



Cruise report 2023

7 July–7 August



About this report

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Forord

Norge fikk i 2009 støtte fra Kontinentalsokkelkommisjonen i FN i kravet om nye store sokkelområder nord for Svalbard. Kunnskapen om sokkelen er liten på norsk side. Andre land har de senere år vært langt mer aktive i Polhavet enn Norge.

GoNorth skal gjennom mobilisering av de fremste kunnskapsmiljøene bringe Norge i front på kunnskap om, for og i Polhavet, slik at vi kan stå frem som den fremste forvalter av miljøet og naturressursene. Vi samarbeider med internasjonale fagmiljøer som deler våre interesser og ambisjoner, og som er innstilt på samarbeid om forskning, fartøyer og finansiering.

Det første GoNorth-toktet gikk fra Longyearbyen 15. oktober 2022 med kurs for Nordmarginen av Svalbard, Nansen-bassenget og Knipovich-ryggen vest av Svalbard. Tokt nummer to gikk fra Longyearbyen 7. juli 2023 med kurs for den nordligste delen av midthavsryggen mellom Svalbard og Grønland. Denne toktrapporten summerer opp det andre toktet på vegne av partnerskapet. Rolf Birger Pedersen, professor ved Universitetet i Bergen, var toktleder ombord og har hatt redaktøransvaret for rapporten.

GoNorth vil gjerne takke Nærings- og fiskeridepartementet, Utenriksdepartementet og Kunnskapsdepartementet for økonomisk støtte til å gjennomføre toktet. Vi takker universitetene i Bergen og Tromsø og Norsk Polarinstitut for at de bidro med finansierte toktdøgn ombord på det isgående forskningsfartøyet Kronprins Haakon. Takk også til Norges forskningsråd for god dialog om utformingen og oppfølgingen av det faglige programmet.

Vi vil også gjerne takke kapteiner og mannskap ombord på FF Kronprins Haakon for godt samarbeid underveis. Dette var et krevende tokt under vanskelige forhold med usedvanlig tunge isforhold. Alt tatt i betraktning ble toktet både faglig og praktisk sett vellykket.

Sist, men ikke minst vil vi takke partnerskapet i GoNorth, og spesielt prosjektets vitenskapelige kjernegruppe, for god planlegging og koordinering av ulike interesser over mange år. GoNorth har vært et usedvanlig krevende prosjekt som så langt er kronet med to vellykkede tokt i 2022 og 2023.

Trondheim, november 2023

Gunnar Sand, prosjektleder for GoNorth og prosjektdirektør i SINTEF

Sammendrag

Norges yttergrense nord for Svalbard går over dyphavsletter i Nansenbassenget og inn på den sørlige flanken av Gakkelryggen. Nansen oppdaget fjellryggen da han drev over Polhavet med Fram og loddet havdypet underveis. I dag vet vi at dette er den nordligste delen av en 65.000 km lang fjellrygg som strekker seg fra Polhavet gjennom Norskehavet og Atlanterhavet, videre gjennom Indiahavet til Stillehavet. Havbunnen dannes langs denne fjellryggen med en hastighet fra omtrent 1 centimeter ved Gakkelryggen til over 10 centimeter i Stillehavet. Gakkelryggen er ikke bare en geografisk ende for den globale midthavsryggen; det er også et geodynamisk endeled for jordens system av spredningsrygger.

Gakkelryggen, samt delene av spredningsryggen som strekker seg gjennom Framstredet, har i stor grad vært utilgjengelig for forskning på grunn av drivis. FF Kronprins Haakon, som er tilpasset bruken av den fjernstyrte undervannsfarkosten Ægir 6000, har åpnet nye muligheter for å utforske denne mest utilgjengelige delen av det globale ryggsystemet.

Gakkelryggen ble utpekt som et mål for GoNorth allerede da programmet ble skissert. Det ble også tidlig klart at en ekspedisjon til Gakkelryggen helst burde gjennomføres som en to-skips-operasjon, og et samarbeid med Alfred Wegener-instituttet (AWI) om felles operasjoner med Kronprins Haakon og Polarstern startet tidlig. Til tross for detaljerte planer tok drivisen region - slik den gjorde for Fram-ekspedisjonen og mange senere polhavsekspedisjoner. Hverken Polarstern eller Kronprins Haakon var i stand til å nå frem til hovedområdene for undersøkelsene.

Planene måtte tilpasses isforholdene underveis. Vi var i stand til å gjennomføre undersøkelser langs den vestligste delen av Gakkelryggen der et vulkansk område og et hydrotermisk felt ble kartlagt og besøkt med undervannsfarkoster. Utsettingen av oseanografiske rigger måtte utsettes til et senere tokt, mens andre deler av planene ble gjennomført så langt som forholdene tillot. Det var mulig å gjennomføre is-studier ved hjelp av instrumenter ombord og ved stasjoner på isen. Det ble også tatt prøver av havbunnsedimenter for ulike formål, og det ble gjennomført et oseanografisk snitt på tvers av Framstredet.

Da vi trakk sørover og ut av den vanskeligste isen for å undersøke 'Lucky Ridge' og videreføringen av Gakkelryggen gjennom Framstredet, snudde endelig lykken. Med hjelp av et dyktig mannskap og fremragende ROV-piloter oppdaget vi et unikt hydrotermisk felt 3000 m under havisen. Jublende forskere overførte Ægir 6000-video av trolske mineralformasjoner og en oase av liv. Vi ga varmekilden det mytiske navnet 'Ultima Thule' - et sted mot nord, bortenfor verdens grenser.

Et tokt som startet med store utfordringer, endte med suksess og jubel.

Bergen, desember 2023

Rolf B. Pedersen, toktleder for GoNorth-2023, professor ved Universitetet i Bergen

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1. Summary and overall objectives

Norway's outer boundary north of Svalbard extends over deep-sea planes in the Nansen Basin and onto the southern flank of the Gakkel Ridge. Nansen discovered the mountain ridge as he drifted across the Arctic Ocean with Fram, sounding the ocean depths along the way. Today, we know that this is the northernmost part of a 65,000 km-long mountain range extending from the Arctic Ocean through the Norwegian Sea and the Atlantic Ocean, further through the Indian Ocean and across Pacific. Along this ridge, the volcanic seabed forms at a rate ranging from approximately 1 cm along the Gakkel Ridge to over 10 cm along the East Pacific Rise. Gakkel Ridge is not only a geographical terminus for the global mid-ocean ridge; it is also a geodynamic endmember in the Earth's system of spreading ridges.

Gakkel Ridge, along with the parts of the spreading ridge extending through the Fram Strait, has largely been inaccessible for research due to sea ice. RV Kronprins Haakon, adapted for the use of remotely operated underwater vehicles like Ægir 6000, has opened new possibilities to explore this most inaccessible part of the global ridge system. Gakkel Ridge was designated as a target for GoNorth from the early stages of program development. It was also evident early on that an expedition to Gakkel Ridge should preferably be conducted as a two-ship operation, and collaboration with the Alfred Wegener Institute (AWI) for joint operations with RV Kronprins Haakon and RV Polarstern commenced early.

The primary goal of this leg of the expedition was to investigate an unusually deep segment of the ridge situated just east of the 4° E meridian. In a collaborative US-German two-ship expedition in 2001, this deep ridge section was initially identified. Notably, mantle rocks were exposed on the seafloor, and reports indicated ongoing hydrothermal activity in the area.

An essential aim of GoNorth-2023 was to thoroughly explore and sample this area using Ægir 6000, specifically searching for signs of hydrothermal activity. Additionally, a key objective was to support Polarstern in conducting a deep seismic survey across this region.

An expedition to the Gakkel Ridge could address various research interests. The objectives of the 2023 cruise encompassed the deployment of moorings and establishment of ice stations in the Amundsen Basin, located north of the Gakkel Ridge. These installations were intended for long-term oceanographic monitoring. Additionally, the expedition aimed to conduct sediment sampling in the Amundsen Basin, en route to the Gakkel Ridge, with a focus on exploring the deep biosphere and facilitating paleo-oceanographic/climate studies.

Furthermore, the goals included sea ice studies, particularly emphasizing pressure ridges. This involved the utilization of both remote sensing techniques and ice coring, implemented across ridges at multiple stations.

Despite our detailed planning, the sea ice dictated the course of the cruise. Neither RV Polarstern nor RV Kronprins Haakon could reach the primary study areas as initially intended. Adjustments to the plans became necessary based on the evolving ice conditions along the way. Nevertheless, we managed to conduct surveys along the westernmost part of the Gakkel Ridge, where we mapped a volcanic area and further explored a hydrothermal field using underwater vehicles.

The deployment of oceanographic moorings had to be deferred to a subsequent expedition, while other elements of the plan were executed to the extent that conditions allowed. Ice surveys were feasible using onboard instruments and at stations on the ice. Samples of seafloor sediments were also collected for various research purposes, and an oceanographic transect was conducted across the Fram Strait.

As we headed south, leaving behind the most challenging ice obstacles to explore 'Lucky Ridge', a distinct ridge structure that appears to mark the spreading axis through parts of the Fram Strait, we finally had a stroke of luck. With the support of a skilled crew and proficient ROV pilots, we successfully mapped and surveyed a section of the ridge where hydrothermal deposits had been dredged by RV Polarstern in 1999. Leveraging the combined capabilities of RV Kronprins Haakon and Ægir 6000, we effectively surveyed a 30 km² area.

At the very end of this exploration effort, we uncovered a large and distinctive hydrothermal field located 3000 m below the sea ice. Ecstatic researchers and crew members eagerly viewed the video footage from Ægir, which captured hot hydrothermal water emanating from fascinating mineral formations and revealed an oasis of life. We named this particular vent site 'Ultima Thule' — a mythical place to the north, beyond the world's boundaries. An expedition that commenced with significant challenges culminated in success and jubilation.

In many respects, the Lucky Ridge site proves to be as scientifically intriguing as the original study area at the Gakkel Ridge. Our results suggest that mantle rocks are currently undergoing exhumation without any discernible signs of volcanic activity. This presents a unique geodynamic feature that can offer new insights into tectonics-dominated seafloor spreading and mantle exhumation.

Furthermore, evidence of a black-smoker hydrothermal field and exceptionally large hydrothermal deposits indicates that the mantle is sufficiently hot to sustain high-temperature hydrothermal activity over extensive time periods. This discovery is important for enhancing our understanding of seafloor massive sulfide deposits. Additionally, the interaction between hydrothermal fluids and mantle rocks typically yields hydrogen-rich fluids with the potential to attain high pH levels. Our preliminary results suggest that this is indeed the case here. These conditions constitute the key factors upon which the current hypothesis regarding the hydrothermal origin of life on Earth is based.

The Ultima Thule site also unveils a rich chemosynthetic ecosystem, driven by chemicals derived from subsurface water-rock interactions. This discovery holds significant implications for deep-sea biology in the Arctic and underscores the biological connectivity between the Polar Ocean and the Norwegian-Greenland Sea. Further studies will also be crucial to comprehend and explore these ecological dynamics.

Finally, I express my gratitude to all the scientists, engineers, students, ROV pilots, and the entire crew aboard RV Kronprins Haakon. I am also thankful to the personnel at IMR and the companies that offered crucial support when we urgently needed assistance to continue the cruise. Special thanks to Daniel Albert for public outreach and daily reporting, and to Gunnar Sand, whose on-land support was invaluable throughout many challenges.

Rolf B. Pedersen

Cruise leader

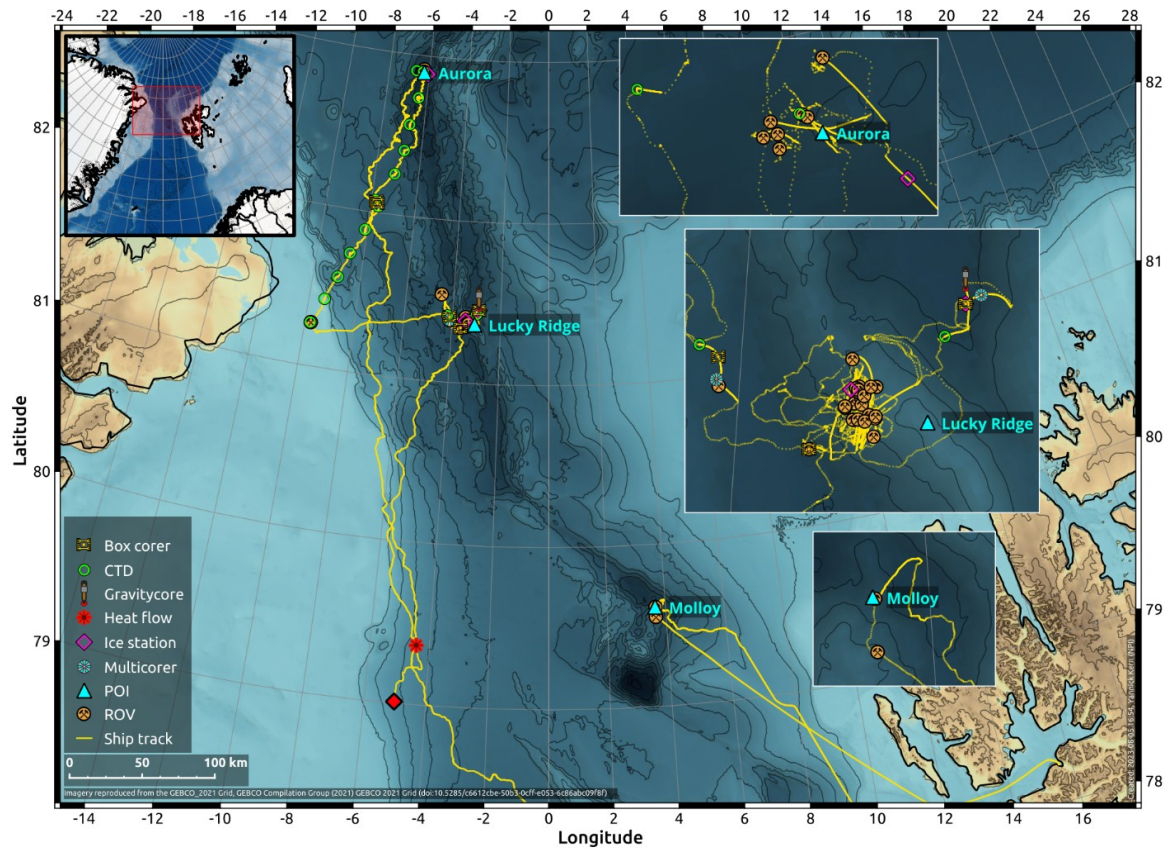


Figure 1. Overview of cruise track and research activities.



Figure 2. Participants of the GoNorth 2023 research cruise. Photo by Daniel Albert, SINTEF/GoNorth

2.List of participants

Table 1. Participants of GoNorth 2023 expedition. UiB = University of Bergen, UiT = University of Tromsø - The Arctic University of Norway, SJSU = San José State University, AWI = Alfred Wegener Institute for Polar and Marine Research, CNRS-LOCEAN = Laboratory of Oceanography and Climate, NPI = Norwegian Polar Institute, NTNU = Norwegian University of Science and Technology, BSA = BSA Offshore AS, DWS = Deep Water Services, IMR = Institute of Marine Research.

