

GEOEO North of Greenland 2024

Scope of Work

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**POLARFORSKNINGS
SEKRETARIATET**
SWEDISH POLAR RESEARCH SECRETARIAT



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BACKGROUND TO GEOEO

1.1 BACKGROUND AND SCIENTIFIC MOTIVATION

The North Greenland Earth-Ocean-Ecosystem Observatory (GEOEO) is a research theme endorsed by the Swedish Polar Research Secretariat (SPRS), following a proposal endorsed in the Polar Research Process (polar.se/stoed-till-polarforskning/polarforskningsprocessen). This Scope of Work (SoW) concerns the GEOEO *North of Greenland 2024* expedition with I/B Oden targeting the marine realm of the northern Greenland Ice sheet (N-GrIS). GEOEO addresses scientific questions focused on providing new knowledge on the N-GrIS' marine cryosphere's dynamic history and response to future climate change, including ecosystem changes and contribution to global sea-level rise. GEOEO also includes non-expedition going projects (such as accessing the remote areas along the N-GrIS margin via numerical modeling) and a synthesis-report directed to policy-makers and stakeholders with the aim to provide effective science-based knowledge of the implications of the research findings to different social and political issues in decision making.

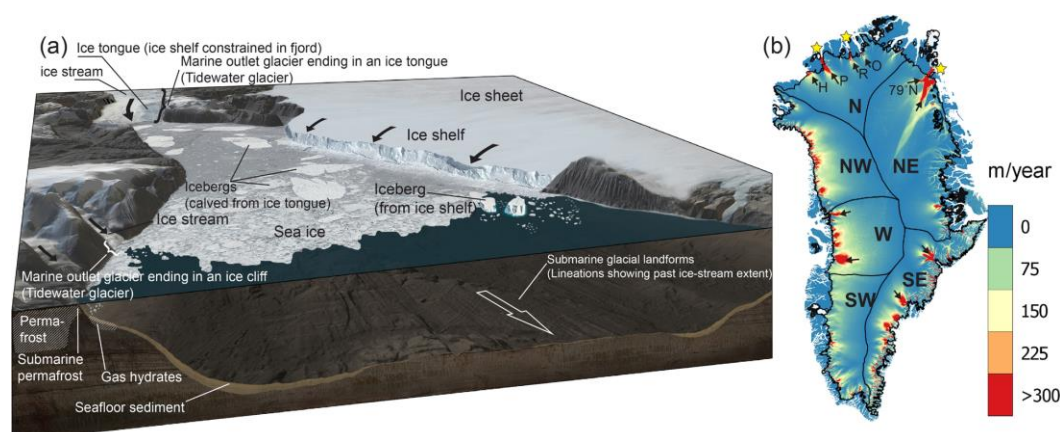


Figure 1.1 (a) Components of the marine cryosphere in focus for GEOEO. **(b)** The Greenland Ice Sheet (GrIS) ice velocity distribution in meters per year from the MEaSUREs project. Ice streams draining the ice sheet toward the ocean are seen by higher velocities. The GrIS is divided into drainage sectors defined by ice-catchment areas (SW=South West, W=West, NW=North West, N=North, NE=North East, SE=South East). GEOEO focuses on the North sector for which the larger marine outlet glaciers marked by black arrows are: H=Humboldt Glacier; P=Petermann Glacier; R=Ryder Glacier; O=C.H. Ostenfeld Glacier. The yellow stars mark the few remaining larger ice tongues; two exist in the North Sector. 79N=79 North Glacier.

The Arctic has warmed nearly four times faster than the rest of the Earth over the last four decades (Rantanen et al., 2022). This has huge implications for the marine cryosphere, the marine and terrestrial ecosystems of the region, and global climate. The

marine cryosphere is here including glaciers draining into the ocean, ice sheets with the underlying bedrock pressed below sea level, sea ice, gas hydrates and subsea permafrost (Fig. 1.1). Specifically, the GrIS has become the largest single contributor to global sea-level rise (Bamber et al., 2018; Sasgen et al. 2020). Its northern sector, N-GrIS, holds an ice volume equivalent to ~93 cm of mean global sea-level rise (Mouginot et al., 2019) and some of the last marine-terminating outlet glaciers with extensive floating tongues, relevant for the stability of the N-GrIS. The IPCC Special Report on the Ocean and Cryosphere in a Changing Climate (IPCC, 2019) emphasizes that improved understanding of the marine cryosphere's dynamic behavior and interaction with the ocean is crucial for better predictions of future sea-level rise. Along the same lines, Siegert and others (2020) have stated six major future research paths to improve sea level rise predictions, including: "Collection of ocean data at ice sheet margins", "Resolving past changes to ascertain key glaciological driving processes", and "Improved coupling between ice, ocean and atmosphere models". GEOEO addresses all these issues and offers a unique opportunity to better understand the marine cryosphere's dynamic history and its response to future climate change in a region where an accelerated rate of change is observed already. A rapidly changing N-GrIS in a warmer world will have implications for ice sheet stability, oceanic and atmospheric circulation in and over the adjacent Arctic Ocean and beyond, marine and coastal ecosystems, and their interconnection as exemplified by sub- and supraglacial hydrology and runoff or carbon- and other biogeochemical fluxes linking atmosphere, cryosphere and the ocean.

The *North of Greenland 2024* expedition builds on the legacies of the *Petermann 2015* and *Ryder 2019* expeditions with Icebreaker Oden.

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Siegert, M., Alley, R.B., Rignot, E. et al., 2020. Twenty-first century sea-level rise could exceed IPCC projections for strong-warming futures. *One Earth* 3 (6), doi.org/10.1016/j.oneear.2020.11.002

1.2 SCIENTIFIC GOALS OF GEOEO

The GEOEO Theme is organized around seven broad scientific goals, which will be addressed by several complementing work packages prior, during and after the *North of Greenland expedition 2024*. The goals and expected new knowledge gained from working towards these goals are summarized below:

Goal I) Unraveling the Late Glacial to Holocene history and dynamics of the N-GrIS

Expected new knowledge: As no field data exist, reconstructions of the NGIS in the Lincoln Sea area are hypothetical. New information on the retreat dynamics, the role of ice shelves/tongues and retreat-pace from palaeo-records (glacial landforms, sediment cores etc) will add to our knowledge on how fast marine based ice sheets can retreat, a critical question considering the present climate warming.

Goal II) Providing new insight into the variability of the marine cryosphere of North Greenland and the adjacent Arctic Ocean

Expected new knowledge: There are no in-situ observations nor paleo-records from the Lincoln Sea area north of 82° 30' to-date. We aim to provide new critical knowledge for assessments of the future development of the marine cryosphere, not only in North Greenland, but in some aspects for the entire Arctic Ocean as the region north of Greenland is hypothesized to be a sea-ice indicator for the entire Arctic Ocean.

Goal III) Investigating the interaction between ecosystem community composition, anthropogenic dynamics and climate fluctuations

Expected new knowledge: Plankton surveys will document the current state of Arctic marine biology in unexplored regions North of Greenland. Genomic analyses will contribute completely novel insights into temporal dynamics in marine biodiversity and how these are related to past changes in climate and sea-ice cover. On the terrestrial side, the analyses will enhance our knowledge on the extent to which pioneering human populations were affected by terrestrial as well as marine changes in ecological community composition, prey population demography as well as Holocene climate fluctuations.

Goal IV) Quantifying ecosystem production and nutrient state in changing marine ecosystems north of Greenland

Expected new knowledge: Through on-board continuous CO₂ and stable isotope water monitoring systems, CTD Rosette profiling for nutrients, microscopic and primary productivity measurements, and chemical profiling of sediments and porewaters we can provide new data for both local and regional synoptic insights of the present and future Arctic marine carbon and nutrient cycles.

Goal V): Mapping of the remote ocean frontiers

Expected new knowledge: The contribution of mapping data from the virtually unmapped seafloor around the N-GrIS margin to the global database of bathymetric data will be priceless and heralded as a remarkable addition to global knowledge. We will provide all mapping data directly to the Nippon Foundation-GEBCO-Seabed 2030

project, which assembles these data to freely available data compilations provided to the community through the General Bathymetric Chart of the Oceans (GEBCO).

Goal VI): Mapping the presence of gas hydrates in marine sediments and gas in the water column and atmosphere

Expected new knowledge: In regional and global assessments of future warming-induced seafloor methane release, it is assumed that hydrates are ever-present along the continental shelf slope off northern Greenland, but this is purely based on assumption. If we reach this area to acquire new data, it will provide the first insights from a region that to-date has no geological base information on gas hydrates in previous assessments.

Goal VII): Numerical modelling of the ice-ocean-atmosphere-geodynamic system

Expected new knowledge: As there are no observation data from the Lincoln Sea north of 80° 30' N or from the fjords north of Sherard Osborn Fjord where Ryder Glacier drains, there are no assessments based on numerical modelling using observational data as boundary and/or initial conditions. Hence the contribution to new knowledge would be profound.

2. TIME PLAN AND EXPEDITION ROUTE

2.1 EXPEDITION TIME PLAN

A detailed time plan for the *North of Greenland 2024* expedition is entirely dependent on the sea-ice conditions encountered in the Lincoln Sea. The overarching goal is to maximize the scientific work under any sea-ice conditions. Specifically, the strategic planning aims to maximize the likelihood of reaching the primary destination, Victoria Fjord, and subsequently go northward to round Greenland and end in Longyearbyen. This is the primary **Plan A** for the expedition but considering the commonly difficult sea-ice conditions in the Lincoln Sea, contingency plans are also developed. The expedition routes for all plans are further described below in Section 2.4, while the overall time schedule for the expedition, including mobilization etc. is summarized in Table 2.1.1. Figure 2.1.1 shows an overview map with three broader work areas I-III in which permits for scientific work have been applied for from the countries' Exclusive Economic Zone (EEZ) and territorial waters they fall within. Plans A-D fit within the broader work areas I-III.

Table 2.1.1. Tentative time plan for the North of Greenland expedition 2024 on Oden (ETD=Estimated Time of Departure, ETA=Estimated Time of Arrival).

Date(s)	Activity
2024-06-10	Deadline for shipping of heavy equipment (> 10 ton) to Helsingborg
2024-06-12	Mobilization of heavy equipment on Oden in Helsingborg (no visitors!)
2024-06-12	Deadline for all shipping (< 10 ton) to Helsingborg
2024-06-17 – 06-19	General mobilization of scientific equipment on Oden in Helsingborg
2024-07-15	ETD Helsingborg, Sweden
2024-07-15 – 2024-08-04	Transit Helsingborg – Thule
2024-08-05	ETA Thule, Greenland
2024-08-05 – 2024-09-17	Expedition (See section 2.4)
2024-09-17	ETA Longyearbyen, Svalbard (or Thule depending on sea-ice conditions)
Approx. 2024-09-18 – 2024-10-01	Transit, Longyearbyen (or Thule) – Helsingborg
2024-10-08 - 2024-10-10	Demobilization in Helsingborg

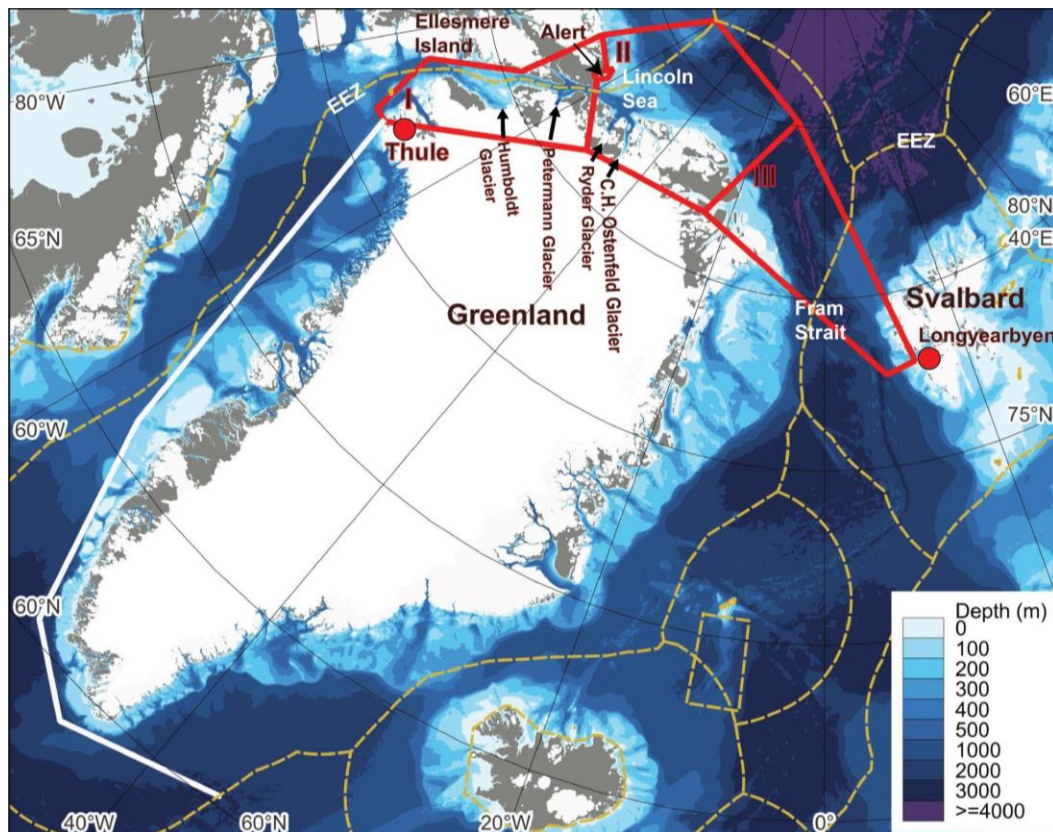


Figure 2.1.1. Overview map showing the main working areas I-III and the generalized track for IB Oden's transit to Thule. This track will be modified slightly to ensure bathymetric transit mapping that fills unsurveyed areas of the seafloor. Along this transect, expendable bathy thermographs (XBT) and/or expendable sound velocimeters (XSV) will be deployed to calibrate the multibeam sonar. Some CTD stations may in addition be carried out to test the equipment. There will be no other station work along this transect. If the sea-ice conditions prevent IB Oden from going north and continue towards Longyearbyer, the return will be from Thule along the similar track as marked on the map.

2.2. SHIPPING DETAILS AND HAZARDOUS GOODS

All shipping details should be coordinated with SPRS (jon.persson@polar.se). Please, see the document "Shipping Instructions" at the Expedition Website. All hazardous goods must be listed and specified in the Fuel plan - Appendix 1, Chemical Plan - Appendix 2, Gas Plan - Appendix 3 and Battery Plan – Appendix 4. These lists are checked in detail by SPRS, the Chief Officer on Oden and the Medical Doctor. All hazardous goods must be stored and handled according to the routines specified in the Appendixes.

2.3 RISK ASSESSMENTS

Risk assessments are the basis for the planning procedure of the expedition and will cover different aspects of risks (medical/logistic/environmental). This work influences

all procedures and will be discussed at the Tool Box talks on-board before any work can start.

2.4 EXPEDITION ROUTE

Background and premises: Due to the difficult sea-ice conditions commonly prevailing in the Lincoln Sea, several optional expedition routes have been developed for the *North of Greenland 2024* expedition. Figure 2.4.1 shows a Modis satellite image from 2019-08-14, which is two days after IB *Oden* managed to enter Sherard Osborn Fjord during the *Ryder 2019* expedition. While the sea-ice conditions were optimal in Sherard Osborn Fjord at this time, the passage from the northern end of Nares Strait to the fjord entrance was through very heavy sea-ice. This illustrates the logistical complexity and emphasizes the need for contingency plans. The main target for the 2024 expedition is Victoria Fjord where C.H. Ostenfeld Glacier drains (Fig. 2.4.2). This fjord is partly covered by clouds in the Modis image from 2019-08-14, but the sea-ice conditions were similar as in Sherard Osborn Fjord in 2019 (see Fig. 2.4.2). The two fjords have been open about every fifth year, but not in a regular predictable pattern.

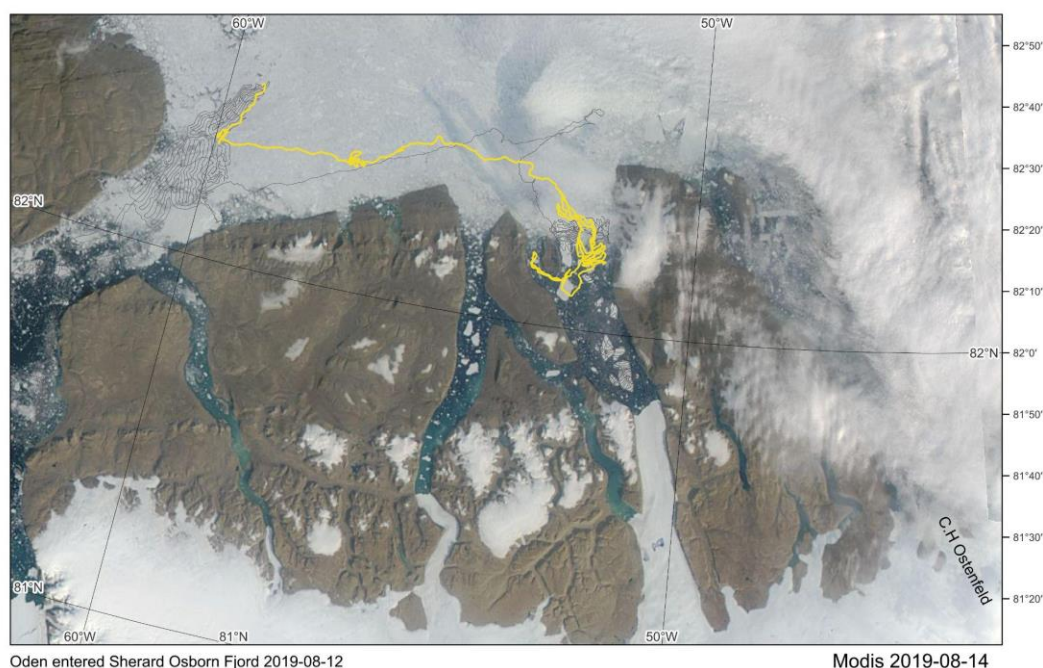


Figure 2.4.1. Modis satellite image from 2019-08-14 when I/B *Oden* made it into Sherard Osborn Fjord where *Ryder* Glacier drains. The yellow line is the track of I/B *Oden* during the days around 2019-08-14, while the black thin line is the icebreaker's complete track from the *Ryder 2019* expedition.

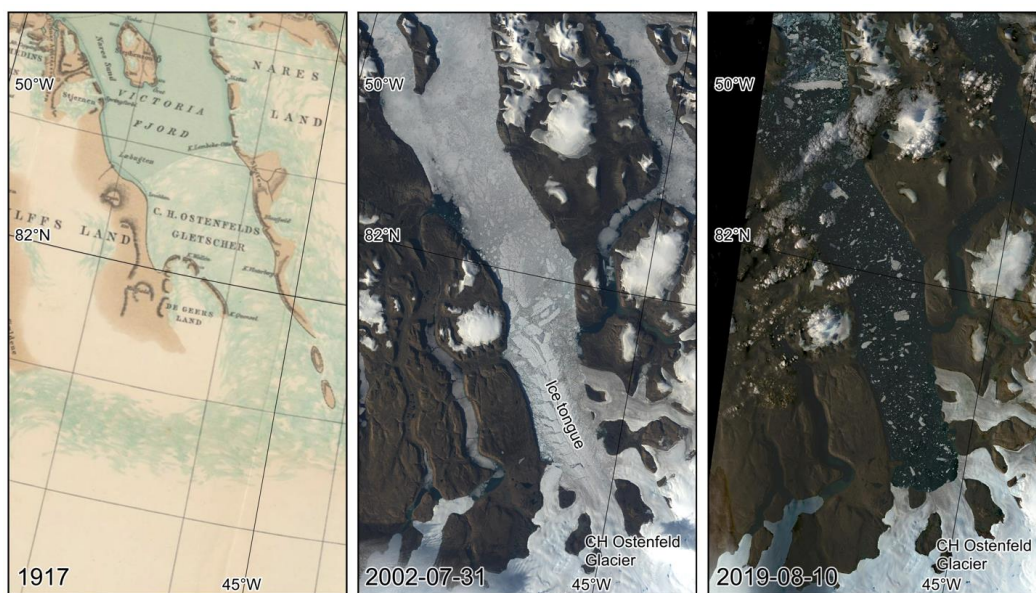


Figure 2.4.2. Maps of Victoria Fjord. **(Left)** Map by Lauge Koch from the Second Thule Expedition 1916-1918 showing a much more advanced floating ice tongue of C.H. Ostenfeld Glacier in 1917 compared to today. **(Middle)** The ice tongue in 2002 before more or less completely breaking up resulting in the present conditions **(Right)**. The mechanism behind the break-up is one of the main scientific questions of the North of Greenland 2024 Expedition.

Plan A: The map in Figure 2.4.3 shows the main “work boxes” (target areas for mapping and sampling) and includes the main route for Plan A, which is summarized with a set of way points (WPs) in Table 2.4.1. The times listed are rough estimates based on the distances between the way points and assumed speed considering ice conditions. A rough estimate of work days for each of the work boxes is assigned. Permits to work in the larger areas I-III shown in red in Figure 2.4.1 are being applied for as these contain all the specific work boxes in the plans.

In summary, Plan A targets Victoria Fjord as the first main sampling/mapping area, followed by going north through the Lincoln Sea to end with scientific work on the Morris Jesup Rise, before transecting the Fram Strait and ending the expedition in Longyearbyen, Svalbard. Some limited station work can be carried out along the transit to Victoria Fjord, but in Plan A the main focus is to get to Victoria Fjord where about 14 days can be spent on mapping/sampling and supporting the various land campaigns. This is followed by continuing north through the Lincoln Sea while mapping and coring. The Lincoln Sea glacial trough (hinted in the existing bathymetry) is here of specific interest, both to answer paleo-glaciological and oceanographic questions, where the latter focuses on the pathways of Atlantic water. About 6 days in addition to the transit time is allocated in the Lincoln Sea box. A transect from the shallow shelf into deeper waters at this location ends this work, with the goal of investigating Atlantic water past (coring) and present flow (oceanographic stations), as well as investigate the slopes for potential gas hydrates. Along the transect to Morris Jesup Rise sampling (coring/oceanography etc.) will be carried out. About 6 days are allocated to dedicated work on the Morris Jesup Rise itself.

