sediments (including 34m of gravity core records).

HAPS corer

Surface sediments were collected from the seafloor using a HAPS sediment corer. The HAPS is highly suitable for taking well defined, undisturbed samples from hard as well as soft sediments. This can be seen by a clear water phase above the sediment surface. When the sediments were covered by seawater, the water was removed using a 50 mL syringe (previously soaked in 1% bleach followed by 70% ethanol rinse). Stones or larger organisms were removed from the surface if necessary. We sampled 10 g of the sediment surface (0-1 cm, stored frozen) for DNA into a sterile Whirl-Pak using a sterile spoon, followed by 20 g for biomarkers (0-1 cm, stored frozen), 20 g for germination (0-2 cm, stored cooled) and 20 g for foraminifer microfossil analyses (0-2 cm, stored cooled). We collected 14 samples for germination, 13 for DNA and biomarkers, and 11 for foraminifers.

Table 4 - List of surface sediment samples taken for eDNA analyses, germination (fresh), biomarkers (freeze), and foraminifers (forams).

#	Station	Sample name	Region	Samples
1	2	LK21ICst.2HAPS1	Uummannaq	fresh
2	3	LK21ICst.3HAPS1	PS26 area	DNA, fresh, freeze
3	12	LK21ICst.12HAPS1	Uper1	DNA, fresh, freeze
4	15	LK21ICst.15HAPS1	Up7	DNA, fresh, freeze, forams
5	17	LK21ICst.17HAPS1	Up9	DNA, fresh, freeze, forams
6	18	LK21ICst.18HAPS1	T1#12	DNA, fresh, freeze, forams
7	21	LK21ICst.21HAPS1	PS25	DNA, fresh, freeze, forams
8	22	LK21ICst.22HAPS1	T2#1	DNA, fresh, freeze, forams
9	24	LK21ICst.24HAPS1	T2#3	DNA, fresh, freeze, forams
10	26	LK21ICst.26HAPS1	Melville1	DNA, fresh, freeze, forams
11	28	LK21ICst.28HAPS1	T3#12	DNA, fresh, freeze, forams, push core
12	32	LK21ICst.32HAPS1	T3#8	DNA, fresh, freeze, forams
13	35	LK21ICst.35HAPS1	T3#5	DNA, fresh, freeze, forams
14	39	LK21ICst.39HAPS1	Melville3	DNA, fresh, freeze, forams

Figure 24 - Deployment of the Haps corer during ICAROS21

Rumohr lot

The Rumohr corer consists of weights to which an unsupported transparent liner made from PC (up to 2m-long and with an outer diameter of 80 mm) is attached. When the Rumohr corer reaches and penetrates the seafloor, the liner is filled with sediment and the loss of tension on the wire causes the lid to release. As the corer is pulled up, the tension closes a small valve on top of the liner, which keeps the sediment from being lost. A Rumohr-lot core makes it possible to retrieve a sediment record of the uppermost seabed without disturbing the sediments. This is possible because the core penetrates the sediment with a relatively small weight compared to that of a gravity core, thereby decreasing the likelihood of sediments being blown away from the seabed. During ICAROS21, the Rumohr lot was deployed using the A-frame and 50kN winch. The liner bottom was capped during recovery (with the corer still attached to the winch) and after each core was secured on deck, a hole was drilled in the liner close to the water-sediment interface to remove the water. The surface sediments were sub-sampled on deck before each core was capped, labelled, sealed, and stored in the refrigerated container.

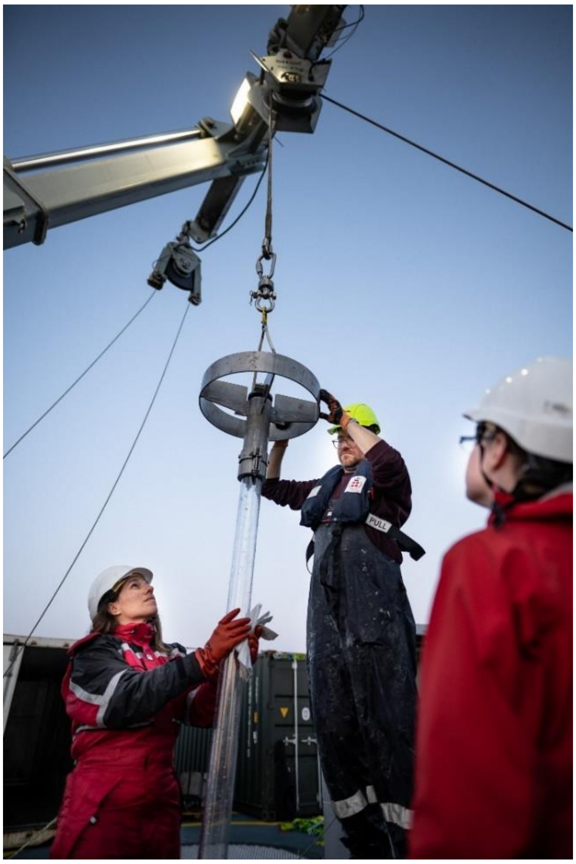

Figure 25 - Mounting of a liner in the Rumohr corer metal frame before deployment

Gravity corer

A gravity corer consisting of a 5.8m-long metal barrel was used to recover soft Holocene sediments. Besides the metal barrel, the gravity corer includes a core catcher, and lead plates making up a total weight of about 1000 Kg. Before each deployment, the core barrel was loaded with a PVC liner with an outer/inner diameter of 125/115 mm. The core catcher prevents the liner with sediments from sliding out of the barrel after recovery. The gravity corer was deployed by using both the ships crane and the A-frame, installed at the starboard side of the ship. The corer was deployed at a velocity of 1 m/s. After recovery, the gravity corer was moved inboard and turned along the ship using the LAKO crane. We carefully removed the core catcher and collected any visible material suitable for radiocarbon dating (e.g. mollusk shells, seaweed fragments, organic warm tubes) as well as core catcher sediments into sample plastic bags. Prior to cutting and to avoid contamination (sedaDNA studies), both the liner and the metal spatula used to slice the sediments were carefully cleaned with bleach and ethanol. The liner was then cut into 1m-long sections and each section was labelled, capped on both ends, sealed with tape, and stored in the refrigerated container (4-7 °C). The deployment of the gravity corer was successful and there were no technical problems, however, since the corer was missing a metal plate, overpenetration occurred at several of the coring sites with soft sediments (see Table below for details).

Figure 26 - Deployment and recovery of the gravity corer

Table 5 – List of Rumohr and Gravity cores retrieved during ICAROS21

#	Station	Water depth (m)	Core type	Core ID	Length (cm)	Core catcher	Comments
1	1	438	GC	LK21ICst.1GC1	573 (6 sections)	Bulk and seaweed	C14: 2 shell samples (B sec 2 and T sec 6), overshot
3	2	600	RUM	LK21ICst.2R1	124	-	Undisturbed surface; about 25cm of the core bottom lost
4	2	601	GC	LK21ICst.2GC1	575 (6 sections)	Bulk	Shell fragments at bottom of section 1, overshot
5	3	368	RUM	LK21ICst.3R1	107	-	Undisturbed surface
6	3	374	GC	LK21ICst.3GC1	575 (6 sections)	Bulk	C14: Core catcher shell, and shell from bottom of sec.1

#	Station	Water depth (m)	Core type	Core ID	Length (cm)	Core catcher	Comments
7	12	998	GC	LK21ICst.12GC1	575 (6 sections)	Bulk	C14: tube worm from bottom, overshot
8	21	747	GC	LK21ICst.21GC1	400 (4 sections)	Bulk	Section 5 lost
9	26	912	GC	LK21ICst26GC1	320 (4 sections)	Bulk	Top recovered, but top ca. 15cm disturbed
10	28	1705	Haps	LK21ICst.28H1	29	-	Push-core from Haps after sampling the surface
11	36	555	RUM	LK21ICst.36R1	53,5	-	Surface tilted, core tube bent
12	36	559	GC	LK21ICst36GC1	256 (3 sections)	Bulk	Surface recovered; slightly disturbed
13	37	570	GC	LK21ICst.37GC1	156	Bulk	Top recovered; Surface collected in a sample bag

7. Permits (leg 1)

In compliance with the Biological Diversity Convention, the Nagoya Protocol and the Greenland Parliament Act no. 3 of 3 June 2016, we obtained a Prior Informed Consent for the collection and use of genetic resources in Greenlandic waters (non-exclusive licence no. G21-041) from the Ministry of Foreign Affairs, Business, Trade and Climate of Greenland on the 10.08.2021. This licence includes an export permit for the genetic resources.