No.	Name	Institution	Role
1	Rolf Birger Pedersen	UiB	Cruise leader, professor
2	Ingunn Thorseth	UiB	Professor
3	Sabina S. Palinkas	UiT/UiB	Professor
4	Ryan Portner	SJSU	Associate professor
5	Eszter Sendula	UiT	Postdoc
6	Christian Katlein	AWI	Scientist
7	Katja Håkli	NORCE	Senior engineer
8	Matthieu Labaste	CNRS-LOCEAN	Senior engineer
9	Yannick Kern	NPI	Engineer
10	Marius Bratrein	NPI	Engineer
11	Bjørn Runar Olsen	UiT	Engineer
12	Håvard H. Stubseid	UiB	PhD candidate
13	Nabil Panchi	NTNU	PhD candidate
14	Oskar G. Veggeland	NTNU	PhD candidate
15	Alexandra Pliss	NTNU	PhD candidate
16	Renée M. Fredensborg Hansen	NTNU	PhD candidate
17	Maja Jæger	UiB	Master student
18	Eirik Siira	UiB	Master student
19	Eirik Valdar	UiB	Master student
20	Fredrik Eskengren	BSA	Surveyor
21	Frode Evensen	BSA	ROV pilot
22	Andreas Storebø	BSA	ROV pilot
23	Jonas Broberg	DWS	ROV pilot
24	Kai Roger Loven	DWS	ROV pilot
25	Johan Sköld	Saga Subsea	ROV pilot
26	Björn Löfqvist	Saga Subsea	ROV pilot
27	Ståle Mikal Skaaden	IMR	Medic
28	Eirik Hellerud	NPI	Sea ice safety
29	Daniel Albert	SINTEF	Communications officer

3. Daily reports

As part of the onboard outreach activities, Daniel Albert from SINTEF diligently compiled daily reports throughout the cruise. These reports here serve as a diary, documenting the various research activities and the daily life onboard. Additionally, they provide a detailed record of the challenges faced and the successes achieved during this expedition.

Day 2 – 7 July

Now we're underway! The day was spent preparing equipment for use by the research team. The Remotely Operated Vehicle (ROV) Ægir, which plays a central role in the expedition, has been a major focus. In the middle of the night but in brilliant sunshine, the research vessel RV Kronprins Haakon received a visit from the research ship RV Helmer Hansen of UiT, delivering crucial equipment.

Next stop: Molloy Ridge. The ship is now en route to the Molloy area in the Fram Strait and is expected to take around 12 hours to reach there. The Molloy area encompasses the Molloy transform, the Molloy Deep and the Molloy Ridge. The Molloy Deep is a nodal deep in the 160 km west of Svalbard. It is the deepest point in the Arctic (around 5550 m) and was discovered in 1972. The ROV will be used for the first time on this expedition at the Molloy Ridge. The crew and research team are in place in Longyearbyen, and everything is ready for the start of the expedition. Due to cruise traffic in Longyearbyen, the RV Kronprins Haakon is anchored a few hundred metres from the coast.



Figure 3. RV Kronprins Haakon transferring equipment from RV Helmer Hanssen. Photo by Daniel Albert, SINTEF/GoNorth.

Day 3 – 8 July

Sailing into the sea ice is always a magical experience. The ice became visible on the horizon early this morning. Fortunately, it's not densely packed ice yet — that would have made today's mission in the Molloy area more challenging. The ship navigated between and through loose ice floes of various sizes for a good part of the morning and reached the destination in the Molloy area just before 1:00 PM.

Molloy Deep. The Molloy Deep is one of the 'Five Deeps' — the deepest points in each of the world's oceans. The very deepest is the Mariana Trench in the Pacific Ocean. However, in the Arctic Ocean, the Molloy Deep takes the lead, with an estimated water depth of 5550 m. It was formed by the movement of tectonic plates away from each other. It is situated between two fault lines (lines where tectonic plates slide against each other). On one side of the depth, between the fault lines, there is a ridge formation, the Molloy Ridge, that arouses much interest among geologists. It is a place where the mantle is exposed. Several ROV dives were conducted last year both in the Molloy Deep and at the Molloy Ridge to determine the composition of this ridge formation, and today another dive was carried out.

"The goal is twofold," says expedition leader Rolf Birger Pedersen. "On one hand, we are learning more about a part of this ridge formation that we know little about. And on the other, we are testing the ROV at a depth of 2880 m. If we encounter any issues, we have enough time to fix them before reaching the Gakkel Ridge."

The mission was a success. The ROV reached the right location on the first attempt. It is not guaranteed that the samples needed are precisely where the ROV descends, but they were this time. This saved time, allowing for another dive to be conducted in the evening to capture high-resolution images at another nearby location of interest to geologists and biologists.

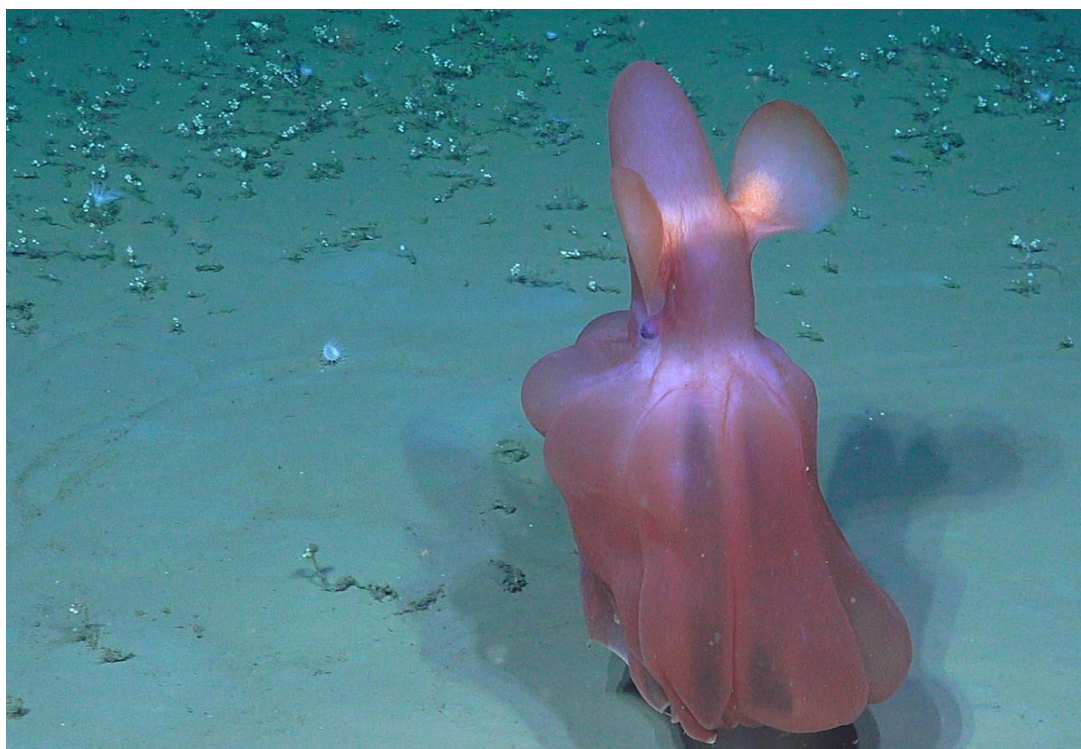


Figure 4. A Grimpoteuthis octopus, better known as a Dumbo octopus, was encountered at 3500 m depth. Photo by Ægir 6000/NORMAR.

Day 4 – 9 July

Yesterday, we shared information about an initial dive near the Molloy Deep. Today, we have results from this dive, and we can also discuss another dive conducted overnight. The focus of the first dive was an area on the east side of the Molloy Ridge. From the initial investigations conducted in the area last summer, we know that a significant portion of this ridge formation consists of exposed mantle — the part of the Earth usually hidden beneath the crust.

Machine learning and ice conditions. If you followed last year's GoNorth expedition, you might remember Nabil Panchi (NTNU), who was on the ship to capture images of sea ice — thousands of them. He is also part of this expedition. The idea is to train machines to analyse images of sea ice. Ships traveling in the northern regions are equipped with cameras, and a system that could help them quickly analyse the ice would be valuable. Additionally, such analyses could be compiled to form a better understanding of ice conditions overall.

One problem Nabil discovered is that images from ships often have disruptive elements: water droplets on the lens. It is possible to use machine learning to remove these droplets, but for that, you need a dataset with images of the same sea ice — some with water droplets and some without. He is currently creating such a dataset. He built a box containing two GoPro cameras behind a window. By spraying the window in front of the lower camera, two images of sea ice can be captured simultaneously: one with droplets and one without.



Figure 5. Alexandra Pliss (NTNU) is using a spray bottle to create water droplets on the glass while Nabil Panchi (NTNU) is adjusting the cameras. Photo by Daniel Albert, SINTEF/GoNorth.

Day 5 – 10 July

RV Kronprins Haakon incurred damage to a positioning instrument from ice during an operation at the Molloy Ridge northwest of Svalbard on Sunday. Now, the ship must make its way to Tromsø for repairs. We hope to resume the journey north to the Gakkel Ridge once the repair is complete.

The terms "challenging" or "complicated" are often used when it comes to conducting research in sea ice. And there's a reason for that. Ice floes can weigh several tens of tons and are not easily stopped when in motion. The ship is built for it, and most of the time, everything goes well, but an unfortunate incident occurred yesterday.

To maintain full control over the underwater positioning of the ROV and other equipment, an instrument called HiPAP (High-Performance Acoustic Positioning) is essential. It uses sound waves to provide an accurate position. The instrument is mounted at the end of a steel tube that is lowered to 4 m below the hull. During operations at the entrance to the Fram Strait, a large chunk of ice struck the tube, causing it to bend and preventing it from being retracted into the hull. The ship must sail at reduced speed as long as the tube protrudes. It also cannot break ice due to the risk of water ingress if the seals around the tube are damaged. The solution is to cut off the tube to close the valve in the hull. This must be done in port, by a diver. It was considered to carry out this operation in Longyearbyen, but conditions there turned out to be unfavorable for such an operation. Therefore, RV Kronprins Haakon is now heading towards Tromsø, where the damaged steel tube can be removed and replaced with a new one. The crew has been in communication with Kongsberg, which has confirmed that they have the necessary part and will deliver it to Tromsø shortly. The crew is already preparing for the repair, which can be carried out on board.

The boat maneuvered out of the ice at a slow speed, pushing the ice floes aside instead of breaking through them. Now it is heading to Tromsø at a speed of 8 knots, which is about two-thirds of the usual speed for sailing in open seas.

Consequences for the expedition. The ship will take a couple of days to reach Tromsø, and the operation there is expected to take up to three days. After that, the ship will set course for the Gakkel Ridge again and carry out as much of the original program as possible. It goes without saying that the program will be somewhat truncated due to the days lost with travel and repairs. Therefore, GoNorth is working on creating a revised plan in collaboration with the affected researchers. We are in ongoing dialogue with the Alfred Wegener Institute (AWI) regarding the planned two-ship collaboration on the Gakkel Ridge.

More information about revised expedition plans will be provided when we have more details.



Figure 6. The tube that was bent by the ice, even with its weight of 1.5 tons and diameter of 15–20 cm. In the top of the photo the hull of the ship is visible, the steel tube is 4 m long with the HiPAP-instrument (red sphere) at the end. Normally the tube should be vertical. Photo by Ægir 6000/NORMAR.

Day 7 – 12 July

RV Kronprins Haakon is en route to Tromsø for repairs, but scientific activities continue on board. Yannick Kern (NPI) is using the time in the lab to analyse water samples from a previous expedition.

When water samples from a specific depth are needed, a device called CTD rosette is used. This is a cylindrical frame with multiple plastic bottles that can be closed when the desired samples are collected. It is equipped with sensors that perform CTD measurements on the way down. CTD stands for "Conductivity, Temperature, Depth," indicating conductivity, temperature, and depth. Water conductivity informs us about its salt content (salinity).

Salinity is particularly interesting in the Arctic Ocean because ice that freezes releases salt into the water. Water with higher salt content is heavier, so it sinks to the bottom, creating a continuous cycle that helps mix water from different depths and transport nutrients. Salinity, along with temperature, can also indicate the water's origin — whether it comes from the Atlantic, for example.

Since CTD measurements occur continuously as the rosette is lowered and raised, it provides a profile of salinity and temperature in the water column from the surface to the deepest point reached during the investigation. To confirm the accuracy of the CTD measurements, Yannick measures the salinity of the water samples in the lab using a portable salinometer. This allows the CTD profile to be calibrated for a more accurate representation of the water column. It is time-consuming work: he has 144 samples to go through.

Preparations for repairs. In a lab on deck 3, the crew has opened a hatch in the floor providing access to the HiPAP — the positioning instrument that will be replaced in Tromsø.



Figure 7. Yannick Kern (NPI) measuring water salinity in a laboratory on the RV Kronprins Haakon. Photo by Daniel Albert, SINTEF/GoNorth.

Day 8 – 13 July

The repairs are in full swing in Tønsvik, north of Tromsø, to remove RV Kronprins Haakon's damaged HiPAP system and replace it with a new one. The positioning instrument is mounted on a steel tube that is lowered 4 m below the hull when in use, and this steel tube was bent by an ice floe. Since the tube is bent, it cannot be retracted as usual, so the damaged part must first be cut away by divers. The top part can be removed through hatches on the ship, but a complex operation is required first.

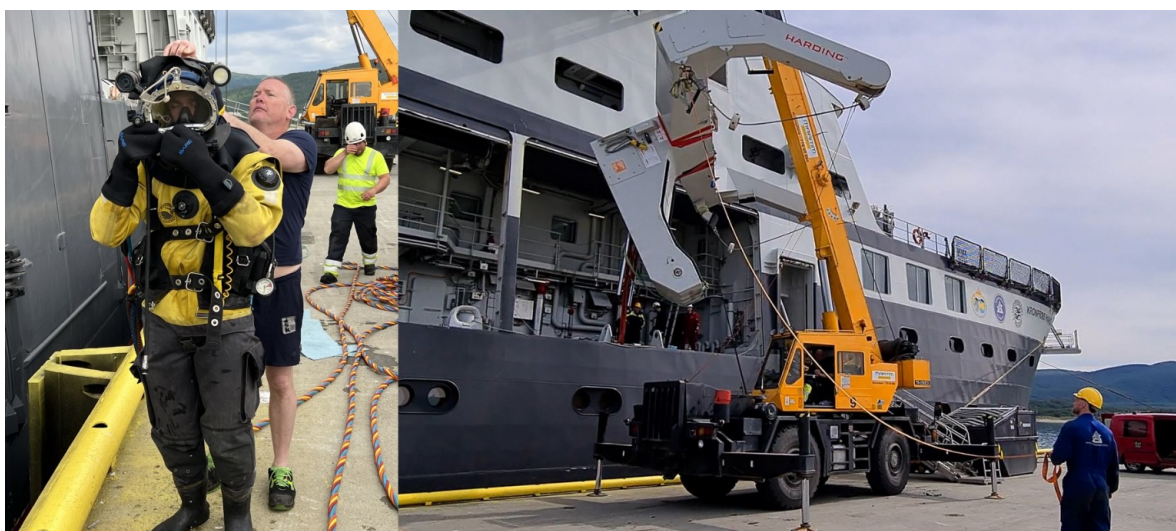


Figure 8. Diver preparing to cut away the bent steel tube (Left). A crane was hired to remove the davit (Right). Photos by Daniel Albert, SINTEF/GoNorth.

Day 9 – 14 July

While this report is being written, RV Kronprins Haakon is sailing north again. The steel tube that was damaged in the ice, part of the HiPAP instrument, has been removed and replaced with a new one. The divers from Fagdykk have done an admirable job dismantling the tube from beneath the hull. Kongsberg Support has sent a new HiPAP tube to Tromsø in record time, arriving almost simultaneously with us. Maritim Sveiseservice has worked tirelessly for two days with the crane to enable the operation.

All in all, this has been an impressive operation that has allowed us to resume the expedition with a smaller delay than we feared for a while. Expedition leader Rolf Birger Pedersen, a professor at UiB, thanks everyone involved, including the captain and crew, for their outstanding work.

Results from Molloy Ridge. Two individuals who didn't waste a moment in Tromsø are Sabina Strmic Palinkas and Eszter Sendula (both from UiT). Their lab is at UiT, and the two have used their time in Tromsø to run analyses on the samples from the first dive in the Molloy area.



Figure 9. The bent HiPAP steel tube after being removed from the ship. The part that was cut off by the divers is seen in the background to the right. Photo by Daniel Albert, SINTEF/GoNorth.

Day 12 – 17 July

RV Kronprins Haakon is back in the ice! The ship encountered the ice edge around 1:00 PM today. At the time of writing, the ship is in a part of the ice edge zone with large areas of open water, making it easier to maintain a good speed northward.