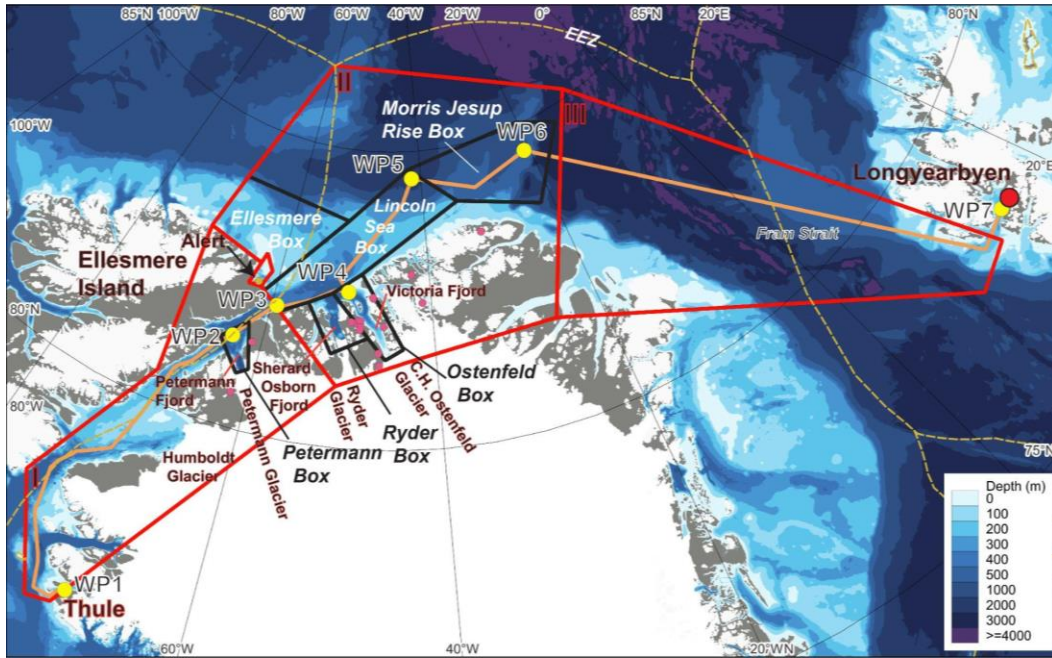


Figure 2.4.2. Map showing the main route for Plan A, and the working areas (boxes). Note that there is no specific time allocated to work in Petermann Box and Ellesmere Box in Plan A, as if the sea-ice conditions permit, all emphasis is placed on work in Victoria Fjord, the Lincoln Sea and then go north to end by working in the Morris Jesup Rise area, where I/B Oden will rendezvous with R/V Kronsprins Haakon. Locations of lakes that are of interest for the land teams are shown with pink dots.

Table 2.4.1. Plan A main way points and times allocated in the works boxes shown in Figure 2.4.2.

Waypoints	Latitude	Longitude	Lat DD MM.M	Lon DD MM.M	Distance (nmi)	Speed (knots)	Days
Start: Thule, Aug 5							
WP1.	76.53423	-68.7051	76°32.1' N	68°42.3'W	0		
WP2.	81.50908	-63.3709	81°30.5'N	63°22.3'W	393	3.5	4.7
Petermann Box	No time allocated in Plan A						0.0
WP3.	82.19074	-59.3663	82°11.4'N	59°22.0'W	53	2	1.1
Lincoln Sea Box							6.0
WP4.	82.61528	-50.68	82°36.9'N	50°40.8'W	75	2	1.6
Ostenfeld Box							14.0

WP5. Greenland shelf edge	84.54521	-41.6215	84°32.7'N	41°37.3'W	140	2	2.9
WP6.	84.56309	-20.9908	84°33.8'N	20°59.5'W	125	2	2.6
Morris Jesup Rise Box							6.0
WP7.	78.1984	14.82057	78°11.9'N	14°49.2'W	514	8	2.7
End: Longyearbyen, 15 Aug							42

Plan B: The difference between Plan A and B is that the latter does not involve moving forward northward after work in Victoria Fjord and its surroundings. This plan would be implemented if the sea-ice conditions in the Lincoln Sea are too difficult to go further north from Victoria Fjord. In Plan B, the work in Victoria Fjord can be extended, and if Sherard Osborn Fjord has operationable sea-ice conditions, surveys complementing those of 2019 can also be made there. For example, acquisition of seismic profiles across the bathymetric sill mapped in 2019 and mapping with the Autonomous Surface Vessels at the ice-front, and mapping with Autonomous Underwater Vehicle (AUV) LoLo underneath the ice tongue of Ryder Glacier. If Sherard Osborn Fjord is ice covered, the alternative of working north of Ellesmere Island to continue extending the surveys of 2019 northward is an option. This could answer questions regarding the Atlantic water pathways as well as the extent of the Innuitian Ice Sheet from Ellesmere Island, and its merge with the N-GrIS. Finally, work in Petermann Fjord may be considered, where it is of specific interest to survey underneath the floating ice tongue.

Plan C: Analyses of satellite images show that both Sherard Osborn and Victoria fjords some years are impenetrable due to sea ice and calved icebergs, while the conditions in the Lincoln Sea would have permitted surveying and sampling. If this scenario occurs in 2024, the time surveying and sampling in the Lincoln Sea could be extended, including the area north of Ellesmere Island, before going northward to follow Plan A with work in the Morris Jesup Rise Box.

Plan D: Should the ice conditions in 2024 prevent going further north than the Nares Strait, we will work in the areas that are accessible. This may, for example, include extensive ASV and AUV surveys at the ice margin of Petermann Glacier or underneath its floating ice tongue.

3. EXPEDITION LOGISTICS

3.1 GENERAL

All routines and regulations will be set by the Expedition Leader Team (Master, Expedition Coordinator & Chief Scientists). Before any work starts, Tool Box Talks must be conducted, focusing on work methods and routines, and risk assessment and mitigation actions. Some general information is summarized in this section. Please, regularly check the Expedition Website for updates.

Chief Scientists: Martin Jakobsson & Nina Kirchner, Stockholm University

The Swedish Polar Research Secretariat will support the expedition with:

- Expedition Coordinator: Åsa Lindgren
- Technicians: Martin Jansson, Jon Persson, Joachim Gyllestad, Einar Sjöbom & John Prytherch
- Medical Doctor: Magnus Lundgren & Nurse: PO Edvinsson
- Meteorologists: Emilie Knutsson & Sara Johansson
- Helicopter Pilots: Mikael Friberg & Ante Svensson
- Helicopter technician: Anders Eringdahl

Master will be Captain Erik Andersson and his crew of 23 in total.

3.2 HELICOPTER FLIGHTS

Oden will be equipped with two helicopters that will be used for ice reconnaissance, flights for aerial work both on ice and terrestrial stations. Scientists that will use the helicopter will have to be identified well in advance and take a helicopter safety course during the transit. Note that all participants stepping on land will have to be vaccinated against rabies.

3.3 SCIENTIFIC WORK LOCATIONS

There will be 10 Work Packages (the practical work for the projects) on board; for project summaries see Chapter 7. However, many scientists will help out and be involved in several work packages.

For the layout and the logistic set-up on board, please refer to the **summary** in the Load Plan, see appendix 5.

Polar will bring Kovacs ice-drills for coring, but if any scientists have equipment - please bring it onboard.

3.4 SOME NOTES ON CLOTHING

Protective clothes for working on deck: Everybody who will work on the deck with CTDs, coring, launching helicopter flights, foredeck mast etc. will need to wear a helmet (available on board) and safety shoes/boots with steel toe protection (bring your own).

Safety clothes for working on the ice are available (flotation suits), but if you prefer your own suit you can bring one contingent on inspection by SPRS. Boots for work on the ice should be brought individually.

3.5 POLAR BEAR SAFETY & WEAPON ROUTINES

Persons that will work on the ice will have toolbox talk and risk assessment prior to the work on ice. It will mainly be SPRS personnel handling the weapons used for polar bear safety and training sessions will occur during the transit to the Arctic. As far as practically possible, bear guards will be supplied by the SPRS logistic staff. When sampling from the helicopter, the helicopter will stay with the team and the pilot will be the polar bear guard.

3.6 WORKING HOURS AND WORKLOAD

Plans for work shifts and contact persons during each shift must be set up by each Work Package (WP) in line with work hour regulations. The plan should include an appropriate workload for each individual in the WP and must be available to the expedition leadership. This is a safety issue and it is also inefficient in the long run to work too intensely for long periods.

Work on the ice or on deck requiring much manpower should be planned for between breakfast (8:15) and dinner (17:45), weather and polar bears permitting. Other times must be coordinated with the expedition leadership well in advance; for example, for helicopter flights taking advantage of beneficial weather or measurements that run continuously or on a fixed schedule, like radio soundings.

3.6 MEAL TIMES

Meal and coffee times in the mess are strictly scheduled and must be respected by everybody:

Breakfast	07:45-08:15
Coffee	10:00-10:15
Lunch	12:00-12:30
Coffee	15:00-15:15
Dinner	17:45-18:15

Oden's crew is smaller in numbers compared to other scientific ships to be able to house the scientific crew. Oden cannot serve meals 24/7 without reducing the scientific crew. It is important to respect meal times onboard, so we can continue with the crew/scientist ratio we have 23/52.

If work is due to take place on the ice/onshore over mealtimes, we will plan this the evening before and prepare meal-packages for those that cannot attend for the meal in question.

The planning of meals for 75 persons for an expedition without the possibility to take on more provisions is a complex task and thus we will be strict regarding the food preferences. This means that we will not allow persons who would like to have flexible diets. The diets offered during GEOEO will mainly be 1) Regular meal plan or 2) Vegan meal plan. Intolerance and specific allergies, i.e. nuts, gluten, lactose etc. will be treated separately. The Captain and the Chefs will gather all participants with special requirements regarding diets and allergies at the start of the expedition to make sure the meal plan is working out well for all of us.

3.7 MEETINGS AND INFORMATION FLOW

The following outlines the process of how the day's activities will be decided. The plan for the day will be continuously updated on the video screens throughout the ship. Everyone should make it a habit to review these any time they pass one, especially as changes may appear at short notice due to the character of the expedition.

The expedition leaders will meet before breakfast to establish the plan of the day. Immediately after breakfast, at 08:15, there will be a brief information meeting, a weather forecast by the meteorologist, and a presentation of the plan for the day by the Expedition Coordinator and the Chief Scientist. Note that this is not a discussion meeting – all wishes and requests for the next day should be made known to the Expedition Coordinator and the Chief Scientist the evening before; see below.

Most afternoons there will be a WP Leaders meeting at ~17.00, immediately before dinner. Here the expedition leaders will collect wishes and requests for next day's activities from the WPs. The expedition leadership will then meet again after dinner to plan for the next day, possibly to be revised the following morning.

4. WORK PACKAGES AND CRUISE PARTICIPANTS

4.1 LIST OF WORK PACKAGES

The GEOEO2024 Work Packages (WPs) are defined to ensure that the scientific objectives of the expedition are met. For each WP there is a Principal Investigator (PI) and a WP-leader (= the scientist responsible for the implementation of the WP on board). The PI and the WP-leader are usually the same person, but for some WPs the PI is shore-based.

Table 4.1 The GEOEO Expedition work packages (WPs) with identified lead Principal Investigators (PIs) (or WP-leader if the PI is shore-based), managing the work on board.

#	Work package name	WP Leader/PI
WP1	Geophysical mapping	Martin Jakobsson/Larry Meyer
WP2	Glacier-Ocean multi-sensor and multi-platform Observatory	Nina Kirchner
WP3	Silicate alteration in marine sediments	Wei-Li Hong
WP4	Marine Geology (Sediment coring and processing)	Matt O'Regan
WP5	Interactions between the North Greenland Ice Sheet and Atlantic Water	Johan Nilsson
WP6	Palaeogenomics of Ecosystem Change	Love Dalén
WP7	Improved analyses of Arctic climate change and its impacts on mid-latitude climate in a multi-century context from climate proxies and models.	Hans Linderholm
WP8	Trace gas dynamics and pelagic ecosystem function	Christian Stranne
WP9	Tectonic Evolution of North Greenland	PI: Jaroslaw Majka WP Leader: Karol Faehnrich
WP10	Arctic Meteorology and Ocean Surface Exchanges & ARCSIX Collaboration	John Prytherch
	Opportunistic Sampling	targeted persons
	ICE-PPR	Lauren Freeman, shore-based

4.2 LIST OF CRUISE PARTICIPANTS

Within the 10 WPs, 39 scientists will participate in the GEOEO expedition (Table 4.2).

Chief Scientists: Martin Jakobsson & Nina Kirchner.

Table 4.2 List of all onboard cruise participants registered for the GEOEO expedition.

WP	Name	Affiliation	Email
----	------	-------------	-------

WP1	Martin Jakobsson	Stockholm University	martin.jakobsson@geo.su.se
WP1	Larry Mayer	University of New Hampshire	larry.mayer@unh.edu
WP1	Björn Eriksson	Stockholm University	bjorn.eriksson@geo.su.se
WP1	Jamie Barnett	Stockholm University	jamie.barnett@geo.su.se
WP1	Felicity Holmes	Stockholm University	felicity.holmes@geo.su.se
WP1	Elias Strandell Erstorp	Stockholm University	elias.erstorp@geo.su.se
WP1	Elizabeth Weidner	University of California San Diego	ereedweidner@ucsd.edu
WP1	Brian Calder	University of New Hampshire	brc@ccom.unh.edu
WP2	Nina Kirchner	Stockholm University	nina.kirchner@su.se
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WP9	George Geier	Dartmouth College	george.r.geier.gr@dartmouth.edu
WP 10	John Prytherch	SPRS Oden National Infrastructure	john.prytherch@geo.uu.se

5. SAMPLING PLAN

5.1 CTD AND WATER SAMPLING

For the planning of the Niskin Bottles and the overview what volumes are requested, a CTD water budget is summarized in Appendix 6.

5.2 DRONE OPERATIONS

Swedish Polar Research Secretariat has a minimum requirement for all UAV (Drone) pilots to have a valid EASA A2 license for drones that operate in the open category. In addition to this, we also require that everyone involved in drone operations during the GEOEO expedition need to attend a UAV specific safety briefing (Toolbox Talk). The briefing will be held at the start of the expedition. No flying is allowed before the toolbox talk.

The toolbox talk will cover:

- Operating procedures before, during and after a flight.
- Radio communication.
- Flight deviation and contingency procedures.
- Emergency conditions and procedures for flight termination.
- External factors.

WP #	Drone type	Parameters measured	How often? & Time of each flight?
SPRS	DJI Mavic 2 Enterprise	Outreach and aerial mapping	Opportunistic
1,2	DJI Mavic 3E	Glacier surface and calving front, plus outreach	In Victoria Fjord/at Ostenfeld Glacier, and/or plan B,C etc glacier-ocean sites; outreach opportunistic
1,2	DJI Mavic 3E	Glacier surface and calving front, plus outreach	In Victoria Fjord/at Ostenfeld Glacier, and/or plan B,C etc glacier-ocean sites; outreach opportunistic

2	eBeeX, Sensefly	Glacier surface and calving front, plus outreach	In Victoria Fjord/at Ostenfeld Glacier, and/or plan B,C etc glacier-ocean sites; outreach opportunistic. OBS cannot start from/land on Oden, start and landing needs to be on land (fixed wing drone needing "runway")
7	DJI Phantom 4 advanced	Aerial mapping and reconnaissance for sampling areas	Oppotunistic

Take off/landing position will primarily be on the starboard side on the foredeck where a simple platform will be established. If helideck is empty, helideck can be used.

5.3 FERRYBOX SYSTEM IN THE MAINLAB

The sensors that will be included in the Ferrybox system are:

Manufacturer	Type of sensor
Sea-Bird	SBE38
Sea-Bird	SBE45
Aanderaa	Aanderaa 4835
Sea-Bird	WetLabs Eco FLNTU (RT)
Sea-Bird	WetLabs Eco FLNTU (RT)
Turner Designs	Turner Cyclops 7

This data will be published with open access on the Swedish National Data Service, see parameter list Appendix 7, SPRS Oden Shipdata.

6. DATA MANAGEMENT

SPRS requires delivery of metadata immediately after the expedition and this will be uploaded to the Swedish National Dataservice (SND). Data collected during the expedition should be uploaded to a data repository with open access, i.e. the Bolin

Centre Database maximally two years after the expedition. Some ship data will be published immediately (see below).

The metadata will also be part of the Expedition Report. Each WP is required to deliver (1) a chapter for the Cruise Report, and (2) a METADATA EXCEL FILE with the full list of samples and data collected type of sample/measurement, date, ship time, UTC time, geographical position, CTD depth, etc. Please, use a separate sheet within your WPs METADATA EXCEL FILE for each type of sample/measurement. Chief Scientists Martin Jakobsson and Nina Kirchner will edit the Expedition Report, where all Work Packages will contribute.

During the expedition, data on position, heading, basic meteorological data (wind direction & speed, air temp, air humidity) and photosynthetically active radiation (PAR) will be continuously logged, see the SPRS Oden Ship Data, Appendix 7. This data will be available on-board during the expedition with a lag of 24h and will later on be published at the Swedish National Data Service <https://snd.gu.se/en>. The multibeam data (EM122) will be published as soon as possible at: <https://oden.geo.su.se/>

Table 6.1 List of repositories for Work Packages

#	Work package name	Repository
WP1	Geophysical mapping	Bolin Centre Data Base NSF Arctic Data Repository (if funded by NSF). Bathymetric data will also be sent to IBCAO and IHO DBD
WP2	Glacier-Ocean multi-sensor and multi-platform Observatory	Bolin Centre Data Base
WP3	Silicate alteration in marine sediments	
WP4	Marine Geology (Sediment coring and processing)	Cores and samples will be stored at the Department of Geological Sciences, Stockholm University. Shipboard core logging data will be published on the Bolin Centre Database
WP5	Interactions between the North Greenland Ice Sheet and Atlantic Water	Bolin Center database
WP6	Palaeogenomics of Ecosystem Change	Lake cores will be stored at the in-house storage facility at the Dept. Geological Sciences at SU for future DNA and other analyses, DNA samples from bones, teeth and tissues will be accessioned into the collections at the Centre for Palaeogenetics in Stockholm Raw DNA sequencing data will be deposited in standard open access repositories (e.g. European Nucleotide Archive). Processed

		<i>data will be made freely available either as supplementary data in publications or in an open access repository (e.g. Dryad). Novel code will be deposited on Github. All biomarker data will be stored on an online repository such as PANGAEA.</i>
WP7	<i>Improved analyses of Arctic climate change and its impacts on mid-latitude climate in a multi-century context from climate proxies and models.</i>	<i>all data generated will be freely available through the Stockholm University Data Repository (https://su.figshare.com/) and the National Centers for Environmental Information at NOAA (https://www.ncdc.noaa.gov/): we will follow the PAGES data stewardship and FAIR data principles (http://pastglobalchanges.org/data/data-guidelines)</i>
WP8	<i>Trace gas dynamics and pelagic ecosystem function</i>	<i>Metadata: Swedish National Data Service (https://snd.gu.se/) Data: Bolin Centre Database (https://bolin.su.se/data/)</i>
WP9	<i>Tectonic Evolution of North Greenland</i>	<i>All the rock samples will be stored at Uppsala University and have an associated International Generic Sample Number (IGSN).</i>
WP10	<i>Arctic Meteorology and Ocean Surface Exchanges & ARCSIX Collaboration</i>	<i>Bolin centre database</i>
	<i>Opportunistic Sampling</i>	
	<i>ICE-PPR</i>	

7. ONBOARD WORK PACKAGES

Below are detailed descriptions of all Work Packages onboard I/B Oden during the North of Greenland 2024 expedition. The onboard WPs are practical and refer to the work to be carried out onboard. This implies that some work WPs onboard the ship may consist of multiple merged scientific work packages, each with its own original PI.

Chief scientists: Martin Jakobsson & Nina Kirchner

7.1 WP 1; MARINE GEOPHYSICAL MAPPING

WP General information

WP full name: Geophysical mapping	WP coordinator: Martin Jakobsson/ Larry Mayer/ Elizabeth Weidner	
WP ID (acronym): GM	Version date: 14th December 2023	
WP Resources		
WP Team Onboard		
Name	Institution	Role
Martin Jakobsson	Stockholm University	Co-PI/WP-Leader
Larry Mayer	UNH/CCOM	Co-PI/WP-Leader
Elizabeth Weidner	UNH/CCOM	Co-PI/WP-Leader
Brian Calder	UNH/CCOM	Operator
Felicity Holmes	Stockholm University	Operator
Jamie Barnett	Stockholm University	Operator
Björn Eriksson	Stockholm University	Operator/Technician
Elias Strandell Erstorp	Stockholm University	Operator/Technician
Manpower:		
A 24-hour operation of Oden’s multibeam/SBP/EK80/ADCP system, henceforth “Geophysical mapping systems” (GM Systems), will utilize <u>six persons</u> , divided into three teams operating during four hours shifts (see below). The seafloor mapping with the small survey boat RV <i>Skidbladner</i> requires <u>three persons</u> , and seismic reflection data acquisition will require <u>three persons</u> . Mapping duties will be shared with participants from e.g. the Kirchner group. Seismic profiling will require <u>four persons</u> , of which two are operators for 24-hour operations, when conditions permit during the expedition.		
Teams:		
Sonar Team 1 (0-4, 12-16):	Operators 1 and 2	
Sonar Team 2 (4-8, 16-22):	Operators 3 and 4	
Sonar Team 3 (8-12, 20-24):	Operators 5 and 6	
RV Skidbladner mapping:	1 driver, 2 multibeam/SBP/EK80 operators and additional assistance during launch and recovery	
Seismic operation:	3 operators, and 4 during launch and recovery.	
Equipment:		
Hull mounted multibeam: A Kongsberg EM122 1°x1° 12 kHz full ocean depth multibeam echo sounder, including the capability of logging the acoustic properties of the water column, is permanently installed on Oden. Due to the ice protection of the transceivers, the usable angular coverage is reduced down to less than 2 × 65°; the swath width that can be counted on for seafloor mapping is typically three-four times the water depth. The system includes a Seatex Seapath 320 for navigation using GLONASS/GPS and motion sensor logging (roll, pitch and heave). The motion sensor		

unit is a Seatex MRU5. A Seapath 200 is brought along as a spare unit.

Hull mounted chirp sub-bottom profiler: A Kongsberg SBP120 3°x3° chirp sub-bottom profiler is hull-mounted on Oden and integrated with the multibeam system. This system operates with a frequency range of 3-7 kHz and has an approximated resolution of 0.35 ms. The penetration is typically 50-200 m in clayey ocean sediments.

Split beam echosounder (EK80): A Kongsberg EK80 is installed, with the three frequencies 70,38,18 kHz.