8. Outreach

A filmmaker from the GEOCENTER Underground Channel (Frederik Teglhus) joined the cruise and collected high-quality visual material for communication and educational purposes. This included professional still photography and short films.
Four short films were produced and are available at the Channel homepage:
https://www.undergroundchannel.dk/videos#64532389
The cruise was promoted via social media (Twitter and Facebook, #ICAROS21) and via a blog hosted at the GEUS homepage:
https://eng.geus.dk/nature-and-climate/palaeoclimate/scientific-expedition-on-board-hdms-lauge-koch
Collaboration with Underground Channel will ensure a professional digital legacy of the cruise for multiple purposes.

9. Acknowledgments

We thank the captain and crew of *HDMS Lauge Koch* for their outstanding support and hospitability. A special thanks to John Boserup and the logistics department at GEUS for providing logistical support and testing the coring equipment during the cruise preparation phase. This research cruise was funded by the Dansk Center for Havforskning, The Independent Research Fund of Denmark (DFF Sapere Aude grant nr. 9064-00039B), and the European Union (Marie Skłodowska Curie Actions). We are indebted to Eik Bristch for his invaluable technical assistant during the cruise and Anna Bang Kvorning for onshore support and for designing the cruise logo.

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11. Appendices

Appendix 1 – Full station Log

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
22-08	2012	RB	1	69,39285	-51,02247	438	0,1	CTD1	Deploy	
22-08	2035	RB	1	69,39345	-51,02079	438	0,3	CTD1	Bottom	
22-08	2044	RB	1	69,39403	-51,01964	439	0,4	CTD1	Recover	
22-08	2118	RB	1	69,39708	-51,01405	439	0,4	CTD2	Deploy	
22-08	2127	RB	1	69,39803	-51,01214	439	0,4	CTD2	Bottom	
22-08	2136	RB	1	69,39881	-51,01061	438	0,4	CTD2	Recover	
22-08	2142	RB	1	69,39937	-51,00966	439	0,4	CTD3	Deploy	
22-08	2146	RB	1	69,39969	-51,00911	439	0,4	CTD3	Bottom	
22-08	2149	RB	1	69,40007	-51,00868	438	0,4	CTD3	Recover	
22-08	2232	RB	1	69,40513	-51,00245	439	0,5	BOX1	Bottom	F
22-08	2250	RB	1	69,40706	-50,99972	439	0,4	BOX2	Bottom	F
22-08	2308	RB	1	69,40898	-50,99741	438	0,4	GC1	Bottom	OK
22-08	2345	RB	1	69,41278	-50,99231	438	0,5	RUM1	Bottom	F
23-08	00:07	RB	1	69,41523	-50,98837	434	0,4	RUM2	Bottom	OK
23-08	14:26	Uummannaq	2	70,82495	-56,03401	600	0,5	CTD1	Deploy	
23-08	14:50	Uummannaq	2	70,82469	-56,03981	601	0,3	CTD1	Bottom	
23-08	15:03	Uummannaq	2	70,82482	-56,04347	601	0,3	CTD1	Recover	
23-08	15:16	Uummannaq	2	70,82470	-56,04712	601	0,2	CTD2	Deploy	
23-08	15:33	Uummannaq	2	70,82506	-56,05304	600	0,2	CTD2	Recover	
23-08	15:54	Uummannaq	2	70,82540	-56,05975	600	0,2	RUM1	Bottom	OK
23-08	16:11	Uummannaq	2	70,82563	-56,06519	599	0,2	CTD3	Deploy	
23-08	16:13	Uummannaq	2	70,82567	-56,06565	599	0,2	CTD3	Bottom	
23-08	16:16	Uummannaq	2	70,82576	-56,06682	599	0,2	CTD3	Recover	
23-08	17:05	Uummannaq	2	70,82535	-56,03454	601	0,3	GC1	Bottom	OK
23-08	17:52	Uummannaq	2	70,83416	-56,05632	597	0,7	ZOO1	Deploy	
23-08	18:06	Uummannaq	2	70,83599	-56,05788	599	0,4	ZOO1	Bottom	
23-08	18:26	Uummannaq	2	70,83760	-56,06124	598	0,4	ZOO1	Recover	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
23-08	18:54	Uummannaq	2	70,83942	-56,06340	596	0,2	ZOO2	Deploy	
23-08	19:23	Uummannaq	2	70,84150	-56,06326	595	0,2	ZOO2	Recover	
23-08	19:57	Uummannaq	2	70,84289	-56,06037	594	0,2	CTD4	Deploy	
23-08	20:59	Uummannaq	2	70,82504	-56,03122	600	0,3	HAPS1	Bottom	Ok
24-08	10:27	PS26	3	72,23448	-58,81641	374	0,5	CTD1	Deploy	
24-08	10:46	PS26	3	72,23539	-58,82120	374	0,2	CTD1	Bottom	
24-08	10:58	PS26	3	72,23600	-58,82226	375	0,3	CTD1	Recover	
24-08	11:08	PS26	3	72,23746	-58,82413	372	0,4	HAPS1	Bottom	OK
24-08	11:28	PS26	3	72,24040	-58,82704	371	0,6	CTD2	Deploy	
24-08	11:54	PS26	3	72,24525	-58,83216	368	0,7	RUM1	Bottom	OK
24-08	13:24	PS26	3	72,23585	-58,81011	374	0,9	GC1	Bottom	OK
24-08	14:29	PS26	3	72,25265	-58,81603	363	0,9	ZOO1	Deploy	
24-08	14:36	PS26	3	72,25466	-58,81678	364	1	ZOO1	Bottom	
24-08	14:51	PS26	3	72,25892	-58,81742	353	1	ZOO1	Recover	
24-08	14:53	PS26	3	72,25958	-58,81759	356	1	ZOO2	Deploy	
24-08	15:01	PS26	3	72,26169	-58,81834	354	0,9	ZOO2	Bottom	
24-08	15:15	PS26	3	72,26480	-58,81988	353	0,8	ZOO3	Recover	
24-08	18:04	UT9	4	72,70420	-58,70636	186	0,5	CTD1	Deploy	
24-08	18:15	UT9	4	72,70576	-58,70838	184	0,6	CTD1	Bottom	
24-08	18:18	UT9	4	72,70625	-58,70835	185	0,6	CTD1	Recover	
24-08	18:58	UT8	5	72,77550	-58,89656	306	0,5	CTD1	Deploy	
24-08	19:15	UT8	5	72,77790	-58,89435	306	0,7	CTD1	Recover	
24-08	19:19	UT8	5	72,77858	-58,89341	306	0,6	CTD1	Bottom	
24-08	19:55	UT7	6	72,85000	-59,10130	460	0,6	CTD1	Deploy	
24-08	20:16	UT7	6	72,85345	-59,09940	483	0,4	CTD1	Bottom	
24-08	20:25	UT7	6	72,85443	-59,09921	485	0,5	CTD1	Recover	
24-08	21:00	UT6	7	72,92488	-59,30095	693	0,3	CTD1	Deploy	