The research team on board has spent a significant part of the day on planning. First, there was the risk assessment meeting with the ROV team — more on this below. Then, the geology team had a meeting to discuss the most interesting areas to explore when we reach the Gakkel Ridge. Finally, there was a planning meeting for the first ice station of the expedition, which is coming in a few days. Two NTNU researchers will take ice samples, supported by many others.



Figure 10. RV Kronprins Haakon going through the ice. Photo by Christian Katlein, AWI.

Day 14 – 19 July

RV Kronprins Haakon has been moving slowly over the past 24 hours as it is currently in an area with older ice. The destination is the Gakkel Ridge, and the first stop will be near the Aurora hydrothermal field. This area has been explored by the German research ship RV Polarstern earlier this month.

Where are we now? As of now (July 19 at 19:30), the ship is located at 82° 26' 46" N, 7° 23' 16" W. The map below shows more precisely where we are and where we are heading.

This map illustrates the ship's route so far. On the left, we see Greenland, and on the right, we see Svalbard. The expedition started in Longyearbyen, moving towards the Molloy Deep. After a positioning instrument was damaged, the ship changed course towards Tromsø, explaining why the route disappears from the map heading south. It reappears on the map on the west side of the Fram Strait. The map indicates where older ice was encountered on July 18 around 17:00. It also shows the next goal: the Aurora hydrothermal field, where an ROV dive is planned. The map also indicates the current location of the German research ship Polarstern, which is also heading towards Aurora to meet us.

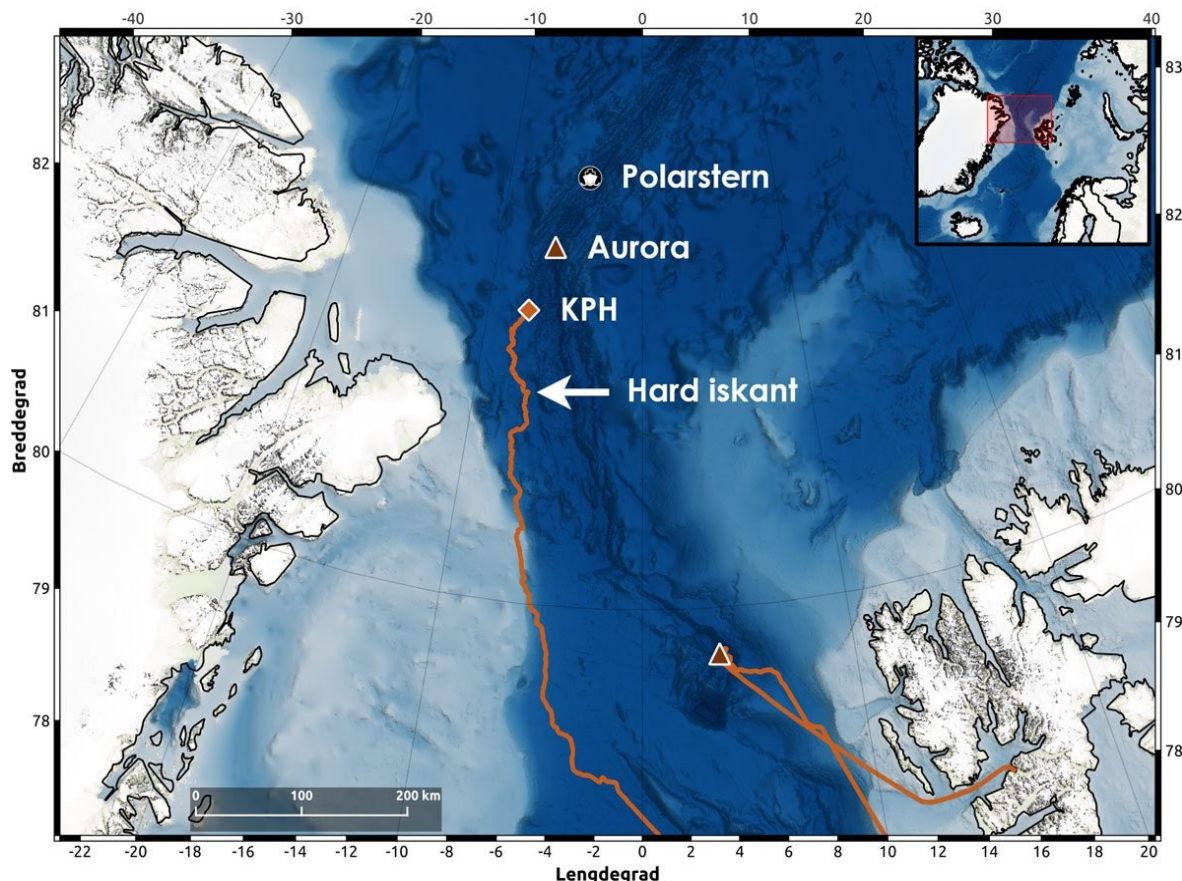


Figure 11. Map showing the current position and track lines of RV Kronprins Haakon (KPH) as well as the German RV Polarstern and the Aurora hydrothermal vent field. Illustration: Map layout by Yannick Kern, NPI – Image reproduced from the GEBCO_2021 grid, GEBCO Compilation Group (2021).

Day 15 – 20 July

Both RV Kronprins Haakon and RV Polarstern have encountered challenging ice conditions in the past few days. The research team on Polarstern had to adjust their plans due to difficult maneuvering conditions. For RV Kronprins Haakon, the average speed today has been even lower than yesterday, primarily due to thick ice.

RV Kronprins Haakon has a moon pool in the main hangar, allowing them to deploy the ROV into the water even when there is ice around the ship. Polarstern, launched in 1982, does not have such a moon pool. When they use the ROV, they have to deploy it from the side. AWI is currently designing Polarstern's successor, and Christian Katlein (AWI) is participating in the GoNorth expedition to learn from Norway's experience with Kronprins Haakon.

Norwegian-German collaboration. There is a planned collaboration between the two ships in the coming days. The researchers hope to establish a joint ice station, with both ships in close proximity. AWI has also shared bathymetric data with the GoNorth team, which will be valuable for the geological surveys we are about to conduct. The ROV team on board Kronprins Haakon will attempt to retrieve a seafloor seismometer that is stuck on the bottom.



Figure 12. Researchers from the German RV Polarstern arriving by helicopter to RV Kronprins Haakon (Left). Rolf Birger Pedersen (UiB), cruise leader on RV Kronprins Haakon, showing the ROV to Vera Schlindwein (AWI), cruise leader on RV Polarstern (Right). Photos by Daniel Albert, SINTEF/GoNorth.

Day 16 – 21 July

RV Kronprins Haakon finally reached the Aurora hydrothermal field, at the entrance to the Gakkel Ridge, after a couple of days with extremely challenging ice conditions. The ROV team conducted a dive to the vent field, and several samples were collected.

As explained in a previous report, the ship must position itself upstream of the ice drift before an ROV dive. This was done early today, but the drift turned out to take the ship too far south, so the ROV had to be hoisted back up, and the ship had to reposition. The second attempt was spot on, and the ROV explored the field for several hours.

Useful information from sea ice images. Ships are often equipped with various cameras that have the potential to provide a lot of information about sea ice when the images are processed. There are some challenges in extracting useful data from such cameras. One of them is that the camera points forward, so ice floes on the image will appear smaller when farther away.



Figure 13. Active black smokers at 3900 m depth at the Aurora hydrothermal field. Photo by Ægir 6000/NORMAR.

Day 17 – 21 July

It's not only GoNorth and RV Kronprins Haakon aiming to go far north this summer; the German RV Polarstern had plans to reach as far as 85° N. However, the ice conditions this summer have been extreme, leading both ships to make changes to their plans.

Polarstern and Kronprins Haakon have been close to each other since Thursday. Before that, RV Polarstern was a bit farther north, struggling through the ice. At one point, it took them 13 hours to traverse an ice ridge. It should be noted that RV Polarstern is a heavier ship than RV Kronprins Haakon, designed to handle even more challenging conditions.

While such thick ice poses no danger to the ships, it requires them to spend a lot of time — and fuel — to navigate through it. The typical pattern for both ships around the Aurora area has been encountering an obstacle, spending a long time overcoming it, having slightly easier progress for a short while, and then facing the next obstacle. In some areas, RV Kronprins Haakon has had an average speed of 0.5 knots (just under 1 km per hour).

It will still be possible to collect water samples, sediment samples, and conduct geological surveys with the ROV, thus accomplishing a significant portion of the program. Unfortunately, this also means that some activities originally planned for farther north will not be carried out.

On the trail of ancient DNA. Last night, a core sample was taken for NORCE. Subsequent analyses will reveal the types of DNA present in the upper part of the sediment column, i.e., the top centimeter of the seabed. The purpose of the study is to create a database of DNA in seafloor sediments, based on samples collected from many different areas. This database will eventually be used to estimate how much ice there was in the Arctic Ocean under historical climate conditions. The idea is that certain species thrive best with ice, while others prefer ice-free conditions. Ancient DNA in sediments can provide clues about past surface ice conditions.



Figure 14. Katja Häkli (NORCE) sampling the uppermost part of a sediment core. Photo by Daniel Albert, SINTEF/GoNorth.

First ice station. Today, we also had the first ice station of the expedition. We won't say much about it now, but we will provide more details tomorrow.

Collaboration with Polarstern. Yesterday, we reported on an exciting ROV dive conducted in the Aurora hydrothermal field. Polarstern contributed to this dive with bathymetric data that proved valuable for the ROV team.

The ice conditions made it challenging for RV Polarstern to carry out a mission they had: retrieving eight seafloor seismometers deployed last year. These instruments are designed to float to the surface on their own when retrieved. However, the mechanism that enables them to float didn't work for one of the seismometers, and expedition leader Vera Schlindwein (AWI) mentioned the issue when she visited Kronprins Haakon two days ago.

The research and ROV teams decided to attempt to retrieve the seismometer for our German colleagues since we were in the vicinity. And it worked! Just before noon today, the ROV pilots located the seismometer.

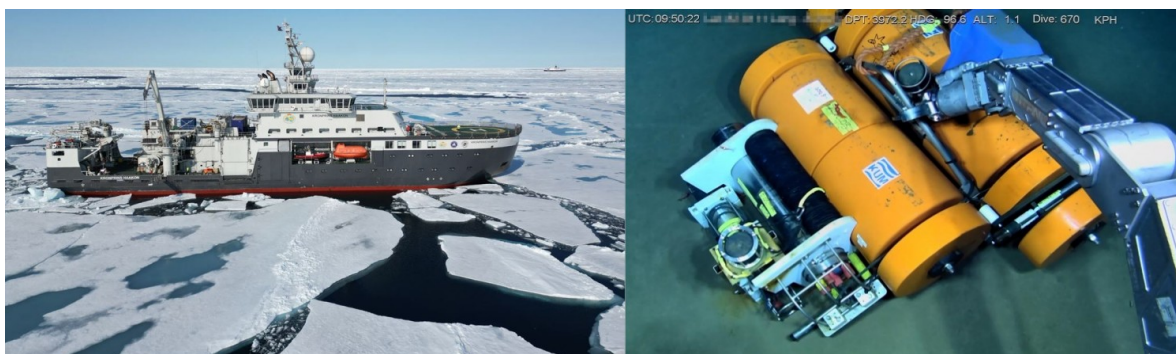


Figure 15. RV Kronprins Haakon in the front, with RV Polarstern in the background (Left). Ægir 6000 retrieving the seismometer for Polarstern (Right). Photos by Daniel Albert, SINTEF/GoNorth (left) and Ægir 6000/NORMAR (right).

Day 18 – 22 July

RV Kronprins Haakon and RV Polarstern continue their collaboration. This morning, the ships were close to each other to transfer equipment to Polarstern. The first item transferred was the seismometer that we retrieved for them yesterday.

Excitement at 3900 m depth. On Sunday night, a dive was conducted in an area recommended by Polarstern. This area features highly impressive hydrothermal chimneys. Before Polarstern arrived there a few days ago, it was unknown that there were active chimneys in this specific location. The tallest of the active chimneys observed was a whopping 10 m high. RV Polarstern managed to capture images of the area but couldn't collect samples. Last night, many rock samples were taken, and today they have been sorted and categorised.

Expedition's first ice station. As promised yesterday, we can now share information about the expedition's first ice station. When two large ice floes are pressed against each other, pressure ridges form—almost like mini mountain ranges of ice. Pressure ridges are poorly studied, despite constituting a significant portion of sea ice. They are visible to satellites equipped with various sensors. But how do we connect data from a satellite to the reality on the sea ice? And how do pressure ridges develop during a melting season? Alexandra Pliss (NTNU) and Renée Mie Fredensborg Hansen (NTNU/DTU) are working on answering these questions.



Figure 16. Crew and researches on the ice for the first ice station of the cruise. Photo by Daniel Albert, SINTEF/GoNorth.

To extract useful information from satellite sensor data, one must compare the information obtained from satellites with physical observations on the sea ice. Therefore, Alexandra and Renée spent much of yesterday measuring ice thickness, temperature, and salinity, along with numerous other parameters, with support from Nabil Panchi (NTNU), Oskar Gjesdal Veggeland (NTNU), and Christian Katlein (AWI).

Safety procedures at the ice station. Also involved in the operation were Eirik Hellerud, Yannick Kern, and Marius Bratrein from NPI, as polar bear guards, along with many others who were on the lookout for polar bears with binoculars from the bridge. When people are on the ice, the procedure is that three individuals should constantly watch for polar bears from the bridge—each responsible for their area, ensuring that all 360° around the ship is covered. This is done for the safety of the ice researchers but also for the safety of the polar bears. An unfortunate encounter between a polar bear and a human can easily be harmful to a bear, and the procedures are also designed to minimise the risk to the bears.

Day 19 – 24 July

It has been a busy period in the last 24 hours. Crews and research teams from the Kronprins Haakon and Polarstern visited each other last night. Then, water samples were collected throughout the night, and the work on sediment sampling began.

The water samples collected are for NPI, focusing on salinity, nutrients, oxygen isotopes, and dissolved colored organic material (which can provide insights into the water's origin). Additionally, dissolved inorganic carbon was measured—an important parameter for oceanographers studying major biochemical processes in the ocean. In total, water samples will be collected at 11 different locations around this area.

Other water samples were taken today for environmental DNA analysis, also known as eDNA. eDNA is a method used to determine which species inhabit a particular area. The analyses will be conducted by Akvaplan-niva.

Efforts were also made to collect sediment samples using a boxcore. This apparatus is lowered to the seafloor and retrieves a sample of 50 cm x 50 cm x 50 cm. Unfortunately, both attempts failed.

Meeting of two ships in the Arctic Ocean. It is not often that you receive visitors in the Arctic Ocean, but it happened yesterday. We welcomed crew and researchers on board, and we also visited the RV Polarstern, which has been Germany's polar research ship since 1982.

Reunion at 82.5° N. Here's a somewhat amusing story. Researchers on the Polarstern are following these daily reports, and a few days ago, during a brief interview with Ryan Portner, one of them said, "I know this guy!" By coincidence, both researchers found themselves in the same area in the Arctic Ocean without knowing it.



Figure 17. RV Polarstern in front, and RV Kronprins Haakon in the back (Left). Felix Genske (Universität Münster) and Ryan Portner (SJSU) studied together in Sydney, Australia, and were friends there, but lost contact and had not met in more than 10 years. They were reunited on Kronprins Haakon when the Polarstern crew and scientists visited (Right). Photos by Daniel Albert, SINTEF/GoNorth.

Day 20 – 25 July

RV Kronprins Haakon continued through the night in a southwest direction to complete the water sampling we mentioned yesterday. The last station was located near the fast ice edge that follows the coast of Greenland in this area.