Sound Velocity Correction: The main data source for correction of sound velocity changes in the water column will be data generated at oceanographic stations using the standard SeaBird 911 + CTD (in collaboration with WP Physical Oceanography). In addition, XBT (eXpendable Bathy Thermograph) and XSV (eXpendable Sound Velocimeter) will be brought and used when necessary.

Synchronization: From 2023, a Kongsberg K-Sync synchronization unit was installed, which synchronizes all installed units (multibeam/subbottom/midwater/ADCP).

RV Skidbladner: This Arronet 20 5 cs aluminum boat is 6.4 m long, 2.4 wide, and weighs about 1.8 ton with all geophysical equipment onboard. Skidbladner has a 150 Hp outboard motor and is equipped with a Simrad GPS-navigation plotter, radar system, AES, and radio. The fuel is 95 octane unleaded standard gasoline and the tank is 157 liter. Fuel consumption during survey in 6 knots is approximately 10 liters/hour. All equipment are supplied with electricity from a Honda 20i generator providing 2 kW. This generator consumes about 1 liter/hour gasoline (alkylade petrol is recommended).

RV Skidblader multibeam: A Kongsberg EM2040p, 200-700 kHz 1°x1°, multibeam is installed on a bow mounted pole that can be hoisted up for transit. This multibeam is capable of mapping the seafloor down to approximately 500 m.

RV Skidbladner navigation and motion sensor: Seapath 330 (GPS/GLONASS), including a Seatex MRU5+ motion sensor mounted in a subsea bottle on the EM2040p transducer casing.

Spare navigation system: Heading for the spare system is acquired using two VS101 Hemisphere GPS compasses mounted with a distance of 0.8 m apart. The main positioning of the spare system is acquired with a R320 GPS/GLONASS receiver mounted in between the VS101 antennas.

RV Skidbladner sub-bottom profiler: Kongsberg EA 640, chirp centered around 15 kHz, mounted on a pole that can be hoisted up or towed behind in specific towfish. This sub-bottom profiler could be towed behind Oden's workboat as well.

RV Skidbladner sound velocity correction: A velocimeter (SV) by Applied Microsystems Limited (AML) is mounted on the EM2040 transducer casing for continuous readings. An additional velocimeter (SVP) by AML is used for measuring the sound velocity profile in the water column.

Acoustic systems on Echoboat ASV: Barrel array MBES, EK80 broadband package, vertical hydrophone array

RTK Correction: A land station for RTK GPS correction will be brought along. This station should be placed on land and a high point in order to broadcast corrections to RV Skidbladner's GPS. Assistance to bring and install this system on land by helicopter will be required from Polar.

Seismic reflection profiling: A SIG pulse L5 portable light-weight seismic reflection sparker system is planned to be brought for acquisition of sub-bottom profiles in the fjords, specifically across bathymetric sills. The system is able to generate sound pulses with energy content up to 2000 Joules. The frequency spectrum of the pulses is generally centered around 1 kHz. This system is likely best operated from Oden's workboat Munin. While acquiring seismic data, we will ensure that no marine mammals are sighted in the area, even if it is a "light system" compared to the common systems based on airguns.

Lab/deck Space (see also summary table in appendix):

The Oden multibeam and sub-bottom profiler system is hull mounted and has a designated operation area. Post-processing will be done at the operator area by the second operator in each team.

RV Skidbladner requires a dedicated place onboard Oden, the cradle on the port side is optimal. Launch and recovery is done. Fuel (gasoline) is required to be stored securely.

Maximum planned operation of 100 hours is planned for the GEOEO expedition implying 1200 liter of gasoline for the outboard engine and 120 liters of alcyate gasoline for the generators. Storage for the gasoline could be in the containers purchased for SWERUS-C3 and kept by Polar. In addition, a small amount of diesel is needed for the heater.

Suitable space (with heat) for storage and troubleshooting for Echoboat ASV, space for pelican cases to store acoustics systems brought for RV Skidblander/WB Munin work. Can be in van if heat is available.

Required conditions for WP (ice, environment, weather, etc.)

Multibeam operation with Oden's hull mounted system is carried out continuously. In addition, survey along planned lines will be carried out.

For use of RV Skidbladner and the Echoboat ASV, there must be open water conditions, clear weather, and calm sea.

Seismic acquisition required light sea ice or open water as the system will not be setup for full icebreaker, with deep towed sources and streamers.

WP task description

Objectives (overall purpose):

The seafloor will continuously be mapped along the entire cruise using Oden's 12 kHz multibeam echo sounder (MBES) and integrated 2-7 kHz chirp sub-bottom profiler (SBP). There are, in addition, specific areas targeted for detailed mapping outlined in the cruise plan. The 24-hour data collection operations will also include MBES, SBP,

ADCP, and EK data collection. Following similar procedures used in previous expeditions, MBES and SBP data will be processed daily in order to provide bathymetric and subsurface context for other shipboard operations (safety of navigation, coring, etc). As time allows, ADCP and EK data will also undergo preliminary processing onboard. MBES survey activities will require, at minimum, daily sound velocity profile updates which can be provided by CTD operations or expendable XBT casts.

RV Skidbladner will be deployed, conditions permitted, to carry out detailed mapping of the shallow (<500 m) parts of the Victoria Fjord and potentially along scientifically interesting stretches along the shores of Nares Strait, or if work will be pursued in other fjords. Acoustic systems will be prepared for deployment (batteries charged, gear mobilized onboard and secured, etc.). The small boats will be deployed following IB Oden standard procedures and total deployment time will be defined by mutual agreement between the Captain and science party.

An RTK station should be setup on land to provide corrections for RV Skidbladner to achieve the best possible positional accuracy.

The deployment of Echoboat ASV is flexible. It will likely be deployed from IB Oden and potentially towed to its data collection location (close to the glacial terminus) by one of the small boats. Alternatively, the ASV could be controlled from the deck of IB Oden or from the shore, if personnel and gear were transported by helicopter. ASV Echoboat will require some preparation onboard IB Oden prior to deployment, including a systems check, battery replacement/charging, etc.

During the expedition, we will also process, visualize, and interpret the collected data. Using the approaches developed during previous expeditions we will map and interpret submarine glacial landforms of Victoria Fjord (the outlet of CH Ostenfeld Glacier) and its surrounding area, processing and visualizing mapping data in real-time and using these data to select coring sites. In addition to supporting the mapping needs of GEOE, we will use acoustic systems to collect oceanographic data around the ice-sheet margins. Our approach will use the small vessel on IB Oden (RV Skidblander and WB Munin) as well as the small autonomous surface vehicle (ASV) Echoboat. We will deploy a series of active and passive acoustic sensors as well as auxiliary sensors and make key measurements and images of the water column structure of near the ice termini we find in Victoria Fjord.

The sonars on IB Oden and RV Skidblander will additionally provide the distribution of acoustically traceable features (meltwater plumes, water mass boundaries, etc.) within the fjord, while the ASV work at the glacier termini will provide high-resolution maps of the submerged glacial terminus and, the mapping, identification, and acoustic characterization of subglacial meltwater plumes emanating from the base of the glacial termini. The ASV will collect active acoustic data and tow a vertical hydrophone array close to the glacial terminus. Acoustic measurements will be supplemented by many CTD and water-property casts that will be collected by the

physical oceanographic teams also on board the IB Oden. These will provide insight into the spatial and temporal character of fjord circulation.

Procedures:

- a) **Preparation:** The annual oversight of the Oden multibeam should be done before the expedition. Preferable operators should follow along with Oden from Luleå to Helsingborg to see that the systems work properly.
- b) **Task execution:** During the expedition, the routines will be setup.
- c) **On-board reporting and post-processing:** All multibeam data will be initially post-processed using Qimera and the sub-bottom profiles using the GSC batch tools. This will be carried out by the multibeam/sub-bottom operation team.

Interface with Oden crew and SPRS

Geophysical mapping from IB Oden – calibration efforts of the acoustic system will require deck assistance for deploying, maneuvering, and recovering the calibration sphere.

Small boat and ASV work will require fueling, deployment and recovery support from IB Oden crew, as well as a small boat operator and general communication during activities. The lift wires arranged by Oden for SWERUS will be required. It is an advantage if the multibeam can be lowered and ready to use in position when lifting in and out the boat.

If a helicopter is used to transport ASV to other locations additional support for these operations will be required. The setup of the RTK station also requires helicopter transport. All of these operations have been done in the past with full cooperation of crew.

WP Risk and counter-measures

Risk identification: Operation with RV Skidbladner must only be done by some selected operator with experience from operating small boats with multibeam. During calibration procedures the calibration sphere will be deployed over the side of IB Oden, requiring personnel to be in proximity and lean over the railings. During deployment of the ASV and small boats the crane will be in use and personnel will need to climb over the side of IB Oden down to the boats to board.

Counter measures (mitigating actions): RV Skidbladner is equipped with radio and AIS. All that go on Skidbladner should wear a survival suit. A satellite phone should be brought while on survey away from I/B Oden. If there is risk for polar bears on land, a gun should be brought in case the team will be stranded.

Calibration procedures will follow previously defined procedures for crew and science personnel safety, including active communication with radios, safety vests and hard hats. During the deployment of the ASV and small boats all personnel will clear the deck and path of the crane. Personnel boarding the small boats will wear immersion suits and life vests.

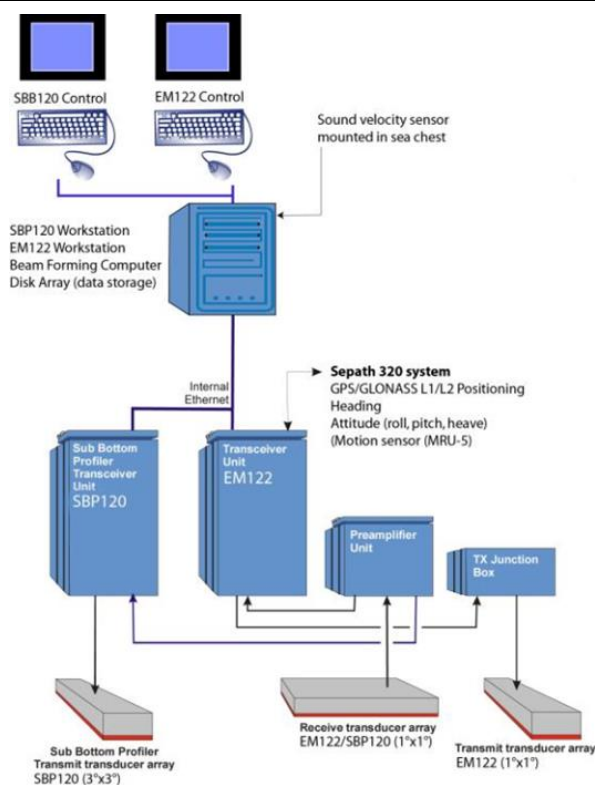
Deliverables and future (after cruise) plans

Processed multibeam data and sub-bottom profiles.
All output data will be uploaded to an appropriate repository e.g. the Bolin Centre for Climate Change data repository and NSF Arctic Data Repository (if funded by NSF). Bathymetric data will also be sent to IBCAO and IHO DBDC.

Outreach activities

This work package will contribute to the daily blog and expedition website.

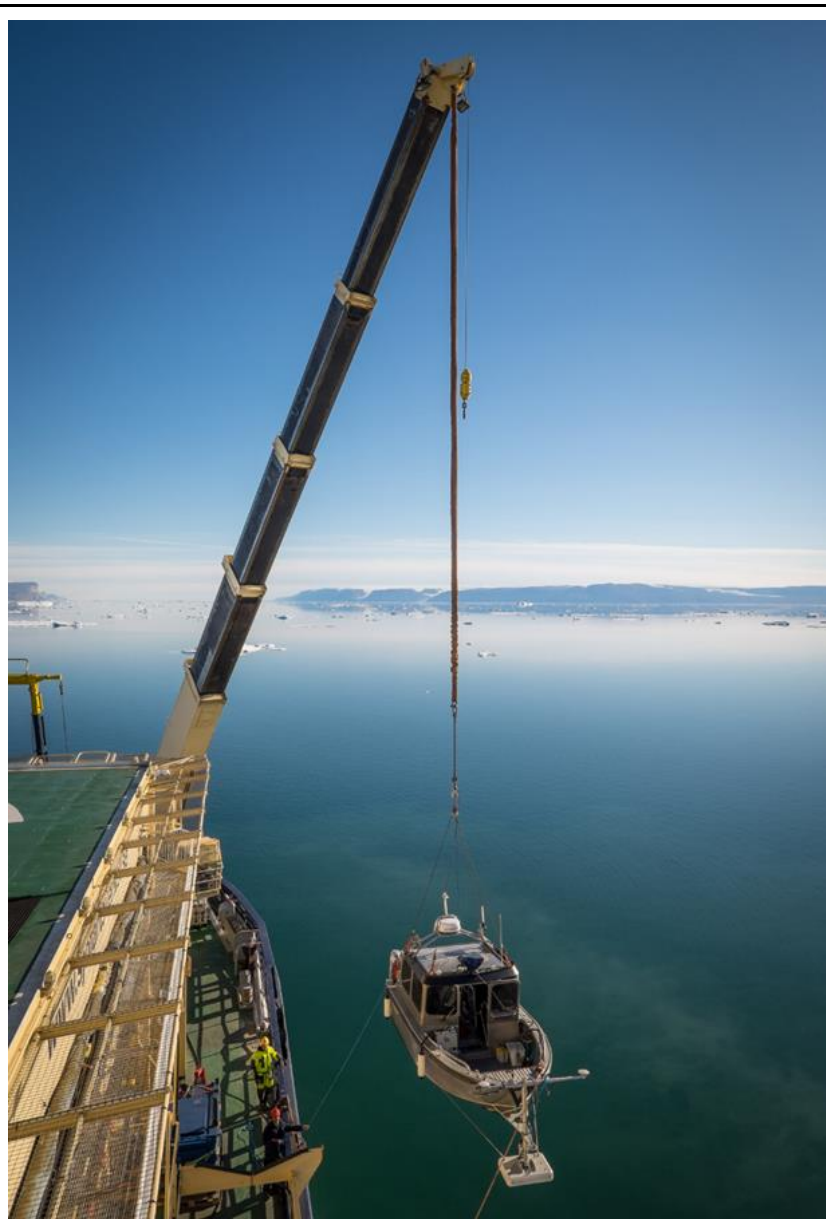
WP Appendix (drawings, pictures, equipment, fact sheet, etc):



Schematic illustration of the EM122/SBP120 system installed on the Oden. The drawings are modified versions of Kongsberg's original. Note that the workstations

were upgraded 2014 for the SWERUS.

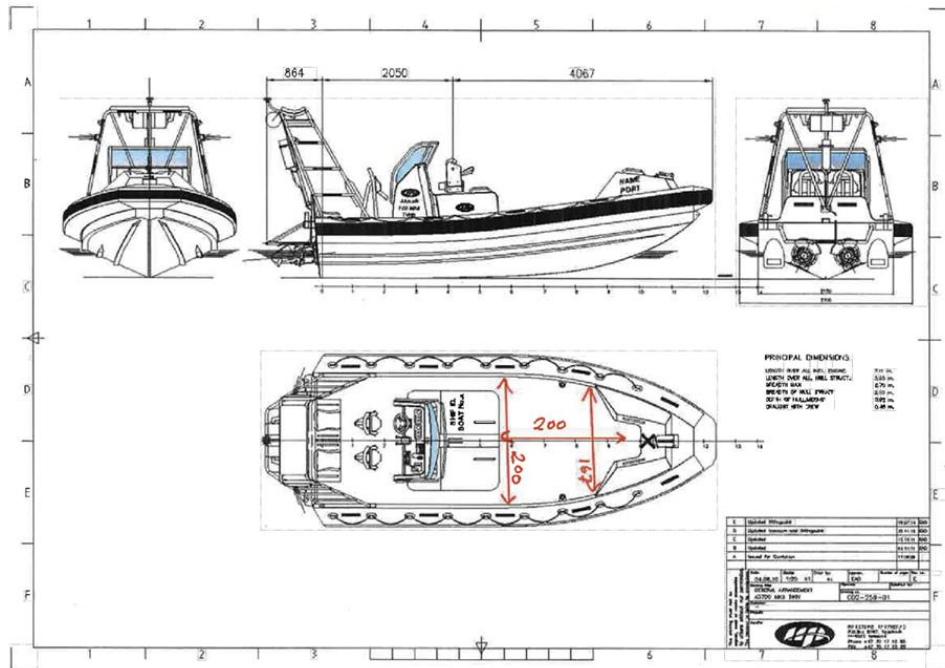
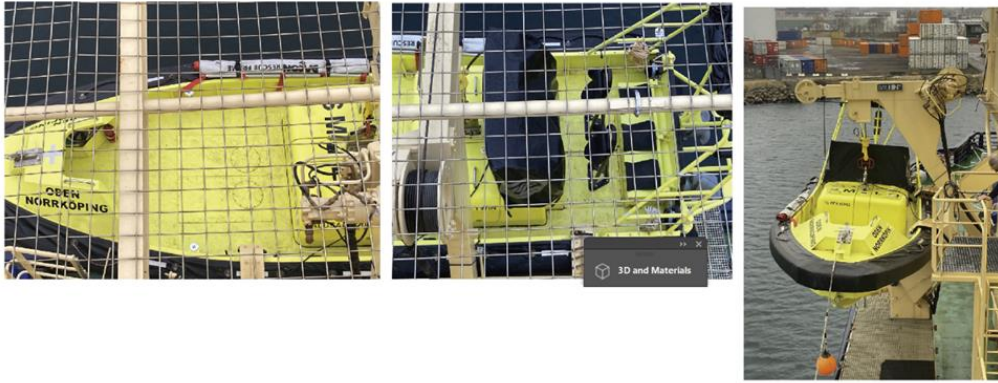




RV Skidbladner launched from Oden during the Petermann 2015 Expedition. The boat has been launched either with one or two operators or with no one inside and then climb into the boat using the rope ladder.



Setup of RTK GPS land station.



I/B Oden new working boat. However, the “old” Munin is likely more suitable for towing the seismic system as it is larger and has an cabin where the acquisition system can be placed.

Summary: Requirements for assistance, laboratory and deck space

Requirement

Comment

Cradle and electricity for <i>RV Skidbladner</i>	The setup during the <i>Petermann 2015</i> and <i>Ryder 2019 Expeditions</i> worked very well in all aspects. Important that we can have electricity to <i>RV Skidbladner</i> while in the cradle so we can have a heater installed, and test equipment.
Gasoline, <i>RV Skidbladner</i> and power generators.	Estimated that we need 1200 liter gasoline for outboard motor 100 liter alkylade petrol for generators. This permits 100 hours of operation. The secure tanks purchased for the SWERUS-C3 expedition are suggested to be used for the gasoline. These included a fueling hose.
Diesel, <i>RV Skidbladner</i> heating system.	40 liters
Launching of <i>RV Skidbladner</i>	Crew assistance is needed for this. The specially made wire with hooks for the SWERUS-C3 expedition will be needed. These are kept at SU and will be brought to Oden by SU.
Container space for XBT device	A space for launching the XBT/XSVs probes is required. A small 10-foot container on the aft-deck used to be used for that. Electricity is needed for a computer and the XBT launch-station as well as internet connection for data transfer to the multibeam operators on the bridge.
Annual service of multibeam following our Kongsberg service contract.	This could be made while Oden is at the harbor before we leave, but operators should follow along from Luleå to southern Sweden in order to perform test of the systems.
Office space in container	An office space for post-processing in one container that can be co-used with other WPs, in case it is not enough space to set up a processing station on the bridge.
Echoboat (1.2 x 0.8 m)	Heated storage location, previous

	deployment from IB Oden taught us the acoustic system and batteries do not work properly if they sit out in the cold overnight.
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7.2 WP 2; GLACIER -OCEAN OBSERVATORY

WP General information	
WP full name: Glacier-Ocean multi-sensor and multi-platform O bservatory	WP coordinator: Nina Kirchner/Peter Sigraay/Riko Noormets
WP 2 (acronym): GO2	Version date: 17 May 2024
WP Resources	

WP Team Onboard

Name	Institution	Role
Nina Kirchner	Stockholm University	PI/WP-Leader
Riko Noormets	UNIS	Co-PI/WP-Leader
Peter Sigray	KTH	WP-Leader
Niklas Rolleberg	KTH	Participant
Clemens Deutsch	KTH	Participant
Erik Sarri	Stockholm University	Participant

Team tasks: The team will install and operate a multi-sensor and multi-platform observatory at the site of investigations (prio 1: CH Ostensfeld glacier/Victoria fjord, other sites such as Ryder/Sheard Osborn, Petermann/Petermann are possible, according to contingency plans).

This implies operating **i/ autonomous surface (ASV)** and **ii/ underwater vehicles (AUV)**; installation (and maintenance when necessary) and recovery, or other short-to medium term operation of, aerial, terrestrial and underwater sensors and instruments such as **iii/ LoTUS buoys**, **iv/ hydrophones**, **v/ Time Lapse Camera**, **vi/drones** and of **vii/ ice penetrating radar**.

The number of persons needed for carrying out individual tasks varies. Details are described below. The team members also support the mapping activities in Workpackage Geophysical Mapping (Jakobsson et al.), and the water sampling activities in the Workpackage Water Column (Stranne et al.)

Equipment brought by the team (see pictures further down):

i/ 2 Autonomous surface (ASV) vehicles - Kuninganna and Anatra3; The ASVs will be used to map bathymetry in otherwise inaccessible regions in the fjord, such as shallow coastal and glacier-proximal regions. They can also be used to map transects across or along the fjord. They can be deployed from either boat or land and can also be easily transported by helicopter (hanging load) to sites otherwise difficult to reach with the icebreaker.

ii/ 1 Autonomous Underwater Vehicle (AUV) LoLo; LoLo will be used to explore under-ice regions, and/or glacier-front proximal regions. LoLo is equipped with a suite of sensors, including multibeam high-resolution echosounder, CTD, turbidity, fluorescence/chlorophyll, dissolved oxygen, sound velocity, and samples along track. The AUV can also be used to map transects across or along the fjord. LoLo can be launched from either boat or land and can also be easily transported by helicopter (hanging load) to sites otherwise difficult to reach.

iii/ 7 Long Term Underwater Sensing (LoTUS) buoys; These are lightweight (football sized) long term sensors for measuring ocean temperature at depth. They only need to be deployed, not recovered, during GEOEO. Deployment is very simple and can be done from ship/boat/helicopter by two persons without any further equipment/support/cranes.

iv/ 2-3 Hydrophones; These are lightweight (<10 kg) underwater sound recorders that will be used to capture the acoustic signature of calving. The hydrophones need to be deployed and recovered in glacier-front proximal fjord areas, preferably from a workboat (deployment from an icefloe has also been attempted during Ryder 2019).

v/ 1 Time Lapse Camera system; To be installed on land, overlooking a calving front in front of which also hydrophones and LoTUS buoys are deployed, and along which AUVs and ASVs are operated. Needs maintenance in the form of battery replacement (solar panels are not reliable).

vi/ 2-3 Uncrewed aerial vehicle (UAV, drone); To be operated from land and/or boat, with the primary aim to acquire high resolution Digital Elevation models of the glacier, and the secondary aim to produce material for outreach and communication.

vii/ 1 Ice penetrating radar. To be operated air-borne, from a helicopter flying over the glacier surface. The ice penetrating radar will give information about the ice thickness, the internal structure of the glacier, and the depth at which bedrock is located beneath the glacier. The larger the number of survey lines, the more detailed the topographic mapping beneath the glacier will become.