24-08	21:30	UT6	7	72,92678	-59,30234	694	0,2	CTD1	Bottom	
24-08	21:47	UT6	7	72,92760	-59,30550	690	0,3	CTD1	Recover	
24-08	22:36	UT5	8	73,00000	-59,49974	651	0,1	CTD1	Deploy	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
24-08	23:03	UT5	8	73,00117	-59,50024	650	0,3	CTD1	Bottom	
24-08	23:12	UT5	8	73,00161	-59,50090	651	0,3	CTD1	Recover	
24-08	23:52	UT4	9	73,07495	-59,70064	534	0,2	CTD1	Deploy	
25-08	00:14	UT4	9	73,07549	-59,70502	523	0,3	CTD1	Bottom	
25-08	00:21	UT4	9	73,07596	-59,70585	517	0,3	CTD1	Recover	
25-08	00:59	UT3	10	73,15197	-59,90391	350	0,4	CTD1	Deploy	
25-08	01:15	UT3	10	73,15310	-59,90418	351	0,6	CTD1	Bottom	
25-08	01:20	UT3	10	73,15364	-59,90403	352	0,2	CTD1	Recover	
25-08	01:55	UT1	11	73,22716	-60,10833	313	0,5	CTD1	Deploy	
25-08	02:12	UT1	11	73,22981	-60,10913	312	0,8	CTD1	Bottom	
25-08	02:16	UT1	11	73,23056	-60,10973	311	0,4	CTD1	Recover	
25-08	11:44	UPPER1	12	72,94534	-55,62004	997	0,2	CTD1	Deploy	
25-08	12:15	UPPER1	12	72,94546	-55,62871	998	0,4	CTD1	Bottom	
25-08	12:28	UPPER1	12	72,94571	-55,63354	999	0,5	CTD1	Recover	
25-08	12:56	UPPER1	12	72,94811	-55,64256	998	0,4	HAPS1	Bottom	OK
25-08	14:00	UPPER1	12	72,94562	-55,62941	998	0,3	CTD2	Deploy	
25-08	14:07	UPPER1	12	72,94590	-55,63098	997	0,3	CTD2	Bottom	
25-08	15:00	UPPER1	12	72,94709	-55,61813	997	0,2	CTD3	Deploy	
25-08	15:03	UPPER1	12	72,94719	-55,61857	998	0,3	CTD3	Recover	
25-08	15:43	UPPER1	12	72,94596	-55,61228	998	0,2	GC1	Bottom	OK
25-08	16:19	UPPER1	12	72,94661	-55,64390	999	0,4	ZOO1	Deploy	
25-08	16:40	UPPER1	12	72,94720	-55,64796	999	0,3	ZOO1	Bottom	
25-08	17:08	UPPER1	12	72,94869	-55,65688	1000	0,4	ZOO1	Recover	
25-08	18:37	UP4	13	72,90899	-55,42068	970	0,5	CTD1	Deploy	
25-08	19:06	UP4	13	72,91040	-55,43286	989	0,4	CTD1	Bottom	
25-08	19:19	UP4	13	72,91070	-55,43654	989	0,2	CTD1	Recover	
25-08	20:11	UP4	13	72,90947	-55,41304	989	0,1	CTD2	Recover	
25-08	21:35	UP6	14	72,94688	-55,69153	999	0,4	CTD1	Deploy	
25-08	22:03	UP6	14	72,94726	-55,68363	999	0,2	CTD1	Bottom	
25-08	22:16	UP6	14	72,94734	-55,68117	999	0,2	CTD1	Recover	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
26-08	11:10	UP7	15	72,96110	-55,84791	1001	0,4	CTD1	Deploy	
26-08	11:39	UP7	15	72,96234	-55,85606	1001	0,2	CTD1	Bottom	
26-08	11:51	UP7	15	72,96247	-55,85837	1001	0,3	CTD1	Recover	
26-08	12:01	UP7	15	72,96263	-55,86056	1001	0,3	CTD2	Deploy	
26-08	12:53	UP7	15	72,96513	-55,87413	1002	0,3	HAPS1	Bottom	F
26-08	13:30	UP7	15	72,96750	-55,87708	1002	0,2	HAPS2	Bottom	OK
26-08	14:15	UP7	15	72,97038	-55,87729	1002	0,2	CTD3	Deploy	
26-08	14:30	UP7	15	72,97095	-55,87751	1004	0,1	CTD3	Bottom	
26-08	14:43	UP7	15	72,97168	-55,87659	1003	0,3	CTD3	Recover	
26-08	14:53	UP7	15	72,97254	-55,87571	1002	0,3	ZOO1	Deploy	
26-08	15:09	UP7	15	72,97373	-55,87534	1002	0,3	ZOO1	Bottom	
26-08	15:39	UP7	15	72,97554	-55,87621	1003	0,3	ZOO1	Recover	
26-08	16:40	UP8	16	72,98787	-56,04905	1005	0,8	CTD1	Deploy	
26-08	17:07	UP8	16	72,99219	-56,04193	1004	0,7	CTD1	Bottom	
26-08	17:20	UP8	16	72,99430	-56,03823	1004	0,6	CTD1	Recover	
26-08	18:48	UP9	17	73,01104	-56,23829	1007	1,5	HAPS1	Bottom	F
26-08	19:08	UP9	17	73,01651	-56,23343	1000	1,5	HAPS1	Recover	F
26-08	20:39	UP9	17	72,99142	-56,24954	-	0,7	HAPS3	Deploy	Ok
26-08	21:03	UP9	17	73,00104	-56,24391	1005	1,7	HAPS3	Bottom	Ok
26-08	21:22	UP9	17	73,00865	-56,23690	1005	1,5	HAPS3	Recover	Ok
26-08	21:36	UP9	17	72,99914	-56,24819	1006	1,1	CTD1	Deploy	
26-08	21:56	UP9	17	73,00585	-56,23779	1005	1,4	CTD1	Bottom	
26-08	22:09	UP9	17	73,01038	-56,23165	1006	1,1	CTD1	Recover	
27-08	11:46	T1 ST12	18	73,49903	-57,19820	-	0,5	CTD1	Deploy	
27-08	12:12	T1 ST12	18	73,49865	-57,19605	-	0,2	CTD1	Bottom	
27-08	12:25	T1 ST12	18	73,49859	-57,19448	-	0,2	CTD1	Recover	
27-08	12:52	T1 ST12	18	73,49815	-57,19063	-	0,1	HAPS1	Bottom	OK, surface
27-08	13:19	T1 ST12	18	73,49740	-57,18605	-	0,3	CTD2	Deploy	
27-08	14:19	T1 ST11	19	73,40050	-57,60663	300	0,3	CTD1	Deploy	
27-08	14:33	T1 ST11	19	73,40184	-57,60938	300	0,6	CTD1	Bottom	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
27-08	14:37	T1 ST11	19	73,40236	-57,61013	300	0,5	CTD1	Recover	
27-08	15:49	T1 ST10	20	73,30166	-58,00702	-	0,4	CTD1	Deploy	
27-08	16:05	T1 ST10	20	73,30295	-58,01346	-	0,5	CTD1	Bottom	
27-08	16:13	T1 ST10	20	73,30349	-58,01691	-	0,8	CTD1	Recover	
27-08	20:04	PS25	21	73,06638	-58,75313	-	0,1	CTD1	Deploy	
27-08	20:28	PS25	21	73,06858	-58,74448	-	0,6	CTD1	Bottom	
27-08	20:37	PS25	21	73,06949	-58,74064		0,4	CTD1	Recover	
27-08	20:59	PS25	21	73,07116	-58,73341	-	0,4	HAPS1	Bottom	OK, surface
27-08	21:15	PS25	21	73,07219	-58,72867	-	0	CTD1	Deploy	
27-08	21:45	PS25	21	73,07288	-58,71506	-	0,6	GC1	Bottom	OK, overshot
27-08	22:17	PS25	21	73,07188	-58,69798	-	0,6	ZOO1	Deploy	
27-08	22:28	PS25	21	73,07121	-58,69189	-	0,7	ZOO1	Bottom	
27-08	22:48	PS25	21	73,07059	-58,68277	-	0,5	ZOO1	Recover	