Microscopic images of chimneys. The rock samples we collected during the previous ROV dive continue to excite. Sabina Strmink Palinkas (UiT) took some microscope images for us. The bottom image in Figure 18 show details from a chimney, collected during the last dive in the Aurora Vent field at approximately 3900 m depth. Some of the minerals identified in the chimneys contain a significant amount of copper. Further analysis will provide us with better insights into the biogeochemical cycle of copper in ultra-slow spreading systems like the Gakkel Ridge. In simpler terms, we are talking about how copper moves from the Earth's crust to the water column and back, often through living organisms.

Ice core analysis. Renée Mie Fredensborg Hansen (NTNU) is dividing an ice core sample into 5 cm pieces. She is wearing a lot of clothes as she works in a lab where the temperature is -15°C — and there are many samples to cut.



Figure 18. The green dots in the map (top left) show the locations of water samples and CTD measurements. Renée Mie Fredensborg Hansen (NTNU) dividing an ice core sample in the -15°C laboratory (top right). A close up image of the inside of a hydrothermal chimney (bottom). The walls of this chimney are primarily composed of the minerals pyrrhotite and chalcopyrite — indicating fluid temperatures above 300°C . Photos by Daniel Albert, SINTEF/GoNorth (top right) and Sabina Strmic Palinkas, UiT (bottom).

Day 21 – 26 July

Kronprins Haakon arrived at a perfect location for an ice station last night. The NTNU team is interested in leads, and there are several good examples in this area. However, there are also polar bears. Today, not just one but four polar bears were observed!

First, a large polar bear appeared. Then a smaller one arrived and scared away the first. Later in the day, a mother with her cub was spotted. Consequently, the ice station was postponed. Nevertheless, significant sampling can be carried out in the area. We have taken a sample with

the box corer. This instrument collects a sample from the seabed measuring 50 cm x 50 cm x 50 cm. Sediment core samples are also currently being taken with the ROV.



Figure 19. Katja Häkli (NORCE) collecting sediments from a box core grab (Left). Polar bears strolling on the ice between Kronprins Haakon and Polarstern seen in the background (Right). Photos by Daniel Albert, SINTEF/GoNorth.

Seabed mapping. While most on board were sleeping last night, the ROV was underwater to calibrate its multibeam echo sounder. A test mapping of a 3-km stretch of the seabed was conducted. The ROV team and the onboard geologists were satisfied with the results, and the ROV will now perform a more extensive mapping mission tonight. We are currently in a part of the Fram Strait called Lena Trough. It is part of the mid-ocean ridge of which the Gakkel Ridge is a segment. In the middle of Lena Trough, there is a mountain called Lucky Ridge. The geologists on board are very interested in exploring it further.

Day 22, July 27

Geomicrobiology is an intersection between geology, which examines the processes that have shaped the Earth as we see it today, and microbiology, which studies microorganisms. A significant reason for this is our understanding that microorganisms play a role in the journey of certain fundamental elements from the Earth's crust to the water column and back. Some of these microorganisms live in the sediments at the ocean floor. One way to learn more about the microorganisms inhabiting the sediments is to take a sediment core sample and measure its oxygen content. Once the oxygen levels have been measured in all layers, smaller sediment samples will be taken and analysed for DNA. This will reveal the bacteria present in the sediments. Porewater samples will also be taken and analysed to determine their chemical

composition, including whether they contain iron or manganese. Bacteria can thrive by "breathing" iron or manganese in the deepest layers where oxygen is scarce.

Mapping Lucky Ridge. The ROV spent a considerable part of the night mapping a section of the Lucky Ridge area. As mentioned before, these seabed maps provide much more detail than existing maps. This could lead to new discoveries — the jackpot would be finding a new hydrothermal field. Lucky Ridge extends a whopping 1600 m above the floor of Lena Trough. This is comparable to the elevation difference between the top of Trollveggen and the valley bottom. Mapping of Lucky Ridge continues with a new dive tonight.

New ice station. The NTNU team ventured onto the ice today. This time, they accessed the ice using the workboat from Kronprins Haakon.

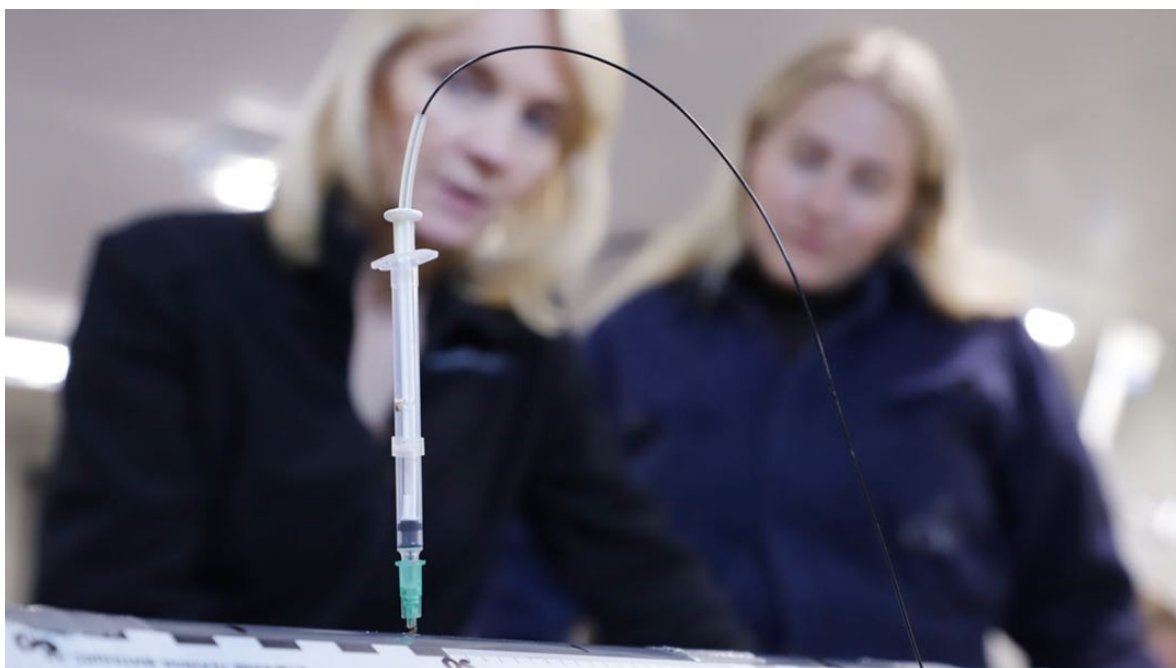


Figure 20. Ingunn Thorseth and Maja Jæger from UiB measuring oxygen content in a sediment core. Photo by Daniel Albert, SINTEF/GoNorth.

Day 23 – 28 July

On a research vessel like Kronprins Haakon, work goes on around the clock, and the night shift had a little surprise for the day shift this morning. The ROV was on a mapping dive for a significant part of the night, and in the middle of the map it produced, there was a 50-m-wide formation marked "Rolf's treasure" by the night crew.

The decision to map the area with the ROV is a result of collaboration with the German research vessel Polarstern. They found a deviation in water temperature nearby, which could indicate hydrothermal activity. Therefore, the plan for today was to conduct a new dive to explore the area, taking pictures and samples of the formation. There is sea ice in the area, and as explained earlier, this means that we must estimate the direction of ice drift as accurately as possible and position the ship upstream of the drift, so the ROV can be lowered while the ship approaches the target area.

Mapping with the ROV continues tonight.

Day 24 – 29 July

Yesterday, the ROV's target was a formation it had discovered the night before, which turned out to be an extinct hydrothermal area; today, we explored the same sector and found even more evidence of hydrothermal activity.

After today's dive, the ROV continued its mapping mission. The ice drift changed its course a bit, and it turned out to be fortunate. In the middle of the map produced, there is a narrow and high ridge with steep edges, which sparked a lot of interest among the geologists.

The new formation will be the target for the next dive, in the search for hydrothermal activity on Lucky Ridge.

Samples from today's dive. Today's dive has provided us with plenty of samples.



Figure 21. Håvard Stubseid (UiB) investigating a rock sample with a magnifying loupe. Photo by Daniel Albert, SINTEF/GoNorth.

Day 25 – 30 July

Another night, another dive — and last night's dive was particularly exciting as it uncovered distinct hydrothermal chimney structures.

It has been known that there is hydrothermal activity on Lucky Ridge since an expedition with RV Polarstern in 2004. Back then, Polarstern collected samples with bottom scrapers, finding sulfide-rich minerals indicative of hydrothermal activity. They also recorded anomalies in the water column, suggesting the presence of hot water rising from the seafloor.

In the past few days, GoNorth has built on these findings. Using the ROV, we have mapped parts of the seafloor in detail. While the icebreaker Kronprins Haakon moves slowly with the ice, the ROV follows 3000 m below the ship, mapping the seafloor using sound waves. The maps show rows of columnar formations over 20 m high in parts of the area. Last night, the ROV dived down to these formations to capture images, video, and collect samples. These samples reveal that the columns are built up by minerals precipitating out of warm hydrothermal water.

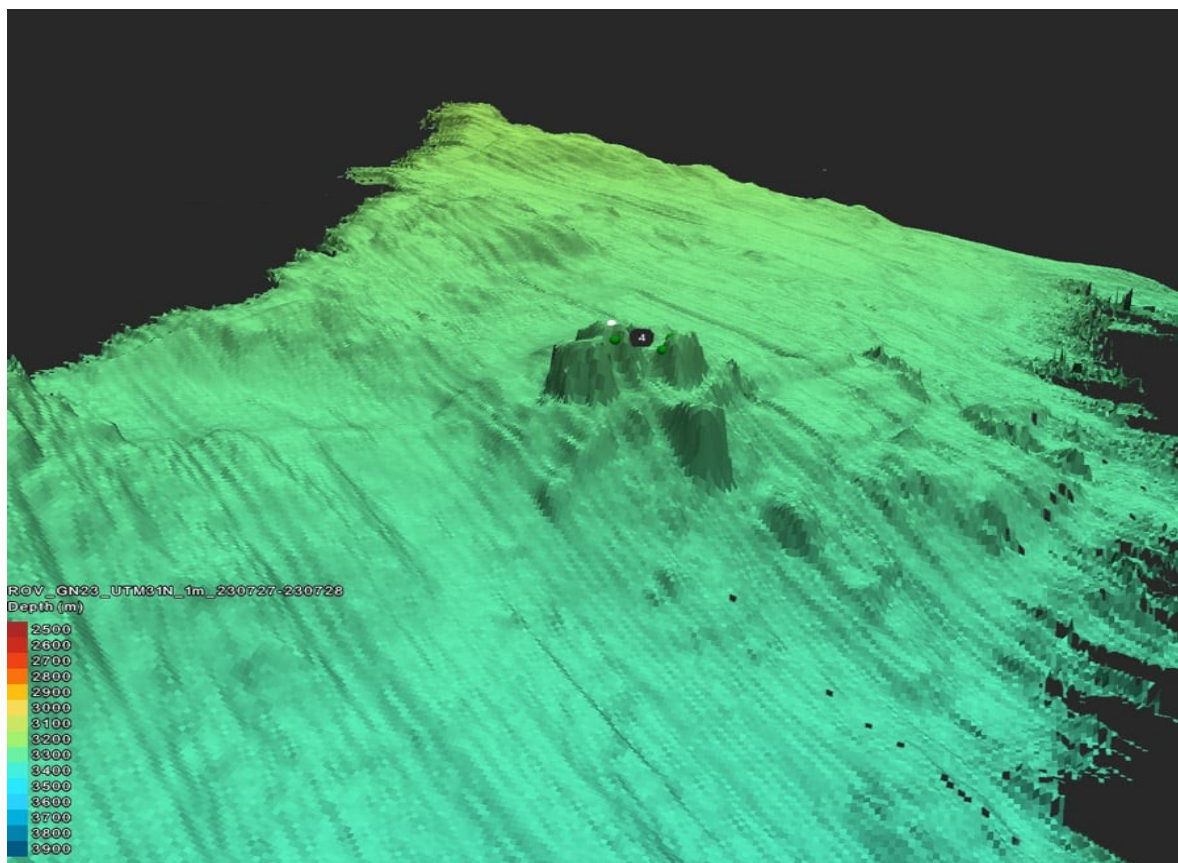


Figure 22. This geological formation was unofficially named after the cruise leader ("Rolf's Treasure"). The map was collected by the ROV "Ægir" and represents a 400-m-by-3-km area.

"We have now found many signs of hydrothermal activity: in the form of minerals, fauna, and columnar formations," says expedition leader Rolf Birger Pedersen (UiB). The seafloor in these areas is unique. Lucky Ridge, as the area is called, consists of mantle rocks usually covered by the Earth's crust. Chemical reactions between mantle minerals and seawater lead to the formation of hydrogen. Hydrogen is an energy source for some types of microorganisms, which, in turn, serve as food for higher life forms. The areas that GoNorth is now mapping are therefore an excellent location to study the interactions between life, water, and minerals.

During these dives, the ROV has collected many samples that will be analysed after the expedition, providing more insights into the geological history and deep-sea environment of the area.

Day 26 – 31 July

RV Kronprins Haakon took a break from ROV dives today and moved a few kilometers northeast to collect sediment samples and conduct the expedition's third ice station. The sediment samples were taken using a multicorer, an apparatus that collects four sediment core samples at once. Only two cores returned to the surface, but they contained good samples. NORCE will analyse the samples to create a database of DNA in seafloor sediments. Ultimately, the database will be used to estimate historical Arctic ice conditions under various climate conditions. SINTEF will also receive some samples to analyse for traces of pharmaceuticals and personal care products.

Water samples. Earlier today, water samples were also collected. Akvaplan-niva will analyse these for environmental DNA (eDNA). Similar to how a criminal leaves behind DNA traces in the form of hair or skin cells, animals and microorganisms in the ocean leave behind DNA traces known as environmental DNA. Such analyses can tell us which animals and organisms are present in an area. It is a non-invasive measurement method, allowing researchers to know which animals are in an area without direct contact with them.

Ice station. The NTNU team conducted the expedition's third ice station with assistance from Christian Katlein (AWI) for sampling, Yannick Kern, Eirik Hellerud, and Marius Bratrein (NPI) as polar bear guards, the ship's crew for proper positioning of the ship and crane operations, and a large part of the research team keeping an eye out for polar bears from the bridge.

Measurements were taken across a pressure ridge. In total, they drilled 15 holes in the ice to measure thickness and structure. Ice core samples were taken from three locations along the same transect.

Gravity corer. The day concluded with an attempt to take a sample with a gravity corer. Despite its name, a gravity corer has little to do with gravity. It is a long sediment core sampler (6 m) that gets its name from gravity pressing it into the sediment layer — it is weighted at the top.

The sediment core from the gravity corer will be used for geomicrobiological analyses. This involves researchers conducting DNA analyses to check which microorganisms inhabit different parts of the core. They will also analyse the chemical composition of the sediments.



Figure 23. Nabil Panchi (NTNU) and Christian Katlein (AWI) drilling through the ice. Photo by Renée Mie Fredensborg Hansen, DTU / NTNU.

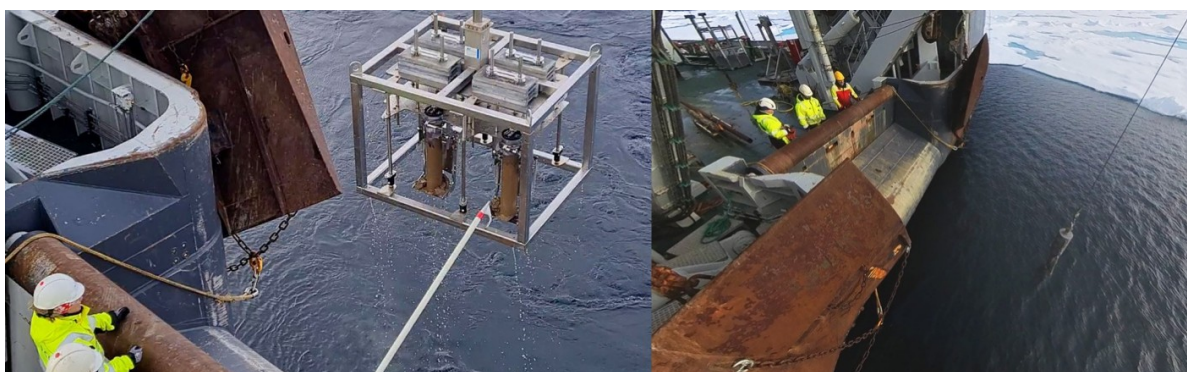


Figure 24. The multicorer being recovered to deck (Left). The gravity corer being lowered into the water from the ships stern (Right). Photos by Daniel Albert, SINTEF/GoNorth.