Lab/deck Space (for storage, see below) Lab (“mechanical workshop”) space is needed to prepare i/ ASVs, ii/ AUV, iv/ Hydrophones, v/ Time Lapse Camera System, vi/ UAV, vii/ Ice penetrating radar for deployment/launch, and similarly after recovery. The frequency with which this happens depends on the conditions encountered in-situ. Deck space is needed for launch and recovery of the i/ASVs, ii/ AUV.
<i>Required conditions for WP (ice, environment, weather, etc.)</i>
i/ 2 Autonomous surface (ASV) vehicles - Kuninganna and Anatra3; The ASVs are best launched/recovered/operated in calm conditions and when there is little sea ice/ice floes/ice debris. If/when transported to a launching site other than Oden, the weather needs to be good enough for helicopter flights. ii/ 1 Underwater vehicle (AUV) LoLo; LoLo is best launched and recovered in calm conditions and open water. If/when transported to a launching site other than Oden, weather needs to be good enough for helicopter flights. iii/ 7 Long Term Underwater Sensing (LoTUS) buoys; The LoTUSes only need a spot of open water for deployment (in the first hand from Oden but can also be deployed from boat or helicopter). iv/ 2-3 Hydrophones; The hydrophones are best deployed and recovered (from Oden or a workboat) in calm conditions and when there is little sea ice/ice floes/ice debris. v/ 1 Time Lapse Camera system; Installation, maintenance (battery swaps) and de-installation requires weather good enough for helicopter flights, because the time lapse camera will be installed on land. vi/ 2-3 Uncrewed aerial vehicle (UAV, drone); Drones will only be flown in good weather conditions. They can be flown from Oden, and from sites on land. vii/ 1 Ice penetrating radar. Operating the ice penetrating radar requires weather good enough for helicopter flights to and across the glacier, following a predetermined survey grid. Radar surveys need to be conducted in good weather conditions.
<i>WP task description:</i>

This WP addresses GEOEO goals II, V, and VII, and informs GEOEO goals I and III. The WP aims to advance knowledge of glacier-ocean interactions, and to assess their implications for the stability of the Northern Greenland Ice Sheet. Specifically, this WP expands into the underwater domain (with the help of maritime robots, deployable sensors and numerical ice and ocean models) and into the glacier domain (ice surface and subsurface), driven by the scientific questions:

1. What are the main drivers of frontal ablation? How do they vary over temporal and spatial scales?
2. What are the mechanisms of interplay between ice dynamics, fjord circulation and frontal ablation?
3. How is the terrestrial and marine cryo- and hydrosphere in the wider NGrIS marginal zone affected?

The shipboard part of the WP is focused on installing a temporary glacier-ocean multi-sensor and multi-platform observatory, using the instruments described above under “Equipment brought by the team”.

A shore-based part will develop a glacier-ocean numerical laboratory simulating glacier and ocean dynamics processes at various spatial and temporal scales, both facilitating collaboration with several other groups.

Procedures:

List the procedures for your operation.

i/ 2 Autonomous surface (ASV) vehicles - Kuninganna and Anatra³; Intended to be deployed in Victoria Fjord (Plan A, alternatives as in the contingency plans), the ASVs can perform first bathymetric mapping transects in uncharted waters. The ASVs can be launched from Oden (by crane, also requiring e.g. a workboat in the water for unhooking etc), or from a site on land, to which they can be flown by helicopter, and where they will simply be pushed into the water from shore. Once in the water, the ASVs are preferably surveyed by an operator on board (either Oden or a smaller workboat). Recovery is simple in shallow coastal regions, where the ASVs can simply be dragged on land. Elsewhere, recovery of the ASVs involves lifting them on deck (of either Oden or a smaller workboat) by crane.

ASV Kuninganna is equipped with an R2Sonic Multibeam Echosounder, operating at frequencies in the range of 200 - 450 kHz, rendering a maximum sounding depth of 200 m.

ASV Anatra is equipped with an ultra short baseline acoustic positioning system operating at 7-17 kHz. Note that the R2Sonic multibeam from Kuninganna can be placed on Anatra if necessary.

ii/ 1 Autonomous Underwater Vehicle (AUV) LoLo; Deployment of the AUV can be arranged in two ways: either **from Oden**, or from a site on land to which it has been transported by helicopter. From Oden, launch will require a crane and ice-free conditions in the area of deployment. Two approaches are possible, and a decision concerning which one shall be employed has to be made at each launch. Option 1 is to position LoLo on its cradle on deck, before the lift, and then lift LoLo with the cradle into the water, where LoLo can then be steered to leave the cradle and to continue on its underwater mission. This approach does not require a work boat in the water next to Oden and LoLo. Once in (and under) water, the AUV might be accompanied by the ASVs (see above) which can provide the AUV with “position fixes” upon surfacing. **From a terrestrial site**, the AUV will be launched into the water using a portable winch. AUV operations will be surveyed by two or three dedicated operators from the team.

Upon **recovery**, the AUV will **approach Oden** and either manoeuvre into the cradle which Oden has lowered into the water, to then take the cradle and LoLo up on deck. Alternatively, LoLo needs to be attached directly to a crane, with help from staff in a workboat alongside Oden and LoLo, to then be lifted on deck. At a **terrestrial site**, the AUV is hauled on land by a portable winch and can then be flown back to Oden once it is emptied of all water. Launch and Recovery of the AUV has been tested in April 2024 from R/V Electra av Askö, with WP team members and SPRS staff.

LoLo's maximum diving depth is 900 m, at a maximum distance of 375 m (theoretically, practically likely less, in the range of 100-150 m) from the seafloor. LoLo is equipped with the following sensors:

Doppler Velocity Logger (DVL), 333 kHz, range max. 375 m,

Forward Looking Sonar (FLS), 360 - 440 kHz

Norbit Multibeam Echosounder, 160 - 240 kHz (opt. up to 700 kHz), range max. 600 m

EK80 Echosounder (upward looking), 38 kHz

EK80 echosounder (downward looking), 38 kHz

Ultra short baseline (USBL) acoustic positioning system. Operating at 7 - 17 kHz

iii/ 7 Long Term Underwater Sensing (LoTUS) buoys; If deployed in Victoria Fjord, a bathymetric survey should be conducted before the deployment of the LoTUSes, to determine the best possible locations (lon/lat), and height above seafloor. The LoTUSes can be at most 800 m below the water surface. Moorings have to be constructed, comprising of a biodegradable anchor (hemp-bag filled with biodegradable material that will be left on the seafloor) and mooring line, fixing the LoTUS at the desired height above seafloor. The LoTUSes are preprogrammed and are ready to deploy once attached to the anchor and the mooring line. Deployment takes place by simply lowering the LoTUSes from deck (Oden or workboat) into the water. The LoTUSes do not need to be recovered.

If deployed in other areas, the same procedure applies but bathymetric surveys may not be needed (locations in Sherard Osborn Fjord and Petermann Fjord can be determined based on the mapping conducted during the Petermann 2015 and Ryder 2019 expeditions).

iv/ 2-3 Hydrophones; If deployed in Victoria Fjord, a bathymetric survey should be conducted before the deployment of the hydrophones, to determine the best possible locations (lon/lat), and depth below sea level (depth rating to 100 and 300 m, respectively) with respect to the calving front of CH Ostenfeld. Sea ice and calved ice-berg and ice-mélange conditions in the fjord will determine how close to the calving front the hydrophones can be placed, however, deployment always takes place at a safe distance. The Hydrophones will be placed on a mooring line, and connected to an acoustic releaser which in turn is connected to a biodegradable anchor weight. The total length of the system cannot be determined in advance, since the bathymetry in the fjord, and therefore at potential mooring sites, is not yet known. Alternatively, to reduce the length of the system, the hydrophones could be anchored on large, stable and rather stationary ice floes, or floes with a predictable motion pattern (as during the Ryder expedition). This is however only recommended if suitable icefloes can be identified. Perhaps floats (to be recovered later with the instrument) will be used along the mooring line, too, to keep the mooring line as vertical as possible. Deployment takes place from deck, or preferably and depending on location, from a workboat. For recovery, an additional acoustic releaser has to be brought, which has to be submerged

partially under water while holding it to send the release command to the moored releaser. Therefore, recovery needs to take place from a smaller workboat.

If deployed in other areas, the same procedure applies but bathymetric surveys may not be needed (locations in Sherard Osborn Fjord and Petermann Fjord can be determined based on the mapping conducted during the Petermann 2015 and Ryder 2019 expeditions).

v/ 2 Time Lapse Camera (TLC) systems; If in Victoria Fjord, reconnaissance helicopter flights should be made to identify the best possible location for positioning the time lapse cameras on land, from where they can overlook the glacier front. At the chosen spots, the camera systems are then installed on a tripod. Each camera is battery powered, and from experience (Ryder 2019, where the same camera system was used), some visits have to be made by helicopter to change batteries and download data from the SD cards. At operations end, the camera systems are de-installed and transported back to Oden by helicopter.

If installed at another site, the same procedure applies except for when in Sherard Osborn Fjord, where the same location can be used as during Ryder 2019.

vi/ 2-3 Uncrewed aerial vehicle (UAV, drone); UAVs can be launched from Oden or from any site on land and/or the glacier. UAV operation requires clear communication with any helicopter operations. UAV surveys flown to create digital elevation models of the glacier (front and surface) will need high positional accuracy, necessitating the setting up of a portable, battery powered RTK base station on land, operating during the UAV surveys. Setting up the RTK station is preferably combined with a maintenance visit at the one the TLC locations but may need a dedicated helicopter transport in some cases. UAV flights targeting the acquisition of outreach/ communication material do not require an RTK base station on land.

vii/ 1 Ice penetrating radar. Ice penetrating radar surveys will be conducted over HC Ostenfeld glacier as the primary target. The radio-echosounding will always be conducted from helicopter, where the instruments needed for the survey will be mounted on a large platform (ca. 15 x 15 m) attached to the helicopter as a hanging load. The acquisition of airborne radio-echosounding data has been tested successfully in April 2024 with CasselAero at Rivgojehhki glacier/northern Sweden, using the equipment to be used during GEOEO, and involving work package members and one of the pilots of the GEOEO expedition.

During initial surveys, a team of 2 persons is needed in the helicopter to operate the radar on the platform hanging ca 15-20 m beneath the helicopter. Further surveys likely require only one operator, also extending the range of the helicopter (and thereby the coverage of the survey) as more fuel can be taken. Establishing fuel depots on the glacier or adjacent to the glacier can be advantageous to maximize the area covered by the radio echo sounding survey.

The radar platform (designed by CasselAero) is decomposable, meaning that it takes rather little space when stored and transported, but also that suitable places for assembly/disassembly must be identified. One alternative is to assemble/disassemble onboard Oden, if space can be made available. In this case, any radio-echo-survey can start from and end on Oden. Another alternative is that the disassembled platform is flown to a location on land or to a safe spot on the glacier, where it can be assembled before and disassembled after the survey. To minimize the risk of damage of the sensitive radio-echo sounding equipment, assembly/disassembly will be carried out only by work package members with previous experience in this matter.

In cases when very good and stable weather conditions be expected and when a radio echo sounding survey is planned on consecutive days, it is an option to leave the assembled platform at a safe site, for instance, on a suitable location on the glacier (minimizing the risk of interference with polar bears as compared to e.g. sites on beaches).

If radar surveys are conducted at another site, the same procedure applies.

Interface with Oden crew and SPRS

Describe how you need assistance.

i/ 2 Autonomous surface (ASV) vehicles - Kuninganna and Anatra3; Assistance is needed during launch and recovery, either from Oden or a small workboat. Assistance is also needed if the ASVs have to be flown to a launch/recovery site on land. For land operations, the assistance of a polar bear guard may be needed.

ii/ 1 Underwater vehicle (AUV) LoLo; Assistance is needed during launch and recovery from Oden, and if/when the AUV has to be flown to a launch/recovery site on land. For land operations, the assistance of a polar bear guard may be needed.

iii/ 7 Long Term Underwater Sensing (LoTUS) buoys; No assistance needed.

iv/ 2-3 Hydrophones; Assistance is needed during launch and recovery from a small workboat.

v/ 2 Time Lapse Camera systems; Assistance is needed for transport to and from the terrestrial sites where the cameras will be located. The assistance of a polar bear guard may be needed.

vi/ 2-3 Uncrewed aerial vehicle (UAV, drone); Assistance is needed when the RTK base station has to be set up on land prior to UAV surveys aiming at acquiring data for digital elevation models. On these occasions, the assistance of a polar bear guard may be needed.

vii/ 1 Ice penetrating radar. Being conducted airborne, radio-echo sounding surveys at any of the marine-terminating glaciers in the scope of GEOEO rely on the availability of a helicopter, and helicopter pilot, for a considerable amount of time. One of the pilots, and 2 of the work package members, have trained data acquisition with the system to be used during the expedition in real conditions in April 2024 at Rivgojehhki glacier, northern Sweden. If the radar platform is assembled/disassembled on land, the assistance of a polar bear guard may be needed.

Assistance is also needed during mobilization and demobilization (lifting equipment on/off board, storing it etc.)

WP Risk and countermeasures

Risk identification:

Team members: Risk of injury

- due to slippery deck
- when lifting/moving of heavy equipment during maintenance (ASV/AUV/ice radar)
- when catching drones (rotating propellers)

Risk of polar bear encounter on land.

Equipment: Risk of damage to equipment during mobilization, demobilization, rough seas, heavy icebreaking, and during transports from Oden to terrestrial sites and to the workboat.

Counter measures (mitigating actions):

Careful handling of all operations. Polar bear safety is under the lead of SPRS or other qualified personnel.

Deliverables and future (after cruise) plans

Data will be published in the Bolin Centre Data Base.

Outreach activities

Blogs etc.

WP Appendix (drawings, pictures, equipment, fact sheet, etc):

If you have any pictures of sampling devices etc., insert some here.

ASV Kuninganna



ASV Anatra3



AUV LoLo (dimensions in mm)



LoTUS buoys (used from Oden since Petermann 2015)



Hydrophones (used during Ryder 2019, pic below from glacial lake Sálajegna 2020)



Time Lapse Camera System (here during Ryder 2019)



Uncrewed aerial vehicles (drones), of various types, to be determined



Airborne Ice Penetrating Radar (here in April 2024 at surveys in the wider Tarfala area)



Storage Requirements	Comments
Warm and dry storage of equipment	ASVs – Kuninganna: 175x70x80 cm, weight 140 kg; Size of storage box: 1.8 m x 0.8 m x 1 m (LxBxH) weight ~140kg. 4 pelicanses with electronics and spare parts Anatra3: inflatable hull in box (1 x 0.6 x 0.6 m, 10 kg), instrument deck (plate 1.5 x 1.5 m, 20 kg), Electronics and propulsion (10 kg, 1 x 0.6 x 0.6 m), Battery (kept in battery hut on Oden, 40 kg). 4 pelicanses with electronics and spare parts AUV - ca. 4.05 m x 1.05 m x 0.85 m and ca. 800 kg (AUV only). Carriage/cart not accounted for (currently being designed together with Oden crew). To be stored in a dedicated container. Design done in collaboration with SPRS. AUV toolboxes (stackable) – footprint ca. Zarges size, ca. 1.2m tall. Weight: ca. 25 kg. Stored in storage container together with AUV. AUV shore deployment rig – 1 Zarges box + 1 rig for deployment (slightly larger dimensions than AUV, weight ca. 50-100kg?) AUV battery two tubes – diameter 0.4 m and length 1.2 m, weight 80 kg each. To be stored in Oden's battery hut. LoTUS buoys: 3 Zarges boxes for 7 LoTUS buoys Hydrophones: 3 Zarges boxes Time Lapse Camera: 1 Zarges box, 1 set of aluminum poles (c 2 m long) Drones: 3 Zarges boxes Ice penetrating radar: 2 radar platforms (constructed by CasselAero, counts as helicopter equipment and therefore not taken up here further. 3 Zarges boxes containing the sensitive radio-echo-sounding equipment to be mounted on the radar platform.

7.3 WP 3; SILICATE ALTERATION IN MARINE SEDIMENTS

WP General information		
WP full name: Silicate alteration in <u>marine</u> <u>sediments</u>		WP coordinator: Wei-Li Hong
WP ID (acronym): MadSilica		Version date: 04-Dec-3023
WP Resources		
WP Team Onboard		
Name	Institution	Role
1. Wei-Li Hong, IGV-SU, WP leader		
2. Nai-Chen Chen, IGV-SU, postdoctoral researcher		
3. Sarath Pullyottum Kavil, IGV-SU, postdoctoral researcher		
4. Sophie ten Hietbrink, IGV-SU, PhD Student		
Equipment: Sediment corer (gravity corer, multi-corer), CTD rosette, field assistance when sampling onland.		

Lab/deck Space:

1. Clean metal-free lab space to process porewater samples and shipboard analyses (fumehood, bench space), clean deionized water needed (e.g., a MilliQ system). I will need ca. 8L of the clean deionized water per day when coring is planned for that day.
2. Deck/lab space for porewater extraction (**Figures. 1, 2, 3**) and Niskin bottle water sample filtration (**Figure 4**), tent space that protects us from severe weather and allows porewater extraction at low temperature. A few degrees of temperature fluctuation is acceptable). Porewater extraction from multicore will be done in O₂-free glove bags, thus access to inert gas (e.g., N₂) bottles will be needed (Figure 1). For multicores, porewater will be extracted vertically (**Figure 2**). For gravity cores, a space to lay the core section horizontally will be needed during the sampling of porewater (takes a few hours usually; Figure 3). Depending on the shipboard situation and the resources available, we may also sample the sediments from gravity/piston cores directly for porewater extraction. In this case, about 50 ml of sediments will be needed for each sample. This can be coordinated with other sampling on the sediments with Matt.
4. Dark and temperature controlled space (e.g., fridges) for core-top incubation (**Figure 5**). A walk-in fridge with access to electricity (constant stirring needed) and a bench or rack to fix the incubated cores will be sufficient for example.
5. Space in fridges and freezers (-20 oC) for water and sediment sample storage until disembark.

Required conditions for WP (ice, environment, weather, etc.)

- Porewater extraction and Niskin bottle water sample filtration: low temperature (ca. 5 oC or as low as possible, some fluctuation in temperature is tolerable), weather protected, access to inert gas bottles (e.g., N₂) for anoxic glove bag operation, access to electricity for a water filtration pump.
- Metal-free clean lab for water sample processing and shipboard analyses: access to bench space, clean deionized water, electricity.
- Core-top incubation: a dark and temperature-controlled space (eg a walk-in fridge) with benches or racks to secure sediment cores. Access to electricity will be needed by constant stirring of the core-top water.

<i>WP task description:</i>

Procedures:

- Collecting porewater/headspace gas samples from both gravity cores and multi-

cores: I plan to use the 8-core Oktopus Multicorer (from Dr. Volker Büchert, Stockholm University) to recover surficial sediments. Porewater will be collected by using Rhizon samplers through pre-drilled holes (ca. 5 mm diameter) on the liners for minimum disturbance of the sediments. Similarly, headspace gas samples can be collected from pre-drilled holes (ca. 5 cm diameter) from cores liners and/or the section bottom of gravity cores. Sediment samples from the core depths where fluid and gas samples are taken will also be requested for further characterization of organic and inorganic carbon (content, ^{13}C , and ^{14}C ages) as well as different silicate phases. The sampling of porewater and headspace gas should be performed in a cold environment (e.g., 4 °C) that could be either in a walk-in fridge or on deck. Subsampling and preservation of samples will be done in a clean laboratory space onboard I/B Oden. Inert gasses (e.g., N_2) will be needed as some of the sampling will be done in anoxic glove bags. Both fridges (4 °C) and freezers (-20 °C) will be needed for sample storage. Protocols for porewater and gas sampling are attached.

- Conducting core-top incubation experiments with multi-cores: The aim of the proposed incubation is to quantify ex-situ benthic fluxes of solutes. By sampling core top seawater with time and later determine fluid composition on shore, time-series changes in the concentrations (e.g., DSi), and isotopic signature (e.g., d^{30}Si), of various solutes can be obtained to calculate benthic fluxes between surficial sediments and bottom seawater. This experiment will need to be performed in a temperature-controlled environment, such as a walk-in fridge or on deck, with a core-top incubator that I will supply. Post onboard incubation, the sediment cores will be preserved (in cold, 4 °C, and ventilated regularly) for an offshore multi-year incubation experiment. Fluid samples will be stored in fridges (4 °C).

- A land campaign to sample meltwater and ice from glaciers as an end-member constraint: For the topics focused in this application, an end-member composition is required for interpreting the results. Fluid samples from glacial ice

and runoff provide composition constraints for the groundwater while particles in the glacial runoff represent the source material in the fjord. These fluid and solid phases will be preserved and incubated similarly as introduced in previous tasks. The sampling will be one-time. Ideally, one member from my team could join the land campaign to glaciers but this can be discussed as long as others can help with the sampling. Potentially coordinate with Hans for this. 1-5 liters of water will potentially be needed for each of the locations we sampled.

- **Performing time-sensitive porewater analyses:** These analyses will be performed onboard shortly after the samples are retrieved. The proposed analyses include alkalinity titration, Fe(II), dissolved silica, chloride concentrations determination through spectrophotometric methods. Analyses of the different items will be performed in a clean laboratory space onboard and can be done by one person with help from the other two members in charge of sampling in the first task. Protocols for the four shipboard analyses are attached.

- **Manual Niskin sampling from the little ship to collect water close to the glaciers.**

- **Water column samples from Niskin bottles:** We plan to sample 10-15 stations from the inner fjord. We plan to take 10-20 depths per station, depending on what we will see from the water column data when lowering the CTD. For each depth, we plan to take one (1) litre of water. For two of the stations, we will need 6L of water per depth (5 depths).