28-08	13:06	T2 ST1	22	75,70937	-60,05970	428	0,4	CTD1	Deploy	
28-08	13:25	T2 ST1	22	75,71153	-60,07299	493	0,8	CTD1	Bottom	
28-08	13:30	T2 ST1	22	75,71221	-60,07736	494	0,8	CTD1	Recover	no water
28-08	14:14	T2 ST1	22	75,70868	-60,06346	440	0,6	HAPS1	Bottom	OK
28-08	15:37	T2 ST2	23	75,59876	-60,42214	550	0,1	CTD1	Deploy	
28-08	15:56	T2 ST2	23	75,60089	-60,42510	500	0,5	CTD1	Bottom	
28-08	16:03	T2 ST2	23	75,60177	-60,42624	485	0,5	CTD1	Recover	
28-08	16:59	T2 ST3	24	75,50827	-60,77865	365	0,1	CTD1	Deploy	
28-08	17:13	T2 ST3	24	75,50886	-60,77863	348	0,2	CTD1	Bottom	
28-08	17:18	T2 ST3	24	75,50900	-60,77874	335	0,1	CTD1	Recover	
28-08	17:30	T2 ST3	24	75,50933	-60,77886	331	0,2	HAPS1	Bottom	OK
28-08	17:45	T2 ST3	24	75,50965	-60,77955	324	0,1	CTD2	Deploy	
28-08	17:49	T2 ST3	24	75,50971	-60,77962	332	0	CTD2	Bottom	
28-08	17:54	T2 ST3	24	75,50974	-60,77940	329	0	CTD2	Recover	
28-08	18:08	T2 ST3	24	75,50978	-60,77893	338	0	ZOO1	Deploy	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
28-08	18:22	T2 ST3	24	75,50977	-60,77979	330	0,1	ZOO1	Recover	
28-08	18:30	T2 ST3	24	75,50993	-60,78045	320	0,1	CTD3	Deploy	
28-08	18:32	T2 ST3	24	75,50999	-60,78066	319	0,1	CTD3	Recover	
28-08	19:36	T2 ST4	25	75,39894	-61,20392	750	0,6	CTD1	Deploy	
28-08	19:58	T2 ST4	25	75,39874	-61,21021	-	0,3	CTD1	Bottom	
28-08	20:13	T2 ST4	25	75,39798	-61,21419	-	0,4	CTD1	Recover	
28-08	21:56	MELVILLE1	26	75,31940	-61,91057	915	0,2	CTD1	Deploy	
28-08	22:22	MELVILLE1	26	75,31760	-61,91300	-	0,2	CTD1	Bottom	
28-08	22:37	MELVILLE1	26	75,31639	-61,91426	928	0,2	CTD1	Recover	
28-08	23:02	MELVILLE1	26	75,31463	-61,91900	-	0,3	HAPS1	Bottom	OK
28-08	23:28	MELVILLE1	26	75,31275	-61,92367	-	0,3	CTD2	Deploy	
29-08	00:00	MELVILLE1	26	75,32023	-61,90548	-	0,2	GC1	Deploy	
29-08	00:13	MELVILLE1	26	75,31963	-61,90679	912	0,3	GC1	Bottom	OK
29-08	00:31	MELVILLE1	26	75,31916	-61,90965	914	0,2	GC1	Recover	
29-08	01:25	T2 ST6	27	75,19948	-62,00181	653	0,2	CTD1	Deploy	
29-08	01:45	T2 ST6	27	75,19934	-62,00465	649	0,1	CTD1	Bottom	
29-08	01:55	T2 ST6	27	75,19919	-62,00595	647	0,1	CTD1	Recover	
29-08	10:26	T3 ST12	28	74,78521	-66,98830	-	0,2	CTD1	Deploy	
29-08	11:05	T3 ST12	28	74,78405	-66,97686	-	0,3	CTD1	Bottom	
29-08	11:33	T3 ST12	28	74,78391	-66,96701	-	0,5	CTD1	Recover	
29-08	12:17	T3 ST12	28	74,78312	-66,94720	-	0,4	HAPS	Bottom	OK, IRD
29-08	13:01	T3 ST12	28	74,78344	-66,92444	-	0,5	CTD2	Bottom	
29-08	13:51	T3 ST11	29	74,89902	-66,99736	1128	0,9	CTD1	Deploy	
29-08	14:18	T3 ST11	29	74,89947	-66,97534	1124	0,7	CTD1	Bottom	
29-08	14:35	T3 ST11	29	74,89909	-66,96174	1116	0,8	CTD1	Recover	
29-08	15:44	T3 ST10	30	75,00743	-66,98386	561	0,8	CTD1	Deploy	
29-08	16:02	T3 ST10	30	75,81600	-66,96934	560	0,7	CTD1	Bottom	
29-08	16:12	T3 ST10	30	75,00854	-66,95777	560	0,8	CTD1	Recover	
29-08	16:56	T3 ST9	31	75,11815	-66,98974	495	0,9	CTD1	Deploy	
29-08	17:17	T3 ST9	31	75,11589	-66,95640	504	1,6	CTD1	Bottom	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
29-08	17:26	T3 ST9	31	75,11498	-66,94110	506	1,6	CTD1	Recover	
29-08	18:14	T3 ST8	32	75,23095	-66,99786	470	0,9	CTD1	Deploy	
29-08	18:31	T3 ST8	32	75,22801	-66,97754	465	1,2	CTD1	Bottom	
29-08	18:42	T3 ST8	32	75,22624	-66,96488	464	1,2	CTD1	Recover	
29-08	19:40	T3 ST8	32	75,23152	-66,98617	463	1,3	HAPS1	Bottom	OK
29-08	19:56	T3 ST8	32	75,22873	-66,96698	467	1,4	CTD2	Deploy	
29-08	20:49	T3 ST7	33	75,34372	-66,99495	431	0,5	CTD1	Deploy	
29-08	21:05	T3 ST7	33	75,34100	-66,97423	429	1,2	CTD1	Bottom	
29-08	21:16	T3 ST7	33	75,33967	-66,96498	429	1,1	CTD1	Recover	
29-08	22:02	T3 ST6	34	75,45541	-66,99640	396	0,2	CTD1	Deploy	
29-08	22:18	T3 ST6	34	75,45341	-66,97757	373	1,2	CTD1	Bottom	
29-08	22:26	T3 ST6	34	75,45259	-66,97081	366	1,2	CTD1	Recover	
29-08	23:12	T3 ST5	35	75,56656	-66,99802	413	1	CTD1	Deploy	
29-08	23:30	T3 ST5	35	75,56681	-66,99641	414	0,5	CTD1	Bottom	
29-08	23:38	T3 ST5	35	75,56699	-66,99270	414	0,4	CTD1	Recover	
29-08	23:51	T3 ST5	35	75,56667	-66,98485	415	0,5	HAPS	Bottom	OK
30-08	00:10	T3 ST5	35	75,56605	-66,97135	419	1,1	CTD2	Deploy	
30-08	10:59	MELVILLE 2	36	75,66760	-65,69608	555	1	RUM1	Bottom	OK
30-08	11:43	MELVILLE 2	36	75,66921	-65,68916	559	1,1	GC1	Bottom	OK
30-08	15:10	MELVILLE 3	37	75,78960	-66,63333	568	1,3	RUM1	Bottom	F
30-08	15:57	MELVILLE 3	37	75,78928	-66,63002	570	1,5	GC1	Bottom	OK
30-08	17:02	T3 ST4	38	75,67617	-66,99157	453	0,9	CTD1	Deploy	
30-08	17:19	T3 ST4	38	75,67573	-67,00771	449	0,7	CTD1	Bottom	
30-08	17:28	T3 ST4	38	75,67552	-67,01500	448	0,9	CTD1	Recover	
30-08	18:16	T3 ST3	39	75,78961	-66,99317	367	1	CTD1	Deploy	
30-08	18:33	T3 ST3	39	75,78992	-67,01300	361	1,1	CTD1	Bottom	
30-08	18:41	T3 ST3	39	75,78996	-67,02180	358	1	CTD1	Recover	
30-08	19:05	T3 ST3	39	75,78860	-66,99822	367	1,1	HAPS1	Bottom	OK, IRD
30-08	19:19	T3 ST3	39	75,78831	-67,01476	366	1	CTD2	Deploy	
30-08	19:24	T3 ST3	39	75,78819	-67,02040	363	1,1	CTD2	Recover	