Day 27 – 1 August

The gravity corer was hoisted on board late last night, carrying a sediment core that was over 4-m long. This can be described as a great success, considering water depths exceeding 4000 m and ice drift complicating the operation.

Ice Drift: After the gravity corer was back on-board last night, the ship began to reposition itself upstream of the ice drift before the next dive. This would take an hour in ice-free waters — perhaps two or three in good ice conditions. However, the ice drift had decided otherwise.

A very large and thick ice floe came from the north, more than 16-km wide. It is now directly over the area we are going to explore with the ROV.

Day 28 – 2 August

For the first time, we have observed, using a camera, warm water rising from the seabed at Lucky Ridge — indicating hydrothermal activity. We already knew there was hydrothermal activity in the area. We observed evidence in the form of fauna thriving in regions with hydrothermal activity, mineral deposits suggesting such activity, and extinct hydrothermal chimneys.

Until this morning, we had yet to witness warm water emanating from the seabed. This has now been achieved. It wasn't a so-called black smoker, where hot water carries minerals and looks like black smoke. The water in this case was completely transparent and could only be observed because it caused a shimmer in the background.

“It's one thing as a researcher to know that there is hydrothermal activity in an area because you have plenty of evidence, but it's even more satisfying to see it with your own eyes,” says expedition leader Rolf Birger Pedersen (UiB).

A random change in ice drift direction took the ship over the area where the water was observed. The plan now is to revisit the area to take water samples.



Figure 25. Amphipods, tube-worms and bacterial mats indicate ongoing hydrothermal activity. Photo by Ægir 6000/NORMAR.

Day 29 – 3 August

After filming warm water rising from the seabed, the ROV revisited the same area and collected a water sample. After obtaining the water sample, the ROV continued to explore the region. Heading south, the ROV discovered more signs of hydrothermal activity, including fauna thriving in areas where hot water emerges and minerals resulting from this activity. Several locations where warm water emanates from the seabed were also identified.

Boxcore experimentation. The expedition's boxcore, an apparatus that collects a sediment sample measuring 50 cm x 50 cm x 50 cm, has encountered some issues on this journey. Twice it came up empty because it hit rocks on the bottom, but several times it surfaced overflowing. To investigate the issue, the research team decided to accompany the boxcorer with the ROV. The experiment revealed that the boxcorer took a sample as intended but penetrated a little too deep into the sediment layer. One challenge with using the boxcorer is that there is no absolute certainty about when it reaches the bottom. This time, that uncertainty was eliminated, as the researchers could observe the sampler through the ROV's cameras. Despite a perfectly executed maneuver, the boxcorer surfaced overflowing with sediments. The problem lies in the fact that multiple researchers are interested in the top portion of the sediment layer, and it's impossible to determine the upper layer when the sample is pressed against the top lid.

Day 30 – 4 August

All good things are worth the wait, as the saying goes, and this was certainly true for the geologists on this expedition. After nine days in the Lucky Ridge area and countless signs of hydrothermal activity, the researchers witnessed the crown jewel of all evidence late Thursday night: towering chimneys spewing hot water resembling black smoke.

This is often referred to as a black smoker and is the most spectacular sign of hydrothermal activity. The observation came on what was supposed to be the expedition's last dive. Through seabed mapping with the ROV, researchers had discovered a large mountainous structure that piqued their curiosity. It was during the exploration of this structure that they found the chimneys.

"At first glance, this hydrothermal field looks special. It has some features that are different compared to similar formations elsewhere in the world," says expedition leader Rolf Birger Pedersen.

Many samples were collected, and these will be analysed in the coming months, shedding light on the unique characteristics of the field.

The "last dive of the expedition" turned out not to be the last after all. The initial visit was only a few minutes, as ice drift took the ship off course. The ROV had to "swim" a considerable distance to reach the chimney and had to turn back after a few minutes to catch up with the ship, which was slowly drifting away with the ice.

As a result, three more dives were conducted (including a false start due to unfavorable ice drift). One dive aimed to map the area with the ROV, and the other was to explore the chimney even more closely. Heading to Longyearbyen. With that, the RV Kronprins Haakon is on its way back to Longyearbyen. The ship must navigate through some ice heading south. Along the way, they will pick up a glider (an autonomous underwater drone). Arrival is expected on the night of Monday, August 7.



Figure 26. The black smoker chimneys that were discovered during the last dive of the cruise. Photo by Ægir 6000/NORMAR.



Figure 27. Maja Jæger (UiB), Sabina Strmic Palinkas (UiT), Håvard Stubseid (UiB), Rolf Birger Pedersen (UiB) and Eszter Sendula (UiT) celebrating the new discovery (Left). The ROV “Ægir 6000” pouring himself a well-deserved cup of coffee after his job is done (Right). Photo by Daniel Albert, SINTEF/GoNorth (left) and Andreas Storebø, BSA (right).

4.RV Kronprins Haakon

The RV Kronprins Haakon is Norway's largest research icebreaker to date, spanning 100 m in length, with a beam of 21 m and a draft of 8.6 m. The vessel provides accommodations for 55 individuals across 38 cabins and typically carries a crew of 15 to 17 people. It features a hangar capable of housing medium sized helicopters.

RV Kronprins Haakon operates on a diesel-electric propulsion system. It houses two 4.5 MW nine-cylinder and two 3 MW six-cylinder diesel engines. These engines generate power to two 5.5 MW azimuth thrusters and two 1.1 MW bow thrusters. This setup provides dynamic positioning station-keeping capabilities at DP Class 1 level. RV Kronprins Haakon has a Polar Class 3 ice class and is tailored for year-round operation in second-year ice, which may include multi-year ice inclusions.

The vessel is well-equipped for oceanographic, marine biology, and geological research. The main deck is primarily devoted to scientific work, featuring 15 laboratories, refrigerated storage, a large working deck with cranes and an A-frame. It also includes underwater acoustics instrumentation in two drop keels for acoustic sensors including: Multi-beam bathymetric echo sounders (Simrad EM710, Simrad EM302); Single beam echosounder (Kongsberg EA 600 12 kHz); Marine biology echo sounders and sonars (Simrad EK 80 split beam echosounder, Simrad SH 90 omnidirectional sonar, Simrad SU 90 omnidirectional sonar, Simrad MS 70 multibeam sonar, Simrad ME 70 multibeam echosounder); Sub-bottom profilers (Kongsberg SBP300-6 Deep, Simrad Topas PS40); Acoustic Doppler Current Profiler (Teledyne RDI ADCP 38 kHz & 150 kHz); Acoustic underwater positioning system (Kongsberg HiPAP).

A notable feature of RV Kronprins Haakon is its 3 x 4 m moon pool, designed specifically for ROV operations. The vessel's sophisticated Launch and Recovery System (LARS) includes rails and a cursor system for guiding the ROV/TMS through the moon pool and into the ocean. In connection with this, it is equipped with an electric, heave-compensated winch with 5500 m of steel jacketed ROV-umbilical, which ensures safe and efficient deployment and retrieval of the ROV for deep-sea exploration.

5. The Remotely Operated Vehicle (ROV) Ægir 6000

The ROV Ægir 6000 is a Kystdesign working class vehicle with a depth rating of 6000 m. Standard equipment on the ROV includes Schilling T4 and ATLAS manipulators, telemetry sensors, 4 horizontal and 3 vertical thrusters, a high precision positioning system, one 4K and one HD forward-looking cameras mounted on pan and tilt platforms, numerous smaller cameras for ROV operation, and an array of fixed and adjustable LED lights. The ROV is connected to a Tether Management System (TMS) that is stacked on top of the ROV when launched and recovered, and that releases the ROV when the operation depth is reached. The ROV is connected to the TMS via a 600 m long tether with neutral buoyancy, which provides a large degree of freedom of movement along the seafloor.

More specific equipment used during the 2023 GoNorth cruise includes: a multi-beam echo sounder (EM2040) for high-resolution mapping that operates at frequencies of 200–400 KHz. The multibeam surveys were typically performed at an altitude of about 40 m above the seafloor at speeds of 0.25–0.5 m/s. A rack holding ten push cores was attached to the TMS to enable larger coring campaigns during single dives. Also available were a temperature probe and a fluid sampler for the collection of hydrothermal fluids. A hydraulic 'basket' was attached to the TMS for the storage of larger tools or samples. Additionally, a new hydraulic lid was mounted underneath the ROV's multibeam to enable seafloor sampling while the multibeam is mounted. This lid protected the multibeam, allowing the ROV to sit down on the seafloor for better control during sampling.



Figure 28. A) The Ægir 6000 in the main hangar of RV Kronprins Haakon standing on the closed hatches of the moon pool. Mounted on top of the ROV is the tether management system (TMS), with a part of the cursor system visible above it. This system guides the ROV and TMS through the moon pool. B) The TMS equipped with a rack of sediment corers attached, showcasing the tooling capabilities of the system. C) The front of the ROV, featuring manipulators, cameras, and lighting, essential for deep-sea exploration and sample collection.

5.1 Positioning

Positioning of the ROV is obtained from a combination of 1) a High Precision Acoustic Positioning system (HiPAP), 2) a Doppler Velocity Log (DVL), and 3) an Inertial Navigation System (INS). The HiPAP system utilises the ship's GPS position and a transducer that receives acoustic signals from transponders mounted on both the ROV and TMS. The Doppler system provides additional information about the direction and speed of the ROV's movement. In the INS, a gyroscope and an accelerometer offer precise data on rotation, velocity, altitude, and horizontal position. This combined system allows for the positioning of the ROV to be accurate within an estimated range of 5–20 m.

5.2 Approaches for ROV operations in sea ice

Approaches for ROV operations in sea ice depend on the station-keeping capabilities of the mother vessel. As the ROV moves slowly along the seafloor, the mother vessel must be capable of slowly following the route, even in bad weather. However, when operating in heavy sea ice, this becomes challenging. When the ROV is in the water, the vessel can no longer break ice, as

the ice may travel below the hull of the ship, potentially damaging the ROV umbilical and instrumentation critical for underwater positioning. Therefore, the vessel will have to drift with the ice, and the ROV will need to follow along the drift route of the vessel. While the ROV may stop briefly to take samples, it will soon have to move along to keep up with the drifting vessel. Reaching and investigating a specific target on the seafloor becomes very difficult under these conditions. The standard method involves predicting the drift route and speed based on ice data, positioning the vessel up-drift of the target, and launching the ROV at a distance that allows it to reach the seafloor before the ship drifts past the target (see Figure 29). However, as this operation can take several hours, changes in the drift direction may occur, potentially causing the ROV to miss the intended target.

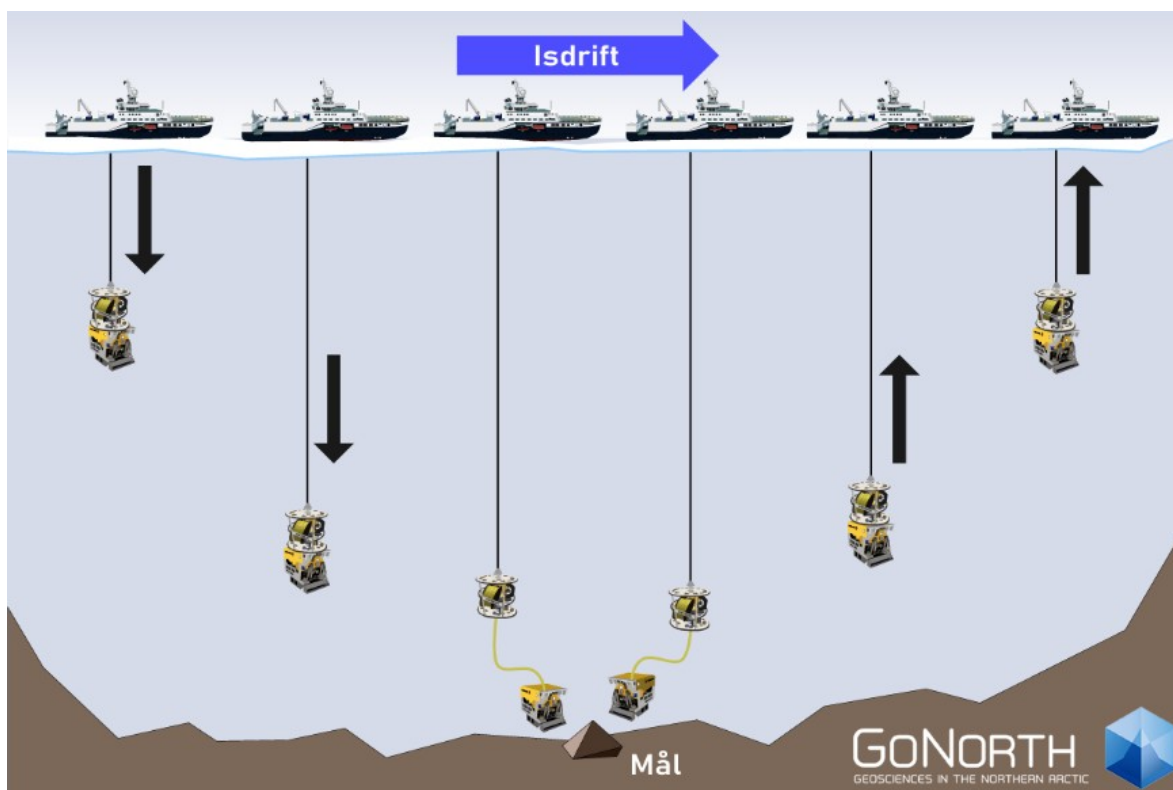


Figure 29. This drawing illustrates the challenges associated with ROV operations beneath drifting sea ice, as detailed in the text. Illustration by Daniel Albert, SINTEF/GoNorth.

5.3 Risk associated with under ice operations.

The operation of an ROV system in sea ice is challenging. First, if the mother vessel attempts to maintain its position by breaking ice, it risks getting ice under the hull. Ice blocks may also fill the moon pool, potentially damaging vital instrumentation as well as the ROV umbilical. Operating ROVs under sea ice, especially when the vessel is drifting with the ice, carries several inherent risks. On the seafloor, the tether can easily become entangled in volcanic features or other rough terrains. As long as the vessel is able to maintain its position, the ROV can usually manage to free the tether itself. However, when the vessel is drifting with the ice, such situations can rapidly escalate. The tether may eventually break, leaving the ROV either stranded on the seafloor or causing it to float to the surface where it could become trapped under the sea ice and drift away.

Furthermore, the main ROV winch, responsible for lowering and retrieving the ROV/TMS from the deep sea, may fail and stop functioning. When not drifting in the ice, there is time for repairs or to take other actions to mitigate the situation. However, when the ship is drifting in the ice, with the ROV operating in seafloor terrains characterised by valleys, canyons, and steep mountains, the ROV could be dragged into mountain sides in tens of minutes or less.

During the 2023 GoNorth expeditions, two significant scenarios occurred. In a test dive in the Molloy area, RV Kronprins Haakon was drifting in the ice with Ægir 6000 operating at the seafloor. Unintentionally, the vessel started to break ice, leading to ice blocks entering the moon pool. This resulted in damage to the HiPAP underwater positioning system, forcing the vessel to retreat from the ice and undergo repairs. On another occasion, the main winch stopped functioning for around ten minutes while Ægir 6000 was operating in mountainous seafloor terrain. This incident highlighted the need for regular training in emergency procedures and a focus on other mitigating operational practices.