<i>Interface with Oden crew and SPRS</i>
For the proposed land-based work. Assistance from crew and SPRS will be needed.
<i>WP Risk and counter-measures</i>
Risk identification: - Counter measures (mitigating actions):
<i>Deliverables and future (after cruise) plans</i>
The material collected during the cruise will be analyzed and processed by a few postdoctoral researchers in the group (two of them onboard and one as shore-based participant). Future master students will be recruited to use the material for master thesis work. Conferences presentation and scientific papers are expected during the coming years.
<i>Outreach activities</i>
Progress will be updated through the group website (https://www.ocean-and-mud.com/) as well as through social media.
<i>WP Appendix (drawings, pictures, equipment, fact sheet, etc):</i>
<i>Figure 1: glove bag porewater sampling</i>



Figure 2: multicore porewater sampling



Figure 3: gravity core porewater sampling



Figure 4: Niskin bottom water sample filtration station



Figure 5: core-top incubation



Other risk assessment and protocols are attached as separated files.

7.4 WP 4; SEDIMENT CORING AND PROCESSING

WP General information		
WP full name: Marine Geology (Sediment coring and processing)		WP coordinator: Matt O'Regan
WP ID (acronym): MG		Version date: 2023-12-10
WP Resources		
WP Team Onboard		
Name	Institution	Role
Matt O'Regan	SU, SE	WP-Leader

Markus Karasti	SU, SE	Coring technician
Julie Lauttaud	Basel, CH	Core processing
Katharina Schwarzkopf	SU (PhD), SE	Core processing
PhD student	SU (PhD), SE	Core processing

Equipment:

Coring

Piston/gravity corer: The Stockholm University piston corer will be used. It was built 1996 to take up to 12 m long sediment cores from the aft of *Oden*. The corer has standard metric dimensions of barrel, screws and couplings. It has been upgraded several times since it was first built. The latest upgrade was made for the SWERUS C3 2014 expedition. This recent upgrade makes it possible to switch between two different dimensions of the core barrel/liner system. The change between dimensions requires changing core barrel, couplings, liner and piston. The core head including release arm remains the same between the two setups. The original liner dimension has an inner/outer diameter of 80/88 mm while the new wider diameter setup can take a liner dimension with an outer diameter of 110 mm. Transparent polycarbonate liners will be used for the smaller diameter while standard PVC pipes will be used for the larger. The small diameter corer with transparent liner is only brought along as a spare unit. The core head can be loaded with a maximum of 1360 kg lead weights. The standard release arm is designed so that a trigger weight of 1/10 of the main core head weight should be used. Hydrostatic safety releases can be used to arm the release arm, although a standard safety pin is commonly used. Three complete core heads will be brought on board, and two setups of barrel/couplings for each of the diameters. Typical pullouts of the piston core system are about 6000 kg. **Piston corer launching system:** A support “cradle” was also build 1996. A rail that launches the cradle was constructed and manufactured for the Lomonosov Ridge of Greenland (LOMROG) expedition 2007 to improve the safety of the coring procedure. This rail should be mounted for the coring operations during the Petermann Expedition. In addition to the main coring winch, a small winch is optimal to have handy for launching and recovering of the corer. This may be the small winch of the GEUS seismic reflection system used during previous expeditions.

Multicorer: An Oktopus 8-core multicorer (Oktopus GmbH, Hohenwestedt, Germany) Version 8-100 will be used to acquire undisturbed surface sediment cores.

Kasten Corer: A 3 m long 20x20 cm wide Kasten corer will be brought onboard. This corer will serve as a spare unit, but may also be used if a lot of sediment is required from a specific coring site.

Sediment Processing

GEOTEK Core Splitter: A specially designed device for splitting sediment cores. Ensures reproducible and constant downcore thicknesses in split cores – which benefits post-cruise sedimentary analysis. The splitter incorporated two cutting

mechanisms (vibratory cutters and razor blades) for the plastic liner. After cutting of the liner, a thin wire is used to manually slice through the sediments.

GEOTEK Multi-Sensor Core Logger (MSCL): Stockholm Universities MSCL is a fully automated core logging system equipped with transducers for measuring compressional wave velocity, magnetic susceptibility sensors to measure the volume of magnetic minerals within cores, a Cs-137 radioactive source to measure sediment bulk density and a non-contact resistivity meter for measuring the electrical resistivity of marine sediments. During the Ryder expedition, only measurements of bulk density and magnetic susceptibility were made. The MSCL is also equipped with a high-resolution line scanning imaging system, used to capture digital images of each split core section.

Minolta Spectrophotometer: A handheld Minolta spectrophotometer (model CM-700d) was used to obtain diffuse colour reflectance measurements.

Spectrophotometric analysis produced three types of data: (1) L^* , a^* , and b^* values, where L^* (lightness) is a total reflectance index ranging from 0% to 100%, a^* is the green (–) to red (+) chromaticity, and b^* is the blue (–) to yellow (+) chromaticity; (2) Munsell colour values; and (3) intensity values for 31 contiguous 10 nm wide bands across the 400 to 700 nm interval of the visible light spectrum.

K-Analysis AB TPS500: Thermal properties of marine sediments were measured using a *K-Analysis AB, Hotdisk TPS500*. This device measured thermal conductivity, thermal diffusivity and specific heat capacity at discrete intervals along the split core surface.

ANTARES Miniature Temperature Probes: *In situ* temperature measurements were collected using reusable ANTARES miniature temperature probes attached to the outside of each core barrel. Each stainless-steel temperature logger was 16 cm long and 1.5 cm in diameter. They were programmed with a laptop computer and small programming station (20.5 x 7 x 12.5 cm) that was also used to download data. 15 probes were brought onto the ship, and 4-5 probes were used on each core. Programming and downloading of the temperature probes were conducted on *Oden's* aft deck inside the coring container.

Binocular microscopes: A pair of binocular microscopes will be brought along and set up in one of the labs. These will be used by the core processing team for picking dateable carbonate material from sieved samples.

Lab/deck Space:

Sediment Coring: A specially designed 20-foot container will be brought that contains all the coring parts and has room for technical maintenance. This container should be placed next to the rail for the coring system on the aft-deck. In addition, a 20 foot container for the multi corer plus addition material is needed on the aft deck as well as a 20-foot refrigerated (4°C) container for core storage that can be placed above the main lab at the front of the ship.

Sediment Processing

GEOTEK Core Splitter: A specially designed device for splitting sediment cores. Ensures reproducible and constant downcore thicknesses in split cores – which benefits post-cruise sedimentary analysis. The splitter incorporated two cutting mechanisms (vibratory cutters and razor blades) for the plastic liner. After cutting of the liner, a thin wire is used to manually slice through the sediments.

Lab/deck Space: The MSCL was set-up in Oden's forward port side lab, where it had been placed on previous expeditions. It has been refurbished in 2023, but has the same dimensions as it did on previous expeditions (Swerus-C3, Ryder-2019). Additional instruments, including the Hotdisk TPS500 and spectrophotometer were used on one of the two bench tops in the lab. Core descriptions and sampling was done on the other. All cores were split in a tent positioned forward of the main lab.

Required conditions for WP (ice, environment, weather, etc.)

Coring is possible to carry out in practically all sea ice conditions as long as a small open area can be arranged behind *Oden*. It is actually less optimal and more challenging with open water conditions, however this is doable provided that the drift is not too high. During Petermann 2015 we cored successfully in open water conditions up to approximately 10-12 m/s, the drift in the Nares Strait was a bigger challenge. The exact wind limit for when coring not can be carried out depends on how rough the sea becomes.

WP task description:

Sediment cores are planned to be taken for a suite of studies (see cruise plan). The coring involves both piston/gravity coring for up to 12 m long cores and multi-coring specifically targeting the uppermost surface sediment sequence. The specific target areas are identified in the separate cruise plan, but at this stage are schematic. Exact coring locations will be selected at sea based on geophysical surveying. Probes for temperature logging will be placed on the core barrel, implying that it is required to have the core sit in the sediment for 2-4 min before retrieval. We expect that often, it will be necessary to deploy 3 coring tools at each station, the multi-core- piston core and gravity core. The duplicate long-cores are needed to accommodate requests by the pore-water chemistry team and the sedimentary DNA team – whose sampling needs are not compatible (i.e pore-water extraction has the potential to contaminate sediments either directly, or through the long-term storage of the cores after holes have been drilled into them).

Procedures: a) Preparation of corers, incl. loading of liners b) Launch of corers c) Retrieval of corers d) Unloading corers and retrieval of liners e) Cut core sections are brought to the forward lab by the Marine Geology group f) Pore water is extracted from some cores g) The cores equilibrate to room temperature / or pore-water is extracted overnight h) They are logged on the Multi-sensor core logger the next day i) They are then split, sampled, imaged and described. At the same time auxilliary measurements of the thermal properties, color and shipboard foram processing is done. j) The split cores are then packaged in D-tubes and stored in the refrigerated container. k) Multi-cores will be handled differently. 1 tube should be frozen for shorebased work, while 1-2 tubes will be sliced by the Marine geology group (1-2 cm slices) and frozen shipboard. This will be done as time permits.
<i>Interface with Oden crew and SPRS</i>
Coring sites will be decided following geophysical mapping. The site selection will be discussed with the Captain and SPRS coordinator. The coring operation is dependent on winch/a-frame assistance by the <i>Oden</i> crew on the aft-deck. No assistance is needed for the core processing.
<i>WP Risk and counter-measures</i>
Risk identification (1): Coring involves very heavy equipment and there is always a risk involved. Fast drifting of the ship may jeopardize the core retrieval. Counter measures (mitigating actions) (1): Pressure release of the piston corer can be used when the water depth permits and if there are ship motions. Only two from the coring team are required to carry out the actual coring on the fan tail, the rest of the team stands back until the core is on deck. Risk identification (2): The core logger contains a radioactive Cs 137 source. Counter measures (mitigating actions) (2): The source is heavily shielded in a lead casing at all times, even when in operation. It is clearly marked and kept closed when not logging core. We will ensure that everyone in the lab and ship's crew are aware of this radioactive source and how it works, and clearly mark small region between the source and detector that people should stay away from.
<i>Deliverables and future (after cruise) plans</i>
Cores and samples will be stored at the Department of Geological Sciences, Stockholm University. Shipboard core logging data will be published on the Bolin Centre Database.

<i>Outreach activities</i>
Have not been determined
<i>WP Appendix (drawings, pictures, equipment, fact sheet, etc):</i>

7.5 WP 5; INTERACTIONS BETWEEN THE NORTH GREENLAND ICE SHEET AND ATLANTIC WATER

<i>WP General information</i>	
WP full name: Interactions between the North Greenland Ice Sheet and Atlantic Water, and its role for sea-level changes.	WP coordinator: Johan Nilsson MISU
WP ID (acronym): Ocean physics	Version date: 2023-11-15
<i>WP Resources</i>	
WP Team Onboard Johan Nilsson, SU, PI Christian Stranne , SU, PI	
Equipment: CTD, and possible moored instruments	
Lab/deck Space: NA	

<i>Required conditions for WP (ice, environment, weather, etc.)</i>
Sea ice, waves, and drift of Oden can affect the possibility to take CTD stations
<i>WP task description:</i>
Procedures: CDT and water samples. Possible moored station with current measurements. To the bottom most of the casts 500 - 1500 meters. oxygen gas turbidity fluorescence
<i>Interface with Oden crew and SPRS</i>
Help with operation of the CTD winch and A-Frame.
<i>WP Risk and counter-measures</i>
Risk identification: Counter measures (mitigating actions):
<i>Deliverables and future (after cruise) plans</i>
Physical oceanography data will be made available on the Bolin Center database.

<i>Outreach activities</i>
We will contribute with writing and photos to outreach.
<i>WP Appendix (drawings, pictures, equipment, fact sheet, etc):</i>

7.6 WP 6; PALAEOGENOMICS OF ECOSYSTEM CHANGE

<i>WP General information</i>	
WP full name: Palaeogenomics of Ecosystem Change	WP coordinator: Love Dalén
WP ID (acronym): PEC	Version date: 231210
<i>WP Resources</i>	

WP Team Onboard

Name	Institution	Role
Love Dalén	Dept Zoology, SU	Land team leader, Field surveys
Anders Götherström	Dept Archaeology, SU	Archaeology, Onboard laboratory
Mikkel Sinding	Greenland Institute of Natural Resources	Permits, Greenland environment
Flore Wijnands	Dept Geological Sciences, SU	Coring, Sediment sampling

WP Team Shore-based

Name	Institution	Role
Peter D. Heintzman	Dept Geological Sciences, SU	Coring logistics, Sedimentary ancient DNA analysis

Equipment:

** Will be provided by the participants.

Notes: The basic plan is to do the lake coring in a light-weight fashion, ideally spending only 1-2 days per lake. A rough estimate is therefore that we need to plan for a maximum of 15 camping days, of which roughly half are for safety reasons in case we become stuck. We have based all estimates on 5 persons to have one spare, and/or for a 5th person from Oden's crew joining us during part of the field work.

Shipbound:

- Ancient DNA lab container
- Freezer
- Fridge
- Core splitter
- DNA laboratory equipment and consumables **

Coring:

- Nesje coring system **
- Zodiac boats and platform parts **
- Tripod and wire+winch system **
- Gouge corer and rods/sleeves **
- Russian corer **
- Misc. equipment: screwdriver, mallet, fisherman gloves, clamp, etc. **
- Water depth measuring device **
- Pipes, caps, etc. **

Camping:

- 5 sleeping tents **
- 5 sleeping bags
- 5 sleeping mats, inflatable
- 10 sleeping mats, foam
- 10 large waterproof bags
- 2 Trangia stoves (with Primus gas adapter)
- Camping gas, small 10 x 230g canisters
- Camping gas, large 25 x 450g canisters
- 2 Water container, 20L
- Food (freeze dried, lightweight) for 15 days (for 5 persons)
- 2 camping chairs (for bear watch)
- Misc. camping items
- Toilet paper
- 2 small shovels **
- Other personal equipment **

Safety:

- 5 survival suits, lightweight, 2h
- 5 life jackets
- 2 shotguns (at least) and ammunition
- 2 Flare guns
- 5 Bear spray
- 2 camping chairs

- 2 Satellite phones
- 2 Garmin InReach
- 5 walkie-talkies (good quality, water proof)
- 2 First aid kits, small (outreach)
- 1 First aid kit, large (base camp)

Marine mammal tagging

- 1 DANiNJECT airgun **
- 4 Satellite transmitters **
- 2 Satellite transmitter deployment arrows **
- 10 Biopsy arrows **
- 5 32g Co2 cartridges **

Other:

- Miscellaneous sampling equipment **

We should be under 600 kg in sling weight with equipment for both lake coring and camping included. Probably even lower (around 500 kg).

Lab/deck Space:

1) We need access to one full lab container, with fresh water access, where we will set up an ancient DNA lab.

2) We also need a post-PCR bench space in a separate lab container. For this, we can share with other projects and only need ca. 2 m² of bench surface plus access to a small fridge and freezer.

Required conditions for WP (ice, environment, weather, etc.)

Once we are established at the lake sites, we can work in most weather conditions except very strong winds. However, we obviously need acceptable flying conditions to get to and from the lakes.

WP task description:

This project will use palaeogenomic methods to investigate past ecosystem changes in northern Greenland, with the aim to generate a detailed record of the timing of arrival of different animals, plants and humans, as well as establishing to what extent demographic changes took place following the initial colonisation. The work will be both onboard the ship and land-based. Onboard icebreaker Oden, we will help collect marine sediment cores in collaboration with other researchers, and conduct subsampling and basic DNA analyses on terrestrial cores and remains. We will also conduct downcore biomarker analyses (gdgt, fatty acids, sterols, hopanols, long chain diol) to track past productivity events (diatoms, bacteria and green algae) and environmental conditions (lake temperature and precipitation) in the lake records. These will complement the palaeoenvironmental reconstructions derived from the sedimentary paleogenomic records. During the land-based work, we will collect lake sediment cores that represent the terrestrial environment, and we will also conduct surveys on foot to identify archaeological sites and to collect samples from ancient animal and plant remains.

Procedures:

Field surveys:

Land surveys will be done in pairs, once the lake coring system has been set up and is running smoothly (see below). We will search for and collect modern and ancient remains of wild organisms for subsequent genomic analysis and radiometric dating. We will subsample large remains for analysis in the field. We will also search for and document (coordinates, photos) archaeological sites. The latter will be done in close communication (via SatPhone) with Greenland authorities, such as the Greenland Institute of Natural Resources. During all the land surveys, there will also be an opportunity to opportunistically collect samples for other projects related to GEOEO.

Lake sediment coring:

We will take lake sediment cores primarily using a raft and Nesje coring system with which we have prior experience using in the European Alps (Figs. 1-3). The raft is constructed by linking two Zodiac rubber boats to create a platform, to which a tripod and winch system is attached. This can be assembled in the field in 45 minutes. Nesje piston coring, in which a single 2-6m long and 10cm diameter PVC pipe is forced into the sediment, is used to recover a continuous sediment sequence up to ~5.5m. Once back at shore, the sediment-filled pipe is immediately cut into 1 m long sections and capped. Prior to Nesje coring, we will measure water depth using a fish-finder and weighted tape-measure system to allow for high spatial precision at the start of coring. To gauge the total depth, stiffness, and composition of sediments, we will also use a rod-extendable gouge corer prior to Nesje coring. We may use a UWITEC gravity corer to collect surficial sediments. As a back-up system to the Nesje, we will also have a Russian corer (as used in Ryder2019). We will also have a smaller Zodiac boat to act as a support vessel for the anchored platform. All lake coring activities at a site, including post-coring dismantling of the raft, can be achieved in a standard work day.

Marine and fjord sediment coring will be performed on icebreaker Oden in conjunction with other ship-based GEOEO teams.

Palaeogenetics and biomarkers:

Marine and lacustrine sediment cores will be scanned using a core logger prior to opening. They will then be opened on board icebreaker Oden and subsampled for DNA, biomarker, and hyper-spectral analyses, in the ancient DNA lab container wearing hazmat suits and full protective gear. DNA and biomarker subsamples will be stored at -20 °C for later transport to Stockholm where DNA extractions, metabarcoding and metagenomics analyses will be performed at the ancient DNA facilities of the Centre for Palaeogenetics. Extraction and analysis of biomarkers will be done at the Department of Environmental sciences at the University of Basel.

Ancient remains collected during the field surveys will be prepared, subsampled and documented in the ancient DNA lab container. We aim to identify species on board using a DNA 'barcoding' approach. Basic DNA extractions and PCR setup will be conducted in the ancient DNA lab. The DNA will be amplified and prepared into Oxford Nanopore libraries for sequencing on a MinION dongle in the post-PCR lab. Further analysis, including whole genome sequencing, of ancient remains will be performed at the Centre for Palaeogenetics in Stockholm.

Marine mammal tagging (side project requested by Greenland Institute of Natural Resources):

Narwhals and/or walruses can be approached slowly using Skibladner, whereupon satellite tags can be deployed remotely at up to 10m distance, using an arrow shot from the airgun. Similarly, biopsies can be collected using a biopsy arrow, which is subsequently collected at the sea surface.

Interface with Oden crew and SPRS

We initially need to conduct light-weight helicopter surveys of the lakes to assess the lakes' suitability for coring (in particular the depth but possibly also the sub-bottom profile). We subsequently need assistance to get us and all the equipment to and from the lake coring sites. Part of the equipment (coring equipment) will need to be heli-slung to the site. Once there, it would also be very helpful to have one crew member (or other researcher) remain on the lake shore on bear watch duty and for other safety reasons, while two of us are conducting the lake coring and the other two do the land-based surveys.

Land-based surveys can also be done during times we are not coring lakes, and the flights to and from different land areas could then be done in collaboration with other land-based teams.

Onboard icebreaker Oden, we need to interact and collaborate with other research teams to facilitate collection of and get access to marine cores for DNA subsampling.

WP Risk and counter-measures

Risk identification:

Risk identification: A) Lake coring will entail risk of falling into the water, and subsequent drowning or hypothermia. B) Encounters with polar bears. C) General risks of moving in an exposed landscape (falls, storms, etc).

Counter measures (mitigating actions):

Counter measures (mitigating actions): A) Lake coring staff (2 persons) will wear life jackets, and likely also survival suits. During lake coring, one shore-based staff will always be on overwatch. B) Staff will be armed with signal flares and bear spray, people will always work in pairs as a minimum and each pair will have a rifle. C) Staff will always work in pairs as a minimum, and will be equipped with warm clothes and personal first aid kits. All pairs will carry a walkie-talkie, a satellite phone and a GPS with emergency beacon capacity (e.g. Garmin inReach).

Deliverables and future (after cruise) plans

Research collections: Lake cores will be stored at the in-house storage facility at the Dept. Geological Sciences at SU for future DNA and other analyses, DNA samples from bones, teeth and tissues will be accessioned into the collections at the Centre for Palaeogenetics in Stockholm.

List data repositories: Raw DNA sequencing data will be deposited in standard open access repositories (e.g. European Nucleotide Archive). Processed data will be made freely available either as supplementary data in publications or in an open access repository (e.g. Dryad). Novel code will be deposited on Github. All biomarker data will be stored on an online repository such as PANGAEA.

Publication and dissemination: We will publish results in international, peer-reviewed journals, with all papers made open access. These publications often generate media attention, which we will facilitate. We will disseminate the results at national and international scientific conferences.

Outreach activities

Blogs etc.

There will naturally be a broad general interest for the expedition, and we should provide entertaining and factual information when possible. We feel that the best format for this is a blog, where we can provide sufficient information in short (three or four paragraphs) but frequent posts that we upload at least several times per week. The blog will cover specific occurrences and conditions that will be of interest to a broader audience. Since we will generate many photos on a daily basis, it is not a time consuming task to prepare 3-4 photo-illustrated blog posts per week. Blogs are easily organised on web hotels such as Wordpress, but if there are restrictions we can also use a blog space at SU as we did on the Ryder expedition. Other types of social media such as X (previously Twitter) and Facebook can also be used. When we have something suitable for X and Facebook, we will use already established accounts at SU, since it takes some time to promote a page and get followers. For example, we will use our Centre for Palaeogenetics account for posts, which has 7,800 followers on X. These platforms can also be used to promote our blog posts.