Day	Time (UTC)	Station	Station number	Latitude (DD)	Longitude (DD)	Depth (m)	Drift speed (knots)	Code	Status	Success (coring)
30-08	19:36	T3 ST3	39	75,78801	-67,03478	360	1	ZOO1	Deploy	
30-08	19:42	T3 ST3	39	75,78784	-67,04135	356	0,9	ZOO1	Bottom	
30-08	19:53	T3 ST3	39	75,78749	-67,05332	352	1	ZOO1	Recover	
30-08	20:25	T3 ST2	40	75,85361	-66,97797	100	0,1	CTD1	Deploy	
30-08	21:04	T3 ST1	41	75,90536	-66,98857	64	0,3	CTD1	Deploy	

Appendix 2 – CTD Operations Log

Date	Time (UTC)	Longitude (W)	Latitude (N)	Bottom (m)	Station Name	Comment
20210822	20:00	51.0193	69.3943	442	LK21001_1	
20210823	14.00	56.0370	70.8334	600	LK21002_1	severe bottom contact[1]
20210823	20:00	56.0609	70.8427	595	LK21002_4	
20210824	10:00	58.8178	72.2345	375	LK21003_1	
20210824	18:00	58.7056	72.7040	192	LK21004_1	
20210824	19:00	58.8967	72.7755	310	LK21005_1	gentle bottom contact[2]
20210824	20:00	59.1011	72.8502	483	LK21006_1	
20210824	21:00	59.3010	72.9250	698	LK21007_1	winch trouble upcast[3]
20210824	23:00	59.4999	73.0000	658	LK21008_1	
20210825	00:00	59.7012	73.0749	536	LK21009_1	orange life form captured
20210825	01:00	59.9040	73.1521	355	LK21010_1	adjacent to iceberg
20210825	02:00	60.1083	73.2273	317	LK21011_1	
20210825	12:00	55.6202	72.9454	1002	LK21012_1	gentle bottom contact[2]
20210825	19:00	55.4215	72.9090	975	LK21013_1	
20210825	22:00	55.6911	72.9470	1003	LK21014_1	
20210826	11:00	55.8481	72.9611	1006	LK21015_1	adjacent to iceberg
20210826	17:00	56.0489	72.9881	1008	LK21016_1	

Date	Time (UTC)	Longitude (W)	Latitude (N)	Bottom (m)	Station Name	Comment
20210826	22:00	56.2420	73.0033	1009	LK21017_1	wire angle >45 deg.
20210827	12:00	57.1983	73.4991	1030	LK21018_1	new set of batteries
20210827	14:00	57.6067	73.4005	313	LK21019_1	
20210827	16:00	58.0070	73.3017	940	LK21020_1	
20210827	20:00	58.7528	73.0664	747	LK21021_1	
20210828	13:00	60.0599	75.7094	470	LK21022_1	
20210828	16:00	60.4222	75.5987	556	LK21023_1	
20210828	17:00	60.7787	75.5083	366	LK21024_1	
20210828	20:00	61.2042	75.3990	784	LK21025_1	
20210828	22:00	61.9107	75.3193	917	LK21026_1	
20210829	02:00	62.0019	75.1994	655	LK21027_1	
20210829	11:00	66.9882	74.7852	1705	LK21028_1	
20210829	14:00	66.9976	74.8990	1133	LK21029_1	
20210829	16:00	66.9836	75.0075	566	LK21030_1	
20210829	17:00	66.9893	75.1181	502	LK21031_1	
20210829	18:00	66.9974	75.2309	468	LK21032_1	
20210829	21:00	66.9947	75.3437	436	LK21033_1	
20210829	22:00	66.9964	75.4554	404	LK21034_1	
20210830	00:00	66.9697	75.5660	426	LK21035_1	new set of batteries[4]
20210830	17:00	66.9927	75.6762	457	LK21036_1	
20210830	18:00	66.9938	75.7896	371	LK21037_1	.hex misses cal. coeff.
20210830	20:00	66.9280	75.8536	105	LK21038_1	adjacent to iceberg
20210830	21:00	66.9884	75.9053	69	LK21039_1	

1. Severe bottom contact resulted in mud passing through the pump and mudy water reaching conductivity and oxygen sensors;
2. Gentle bottom contact resulted in mud traces on the frame but not inside the pump tubing;
3. Load sensor of winch was turned off after the winch system goes into error mode without reason;
4. CTD failed after battery voltage reaches 11.3 V;

Appendix 3 – List of water samples for biogeochemistry

Date	Station	Description	Sample depth	Nutrients	Filtered volume (Chla)
22-08-2021	1	Rodebay (full)	1	2 reps	500 ml
22-08-2021	1	Rodebay (full)	5	2 reps	500 ml
22-08-2021	1	Rodebay (full)	10	2 reps	500 ml
22-08-2021	1	Rodebay (full)	20 (=DCM)	2 reps	500 ml
22-08-2021	1	Rodebay (full)	30	2 reps	500 ml
22-08-2021	1	Rodebay (full)	50	2 reps	500 ml
22-08-2021	1	Rodebay (full)	100	2 reps	-
22-08-2021	1	Rodebay (full)	200	2 reps	-
22-08-2021	1	Rodebay (full)	BOT:400	2 reps	-
23-08-2021	2	UMQ (full)	1	2 reps	500 ml
23-08-2021	2	UMQ (full)	5	2 reps	500 ml
23-08-2021	2	UMQ (full)	10	2 reps	500 ml
23-08-2021	2	UMQ (full)	20	2 reps	500 ml
23-08-2021	2	UMQ (full)	30	2 reps	500 ml
23-08-2021	2	UMQ (full)	50	2 reps	500 ml
23-08-2021	2	UMQ (full)	100	2 reps	-
23-08-2021	2	UMQ (full)	200	2 reps	-
23-08-2021	2	UMQ (full)	BOT:570	2 reps	-
23-08-2021	2	UMQ (full)	DCM:35	2 reps	500 ml
24-08-2021	3	PS26 (full)	1	2 reps	500 ml
24-08-2021	3	PS26 (full)	5	2 reps	500 ml
24-08-2021	3	PS26 (full)	10	2 reps	500 ml
24-08-2021	3	PS26 (full)	20	2 reps	500 ml
24-08-2021	3	PS26 (full)	30	2 reps	500 ml
24-08-2021	3	PS26 (full)	50	2 reps	500 ml
24-08-2021	3	PS26 (full)	100	2 reps	-
24-08-2021	3	PS26 (full)	200	2 reps	-
24-08-2021	3	PS26 (full)	BOT:350	2 reps	-
24-08-2021	3	PS26 (full)	DCM:42	2 reps	500 ml
24-08-2021	7	4th stn of UT transect (crosses T1)	1	1 rep	500 ml
24-08-2021	7	4th stn of UT transect (crosses T1)	10	1 rep	500 ml
24-08-2021	7	4th stn of UT transect (crosses T1)	20	1 rep	500 ml
24-08-2021	7	4th stn of UT transect (crosses T1)	30	1 rep	500 ml
24-08-2021	7	4th stn of UT transect (crosses T1)	40	1 rep	500 ml
24-08-2021	7	4th stn of UT transect (crosses T1)	50	1 rep	500 ml
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	1	1 rep	500 ml
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	5	1 rep	500 ml

Date	Station	Description	Sample depth	Nutrients	Filtered volume (Chla)
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	10 (=DCM)	1 rep	500 ml
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	20	1 rep	500 ml
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	30	1 rep	500 ml
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	50	1 rep	500 ml
25-08-2021	12	"Uper 1" (mid-Upernavik, full station)	100	1 rep	-
25-08-2021	13	"Uper 4" (inner fjord, full water)	1	1 rep	500 ml
25-08-2021	13	"Uper 4" (inner fjord, full water)	5	1 rep	500 ml
25-08-2021	13	"Uper 4" (inner fjord, full water)	10	1 rep	500 ml
25-08-2021	13	"Uper 4" (inner fjord, full water)	20	1 rep	500 ml
25-08-2021	13	"Uper 4" (inner fjord, full water)	50	1 rep	500 ml
25-08-2021	13	"Uper 4" (inner fjord, full water)	100	1 rep	-
25-08-2021	13	"Uper 4" (inner fjord, full water)	200	1 rep	-
25-08-2021	13	"Uper 4" (inner fjord, full water)	DCM:3	1 rep	420 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	2	1 rep	500 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	5=DCM	1 rep	500 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	10	1 rep	500 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	20	1 rep	500 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	30	1 rep	500 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	50	1 rep	500 ml
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	100	1 rep	-
26-08-2021	15	"Uper 7" (mid fjord, full water and multinet)	200	1 rep	-
26-08-2021	17	"Uper 9" (outer fjord)	2	1 rep	500 ml
26-08-2021	17	"Uper 9" (outer fjord)	5	1 rep	500 ml
26-08-2021	17	"Uper 9" (outer fjord)	10	1 rep	500 ml
26-08-2021	17	"Uper 9" (outer fjord)	20	1 rep	500 ml
26-08-2021	17	"Uper 9" (outer fjord)	30	1 rep	500 ml
26-08-2021	17	"Uper 9" (outer fjord)	50	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	2	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	5	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	10	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	20	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	30	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	50	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	100	1 rep	500 ml
27-08-2021	18	T1 1st stn (near coast)	DCM:13	1 rep	500 ml