5.4 Modifications made to the system to reduce risks

Following a risk assessment on the under-ice operations of Ægir 6000 on RV Kronprins Haakon, the ROV system has undergone modifications to mitigate risks that were both predicted and later experienced during operations:

- In 2019, the TMS was rebuilt to accommodate a tether with a larger diameter and slightly positive buoyancy. This adjustment keeps the tether off the seafloor, significantly reducing the risk of entanglement on rock formations.
- A buoyancy releasing mechanism was added to the system, designed to release part of the buoyancy if the tether breaks. This ensures that the ROV settles on the seafloor at a known position, preventing it from floating to the surface and drifting away under ice rafts.
- An emergency running latch was developed to enable the retrieval of the ROV to the vessel if the launch and recovery system fails.
- Prior to the 2023 GoNorth cruise, a spare hydraulic system was developed, allowing for the ROV's retrieval through the moon pool if the TMS winch fails.

A series of operational procedures aimed at reducing risks has been established. For example, operations at the seafloor should cease when the ice drift speed exceeds the ROV's maximum speed. The ROV should then retreat to a safe distance above the seafloor. The TMS should, as far as possible, be positioned above the shallowest depth of the surrounding areas to ensure that the ROV can retreat to a safe depth if the main winch fails. The ROV supervisor has a reinforced mandate to particularly focus on ice-drift-related risks before and during operations.

As a result of the experiences acquired during the 2023 GoNorth cruise, a series of further actions that may increase the efficiency of sampling and data collection has been identified. This is particularly important when operating under ice, where ice drift restricts the time the ROV can stay at a specific station, and where returning to a specific site can be very challenging and time-consuming. With these implementations, the Ægir 6000 will further stand out as a unique platform for deep-sea explorations under ice.

6. Bathymetric data processing

The NaviPack software package was used to process the collected echo sounder data in a three-step process. Firstly, NaviEdit was utilised to preprocess the data files so they could be imported into NaviModel. The data files were always imported into NaviEdit and depending on if they were from the ROV or the hull mounted echo sounder they were processed accordingly. If from the ROV, the pitch, roll and heading were changed to fit according to the placement of the multibeam on the ROV, whereas for the hull mounted echosounder this was not needed. Secondly, the data were cleaned in NaviModel, and the ROV track and coordinates of the sampling locations, were added to the map. Then it was gridded and exported with the bathymetry and contour lines. Thirdly, to create the final map the contour lines and the Digital Terrain Model (DTM) were added to NaviPlot, and then a scale bar, north arrow, title, and any other information needed were added. Also, maps with ROV tracks and rock samples was produced for each dive. Preliminary bathymetric maps can be found in the appendix.

7. Ice imagery from satellites and the drift predictions

by Y. Kern and C. Katlein

To support navigation through the ice, satellite data were downloaded and prepared for visualization in a QGIS project made available to both bridge personnel and scientists. With the help of this tool, the current sea ice situation with potential routes and implications for expedition planning was presented and discussed in daily science meetings.

Satellite data included synthetic aperture radar (SAR) imagery from Radarsat2 and Sentinel 1 and was downloaded using a Starlink high bandwidth internet connection provided through the ship's network. Radarsat2 pictures were directly ordered from KSAT via the Norwegian Polar Institute. Sea ice concentration data retrieved from AMSR2 (Advanced Microwave Scanning Radiometer 2) was obtained from the University of Bremen. For cloud-free conditions optical data from MODIS (Moderate Resolution Imaging Spectroradiometer, Terra/Aqua) or Landsat 8-9 were downloaded from Nasa Worldview and the U.S. Geological Survey (USGS) Earthexplorer applications, respectively. As a backup solution during times of low bandwidth connectivity, Sentinel 1 and AMSR2 data were accessed via the IcySea application, which was made available by Drift&Noise Polar Services.

Challenging ice conditions were met during the cruise due to the presence of thick multiyear sea ice and a high amount of heavy ridges in the cruise's main working areas. Frequently updated ice maps were crucial for effective navigation. A current map display showing the ship track together with the latest Satellite pictures was updated programmatically every minute and shown on the ship's IPTV information system (Figure 30). The map was updated every time new images were available and was corrected for drift daily using available drift information (described in paragraph below) and the ship's own ice radar. The map was also shown via QGIS on one of the bridge navigation screens with the overlaying live GPS position of the ship (using the PosiView plugin) for direct access by ship personnel.

Since one of the main cruise objectives was targeted dives with the workclass ROV Ægir 6000 to specific sites on the seafloor, analyzing and forecasting the drift direction and speed was critical. This effort was supported by data from two drifting sea ice buoys (Pacific Gyre Microrider) deployed by a collaborating team onboard RV Polarstern. The hourly position data was received on RV Kronprins Haakon and visualised in a drift display incorporated into the sea ice information screen updated once per minute (Figure 31). This plot also added information about the current ship drift direction, as well as two ice drift forecasts to enable a complete assessment of the current ice drift situation. One forecast was based on a free-drift assumption using measured wind data onboard RV Kronprins Haakon, while the second forecast was provided by the SIDFEx consortium. The latter combined results from coupled sea-ice ocean models and was kindly provided by Helge Gößling and Valentin Ludwig from AWI. A third drift forecast source, PRIIMA drift analysis based on TOPAZ wind model data was accessed through the IcySea App.

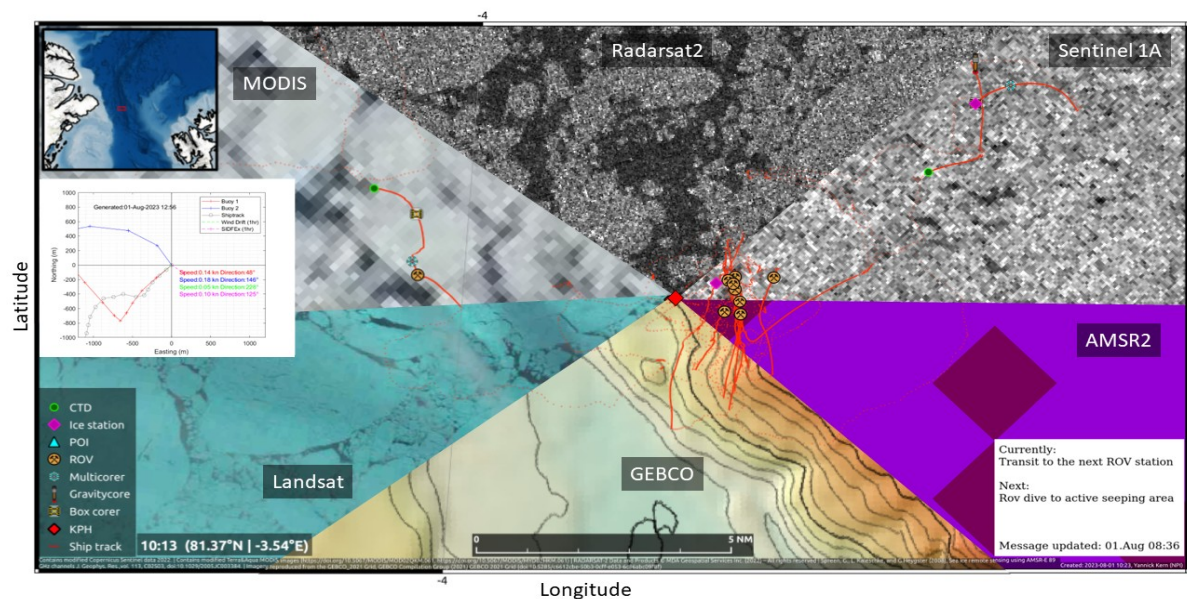


Figure 30. Information on the current position, last and ongoing stations, as well as bathymetry, radar or optical satellite images was made available in such a self-updating graphic on the IPTV system. Note: images are not from the same date but at the same location and are chosen for the purpose of illustration of the different products. [Contains modified Copernicus Sentinel data 2022. | Contains modified Terra&Aqua MODIS images, (MODIS Science Team ,2017a and MODIS Science Team, 2017b) | Landsat 8-9 OLI/TIRS C2 L1 image courtesy of the U.S. Geological Survey | RADARSAT-2 Data and Products © MDA Geospatial Services Inc. (2022) – All rights reserved | Spreen et al. (2008) | Imagery reproduced from the GECO_2021 Grid (GECO Bathymetric Compilation Group, 2021).]

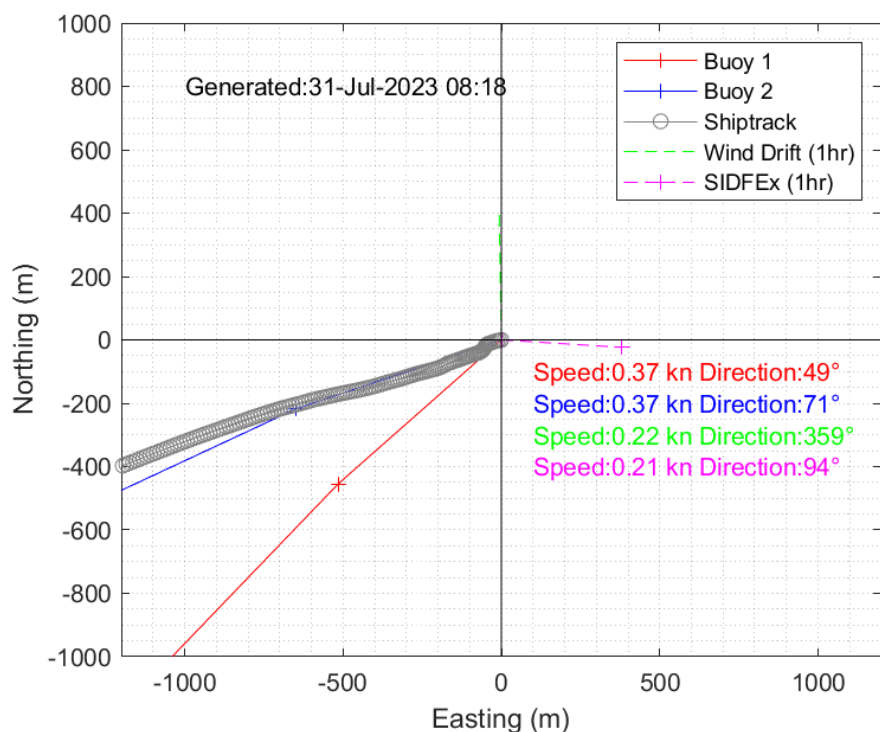


Figure 31. Example of a self-updating display with an up-to-date overview about the ice drift situation published on the information screen. It contains the drift speed and direction of two drifting buoys deployed by RV Polarstern (red & blue), the ship (KPH, grey), and a local forecast derived from current wind measurements (green) and the current SIDFEx consensus forecast both for the next hour.

The extremely compacted ice situation around the Aurora Vent field made drift forecasts very challenging, as the ice pack was clearly not directly wind-driven and hence not following the predictions given by the free-drift assumptions. Moreover, tidal/inertial oscillations were only able to explain parts of the variability in observed drift direction changes. Nevertheless, forecasts helped to assess the drift situation before deployment of any deep-sea instrumentation.

7.1 Weather forecast

In addition to direct access to weather forecasts online a low bandwidth solution was set up. Its benefit was to be directly available in QGIS making it more practical for navigational purposes. In Figure 32 an example visualization of wind forecast is shown, but other parameters were also available such as temperature or wave height forecast. Data were downloaded via the QGIS QGribDownloader lugin from opengriffs.org. Usually, the GFS (Global Forecast System) weather model by NCEP (National Centers for Environmental Prediction) was used with 3-hour time steps and 0.25-degree resolution.

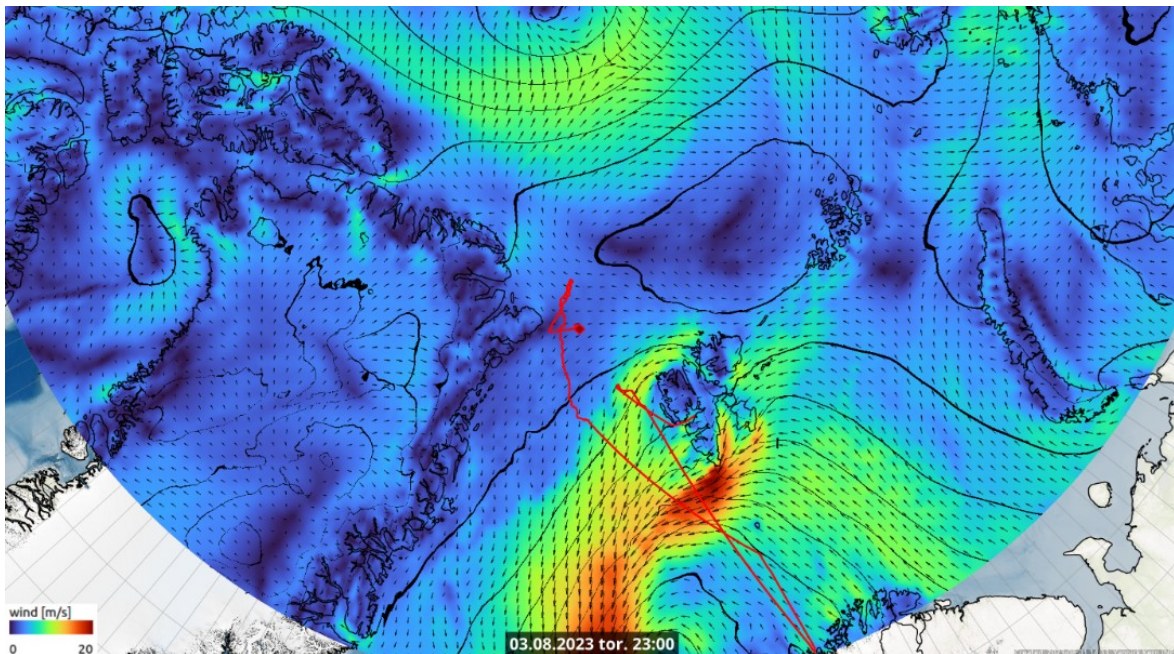


Figure 32. Example forecast for wind speed and direction and indication of isobars; based on data from opengriffs.org. The red line shows RV Kronprins Haakon track.

8. Sea ice safety

by E. Hellerud

8.1 Stablising the ice stations

Upon establishing the ice stations, a meeting was held with the ice team on the bridge at 07:10 AM to get an overview of potential ice ridges for study. Target sites were identified depending on the conditions of the day, the cruise plan and the overall structure of the ice-floes. The morning meeting would involve a rundown of the factors most likely to impact safety, such as visibility, polar bears, weather, SAR cover, etc. Scientists explained their plan for the day by giving a rough overview and an overall understanding for the workstation was met.

8.2 Safety implementations on the GoNorth sea-ice work

Sea-ice work on the GoNorth cruise followed safety implementations in accordance with current NPI/IMR procedures as listed below. Potential improvement points and assessment of existing protocols are described below.

- PWOM Arbeid på sjøis (Ref.id.: KS&SMS-03-2-13-8-1-28)
- PWOM - Operasjoner i lave temperaturer – Personell (Ref.id.: KS&SMS-03-2-13-8-1-07)
- PWOM - Sikkerhetsprosedyrer for isbjørn (Ref.id.: KS&SMS-03-2-13-8-1-27)

Lookout on the bridge according to a time schedule would start at 08:15 AM, with ice-thickness and quality to be checked shortly after. As the work site and other ongoing activities had to be considered, all ice stations were delayed later into the day, or to the following day, due to either observation of polar bears, repositioning of the vessel, or unfavorable ice conditions.

8.2.1. Assessing the ice floe and setting up workstations

When a potential ice-floe was chosen, it was accessed by crane, gangway or workboat, and inspected with drill and auger to verify overall thickness and quality. For operations with snowmobiles, NPI procedures is set at minimum 30 cm thickness (10 cm on foot), but they were not used on this cruise due to melt ponds and low amounts of snow cover. Upon checking the ice with a Kovacs 2-in ice auger, we could verify the thickness to be well beyond the requirements. Once the ice was assessed to be safe, a further check for cracks was conducted particularly in the vicinity of the gangway. Crew would then be given a green light to unload their gear.