WP Appendix (drawings, pictures, equipment, fact sheet, etc):

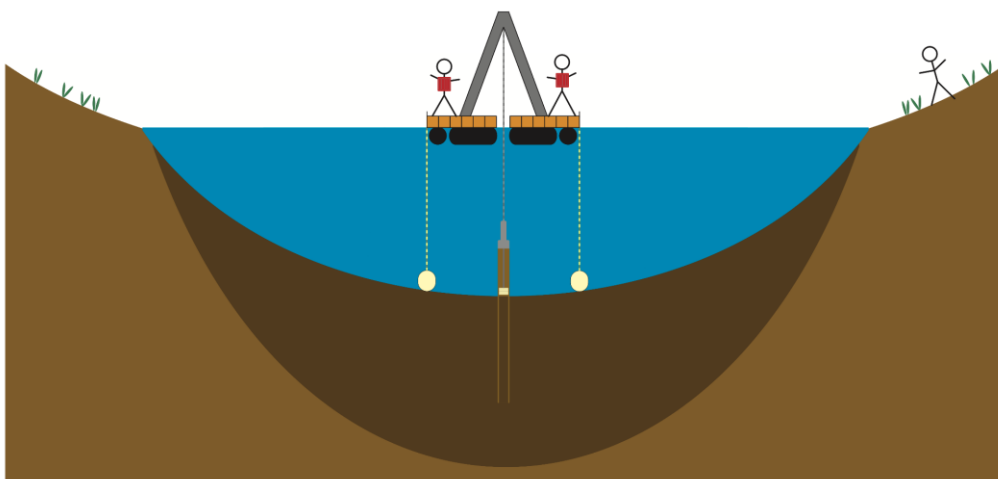


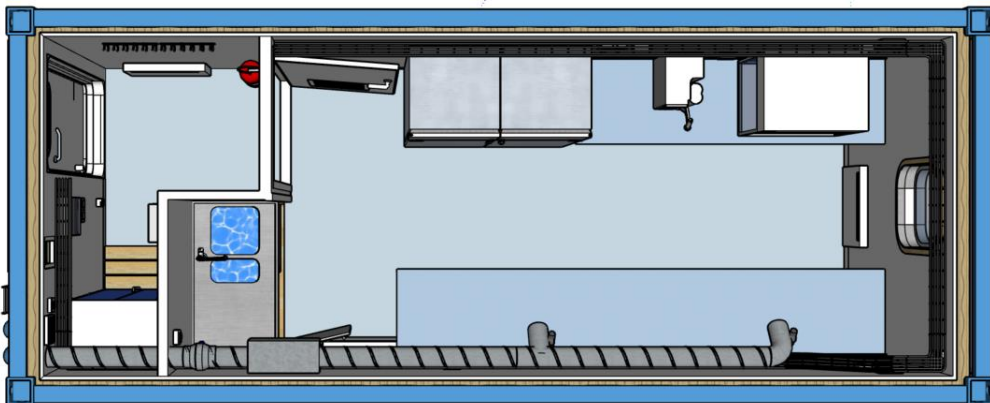
Fig. 1. Cartoon of the raft and Nesje coring setup previously used by Heintzman in the European Alps.



Fig. 2. The assembled raft that was previously used by Heintzman in the European Alps.



Fig. 3. The assembled raft and Nesje coring system that was used in the European Alps.



Sketch of clean lab space; Mainly freezer space, some fridge space, milliQ, UV-hood, filter for outside air, changing room with locker, hangers, latex glove dispenser.

7.7 WP 7; IMPROVED ANALYSES OF ARCTIC CLIMATE CHANGE

WP General information		
WP full name: Improved analyses of Arctic climate change and its impacts on mid-latitude climate in a multi-century context from climate proxies and models.		WP coordinator: Hans Linderholm
WP ID (acronym): <i>ARCCLIM</i>		Version date: 2023-11-10
WP Resources		
WP Team Onboard		
Name	Institution	Role
Hans Linderholm	GU	WP-Leader
Björn Gunnarson	SU	Operator/Processing

Equipment:

Targeted sampling sites, selected prior to the expedition from analysis of satellite imagery, will be surveyed via helicopter and drone (Phantom 4, see figure 1), and on foot.

Driftwood samples, in the form of discs cut across the growth rings, will be collected with a chainsaw (see figure 1). The geographic position (latitude/longitude) and altitude of each sample will be recorded with GPS, and the discs labelled and stored in plastic bags. The discs will be processed (e.g. exposing fresh surface with a razor to enhance the cell contrast to distinguish individual rings) in the workshop and laboratory on Oden (see figure 1).

Of the dwarf shrub (see figure 1) samples, the continuous below- and above-ground root and stem system of each specimen will be excavated with a spade. In the laboratory on Oden, individual plants will be weighed (dry wood weight), measured (length of roots and above ground branches), and the taproot labeled and cut off (ca. 10 cm/sample). Microsections will be taken with a microtome.

Lab/deck Space:

We will need storage space for chainsaws (one electrical and one gasoline) and oil and gasoline, and two large plastic boxes will be sufficient. We will need access to the workshop on *Oden* to maintain and sharpen the chainsaws and prepare the driftwood/shrub samples for analyses.

Driftwood and shrub samples will be stored in plastic boxes in one of the lab containers. We need lab space for a microscope, measuring equipment from Velmex, connected to the TSAP-Win software from Rinntech, to measure and crossdate the driftwood samples (see figure 1), and microtome for shrub samples.

Required conditions for WP (ice, environment, weather, etc.)

We have to be transported by helicopter from *Oden* to land sites, and back, which makes our work sensitive to ice and weather conditions, but also by competing demands for helicopter use. If opportunities arise (depending on the other land team), we may stay ashore in tents for a shorter time. We also require snow-free conditions and sea-ice-free shores to locate driftwood and dwarf shrubs.

WP task description:

Regardless of which emissions scenario is followed over the next few decades, the Arctic will be a substantially different environment at mid-century than at present. However, the scientific understanding of Arctic climate change is far from complete, because we do not fully understand the underlying processes due to short and incomplete observational records and large biases of climate models in these regions. This means that any projection of future Arctic climate, and potential impacts on lower latitudes, will be very uncertain. We aim to overcome this knowledge deficit by providing highly resolved proxy data on such spatial scales that they represent the whole Arctic from the present and back in time. Given the increasing interest in understanding and quantifying vegetation changes in the Arctic, several efforts have been made to collect shrub data, including ring measurements. Shrub-ring data, which to large degrees are freely available (see below) have been used in recent key studies looking at the climate sensitivity of shrubs, changes in environmentally triggered changes in plant functional traits and influences of sea-ice decline on shrub growth. However, no attempts have been made to utilize the full climatological potential of shrub-ring data in terms of large-scale synoptic climate reconstruction. We will provide unique data sets that will significantly advance our understanding of Arctic climate and environmental change and how this sensitive region may be linked to lower latitudes in a long-term context.

Background

Since the 1980s, Arctic temperature increases have exceeded those of the Northern Hemisphere average by a factor of two¹. This Arctic amplification (AA) results from the combination of increased greenhouse gases and positive feedbacks involving sea ice, snow, water vapour, and clouds, and has a profound impact on local ecosystems and societies. Evidence suggest that AA also influences weather and climate at lower latitudes through the large-scale atmospheric circulation by reducing the latitudinal temperature gradient. However, recent modelling studies offer contradicting predictions. Because of the limited number of meteorological stations north of 70°N, where only a handful extends more than 100 years, it is difficult to assess spatial and temporal rates of Arctic climate change in the instrumental era. Moreover, the contradicting viewpoints regarding the Arctic influencing on mid-latitude weather, which we recently highlighted⁵, are unlikely to be resolved before improved high-resolution climate data representing the entire Arctic extending back into pre-industrial times is available. This also hampers the detection of changes in, and understanding the mechanisms controlling, climate variability on multiple timescales.

Such uncertainties impede reliable estimates of future changes. Clearly, there is a need for a better data coverage of this highly sensitive region.

Aim and objectives

We will approach a major scientific challenge in climate change research – Arctic climate change and its impacts, both local and remote. Characterizing climate in an era of distinct Arctic climate change is problematic because of the rapid change and that observational data are relatively short, sparse, and primarily from a time of dramatic change. We will address this by 1) creating a database of high-resolution climate sensitive proxies from existing and new data with much improved spatial representation of the terrestrial Arctic, and 2) use this data to provide a novel field reconstruction of temperature for the northernmost land latitudes, aiming for the last centuries. We will also attempt hydroclimate field reconstructions for sub-regions where data allows.

Combining the new reconstructions with climate modelling, we will 3) provide an improved description of Arctic climate, from pre-industrial to present, including extreme climate events and abrupt changes, forcings and feedbacks. This will allow us to 4) resolve the widely debated question whether Arctic climate change has an impact on mid-latitude extreme weather and climate events or not.

Additionally, by increasing the already existing dataset of Arctic driftwood, focusing on pre-20th century material, we will provide detailed information regarding the spatiotemporal characteristics of driftwood transportation. This information will be used to infer past sea-ice conditions and ocean currents. This, in turn, will allow us to reconstruct past variability of atmospheric circulation patterns (such as the AO) in the Arctic and evaluate the effects of their variability on mid-latitude climates.

Our results will be highly important for climate model calibration, resulting in less uncertainty in future predictions. The improved reconstructions allow us to test how well climate models used to make scenarios reproduce historical Arctic climate: by selecting models that best represent the Arctic, we will untangle the different processes driving Arctic climate. This will facilitate further development of the next-generation models to provide better scenarios of future climate with less uncertainty. Untangling the mechanisms causing the Arctic to influence mid-latitude weather can lead to improved forecasts of extreme events and will thus have immense societal relevance. Overall, we will provide new understanding that is critical for supporting the needs of an ever-broadening spectrum of society's decision-makers as they strive to deal with the influences of Arctic climate change.

Procedures:

Preparation

Prior to the expedition we will survey the areas surrounding Victoria fjord for suitable sites. We will use the experience gain from earlier expeditions (Greenland & Svalbard) on which geographical settings are required for finding driftwood. We will also discuss joint operations/sites with the other land teams, where we are more flexible when it comes to the sampling sites of the shrubs.

Fieldwork

Shrubs

We will sample deciduous and evergreen Arctic tundra dwarf shrub species with easily identifiable annual growth rings, and which have previously been used for dendrochronological studies. These species include *Salix spp.*, *Betula nana* and *Cassiope tetragona*. Shrubs will be collected in elevational transects from both moist and dry sites so that we can extract both temperature and hydroclimate information. This will also allow for assessing the impact of anomalously high summer temperatures on growth. Within selected plots (representing local growth environments) sampling will be concentrated on collecting the widest possible range of plant sizes. To determine the maximum number of annual growth rings, and thus absolute plant ages, both the continuous below- and aboveground root and stem system of each specimen are excavated. All samples are carefully labelled and sealed in plastic bags, preserved in a 50% aqueous alcohol solution.

Driftwood

Based on preliminary analysis of satellite imagery and digital elevation models (DEMs), potential driftwood (DW) sites adjacent to the visited Fjords will be targeted. During the Ryder 19 expedition, these were surveyed via helicopter and drone (Phantom 4), and by traversing beaches on foot, and we will employ the same methods this time. When present, DW samples, in the form of discs cut across the growth rings, will be collected with a chainsaw. The geographic position (latitude/longitude) and altitude of each DW sample will be recorded, and the discs labelled and stored in plastic bags. The remaining wood material will be left in their original positions, and we aim to leave as little trace from the sampling as possible.

Laboratory procedures

Shrubs

In the laboratory, after species identification, thin sections (10–25 µm) are cut with a sliding microtome from the oldest part of the stem, the so-called root collar. After moistening the cross-sectional surfaces, the samples are bleached and then colour stained to enhance the lignified and non-lignified structures. Afterwards they are rinsed with alcohol to remove excess staining and Xylol added to ensure no water remained either. The micro sections are then added to microslides and oven-dried at 60 °C for at least 12 hours. From each thin section, the longest xylem radius is measured; the consecutive number of rings counted, and the corresponding bark thickness recorded. To ensure that all annual rings are accounted for, all raw ring width measurements will be cross dated, first within each plant and then between all samples from each site, resulting in a precisely dated shrub chronology at each High Arctic site with annual resolution. Because of the lengthy procedure, most shrub rings will have to be analysed when we get back, but we will try to equip the laboratory so that we can do some analyses already on Oden.

Driftwood

The discs will be processed (e.g. exposing fresh surface with a razor to enhance the cell contrast to distinguish individual rings) in the shipboard laboratory, where we will count and measure the annual rings and subsequently compare the analysed DW to reference chronologies for provenance and dating.

All samples will be shipped back to Sweden after the expedition has ended. Samples not having been measured and dated on Oden will be analyzed at the university tree-ring lab in Göteborg.

<i>Interface with Oden crew and SPRS</i>
No need foreseen beyond coordination and execution of helicopter transfers.
<i>WP Risk and counter-measures</i>
Risk identification: 1) Not being able to go ashore 2) Accident with chainsaw while sampling 3) Encounters with polar bears and wolves 4) Having to stay on land if weather conditions deteriorate and helicopter transfer back to the ship is impossible. Counter measures (mitigating actions): 1) In the unlikely event of not being able to go ashore during the entire expedition, we will assist other projects. One important part of the project is collecting shrub samples, which we know from last expedition grow all along the coast of Northern Greenland, we are confident that we will be able to get sufficient material even from few land trips. 2) We will use safety equipment and clothing when operating the chainsaw (trousers, boots, gloves and ear protection) and also bring a first aid kit. 3) Team members will carry at least one shotgun (armed with slugs) and a flare gun. One member has a firearms licence and the team members previously took a short course, on Svalbard, on firearms and polar bears, updated on the Ryder expedition 4) We will bring an emergency kit with a tent, provisions, and spray to deter polar bears in case they needed to stay on shore.
<i>Deliverables and future (after cruise) plans</i>

The first deliverable is a database containing all metadata and tree/shrub ring measurements. All tree/shrub-ring data (measurements) from the expedition will be made freely available through NOAA's National Center for Environmental Information (www.ncdc.noaa.gov). All site meta-data and ecosystem information will be uploaded to the Arctic Biodiversity Data Service (abds.is/index.php/contribute-data).

The collected shrub and driftwood data will be used to produce high-resolution spatial-field reconstructions of temperature and hydroclimate in form of maps and time series (examples of such maps are given here: drought.memphis.edu/NADA/animation/Animation.aspx). These will be published in high-impact open access journals. At the end of the project, all data generated will be freely available through the Stockholm University Data Repository (<https://su.figshare.com/>) and the National Centers for Environmental Information at NOAA (<https://www.ncdc.noaa.gov/>): we will follow the PAGES data stewardship and FAIR data principles (<http://pastglobalchanges.org/data/data-guidelines>).

We will create a database of mid-latitude extremes the past centuries, which will be visualized in GIS, showing the spatial extent and intensity of each extreme event, and include concurrent Arctic conditions. The database will be accessible from a dedicated project website at the host department. The comprehensive analysis of Arctic influences on mid-latitude extreme events from proxies and climate models will be published in a high profile, open access journal.

All physical samples will be stored and analyzed at the Gothenburg University Laboratory for dendrochronology (GULD, www.gu.se/en/research/guld). When the species of each individual DW sample has been determined, and the annual tree-ring widths measured and dated, we will add the data to the database of DW collected on the Ryder 2019 expedition and Svalbard 2014 (in progress). Discussions are ongoing with other international research groups to create a dedicated database for all Arctic DW. Similarly, a database of annual ring widths of the shrubs will be constructed. All data generated by our project will be stored at the dedicated server at GULD. All driftwood discs and dwarf shrub parts used for analyses will be stored at the Department of Earth Sciences, University of Gothenburg. All data produced in the project will be made freely.

Outreach activities

We will have two blogs, one for SU (Björn Gunnarson) and one for GU (Hans Linderholm)

The fieldwork will be presented in a chapter of Ymer 2025 (the yearbook of the The Swedish Society for Anthropology and Geography): “Fantastiska Ringar”, edited by Hans Linderholm.

7.8 WP 8; TRACE GAS DYNAMICS AND PELAGIC ECOSYSTEM FUNCTION

WP General information		
WP full name: Trace gas dynamics and pelagic ecosystem function		WP coordinator: Christian Stranne
WP ID (acronym): WaterColumn		Version date: 2023-12-10
WP Resources		
WP Team Onboard		
Name	Institution	Role
Christian Stranne	SU	WP coordinator, CTD, discrete sampling, mooring deployment/recovery
Marcelo Ketzer	LNU	Discrete water sampling
Camille Akhoudas	SU	WEGAS (on Oden, Work boat, Skidbladner), Niskin sampling
Tirza Weitkamp	SU	Bongo net, foraminifera incubations, FRRF, surface sediment forams
Julia Weissenbach	LNU	Niskin sampling, DNA/RNA filtration, Chlorophyll a, Bacterial abundance, Phytoplankton, Nutrients
Wilma Ljungberg	GU	Carbonate chemistry
Equipment:		
WEGAS (spectrometer, pump, equilibrator, Radon spectrometer with separate equilibrator), diesel generator for running the system on the work boat		
200 sample kits for noble gas samples		
600 vials of each below (plus 60 for glacier, rivers, creeks, lakes, sea-ice, etc.)		

- CH₄ concentration and d¹³C - 200 ml vials (**100 ml water**). Pre-prepared with 10% benzalkonium chloride
Stored at 4°C
- DIC concentration and d¹³C - 60 ml vials (**5 ml water**). Pre-prepared with phosphoric acid
Stored at 4°C
- DOC concentration and d¹³C - **10 ml** vials (full). Filtered with 0.2 µm syringe filter
Stored at -20°C (??)
- d¹⁸O - **5 ml** (??) vials.
Stored?
- Nutrients - **10 ml** with 0.2 µm syringe filter
Stored at -20 °C
- Metals 1 (quantification, mainly Fe, Mn + all trace metals via ICP-MS) - **10 ml** vials. Pre-prepared with HNO₃
Stored at 4 °C
- Metals 2 (quantification, mainly Fe, Mn + all trace metals via ICP-MS) - **10 ml** vials with 0.2 µm syringe filter. Pre-prepared with HNO₃.
Stored at 4°C
- Sulphate concentration - 15 ml (plastic). Filtered with 0.2 µm syringe filter
Stored at 4 °C

5 station fjord transect (plus 10 for glacier, rivers, creeks, lakes, sea-ice, etc.)

- Neodymium (??? ml)
Store (??)
- N₂O concentration and isotopes - **1200 ml** (2 x 220mL serum bottles to 2x overfill + fill)
- Nitrate isotope composition: 28-32 ml water in 40 ml Falcon tubes 0.2 micron filtered and frozen.

Store at room temperature, treat with 4 ml 3M NaOH after closing and crimping the stopper using two needle-technique; suggested depth sequence: Depths: 5, 10, 20, 30, 40, 50, 75, 100, 150, 200 m and two more bottles to bottom
- Metals 3 (speciation studies) - 1500 ml
Avoid oxidation, freeze quickly in -20 °C
- Metals 4 (Fe-isotopes) - Geological Survey of Finland (volume to be determined)

Stored (??)

Wei-Li (10-20 stations) - TBD

Carbonate chemistry:

1. Spectrophotometric (Agilent 8453) measurements of seawater pH on the total scale.
2. Semi-closed cell titrator for total alkalinity
3. Apollo SciTech AS-C6L DIC analyzer
4. Contros HydroFIA pH for continuous spectrophotometric measurements of seawater pH on the total scale
5. Contros HydroFIA TA for continuous spectrophotometric titrations of total alkalinity
6. RAD7 Radon Detector for continuous spectral analysis of Rn.
7. Samples bottles, vials, water baths

- Fluorometer for Chl *a* measurements
- Vacuum pump and seawater waste trap
- Filtration ramps
- 2 Peristaltic pumps, silicon tubing
- 10 x 10L Carboys for sampling
- 50 L tanks for ice-core melting
- Dewar for flash-freezing
- 13 4.7L Bottles amber – for chl *a* sampling
- Fixatives (glutaraldehyde, formalin, paraformaldehyde)
- 200 ml amber bottles for phytoplankton fixation
- 5% HCl for washing equipment
- 10% HCl for Chlorophyll measurements
- Ethanol for Chl *a* measurements
- 10 L Acid washing bath
- Acid Lugols solution
- Alkaline Lugols solution

Planktonic foraminifera (micro zooplankton)

- Hydrobios Bongo CalVet-Net (Twin Plankton net), with different net mesh/ collector-cup options (50 μ m, 150 μ m, 100 μ m). 250 cm net length, each net 60 cm diameter

-Microplankton in-lab filtering system, for filtering from the seawater intake (planktonic foraminifera): a filter comprising 50 µm mesh fabric stretched over 18 cm diameter tension rings.

-Foraminifera picking equipment (petri dishes, watch glasses, cool-packs, brushes). Falcon tubes for storage of excess cod-end sample material (ethanol base).

-Two stereo dissecting microscopes (Zeiss Stemi 508, with integral swan neck lights with Zeiss digital camera systems). NB. one of these will serve the sediments WP.

-Foraminifera chloroplast activity assessment: Fast Repetition Rate (FRR) fluorometer, DF-03/ DF-14 (Kimoto Electric Co., Ltd.)- AC 100V, step-down transformer needed (will bring) (220V --> 100V)

-Foraminifera chromosome analysis: (ploidy assessment): Buffer solutions for foraminifera preservation (DOC and RNALater). DOC = 30 mls (enough for 750 specimens) RNALater = 75mls. Foraminifera crushing equipment: customized glass-tipped pipettes, 0.1 Mol HCl for cleaning (2 x 50 ml bottles HCl).

-Equipment for scraping/sampling multicore surfaces

-Petridishes for incubation (space needed for incubations -12. Hours-, dark container/ box/ cupboard), sieves for wet sieving,

Necessary equipment/requirements not brought or covered directly by the foraminifera project:

-Lead weight with ring attachment-point, ca 10 kg? -for adding to the bongo net during deployment

-Box core sampler or multi-corer operated from ship (sediments WP)

-Requirement for filtered seawater from CTD rosette for diluting/washing/incubating collected planktonic foraminifera (cooperation with Julia Weissenbach - DNA/RNA/microbial filtration) this WP): requested volume: ca. 1 liter per station when planktonic foraminifera are collected (Bongo net and/or seawater pump and box core/multicore sampling stations), from the upper 100 m Niskin sampling.

Note that live foraminifera collection from both the water column and sediment is time sensitive (specimens only viable within 1 hour of collection). Therefore, timing of netting/sediment coring activities should be planned to give sufficient time to filter seawater prior to deployment.

Mooring platform, wideband autonomous transceiver, 2 lithium batteries, 2 transducers, pressure switch, ADCP (alkaline battery), 3 acoustic releasers (alkaline), weight.

Approx 300 m depth, wire + acoustic releaser. Deploy on bottom, release system and recovery. Deployment procedure TBD.

Lab/deck Space:

Ca. 3 m bench space in the main lab for WEGAS control data computer. Seawater intake for the WEGAS system: it needs 2-3 m space next to a sink, water from a tap on the underway line is pumped into the equilibrator from which the instrument measures, and drains to sink.