Date	Station	Description	Sample depth	Nutrients	Filtered volume (Chla)
27-08-2021	19	T1 2nd stn	2	1 rep	500 ml
27-08-2021	19	T1 2nd stn	5	1 rep	500 ml
27-08-2021	19	T1 2nd stn	10	1 rep	500 ml
27-08-2021	19	T1 2nd stn	20	1 rep	500 ml
27-08-2021	19	T1 2nd stn	30	1 rep	500 ml
27-08-2021	19	T1 2nd stn	50	1 rep	500 ml
27-08-2021	20	T1 3rd stn	2	1 rep	500 ml
27-08-2021	20	T1 3rd stn	5	1 rep	500 ml
27-08-2021	20	T1 3rd stn	10	1 rep	500 ml
27-08-2021	20	T1 3rd stn	20	1 rep	500 ml
27-08-2021	20	T1 3rd stn	30	1 rep	500 ml
27-08-2021	20	T1 3rd stn	50	1 rep	500 ml
27-08-2021	21	"PS25"	2	1 rep	500 ml
27-08-2021	21	"PS25"	5	1 rep	500 ml
27-08-2021	21	"PS25"	10	1 rep	500 ml
27-08-2021	21	"PS25"	20	1 rep	500 ml
27-08-2021	21	"PS25"	30=DCM	1 rep	500 ml
27-08-2021	21	"PS25"	50	1 rep	500 ml
27-08-2021	21	"PS25"	100	1 rep	-
27-08-2021	21	"PS25"	200	1 rep	-
27-08-2021	21	"PS25"	BOT:350	1 rep	-
28-08-2021	23	T2 2nd (50 m water)	2	1 rep	500 ml
28-08-2021	23	T2 2nd (50 m water)	5	1 rep	500 ml
28-08-2021	23	T2 2nd (50 m water)	10	1 rep	500 ml
28-08-2021	23	T2 2nd (50 m water)	20	1 rep	500 ml
28-08-2021	23	T2 2nd (50 m water)	30	1 rep	500 ml
28-08-2021	23	T2 2nd (50 m water)	50	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	2	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	5	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	10	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	20	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	30	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	50	1 rep	500 ml
28-08-2021	24	T2 3rd (type 3)	100	1 rep	-
28-08-2021	24	T2 3rd (type 3)	BOT:275	1 rep	-
28-08-2021	24	T2 3rd (type 3)	DCM:35	1 rep	500 ml
28-08-2021	25	T2 4th (50 m water)	2	1 rep	500 ml
28-08-2021	25	T2 4th (50 m water)	5	1 rep	500 ml
28-08-2021	25	T2 4th (50 m water)	10	1 rep	500 ml

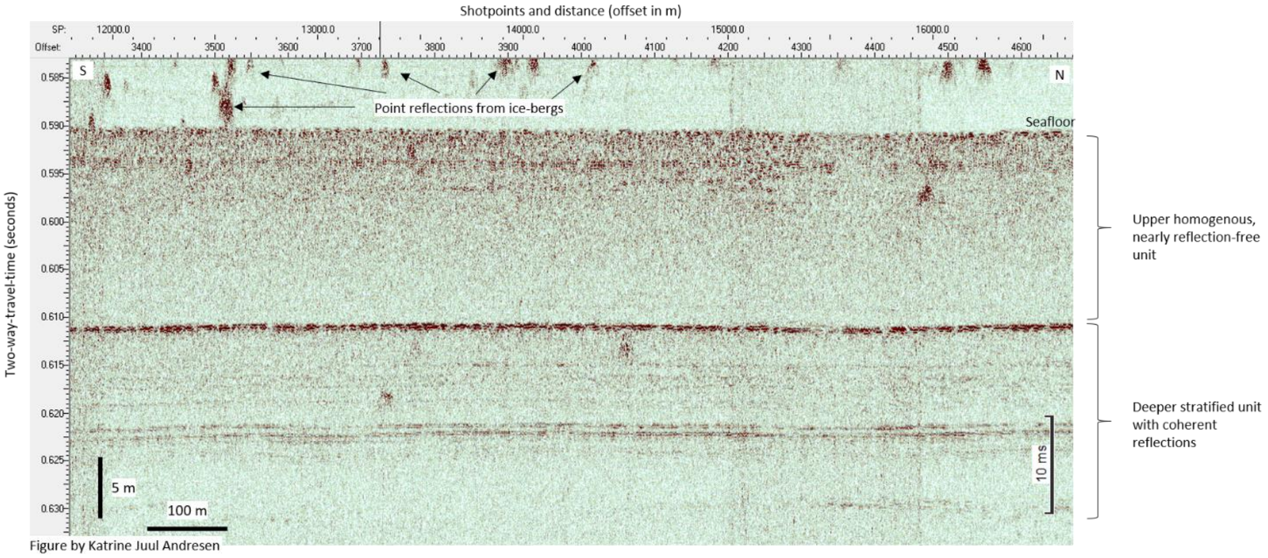
Date	Station	Description	Sample depth	Nutrients	Filtered volume (Chla)
28-08-2021	25	T2 4th (50 m water)	20	1 rep	500 ml
28-08-2021	25	T2 4th (50 m water)	BOT:740	1 rep	-
28-08-2021	26	T2 5th (full)	2	1 rep	500 ml
28-08-2021	26	T2 5th (full)	5	1 rep	500 ml
28-08-2021	26	T2 5th (full)	10	1 rep	500 ml
28-08-2021	26	T2 5th (full)	20	1 rep	500 ml
28-08-2021	26	T2 5th (full)	30	1 rep	500 ml
28-08-2021	26	T2 5th (full)	BOT:	1 rep	-
28-08-2021	26	T2 5th (full)	DCM:40	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	2	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	5	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	10	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	20	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	30	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	40	1 rep	500 ml
28-08-2021	27	T2 6th (50 m water)	50	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	2	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	5	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	10	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	20	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	30	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	50	1 rep	500 ml
29-08-2021	28	T3 12th stn (start southern end)	100	1 rep	-
29-08-2021	28	T3 12th stn (start southern end)	BOT:1400	1 rep	-
29-08-2021	28	T3 12th stn (start southern end)	DCM:33	1 rep	500 ml
29-08-2021	29	T3 continued	2	1 rep	500 ml
29-08-2021	29	T3 continued	5	1 rep	500 ml
29-08-2021	29	T3 continued	10	1 rep	500 ml
29-08-2021	29	T3 continued	20	1 rep	500 ml
29-08-2021	29	T3 continued	30	1 rep	500 ml
29-08-2021	29	T3 continued	50	1 rep	500 ml
29-08-2021	30	T3 continued	2	1 rep	500 ml
29-08-2021	30	T3 continued	5	1 rep	500 ml
29-08-2021	30	T3 continued	10	1 rep	500 ml
29-08-2021	30	T3 continued	20	1 rep	500 ml
29-08-2021	30	T3 continued	30	1 rep	500 ml
29-08-2021	30	T3 continued	40	1 rep	500 ml
29-08-2021	30	T3 continued	50	1 rep	500 ml
29-08-2021	31	T3 continued	2	1 rep	500 ml

Date	Station	Description	Sample depth	Nutrients	Filtered volume (Chla)
29-08-2021	31	T3 continued	5	1 rep	500 ml
29-08-2021	31	T3 continued	10	1 rep	500 ml
29-08-2021	31	T3 continued	20	1 rep	500 ml
29-08-2021	31	T3 continued	30	1 rep	500 ml
29-08-2021	31	T3 continued	40	1 rep	500 ml
29-08-2021	31	T3 continued	50	1 rep	500 ml
29-08-2021	32	T3 continued	2	1 rep	500 ml
29-08-2021	32	T3 continued	5	1 rep	500 ml
29-08-2021	32	T3 continued	10	1 rep	500 ml
29-08-2021	32	T3 continued	20	1 rep	500 ml
29-08-2021	32	T3 continued	30	1 rep	500 ml
29-08-2021	32	T3 continued	50	1 rep	500 ml
29-08-2021	32	T3 continued	100	1 rep	-
29-08-2021	32	T3 continued	DCM:35	1 rep	500 ml
29-08-2021	33	T3 continued	2	1 rep	500 ml
29-08-2021	33	T3 continued	5	1 rep	500 ml
29-08-2021	33	T3 continued	10	1 rep	500 ml
29-08-2021	33	T3 continued	20	1 rep	500 ml
29-08-2021	33	T3 continued	30	1 rep	500 ml
29-08-2021	33	T3 continued	40	1 rep	500 ml
29-08-2021	33	T3 continued	50	1 rep	500 ml
29-08-2021	34	T3 continued	2	1 rep	500 ml
29-08-2021	34	T3 continued	5	1 rep	500 ml
29-08-2021	34	T3 continued	10	1 rep	500 ml
29-08-2021	34	T3 continued	20	1 rep	500 ml
29-08-2021	34	T3 continued	30	1 rep	500 ml
29-08-2021	34	T3 continued	40	1 rep	500 ml
29-08-2021	34	T3 continued	50	1 rep	500 ml
29-08-2021	35	T3 continued	2	1 rep	500 ml
29-08-2021	35	T3 continued	5	1 rep	500 ml
29-08-2021	35	T3 continued	10	1 rep	500 ml
29-08-2021	35	T3 continued	20	1 rep	500 ml
29-08-2021	35	T3 continued	30=DCM	1 rep	500 ml
29-08-2021	35	T3 continued	50	1 rep	500 ml
29-08-2021	35	T3 continued	100	1 rep	-
29-08-2021	35	T3 continued	BOT:350	1 rep	-
30-08-2021	38	T3 continued	2	1 rep	500 ml
30-08-2021	38	T3 continued	5	1 rep	500 ml
30-08-2021	38	T3 continued	10	1 rep	500 ml