8.2.2. Visibility and polar bear lookout

Visibility dictates the work range from the ship which is decided in the morning-meeting, and this should be flexible. This means that the scientists could potentially work further away from ship but would have an alternative plan in case visibility changed during the day. Since science priority changes during a work station could potentially weaken the situational awareness on the bridge communication over VHF radio was key. To keep track of personnel and equipment on the ice, checking personnel in and out via VHF to the bridge by the gangway was routine. An overview of all names was listed on a whiteboard, combined with magnets indicating “ON ICE” or “ON SHIP”. In addition, the list of safety gear used on ice was provided to the bridge to give an overview of who-has-what, in the event of VHF loss etc.

During an ice station “non-ice personnel” from the ship and one ice safety leader from NPI would take turns spotting for polar bears from three locations on the bridge. New personnel would rotate in every 30–60 minutes. This key task required a lot of resources (people), and as a result would interfere with on-going scientific work being performed onboard (such as lab work) simultaneously with the ice work. Depending on the extent of activity on the ice and on the ship (such as CTD), the task was shared between available personnel that day.

The important and necessary task of being on lookout comes with a certain responsibility. VHF radios were placed by each of the three lookouts to enable lookouts to follow communications on ice, but the signal however didn’t always come through on the far side of the bridge. Each lookout position had binoculars, VHF and a simple sketch, using the heading of the ship as a layout, explaining how to report observations to the bridge.

To improve the task of assessing distance in varying visibility, flagged markers could be placed on the ice with a 100 m spacing. Distance could also be assessed by using a handheld rangefinder, which was not available on this cruise. This would greatly improve ice safety on future cruises as there was often an observed gradient in visibility from the ice surface up to the relative position of the bridge, creating a mismatch between the assessed visibility on “sea-ice level” and from the bridge. Markers on ice or using the rangefinder could clarify the perceived range.

8.2.3. Temperature management

Temperatures on the GoNorth cruise strayed between 0 and 5°C. In combination with wind however, windchill could at times make it colder during stationary work such as polar bear guarding on ice. Though the Viking survival suit is waterproof, it is also colder to wear. The steel shoe tip has a particular cold-effect on the feet, and overshoes are good to have as a backup if needed. On this cruise, Regatta Floatation Suits were used by the science team, as Regatta suits are warmer and easier to regulate temperature with. We also received feedback regarding the problem of overheating when preparing for the day, resulting in a wet baselayer and the following potential of getting cold when the work becomes more stationary. Normal winter clothing could in these cases be considered worn in combination with a lifejacket to ease ventilation. However, this is not an option today in accordance to the current NPI/IMR procedures.

8.2.4. Contingency planning

The hospital room on KPH is located on deck 6, by the helicopter hangar. In the event of an accident occurring on the sea ice or onboard, familiarization of the entry point beforehand was such mandatory. In a potential accident scenario the crew in RV Kronprins Haakon would take over the management of the situation. Transporting an unconscious patient from the sea ice to deck 6 is possible from 4 approaches; staircase (steep, not ideal), elevator used for equipment (can’t fit the stretcher properly), by crane or helicopter. Each approach comes with certain challenges. During the planning process, we also received estimates on response time from Greenlandic/Danish (Station Nord) and Norwegian (Longyearbyen, CHC) rescue services, in the event of a need to evacuate a person. In summary: the further north, the longer the wait — and potentially larger the consequences of an incident. Having a realistic view regarding the remoteness of the cruise on a potential incident was necessary.

8.2.5. Aft deck risk potential

As we encountered several polar bears during this cruise, personnel onboard got accustomed to witnessing the occasional polar bear approaching the vessel. One of these bears stopped between 5–10 m from the stern of the ship, with both crew and scientists on the aft deck. The aft

deck measures ~3.5 m from the sea ice surface to the railing, with a sloped angle up the ramp on which trawling nets are deployed. In this case, there was open water between the polar bear and the ship, while personnel were on deck. However, in the event of an ice ridge being close or packed against the aft of the ship, the potential for a bear to climb onboard increases, and should not be underestimated. It would therefore be wise to implement a routine that restricts personnel on the aft deck when a polar bear is spotted, until deemed safe by both bridge and sea-ice safety personnel.

9. Geology

9.1 The Molloy Deep

by H. Stubseid, S. Palinkas and E. Sendula

9.1.1. Objective

The main objective at Molloy Deep was to test the ROV-TMS system at great water depths before approaching the pack-ice covered Gakkel Ridge. Additionally, we aimed at sampling an unexplored area from the northeastern Molloy Ridge and to collect 4K video of a natural oil seep and surrounding fauna.

9.1.2. Sampling, Sample Preparation and Analytical Methods

A total of 11 samples of silicified sedimentary rock were collected during the first dive (ROV01). On the second dive (ROV02), we successfully collected three samples of a carbonate-clay crust. All samples were cut using a rock saw, and further imaged and described. See Appendix A for detailed sample description. During a two-day stay in Tromsø for repairs, we had the opportunity to further examine some of the collected samples from the first and second dive with secondary electron microscope (SEM).

The first dive brought up silicified sandstone samples crosscut by quartz veins. Brecciation was also observed in some of the samples. Some quartz veins contained oxidised pyrite grains and clay. Detrital grains such as monazite were also observed with SEM. Preliminary results of fluid inclusion microthermometry suggests mixing of high temperature fluids ($>300^{\circ}\text{C}$) with seawater. Indication for the presence of CO_2 in the fluid phase was also recorded.

Samples from the second dive (ROV02) are siltstone/mudstone cemented with calcite and contain detrital grains such as quartz, albite, and clay minerals. A few grains of monazite, rutile, and barite were also observed. Sample KH23-249-ROV02-R02 shows layers/lenses of siltstone in the dominantly clay-sized fraction. The siltstone fraction seems to be a pathway for fluids and contain Fe-(oxy)hydroxides and barite. This sample also contains framboidal pyrite.

9.2 Aurora Hydrothermal Vent

by H. Stubseid, S. Palinkas and E. Sendula

9.2.1. Objective

The second dive target of the cruise was to continue exploration of the Aurora hydrothermal vent field at the southern terminus of the Gakkel Ridge. Ship-based multibeam bathymetry with a resolution of 25 m of the area was collected to guide ROV dives. Dives were directed towards visual inspections of the vent field and sampling of lavas, sediments, and hydrothermal deposits from active and inactive parts of the vent field.

9.2.2. Preliminary Results

Active venting was observed in two areas, one of which was previously unknown. The areas of active venting at the Aurora vent have previously been described. Venting emanated directly from a hole or collapse structure on the seafloor, with little to no chimney (Figure 33).

Underwater image of a "collapse structure"-type black smoker. In vicinity of the actively venting areas, we observe large areas with inactive chimneys and highly weathered mineral deposits. These deposits are very fragile and difficult to sample. A large part of the deposit was

covered in >1 m thick sediment. Outcrops of pillow lavas are observed both in and around the vent field. The volcanics are heavily sedimented and no young or fresh-looking lavas were observed. A total of four lava samples were collected, 3 of which having fresh glass.

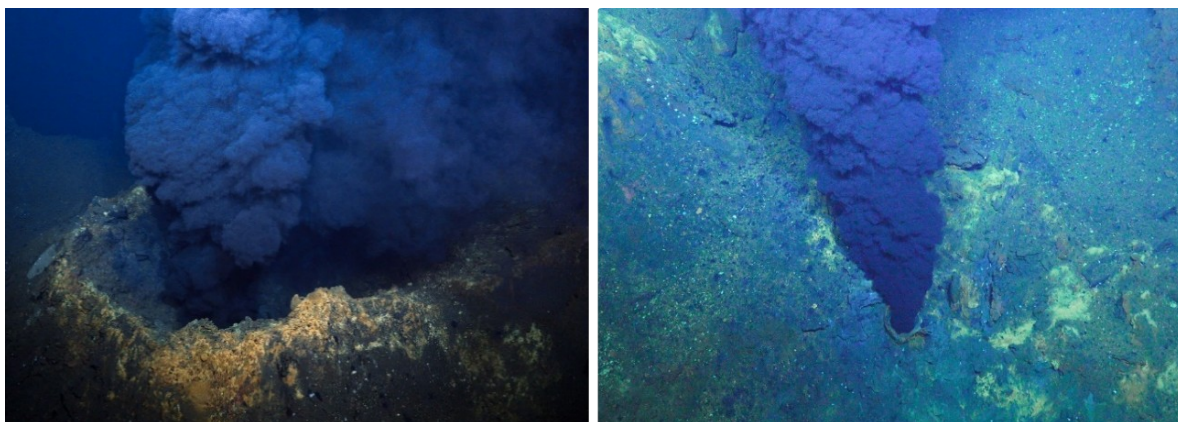


Figure 33. Active venting from a collapse structure on the seafloor (left) and hole in seafloor (right). Photo by Ægir 6000/NORMAR.

A total of 8 ROV sediment cores were taken from the vent field. Cores fully penetrated into the sediment but once brought on deck yielded only ~70% recovery, likely due to compaction during the coring process and/or sediment falling out from the bottom upon stowing into the TMS system. Cores were taken along transects into and out of the active venting area.

Approximately 120 m south-west of the previously discovered vent site, scientists onboard the RV Polarstern reported a temperature anomaly. We located several actively venting chimneys there during one ROV dive (ROV06; Figure 34). The chimneys were up to 10 m tall and emitted black smoke. Mounds around the chimneys are largely comprised of piled up chimney fragments. Eight sulfide samples were collected here. The samples consist of massive sulfides with a mineralogy of mostly pyrite, pyrrhotite, and chalcopyrite. Minor amounts of bornite, covellite, and atacamite were also observed. Red Fe-(oxy)hydroxide is present on the surface of most samples.

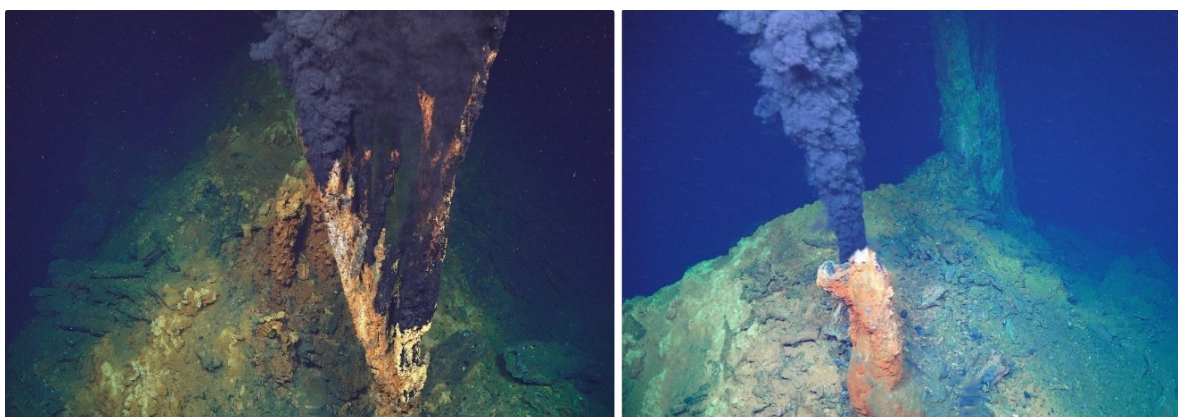


Figure 34. Black smoke coming out from multiple channels on a chimney structure (left). Actively smoking chimney with large chimney seen in the background (right). Photo by Ægir 6000/NORMAR.

9.3 Lucky Ridge

by H. Stubseid, M. Jæger, S. Palinkas, E. Sendula, E. Valdar and E. Siira

9.3.1. Objective

The Lucky Ridge, in the central Lena Trough, has been interpreted to represent a horst-like structure where the rift valley on each side has been down-faulted. Several older dredges from the area recovered mainly peridotites. Minor occurrences of sulfides and plutonic rocks were found in 3 dredges from the Lucky Ridge. The nearest volcanic rocks were dredged 50 km to the south.

During the current and older Polarstern cruises, scientists documented temperature anomalies and the presence of particles in the seawater. Scientists from Polarstern also indicated the possible presence of lavas on the ridge top (from bottom tow cameras). With this information, the RV Kronprins Haakon cruise party developed three main objectives prioritised in the following order:

1. Study and sample in-situ peridotites.
2. Locate and sample both active and inactive hydrothermal areas.
3. Look for lavas on the ridge top and sample sediment for any recent ridge-produced volcanic ash.

9.3.2. Bathymetric mapping approach

The central part of the Lucky Ridge, where sulfides and temperature anomalies were reported, was mapped at 25-m resolution using the multibeam echo sounders on the ship. These coarse resolution maps were used to identify targets for high resolution (1 m) ROV multibeam maps, since the ship-based maps were too low resolution to see hydrothermal features.

A test dive on relatively flat terrain to the west of Lucky Ridge was used to experiment with different setups for the ROV multibeam mapping approach. Results indicate that flying the ROV at 200 m above the seafloor while attached to the TMS produced the best results. This setup provided a map with a width of 300–400 m for each line. The orientation of the lines was controlled by the direction of the ice and ship drift. Interesting features in the maps were then selected for visual ROV observations and sampling. This exercise, of mapping and subsequent visual inspections, was repeated multiple times to document any hydrothermal activity.

9.3.3. Preliminary results

The first ROV dive to the seafloor (ROV08) had three hydrothermal vent targets. The first two turned out to be large boulders of peridotite. Further south, a 50-m-wide and ~15-m-tall structure (unofficially referred to as Rolf's Treasure) was investigated (Figure 35). This structure consists of weathered sulfide minerals and iron oxyhydroxides. Relatively thick layers of manganese crust (up to 1 cm) document that this is an old structure. Several samples were collected from the structure and of peridotites in the surrounding areas.



Figure 35. Top part of large extinct hydrothermal deposit structure at Rolf's Treasure. Photo by Ægir 6000/NORMAR.

The next dive (ROV09) aimed for an area where RV Polarstern had reported a strong plume signal. No active venting was documented, but an increase in life on the seafloor was observed including amphipods, gastropods, and tube worms (Figure 36). These faunas are all indicative of diffuse hydrothermal venting in the area. Dive ROV09 proceeded toward the “Rolf's Treasure” for further investigations of some smaller structures around it. A total of 16 samples of peridotite, serpentinites, and iron oxyhydroxides were sampled.

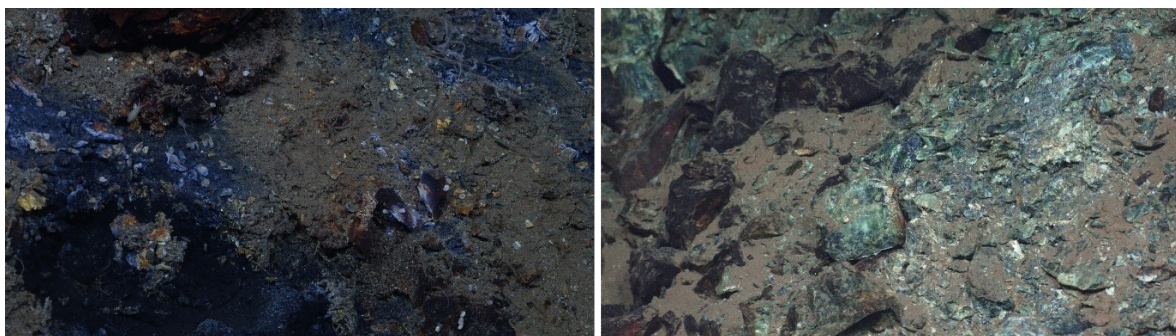


Figure 36. Vent fauna with amphipods, gastropods, and tube worms (left). Blue and green serpentinites in a shear zone (right). Photo by Ægir 6000/NORMAR.

ROV10 aimed to further investigate the area with vent fauna and diffuse venting. No fluid venting, shimmering water, was observed, but white bacterial mats were documented (Figure 37). Only one rock sample was collected during the dive. The rest of the dive was used to extend our high-resolution map eastward from “Rolf's Treasure” to look for new targets.