Carbonate chemistry:

Discrete pH, TA and DIC analysis: Starboard main lab or lab container above main lab for analysis of discrete pH, TA, and DIC samples. Electricity, tap water, sink, point source ventilation, synthetic air (CO₂ free) (see figure for setup and space requirements). Access to 2 L MQ water per day.

Underway pH and TA sampling: Starboard main lab, starboard-bow bench. Electricity, benches on each side of the sink with seawater tap, direct access to sink and seawater tap. A water line splitter is necessary from the seawater tap (see figure for setup and space requirements).

Underway Rn sampling: Starboard main lab, port-bow bench. Electricity, direct access to seawater drainage sink and seawater tap (see figure for setup and space requirements).

- Storage space for 50 mL falcon tubes in -20°C freezer.
 - MilliQ water production unit (1 L/day)
 - Fume hood for preservation FCM samples with glutaraldehyde
 - Storage of FCM samples at -80 °C
- Storage of Lugol samples at +4 °C
- Cold van 4°C space 2000 x 500 mm for filtering
- Lab bench space in room temperature 2000 x 500 mm (this does not need to be in the main lab)
- Dark space for Chla fluorescence measurements (curtains around lab bench or other method?)
- Space in -20°C for storage of samples for microscopy and nutrient analyses, one shelf
- Space in -80 °C for sample storage (flow cytometry, DNA, NanoSIMS)
- Space at +4°C for dead samples (full fridge – fixed phytoplankton samples)
- Safe storage space for 5% and 10% HCl
- Space in RT for 5 x 50L tanks for thawing ice-cores

Planktonic foraminifera

-Room temperature microscope lab space, mid-ship away from engine: Bench with sitting space for 1-2 microscopes and power outlets. We will need space adjacent to the microscope station for the FRRF. The method requires foraminifera to be picked under the microscope before being introduced to the FRRF chamber, so it would be good to have this equipment together. Ideally this would be part of our allocated

space in the main lab for our WP: room for two microscopes, the FRRF and a small bit of bench space to work on next to the FRRF.

- Space in -20°C freezer for 4 Eppendorf tube boxes -space required 220mmx370mmx140mm (4 x polystyrene boxes)
- Space in 1-2°C fridge for 4 Eppendorf tube boxes -space required 220mmx370mmx140mm. (4 x polystyrene boxes)
- Space in flammables cabinet for Ethanol (2 litre EtOH[]) for preserving extra Bongo-net plankton samples
- Cool lab: Bench space for Fast repetition rate (FRR) fluorometer. 1 m² bench space for culturing in a cool lab.
- Access to shipboard seawater intake for surface plankton-pumps/plankton filtering
- Need for filtered seawater from CTD rosette (ca. 1 l/foram station, cooperation with Julia, in this WP).
- Bench or cupboard space for sediment-sample foraminifera incubations.
- Storage space on deck/container for bongo/multinet

Required conditions for WP (ice, environment, weather, etc.)

Ice/weather conditions may affect the CTD/plankton net operations and thus the whole WP. Underway systems are sensitive to sea-ice clogging of the seawater-intake system or a general failure of the surface water intake system, leading to a failure or reduction of the seawater flow rate.

WP task description:

The overall WP involves making physical, chemical and biological observations of water column structure and biology, with several sub WPs.

Collecting discrete observations of the marine carbonate system: pH, total alkalinity (TA), and dissolved inorganic carbon (DIC) from the CTD/Rosette and terrestrial survey is a key part. The WP will also be responsible for continuous measurements of seawater surface pH and TA, either coupled to the Ferrybox system or standalone. By combining bathymetry, hydrography, biogeochemistry and oceanographic tracers, this WP aims to:

- 1) quantify the current state and drivers of the marine carbonate system and ocean acidification north of Greenland with respect to physical, chemical, and biological processes,
- 2) quantify the influences of different freshwater sources (sea-ice melt, glacial melt, river runoff) on physical and biogeochemical processes with respect to the marine carbonate system and ocean acidification,
- 3) assess the North Greenland region's interaction with the upstream central Arctic Ocean (Transpolar Drift, Upper Halocline, Atlantic water)
- 4) assess the regions' importance for the downstream outflow regions (Nares Strait, East Greenland Shelf, Fram Strait).

5) assess land-ocean interactions using the natural tracer radon-222 using automated surface observations.

We will investigate the question how does community composition, abundance, and biomass in seawater and sea ice vary along the expedition track.

The overall objective of this work is to establish the impact of nutrient inflow of central Arctic and Atlantic derived waters and of land-derived sources, whether the latter are glacial particulate and dissolved glacial discharge and erosion or via a benthic feedback loop.

We will collect samples for the quantification of chlorophyll contents, and the abundance, identity, and function (based on RNA and DNA sequence analysis) of the microbial assemblage. Together these data will help us assess the current spatial distribution of primary producers, nutrient uptake, and N₂ fixation proxy by *nifH* gene expression. We will also collect water samples for the analysis of the natural abundance nitrogen isotope composition of nitrate and nitrous oxide to distinguish microbial nitrogen transformation processes and land versus ocean source of nitrate.

Planktonic foraminifera

The goal of the planktonic foraminifera aspects of this WP is to explore high-Arctic planktonic foraminifera ecology and life history, including trophic strategies in dense sea ice regions, and the possibility of a 'sediment resting stage' in shelf sediment systems as an adaptation to severe polar conditions.

Using plankton nets and plankton pumps (lab seawater intake), we will collect samples of the polar species *Neogloboquadrina pachyderma*. Shipboard we will conduct biological incubations and experiments to explore the biology and ecology, and preserve specimens for subsequent genetic analysis, including of chromosome number (ploidy). A key question is: how does *N. pachyderma* survive the extreme ice conditions north of Greenland? What does it eat, how does it reproduce and does it use the seafloor as a seasonal refuge? This information is needed to understand how it and other plankton will be affected by Arctic warming and habitat change under climate warming. *N. pachyderma* has wider importance because the shells, which readily become fossils in seafloor sediments, capture vital geochemical and biological signals on past ocean-climate conditions.

Our biology results will help us better use fossil *N. pachyderma* for reconstructing past patterns of ocean and climate change in relation to the GEOEO expedition goals.

Procedures:

Water samples for the marine carbonate system variables will be collected from full-depth CTD casts and terrestrial surveys (lakes, streams, meltponds). Samples will be analyzed directly onboard. Underway pH and TA will be measured continuously every 10 minutes.

Underway radon observations will require seawater flow of about 3 L per minute and a sink to drain the water back to the ocean. The detector will log a value every 30 minutes.

Seawater samples from CTD casts will be collected during the expedition and will be analysed back at Bremen University for nobles gases (Neon, Helium) and Tritium.

- 100x1L PET bottles rinsed with tap water and dried will be used for samples for tritium in seawater.
- 200x50mL copper tubing will be used for samples for helium isotope measurements. The tubes will be temporarily sealed with a few cm length of silicon tubing over each end, one end connected to the pumping line, the other end the short hose will be narrowed to increase the water pressure in the tube. The copper tubes will be flushed at least 10 times and air bubbles will be released by hitting the aluminium rack with a stiff tool. The permanent sealing will be done using crimp clamps, which will be screwed down tightly over the copper tubes.

Surface seawater CO₂ and CH₄ concentration will be measured continuously from the Oden underway system.

- CRD spectrometer measurements will be used to continuously monitor CH₄ and CO₂ concentrations of gas stripped via headspace equilibration from the seawater using the Water Equilibration Gas Analyser System (WEGAS). It consists of water handling system including showerhead equilibrator (head space volume 1L) fed by seawater, cavity ring down spectroscopy gas analysers for CO₂ and CH₄ concentrations (Picarro **G2201-i**), gas handling system with circulation pumps for headspace and ambient air pumped from meteorological station (we can do that but this means long tubing (70 m) otherwise we just take air outside the main lab) and data control system. Continuous measurements of surface water will be performed using the continuously flushed Oden seawater intake system with water pumped from 8 m depth and distributed within the main lab. In addition, the WEGAS system will be used to determine CO₂ and CH₄ concentrations in the water column (vertical profiling within the first 40 m) on board *Skidbladner* and/or the work boat.

Basic sampling of the upper water column from Niskin bottles

Chlorophyll a: We will perform Chlorophyll measurements. Samples will be collected in duplicate for total chlorophyll on Advantec 0.3 µm glass fiber filters as well as 2.0 µm filters to determine the contribution of picophytoplankton size fraction. Chlorophyll samples will be sampled on a standard filtration rig using an ethanol extraction method. Fluorescence measurements will be conducted in a dark room or dark area in the lab.

Bacterial abundance: Flow cytometry samples will be collected for virus, bacteria and picophytoplankton enumeration and diversity. Picophytoplankton will be identified using the fluorescence of phycoerythrin, phycocyanin, and chlorophyll.

Nutrients: samples for nutrients will be collected and stored frozen after filtration through 0.2 micron filters Nitrous oxide: samples will be together with other gas samples early from the Niskin samples and stored cold after poisoning with 3M NaOH.. Phytoplankton composition: samples will be fixed and stored at 4C DNA/RNA: Filtrations on Sterivex filters with peristaltic pumps for DNA (bacterial+viral) and RNA samples Basic sampling of ice-cores Ice-cores will be collected and thawed Salinity will be measured and basic sampling will be performed on melted ice like described above. RNA will not be collected Sampling of planktonic foraminifera A series of vertical plankton hauls (Bongo net) with small mesh size (53 µm), at a minimum 10 stations in deeper water, in the upper water column (max. 250 m) will be collected. These should be paired with multicore sampling (liaise with WP4, Sediments) at the seafloor to sample underlying sediment. Shipboard, planktonic foraminifera will be manually picked from plankton samples for the following procedures: curation of specimens from net samples, experiments with live specimens to evaluate photosynthetic activity (FRR fluormetry), and biological preservation (fixing in buffers) of specimens for shore based molecular analysis (chloroplast counting and ploidy assessment). Sediment samples from shelf regions will be analysed to investigate whether live planktonic foraminifera occur in sediments. This is to explore the hypothesis that <i>N. pachyderma</i> has a 'resting stage' and can 'reseed' the water column from sediments. All studies with living foraminifera are time sensitive (on the scale of hours to days for different methods). Planktonic foraminifera procedures: 10 stations, experiment with outer fjord regions, focus on deeper water stations -Bongo net sampling -Microplankton in-lab filtering. -Microscope analysis for foraminifera extraction. Biological fixing of specimens for subsequent molecular analysis. Storage of excess cod-end sample material (ethanol). -Foraminifera chloroplast activity assessment: Fast Repetition Rate (FRR) fluorometry. -Foraminifera chromosome analysis: (ploidy assessment). -5 stations in-sediment, live foraminifera collection/incubation to explore vitality.

<i>Interface with Oden crew and SPRS</i>
Assistance from SPRS technicians will be required during deployment and recovery of CTD. Bongo/multi net operations WEGAS – work boat, skidbladner Discrete water sampling – helicopter Plankton sea-ice sampling – helicopter Assistance will be required during mobilization and demobilization of Oden (crane operations of equipment boxes to main lab). Close communication and monitoring of the performance of the surface seawater intake system (clogging, failure, planned shutdown). For live planktonic foraminifera work we will need to be allocated water from the CTD on days when the bongo net/shipboard plankton filtering or foraminifera surface sediment activities are happening (1 L per time). Bongo/multinet operations: For the multinet/bongo net, one scientist is required on deck to deploy, control, and recover samples. They would require assistance from two SPRS personnel: a crane operator and an A-frame winch operator. Box cores/ multi-cores: The living foraminifera specialist would like core top sediment scrapes from shallow, mid-depth and shelf edge stations.
<i>WP Risk and counter-measures</i>
Risk identification: Risk of injuries and damage to equipment during mobilization, demobilization, rough seas, heavy icebreaking, CTD operations. Risk of injuries due to slippery decks. Risk of injuries when handling chemicals. Planktonic foraminifera Loss / breakage of equipment and nets. Operation of heavy equipment (nets) on deck. Use of hazardous materials Counter measures (mitigating actions): Hard-helmet and safety shoes/boots are required during mobilization, demobilization, and CTD operations. Proper lashing-sown of equipment is important. No running on deck. GU and SU lab safety procedures are followed for working with chemicals (e.g., safety glasses, protective clothing, gloves, waste disposal, storage of chemicals). Confer with Oden crew or SPRS technicians. Planktonic foraminifera

We have spare nets and collection cups for the Bongo net. In the event that the Bongo net is lost, and/or as a complement to optimize planktonic foraminifera numbers, we can extract micro plankton from pumped surface water using an onboard filtering set up.

Only tiny amounts of hazardous chemicals are needed (0.1M HCl, < 10 mL). These will be declared, transported and stored appropriately. Waste will be collected in appropriate storage vessels and disposed of as hazardous waste upon return.

Deliverables and future (after cruise) plans

Discrete data: DIC, TA, pH

Underway data: TA, pH, Radon, Ferrybox

Publications in international peer-reviewed scientific journals and communication of results to the public and scientific community at international conferences.

Carbonate chemistry and CTD data will be part of Wilma Ljungberg's PhD thesis.

Documentation of planktonic foraminifera in the remote northern Greenland fjord-to offshore settings, and perspectives on their under ice ecology

Data repositories:

Metadata: Swedish National Data Service (<https://snd.gu.se/>)

Data: Bolin Centre Database (<https://bolin.su.se/data/>)

Outreach activities

Blogs etc.

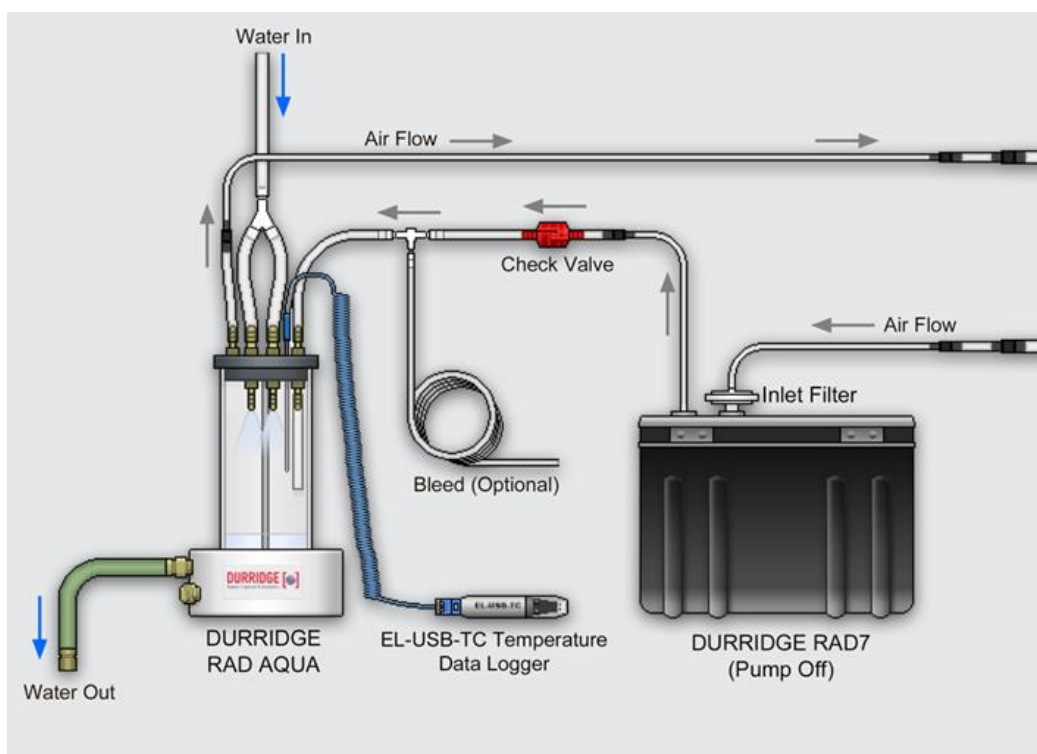
If you have any pictures of sampling devices etc, insert some here.



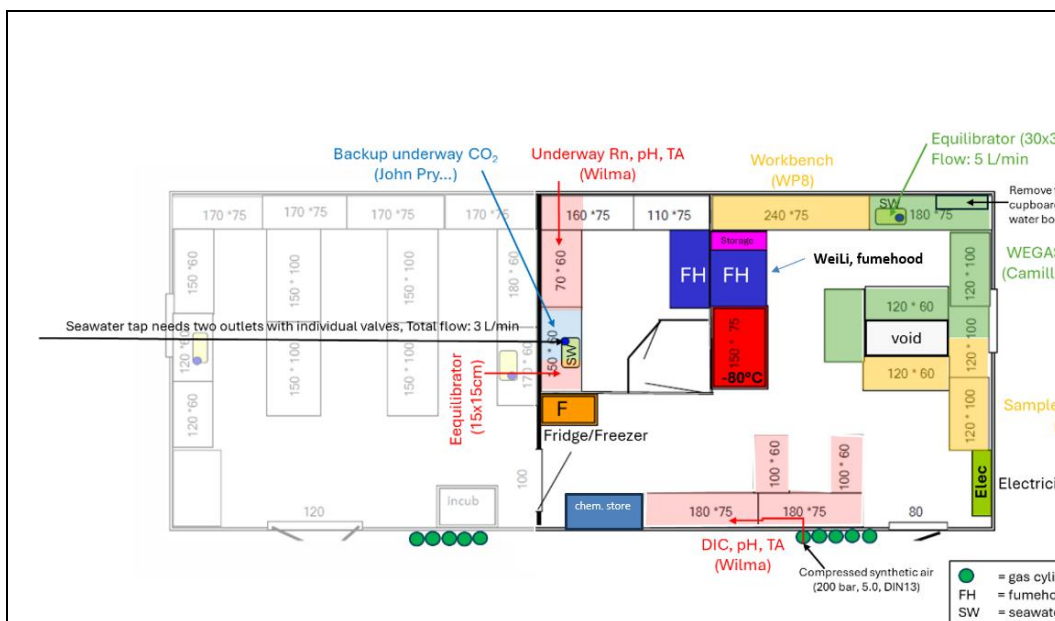
Example setup for discrete analysis of pH, dissolved inorganic carbon (DIC), and total alkalinity (TA). The DIC analysis requires compressed synthetic air 5.0 DIN13.



Contros HydroFIA TA and pH for underway measurements every 10 minutes. A water line splitter is necessary from the seawater tap.



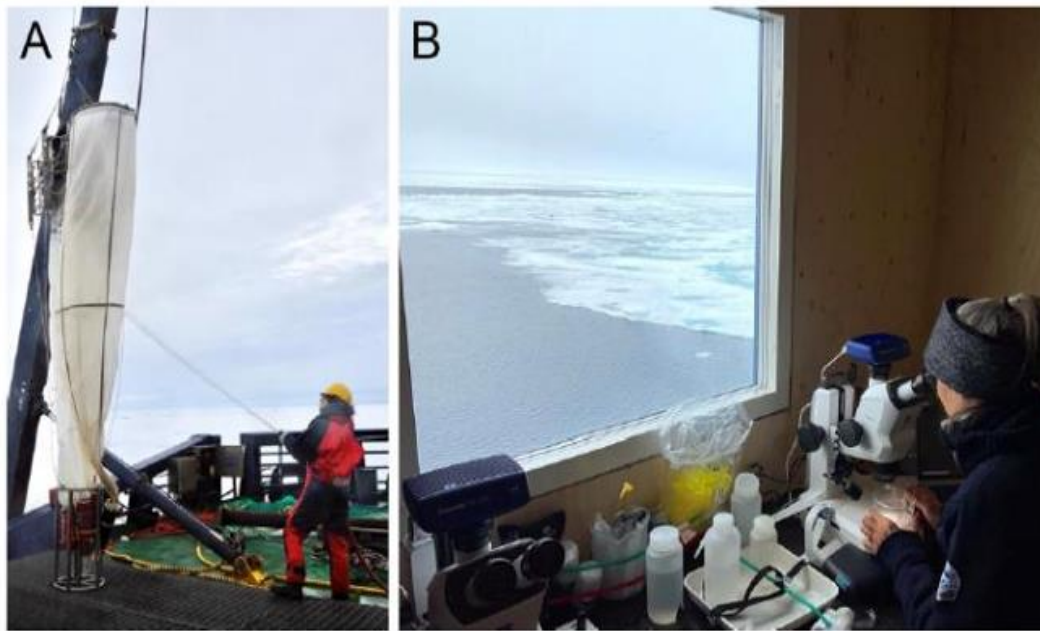
RAD7 continuous radon detector setup. The setup requires a sea water intake and a seawater drainage sink for the DurrIDGE RAD Aqua exchanger. Proposed work setup (Alternative 1) in main lab for continuous and discrete carbonate instruments. The DIC analysis requires compressed synthetic air 5.0 DIN13.



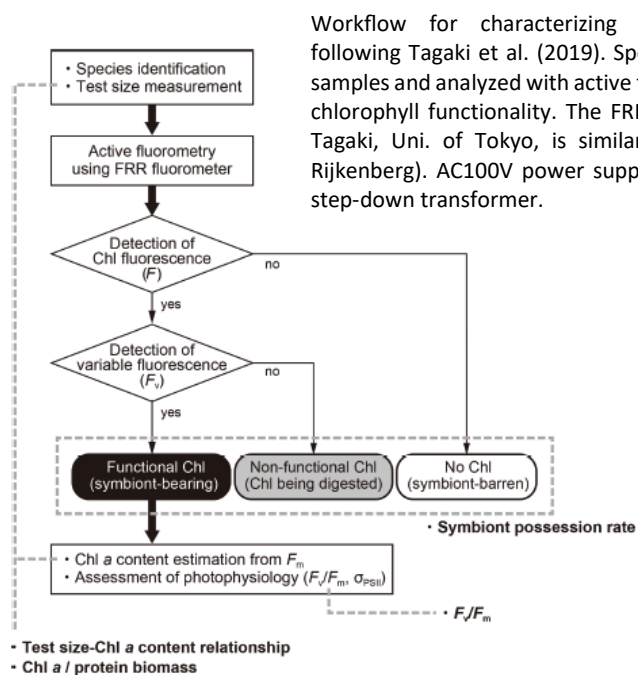
Proposed work setup (Alternative 2) for discrete carbonate measurements in container. The DIC analysis requires compressed synthetic air 5.0 DIN13.



The complete WEGAS setup



Bongo net deployment (A) and planktonic foraminifera microscope analysis (B) during SAS ODEN 2021. Flor Vermassan and Clare Bird.