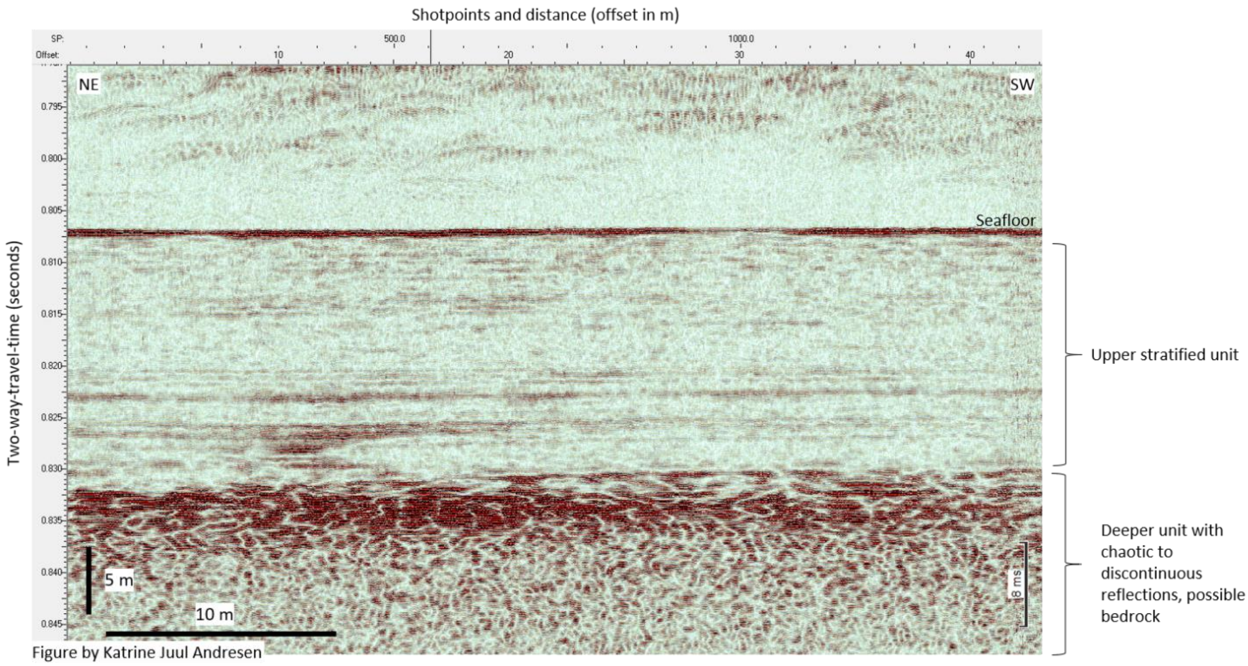
Date	Station	Description	Sample depth	Nutrients	Filtered volume (Chla)
30-08-2021	38	T3 continued	20	1 rep	500 ml
30-08-2021	38	T3 continued	30	1 rep	500 ml
30-08-2021	38	T3 continued	40	1 rep	500 ml
30-08-2021	38	T3 continued	50	1 rep	500 ml
30-08-2021	39	T3 continued	2	1 rep	500 ml
30-08-2021	39	T3 continued	5	1 rep	500 ml
30-08-2021	39	T3 continued	10	1 rep	500 ml
30-08-2021	39	T3 continued	20	1 rep	500 ml
30-08-2021	39	T3 continued	30	1 rep	500 ml
30-08-2021	39	T3 continued	50	1 rep	500 ml
30-08-2021	39	T3 continued	100	1 rep	-
30-08-2021	39	T3 continued	200	1 rep	-
30-08-2021	39	T3 continued	BOT:	1 rep	-
30-08-2021	39	T3 continued	DCM:15	1 rep	-
30-08-2021	40	T3 continued	2	1 rep	500 ml
30-08-2021	40	T3 continued	5	1 rep	500 ml
30-08-2021	40	T3 continued	10	1 rep	500 ml
30-08-2021	40	T3 continued	20	1 rep	500 ml
30-08-2021	40	T3 continued	30	1 rep	500 ml
30-08-2021	40	T3 continued	40	1 rep	500 ml
30-08-2021	40	T3 continued	50	1 rep	500 ml
30-08-2021	41	T3 continued	2	1 rep	500 ml
30-08-2021	41	T3 continued	5	1 rep	500 ml
30-08-2021	41	T3 continued	10	1 rep	500 ml
30-08-2021	41	T3 continued	20	1 rep	500 ml
30-08-2021	41	T3 continued	30	1 rep	500 ml
30-08-2021	41	T3 continued	40	1 rep	500 ml
30-08-2021	41	T3 continued	50	1 rep	500 ml

Appendix 4 – Sub-bottom profiles at gravity core positions

LAKO2021-ST01-GC



LAKO2021-ST02-GC



LAKO2021-ST03-GC

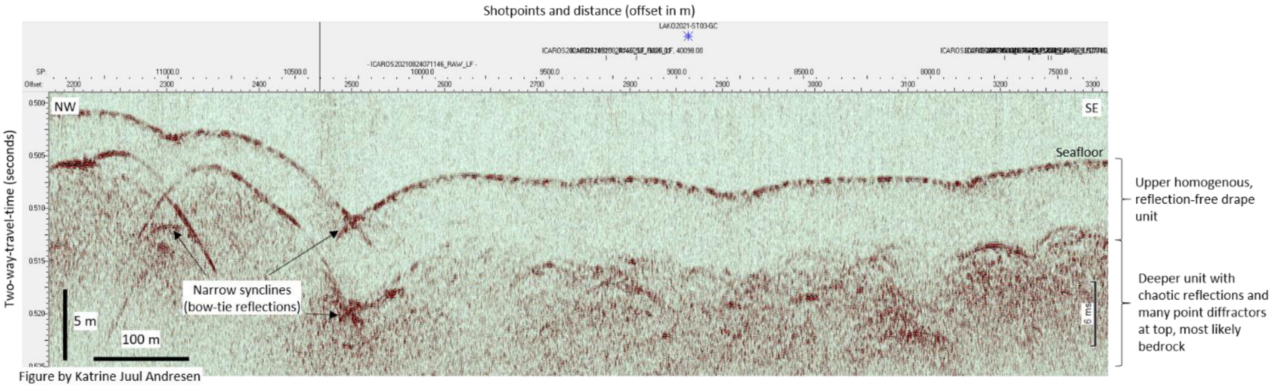


Figure by Katrine Juul Andresen

LAKO2021-ST12-GC

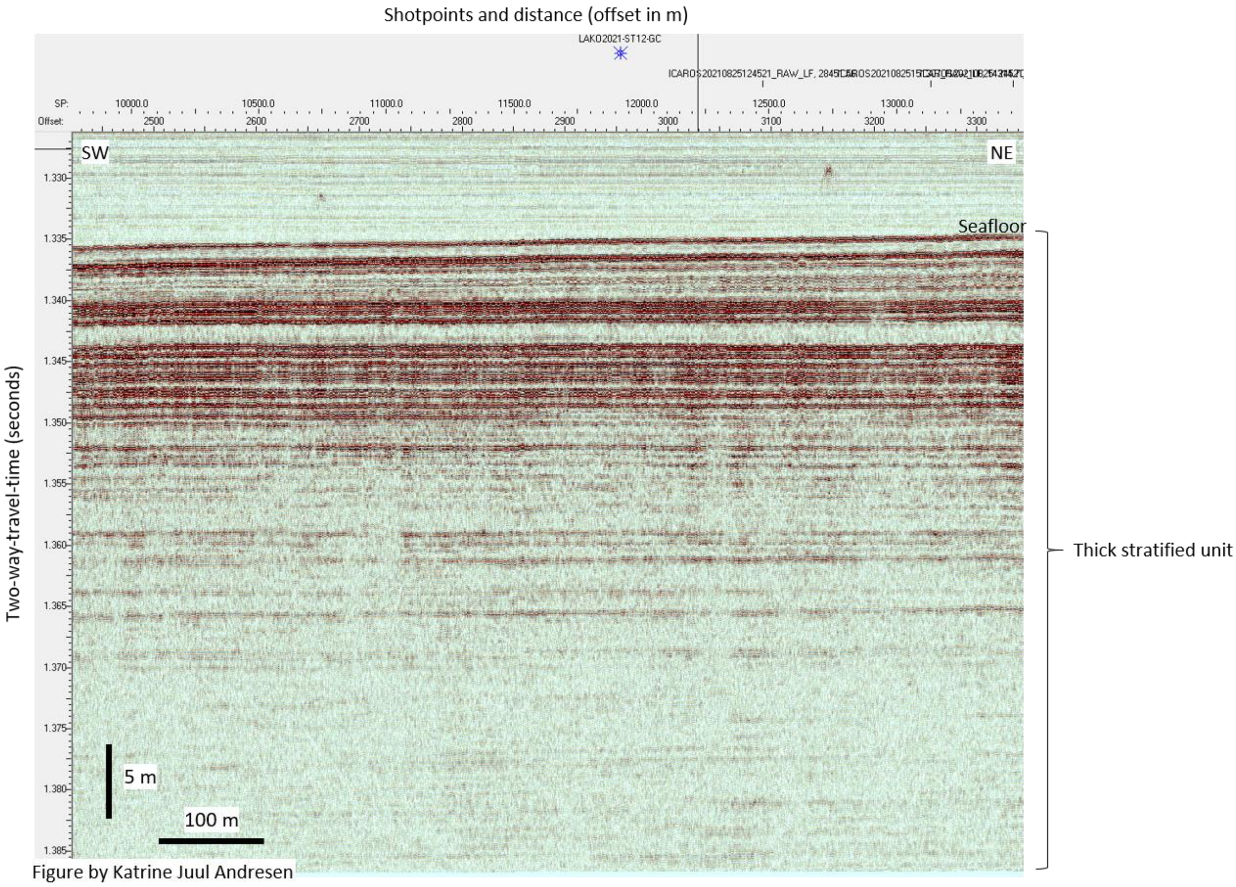
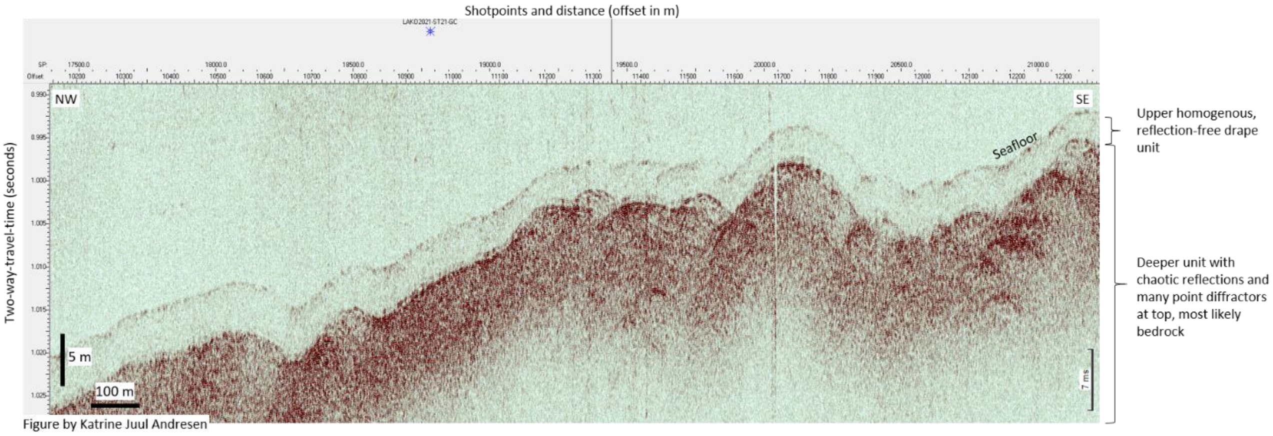


Figure by Katrine Juul Andresen

LAKO2021-ST21-GC



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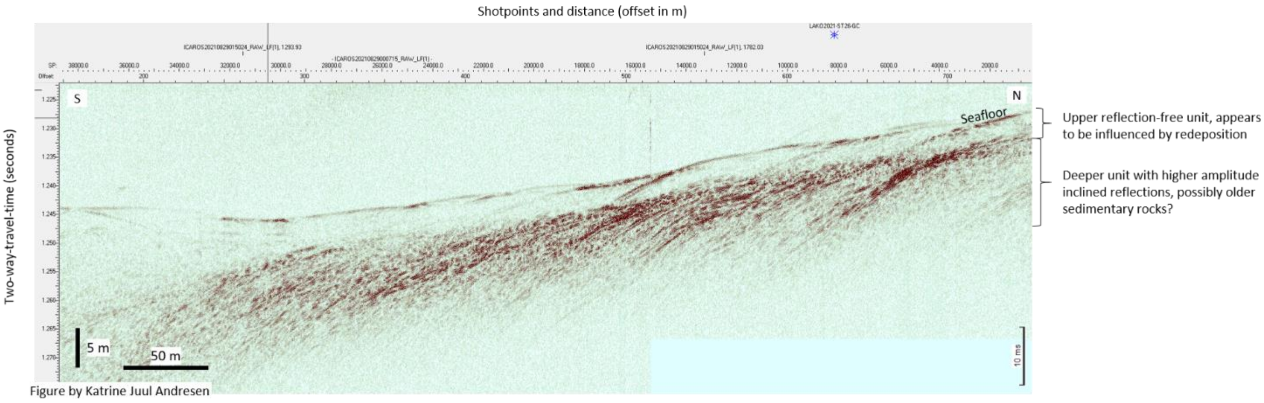
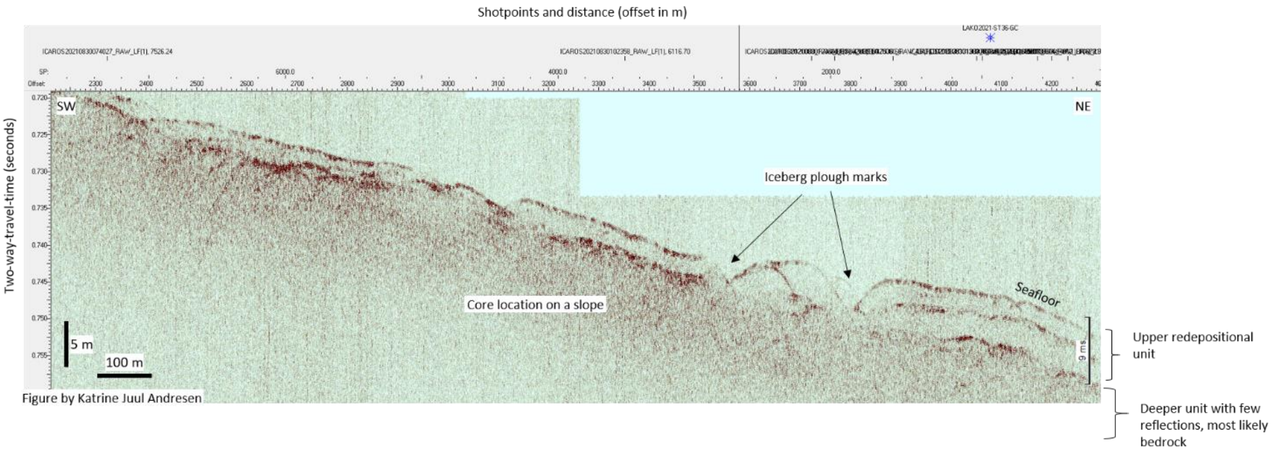


LAKO2021-ST36-GC



LAKO2021-ST37-GC