WP Appendix (drawings, pictures, equipment, fact sheet, etc):

7.9 WP 9; TECTONIC EVOLUTION OF NORTH GREENLAND

WP General information		
WP full name: Tectonic Evolution of North Greenland		WP coordinator: Jaroslaw Majka
WP ID (acronym): TENG		Version date: 2/9/24
WP Resources		
WP Team Onboard		
Name	Institution	Role
Karol Faehnrich	University of Adelaide	Co-PI/WP-Leader
George Geier	Dartmouth College	Participant/PhD student
WP Team Shore-based		
Jaroslaw Majka	Uppsala University	PI/WP-Leader
Christian Schiffer	Uppsala University	PI/WP-Leader
Equipment: Deployment of seismometers: - Seismometers (18x21x28.6 cm,, 2.4 kg) x 8 - Digitisers (10x10x8 cm, 1.15 kg) x 8 - Batteries (35.3x17.5x19 cm, 30 kg) x 24 - cables, boxes, insulation material, sand bags, other building material (all packed in 80x55x31cm boxes, circa 25 kg) x 8 - Shovel x 1 - Concrete plates (30x30x6 cm, 12 kg) x 8		

- tools, 20 kg Camping: - Personal tents x 3 - Cooking tent x 1 - Sleeping bags x 3 - Seeping mats x 3 - Stove - Cooking equipment (pot, utensils, bowls, cups etc.) for 3 people - Camping gas for 20 days (for 3 people) - Food (freeze dried, lightweight) for 20 days (for 3 people) - Toilet paper - Small shovel Safety: - Polar bear fence (wire, poles and explosives if available) - Firearm and ammunition x 1 - Flare gun x 1 - Satellite phones x 2 - Garmin InReach x 2 - Radio for contact with helicopter pilot - First aid kits Other: - Sample bags - Portable Raman spectrometer
Lab/deck Space: We will need storage space for seismometers (up to 2 m³) and collected samples that can be organized in metal ca. 5-gallon buckets (ca. 20 needed). We will need a table/desk for onboard Raman analyses.
<i>Required conditions for WP (ice, environment, weather, etc.)</i>
The work requires access to sites on land by helicopter, which will depend on weather conditions and helicopter use by other groups. Most of the field work will also require relatively little to no snow on the ground.
<i>WP task description:</i>
North Greenland is one of the least investigated regions in the Arctic and a critical location to test geological models for the tectonic development of the wider Arctic-

North Atlantic region. In this project, we aim to collect an integrated geological and geophysical data set that will test multiple hypotheses related to the geological evolution of North Greenland within an Arctic framework. Current evidence shows that an as-yet-unrecognized continental suture likely exists in North Greenland. Sedimentary units of broadly similar age in North Greenland are separated by a major fault system, the Harder Fjord Fault Zone (HFFZ). While late Proterozoic to Paleozoic units south of the HFFZ represent the continental margin of Laurentia (North America), the poorly understood succession north of the fault zone may have links to Svalbard (Norway) and/or the Pearya terrane of northern Ellesmere Island (Canada) which have been restored to the paleocontinent of Baltica (Scandinavia). In this project, we test how fragments of continents were dispersed across the circum-Arctic. This dispersal can be accompanied by increased volcanic activity or rates of chemical weathering. These in turn have an important impact on global climate, but these connections in deep time depend on precise estimations of the timing of tectonic events and their nature.

The main goals of this project are to: (1) characterize late Neoproterozoic to Carboniferous (ca. 600-320 Ma) sedimentation, deformation, and metamorphism across the HFFZ to evaluate possible ties between North Greenland, Svalbard, and Pearya; (2) evaluate the significance of Neoproterozoic (ca. 640-570 Ma) orogenic activity in North Greenland in units adjacent to the HFFZ; and (3) image the deep crust/upper mantle architecture across North Greenland and the HFFZ using seismology.

There are three tasks within this project:

Task 1: Stratigraphy and geochronology of the North Greenland Franklinian Basin.

Tectonic models of the High Arctic link the geology of Svalbard and the Pearya terrane to East and North Greenland; however, these broad comparisons are increasingly difficult to support with new observations. Recently we documented clear stratigraphic and provenance mismatches between the Southwestern Basement Province of Svalbard and coeval Laurentian units in North and East Greenland which would suggest correlations to Baltica instead. We hypothesize that counterparts to these units of Svalbard and Pearya may be in complexly deformed sedimentary and metasedimentary assemblages of North Greenland north of the HFFZ. To test this hypothesis, it is critical to assess whether: (1) the sediments have a similar provenance (i.e., similar source regions) to their time equivalent units in Svalbard and Pearya; (2) metamorphic rocks of North Greenland record Caledonian (ca. 420 Ma) and/or Ellesmerian (ca. 360 Ma) metamorphic events. To make these assessments we will collect samples for detrital zircon U-Pb geochronology across the HFFZ and reconstruct their timing of deposition using chemostratigraphy or fossil collections. Studies of metamorphic rocks adjacent to the HFFZ will include pressure-temperature (P-T) estimates, geochronology of metamorphic fabrics and fault zones, accompanied by thorough structural analysis at outcrop and thin section scale.

Task 2: Structural, metamorphic, and geochronological characterization of Neoproterozoic–Paleozoic exotic units north of the HFFZ.

The Neoproterozoic Timanide orogen extends from the southern Urals to Novaya Zemlya in Russia, and the Varanger Peninsula in northern Norway, which is tied to Baltica. Recent geophysical studies propose a possible continuation of Timanian structures through the western Barents Sea and towards Svalbard. Displaced portions of the Timanide orogen in the High Arctic were also suggested based on discoveries of units broadly coeval with Timanian rocks on Svalbard, Pearya, and the Lomonosov Ridge. There are reported ca. 640-570 Ma arc-related felsic-to-intermediate rocks in North Greenland indicating that vestiges of the Timanide orogen can be traced into North Greenland, but their tectonic position with respect to the Laurentian margin is a matter of debate. The presence of Timanian rocks requires a significant suture in North Greenland. Using geochronological (zircon U-Pb) and elemental/isotopic geochemistry we will test whether Cryogenian to Ediacaran arc-related rocks in North Greenland are local or exotic to Laurentia and possibly related to classic Timanian associations, thus confirming whether or not a major suture exists on North Greenland.

Task 3: Imaging of the deep crustal structure.

The deep crustal and upper mantle structure of North Greenland can provide critical independent constraints for evaluating the presence of a major lithosphere-scale suture in North Greenland. For example, variations in Moho depth and intra-crustal structure can identify different crustal blocks, and thereby support the interpretation of thrust, normal or strike-slip deformation, as well as the orientation of faults at depth and their relation to structures exposed at the surface. Such information on the lithospheric structure is extremely sparse in North Greenland, limited to two permanent seismometers on the west and east coasts (Thule Air Base and Station Nord), and four temporary stations (GEUS) comprising the only lithospheric-scale geophysical database in the region. We will establish the lithospheric velocity structure and geometry of lithosphere-scale structures in North Greenland in order to constrain multiple potential orogenic events (Timanian, Caledonian, Ellesmerian and Eurekan) and to determine whether the HFFZ is a first order suture between Laurentia and rocks of Baltican affinity.

Procedures:**Tasks 1 and 2: Fieldwork and sample collection**

These tasks require the collection of field observations, geological mapping, and sampling of rocks. Ideally, we would be able to set up short 3-5 days camps in critical locations to collect detailed observations and cover more land without competing for helicopter time with other groups. The camps would include two participants and a bear guard. If these are possible, we would identify camp locations based on satellite

images. We would consult these locations to ensure they are within a safe flying distance from Oden.

These short camps will be supplemented with helicopter stops across key locations in larger areas, at each stop we will spend around 2 hours, collecting observations and samples. If on-land camps are not possible we would revisit certain locations multiple times.

The collected samples will include fist-size rock samples and bags of rock samples up to 5kg. These are collected for age determination, provenance (sediment source), trace element and isotope geochemistry, thermochronology, or paleontology. Samples will need to be shipped and processed in labs on land.

Task 3: Imaging of the deep crustal structure.

This task involves the deployment of 8 seismometers along a ca. 150 km long N-S transect, with approx. 15-20 km between each station (see Fig. 1). Each station should be installed at a high elevation to reduce the risk of interference by polar bears, on bedrock and at visible landmarks whenever possible. The final location of these stations will depend on the ice conditions, track of the icebreaker, and reachability by helicopter. The idealized profile designs in Fig. 1 (blue) are obviously not final and will likely deviate substantially, depending on the icebreaker's actual track helicopter reach, ice- and weather conditions, and local site conditions. If the icebreaker's track is not in concordance with the planned station design or substantially deviated (e.g. if access is limited by ice/weather conditions) new locations will be identified on site. In the end, the seismic experiment design is very flexible, however, the deployment has priority to cross the geological structures in the area (HFFZ, NFE, see Fig. 1)

For this task, we will require 8 helicopter stops, at each we will:

- 1) Survey the location and find a suitable spot for the station.
- 2) Install the equipment (sensor, digitiser, batteries) either on bedrock or on a concrete plate.
- 3) Cover the installation with rocks or bags filled with sand collected nearby.

At each stop, we will need to spend approx. 2-3 hours preparing the stations. Geological sampling can be combined with these stops.

Interface with Oden crew and SPRS

For short camps on land, we will need a bear guide with us from SPRS. Otherwise, we will need to coordinate helicopter time with other researchers. We can share a camp with other teams and could join other teams if their locations are close to our targets.

<i>WP Risk and counter-measures</i>
Risk identification: 1) Encounters with polar bears. 2) Adverse weather conditions (snow, strong wind). 3) Not being able to transfer back to the ship from land. Counter measures (mitigating actions): 1) We will work as a pair with a bear guide, have a flare gun and a firearm. During camping we will have a bear fence. One member has a previous training on polar bear safety from Svalbard. 2) We will have appropriate clothing and gear. 3) We will always have an emergency kit with additional food rations.
<i>Deliverables and future (after cruise) plans</i>
Samples: All the rock samples will be stored at Uppsala University and have an associated International Generic Sample Number (IGSN). Data: Processed and published seismological data will be made freely available online. Otherwise, the generated data will be published in supplements of relevant publications. Publications: We will publish results in peer-reviewed publications, preferably open access. We will also present results at national and international conferences.
<i>Outreach activities</i>
We will work with home institutions in Sweden, USA and Australia to produce press releases regarding the expedition and published results. We will use established social media accounts of all these institutions (Uppsala University, Dartmouth College, University of Adelaide) to share these releases. There will be opportunities in all these institutions to informally showcase the nature of field work in North Greenland and share details of the expedition.
<i>WP Appendix (drawings, pictures, equipment, fact sheet, etc):</i>

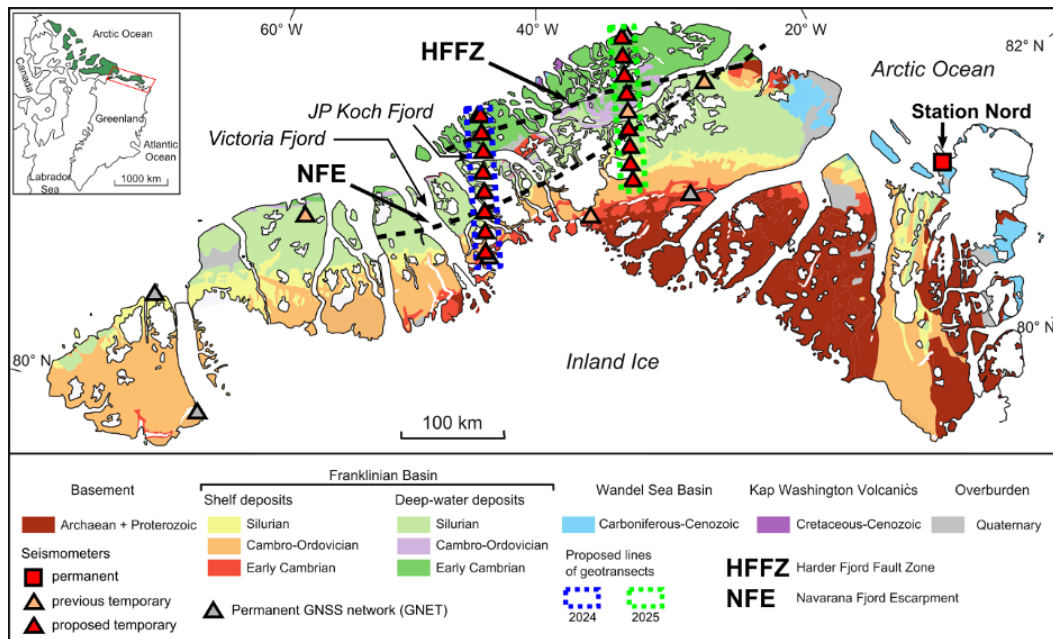


Figure 1. Simplified geological map of North Greenland with location of the Harder Fjord Fault Zone (HFFZ) and proposed sites for deployment of seismometers east of the Victoria Fjord.

7.10 WP10; ARCTIC METEOROLOGY AND OCEAN SURFACE EXCHANGES

WP General information		
WP full name: Arctic Meteorology and Ocean Surface Exchanges		WP coordinator: John Prytherch
WP ID (acronym): AMOSE		Version date:
WP Resources		
WP Team Onboard		
Name	Institution	Role
John Prytherch	Uppsala University / SPRS	WP leader
(Michael Tjernström	Stockholm Uni. MISU	on-shore collaborator)

Equipment:

The majority of the AMOSE instrumentation is intended to be installed and operated in the same way as for ACAS during the Synoptic Arctic Survey 2021 and ARTofMELT 2023 expeditions. The installed instrumentation will operate continuously throughout the expedition. In addition, weather balloons will be launched at 12hr intervals from the helideck throughout the expedition, and instrumentation will be deployed and water samples taken manually from boats during work in fjords and/or from sea ice where conditions allow.

Remote sensing

A motion-stabilized, vertically pointing, W-band Doppler cloud radar (active), and a microwave radiometer (passive) installed on a flat rack, mounted on the roof of a container on the 4th deck, close to the ship's centerline. The container itself houses control and data logging systems for the remote sensing instrumentation, and for the other measurement systems listed below. A ceilometer (lidar, active) is also part of the 7th deck weather station installation (see below).

Foremast installation

An eddy covariance flux package at the top of Oden's foremast will measure surface fluxes of momentum, heat, water vapour, CO₂ and CH₄. A laser spectrometer, large scroll pump, and other equipment relating to the CO₂ and CH₄ flux measurements will be installed in the 'hockey goal' shelter at the bottom of the foremast.

7th deck weather station

Meteorological instrumentation will be installed at several locations on Oden's 7th deck, adjacent to the fore railing. Instrumentation consists of a weather station measuring wind, temperature humidity and also long and shortwave downwelling radiation (located close to Oden's centerline), a present weather sensor, measuring visibility and precipitation, and a vertically pointing ceilometer (active Lidar; eye safe) measuring cloud base, cloud fraction, and Lidar backscatter profiles. Downward-looking infrared sensors on each wing are used to measure the temperature of the surface at each side of the ship.

Radio soundings

Radiosondes (weather balloons) will be launched either 2 times daily (at either 12 and 00 UTC, or 6 and 18 UTC) throughout the expedition. Radiosondes have been routinely launched from the helideck on previous expeditions and their operation can be easily worked around helicopter operations. A balloon filling station with helium bottles and a balloon holder (approx. 2 m²) will be installed on deck 2 on the starboard side near the base of the staircase leading up to the helipad. The receiver station will be installed on the 7th deck (in Container 25) for communication with the sonde and for preparation of each launch.

Main lab

A membrane equilibration pCO₂ sensor will sample continuously from the underway

line. This instrument requires 1m benchspace adjacent to a sink. It has previously been installed successfully in the clean room.

Boat measurements

Flux measurements and water sampling will be carried out from boats, in close collaboration with the Stranne / Akhoudas WP. This will target fjord waters in general and in particular waters and mixed sea ice-water areas closer to glacier edges than possible to reach with *Oden*. Additional measurements should be made within the 'footprint' of the foremast eddy covariance system (upwind of *Oden* when bow-to-wind, approximately 200 m to 2km distant). General surveying of these areas and transects towards/away from ice tongue edges will be useful. During boat work, floating chambers will be deployed directly from the boat. Each flux measurement takes approximately 10 minutes, during which the chamber should be allowed to drift freely. The flux instrumentation is powered with 12v batteries. Upper ocean profiling using hand deployed CTD and water samples of lead water (at the surface, and at depth using e.g. a Ruttner sampler, to depths of perhaps 20 m) for determination of CO₂ and CH₄ concentration will occur simultaneously while the flux system is deployed.

Sea ice measurements

During suitable conditions (i.e. where *Oden* is stationary in ice during CTD / coring stations, such as in the Lincoln sea) the chamber flux instrumentation and water sampling as described in the Boat measurement section can instead be deployed directly from sea ice into leads, ideally upwind of *Oden* and outside of her immediate influence (> 100m distant). Such sea ice deployments were done successfully during SAS2021 with the sea ice accessed either directly from *Oden* or using the helicopter. 2h ice station.

Lab/deck Space: 4th deck container / rooftop (ACAS container) and 7th deck, below helideck (filling station for helium bottle), and foremast space as used on previous ACAS deployments. Access to underway line in main lab (approx. 1 m of bench space adjacent to sink). Dry / warm location in stern of ship for storage of chamber flux system (approx. 2m * 0.5m).Ska användas under ice/boat stations. Location for charging 4*12V batteries.
<i>Required conditions for WP (ice, environment, weather, etc.)</i>
We prefer Oden to be bow-to-wind where possible.
<i>WP task description:</i>

Procedures:

The majority of the instruments operate continuously and autonomously, needing only regular checking, and repair and maintenance as required. During or after icing conditions, the foremast will need to be lowered to allow removal of ice from one of the sensors. The ice cleaning takes approximately 10 minutes and the whole lowering/cleaning/raising procedure approximately 30 minutes. A one off calibration of the microwave radiometer, that requires approximately 50 litres of liquid nitrogen, needs to be performed during clear sky conditions either during mobilisation, or early during the expedition.

Radiosondes will be prepared every 12 hours, with the weather balloon filled with Helium gas (approx. 1m³) in a custom holder on the 2nd deck by the stairs up to the helideck. Balloons are launched from the helideck, after coordination with the bridge to ensure safety around helicopter operations. The launch procedure takes approximately 30 s. Following completion of the sounding (1.5 to 2hrs after launch), the data is transmitted to the GTS for ingestion into the global weather forecast system. This is usually done using FTP and an SPRS laptop that has a data connection.

During boat operations, multiple chamber flux measurements will be made during each boat voyage. Each measurement takes approximately 10 minutes. At least 4 measurements need to be made for the deployment to be worthwhile, and the more that can be made the better. The system is powered by 2*12V car batteries and has approximately 6 hrs duration. The chamber flux system is approximately 1.5 m long and weighs 40kg. It can be mounted in a covered pulka to provide weather protection. During the flux measurement time, surface and shallow profile water measurements can be made from the boat. This work is intended to be done in close collaboration with Stranne / Akhoubas, and their planned operation of the WEGAS system from small boats. The measurements of the different systems and complimentary and can be performed simultaneously, and the workload can be shared.

During sea ice operations, the ice can be accessed with the necessary equipment using either gangway, bosun's chair/cage or helicopter. The chamber flux system is installed inside a covered pulka and can be dragged over the ice to a suitable location – i.e. where there is access to a natural lead or other water surface in which the chamber can be deployed, ideally upwind and > 100m from Oden. Approximately 2hrs is required to perform a full set of measurements from the ice (4-8 chamber flux measurements, and water samples). In addition to usual on ice work precautions (e.g. bear guarding, flotation suits), to deploy the chamber in lead waters and take water samples, access to ice edges is needed, and hence additional precautions (ice strength testing, harness and ice spikes) are required. This work may also be performed in collaboration with Stranne / Akhoubas.

<i>Interface with Oden crew and SPRS</i>
Assistance with raising / lowering the mast. Assistance with LN for radiometer calibration. Coordination with bridge for radiosonde launches. Assistance with preparing the computer FTP system to transmit radiosonde data to the GTS. Assistance with small boat – boat operations and loading/unloading of equipment. Assistance with on-ice work – bear guarding, ice safety equipment (harness, spikes, flotation suits)
<i>WP Risk and counter-measures</i>

Risk identification:

- Difficult radiosonde launch in high winds – difficult to handle balloon, risk of being dragged off feet by high wind on balloon on icy deck.
- LN spillage on person/deck.
- Ice fall from mast during raising/lowering.
- Fall into water from small boat.
- Polar bears during on ice work.
- Fall into water from ice edge.

Counter measures (mitigating actions):

- Most radiosonde launches can be handled by a single person, but in strong winds a second person should be on hand to assist with balloon and ensure safety. If in doubt, primary operator should call for assistance, delaying launch if necessary.
- LN should be handled by two people, with appropriate PPE and in suitable conditions (*Oden* stationary).
- Helmet during mast raising / lowering.
- Suitable flotation / cold water gear. Securing lines when raising / lowering sampler?
- Bear guarding.
- Flotation suits, ice spikes, harness when near ice edge, and careful testing of working edge.

Deliverables and future (after cruise) plans

List data repositories

Bolin centre database

<i>Outreach activities</i>
<i>WP Appendix (drawings, pictures, equipment, fact sheet, etc):</i>

7.9 WP: ICE-PPR; THE INTERNATIONAL COOPERATIVE ENGAGEMENT FOR POLAR PROJECTS AND RESEARCH

The International Cooperative Engagement for Polar Projects and Research (ICE PPR) Memorandum of Understanding (MOU) is an agreement across seven nations with interest in high latitude environmental conditions, human performance, and operations. Within the ICE PPR group, there is an Ocean and Atmosphere working group focused on improved scientific understanding, measurements, and models of the environment from below the ice to aerial remote sensing. This is a request for three environmental moorings to be deployed from the GEOEO cruise in support of ICE PPR oceanographic research. The moorings shall include sensors for passive acoustics (hydrophones), temperature, salinity, and depth. They will not include any active acoustic emissions. The moorings will have a small anchor, sensors along a line (spectra), and sub-surface floats. Sub-surface floats shall not be shallower than 50m from the ocean surface. These moorings are to be deployed for one year (12 months) to track diel and seasonal trends in the soundscape including variations in biological ambient noise from fish, invertebrates, and marine mammals; contribution of ice dynamics and sea ice cycles to ambient noise; contribution of glacial outflow to ambient noise; and physical wind-driven ambient noise. The data collected by these environmental moorings will be available across the ICE PPR community. The scientist leading the environmental mooring effort (Dr. Lauren Freeman, USA) is in coordination with researchers in Greenland to disseminate vocalizations and observations of narwhal calls back to the local community for both scientific research and to be made available for educational outreach.

LIST OF APPENDIXES:

Appendix 1; Fuel plan

Appendix 2; Chemical Plan

Appendix 3; Gas Plan

Appendix 4; Battery Plan

Appendix 5; Load plan

Appendix 6; CTD water budget

Appendix 7; Oden Ship data