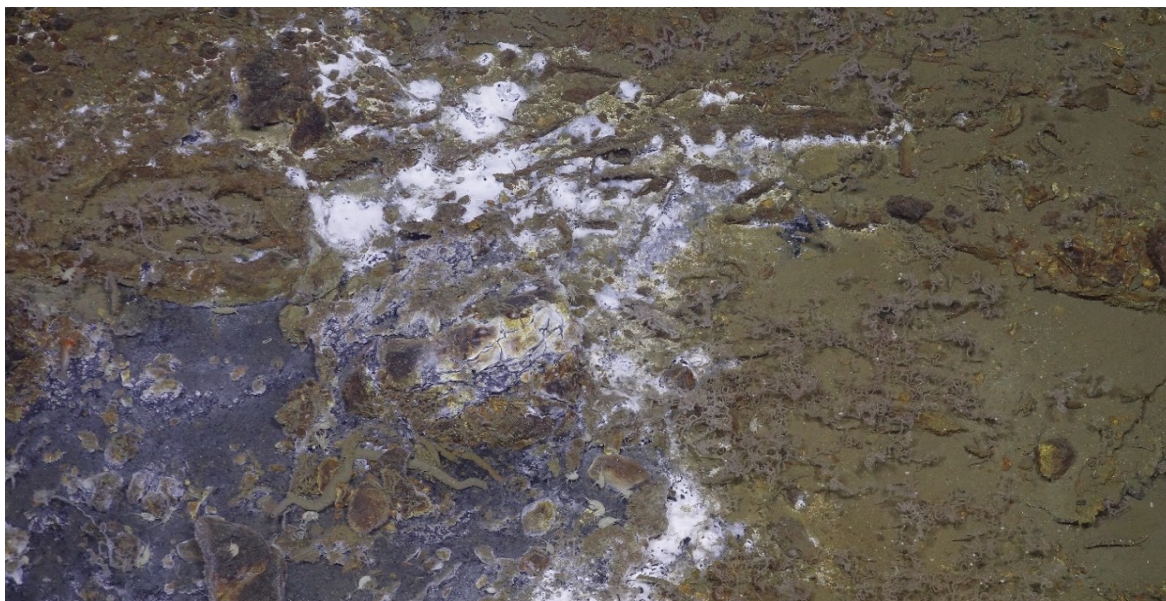


Figure 37. White bacterial mats as a strong indicator that low-temperature diffuse venting is taking place through the sediments. Photo by Ægir 6000/NORMAR.

ROV dive 11 extended the multibeam map coverage in the same area as the previous dive and explored new targets on the map from the previous dive. The new targets look similar to the previous dive targets during ROV08–10, being massive and rising 20 m above the surrounding seafloor. Several samples of massive sulfides were collected. Based on the thickness of both the weathered surface and the manganese crust, these structures might be slightly younger than those further west. At the top of one structure, small chimney-like features that were hollow inside were observed (Figure 38). This was clear evidence for fluid flow and helps support the conclusion that all these structures are the result of hydrothermal activity. A total of 13 rock samples were collected.



Figure 38. Small chimney-like features on top of larger structures. The chimneys are approximately 10 cm wide. Photo by Ægir 6000/NORMAR.

ROV dive 12 also started with multibeam mapping before reaching the seafloor for visual inspections and sampling. During the dive, a total of eight rock samples were collected. Two push cores were recovered at the end of the dive. One of the most significant observations during this dive was the discovery of a serpentinised fault plane with slickensides (Figure 39). This probably represents a fault surface that uplifted the mantle rocks when the Lucky Ridge was formed. Towards the end of the dive a rusty sediment layer with coarse clasts covered by fine grained orang-weathering material was observed (Figure 40).



Figure 39. Fault plane consisting of serpentinites with clear slickenside formed when the mantle rocks were uplifted. Photo by Ægir 6000/NORMAR.

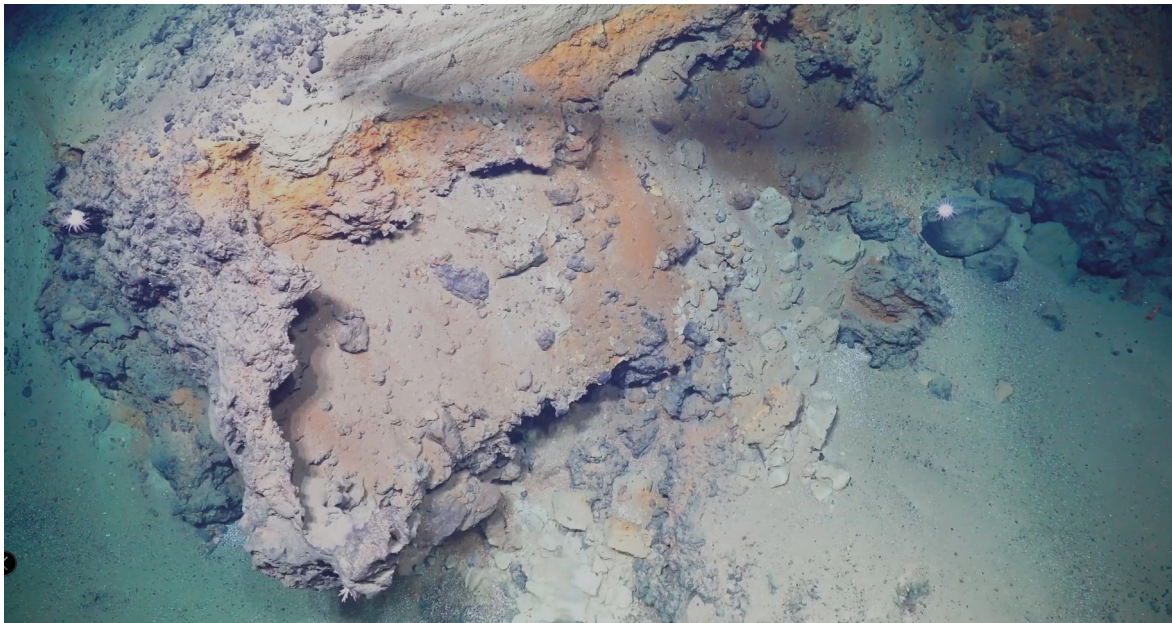


Figure 40. Layer of rust covered by thin fine-grained layers of sediment were observed at the end of dive 12. Photo by Ægir 6000/NORMAR.

Due to unfavourable drifting currents, dive 13 took us to a location closer to the top of Lucky Ridge. Bottom tow-camera images from RV Polarstern along the top of the ridge suggested that basaltic lavas may occur here. Mapping with the multibeam during ROV dive 13 was

performed in the beginning of this dive and subsequent bottom observations near the top of the ridge revealed serpentinised ultramafic rock outcrops. Seven highly serpentinised samples were collected and no basaltic lavas were recovered.

For ROV14, additional multibeam mapping covered the ridge. After reaching the seafloor, we observed fauna with tubeworms, amphipods, snails, and shrimps (Figure 41). The seafloor had similar structures to what was observed earlier in the area with big boulders and large structures. More bacterial mats were spotted, and more fish than previously seen on the cruise. After a rapid change in the drift and drift direction, the ROV ascended from the seafloor and continued more mapping of the ridge and south. No samples were collected on this dive.



Figure 41. Some of the tubeworms observed near bacterial mats on dive 14. Photo by Ægir 6000/NORMAR.

ROV15 started with multibeam mapping while drifting east-northeast toward coordinates of a strong plume signal provided by RV Polarstern. However, some 250 m before we hit the target the drift changed to the south sending us off course. We kept mapping with multibeam until we arrived in the area where tubeworms and vent fauna had previously been observed. The ROV then descended to the seafloor and investigated patches of diffuse venting that followed the fault-like structure that we previously observed on the bathymetric maps. In one of these patches, slightly uphill and southeast, shimmering water was observed (Figure 42 and Figure 43). This activity is interpreted as weak focused venting of fluids hotter than the cold ocean water. The fluids were clear indicating that dissolved metals were absent or in very low concentration suggesting relatively low temperature. Fluid temperatures were not measured due to broken ROV thermometers. This was the first visual evidence of active focused venting seen on Lucky Ridge. No rock samples were collected during this dive.

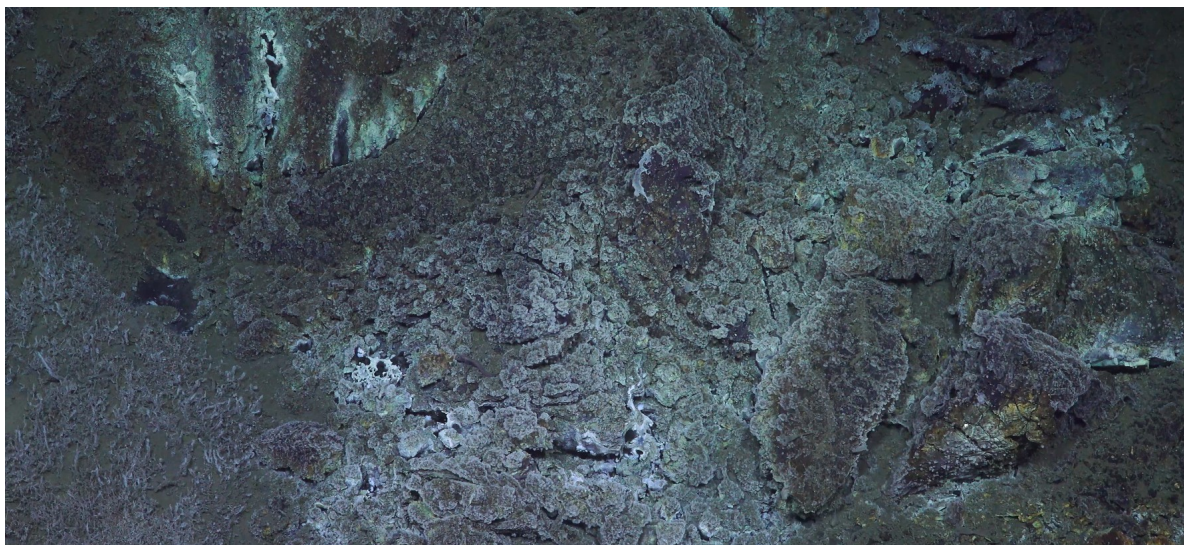


Figure 42. The location where shimmering was observed on dive 15. The diffuse venting takes place on a single isolated patch surrounded by sediments. Photo by Ægir 6000/NORMAR.



Figure 43. A closeup of the shimmering observed on the patch on dive 15. The venting takes place from cracks in between the rocks. The cracks were surrounded by abundant bacterial fauna and some small fish. Photo by Ægir 6000/NORMAR.

The next dive (ROV16) was a pure multibeam-mapping dive in the north of the surveyed area. This was a result of the direction of the ice drift changing toward the north after we launched the ROV, thus sending us into an area that we had not mapped and that was removed from the area where we found evidence of diffuse and weak focused venting. The dive ended quickly due to major ice floes in the area moving away from each other and opening a window for us to reposition and dive in the hydrothermally active area observed from the previous dive.

ROV17 started with multibeam mapping west of the target while we drifted toward it. When reaching the target, we descended to the seafloor and observed the same hydrothermal and

sulfide-rich terrain (sulfide crusts, massive sulfides, bacterial mats and other life, clear venting/shimmering, etc.) that was seen on ROV15. Eleven samples were taken during the dive, and while there were some solid massive sulfides, most were very brittle and fragile and thus had to be scooped up with the shovel. Two types of chimney-like structures were sampled: “normal” ones and white ones. A successful fluid sample was also collected from one of the active clear fluid vents identified during ROV14. In general, the whole area that we surveyed was clearly rich in both sulfides (possible diffuse venting over a larger area?) and vent fauna. Although shimmering water and weak clear venting occurred in some places from small chimney-like structures (Figure 44), no “black” smokers were detected. Prior to finishing the dive more multibeam mapping was done before the boat drifted away from the target area.



Figure 44. One of the observed chimneys showing clear venting along the seabed. A fluid sample was collected from this chimney structure. Photo by Ægir 6000/NORMAR.

ROV18 aimed for a big new structure that was discovered while multibeam mapping during the previous dive. A 400-m-wide circular structure was identified on the previous day’s multibeam and was set as a new target. While moving towards the top, we saw an increase in bacterial mats and amphipods. Big spires of sulfides were observed throughout the structure and several chimneys emitting black smoke were observed at the top of the structure.

In the early hours of August 4, we were in a good position with the ship drift-wise, and thus launched the ROV again. This dive was a pure mapping dive where we mapped the huge hydrothermal mound discovered the previous evening during ROV18. With the map of the mound finished we repositioned for one last dive.

The last dive (ROV19) of GoNorth 2023 commenced right before lunch and the seafloor was reached an hour later. With the new map available two interesting mound-like structures to the north of the larger black smoker mound were investigated. They were both found to be long-extinct hydrothermal mounds. When we reached the active vent site discovered on ROV18 we observed shimmering, clear venting, black smoke from the main chimneys, and incredible amounts of vent fauna (Figure 45 and Figure 46). Seven samples were taken of massive sulfides, mostly on the main mound. We also collected 4K video of the venting and the fauna, but due to the ice drift we had to abandon the area after around 30 min.



Figure 45. White smoke with lots of amphipods, bacterial mats, and a fish. Photo by Ægir 6000/NORMAR.

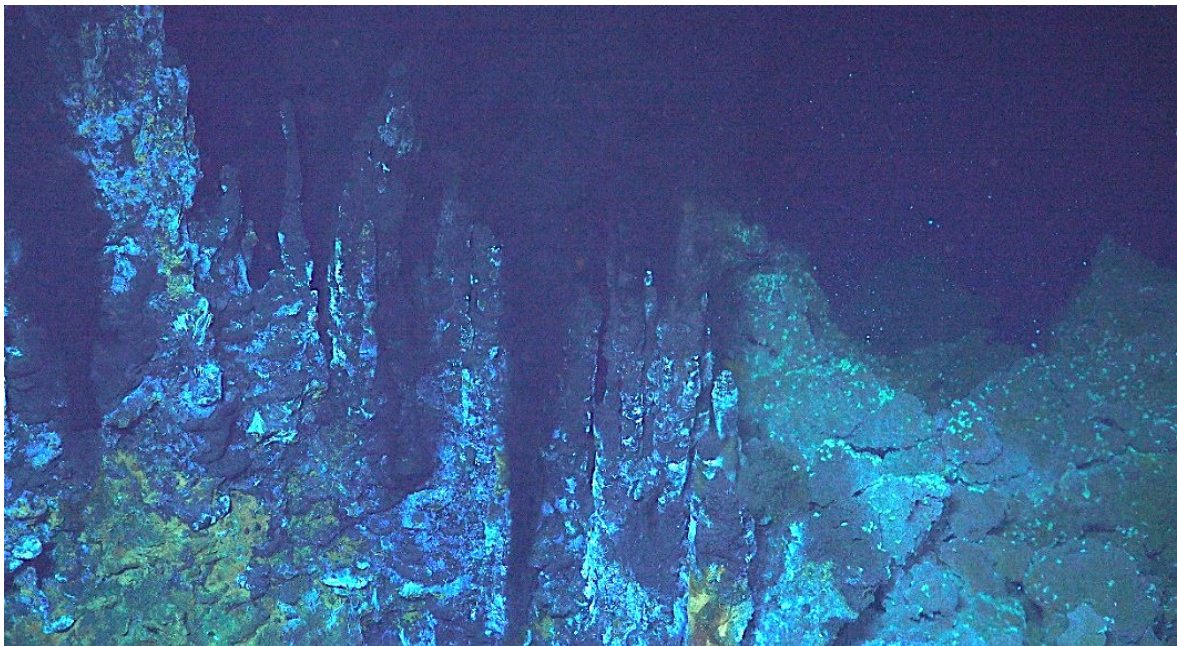


Figure 46. Active black smoker chimneys. Photo by Ægir 6000/NORMAR.

10. Sea ice work

by R. M Fredensborg Hansen, A. Pliss, O. Veggeland, N. Panchi

10.1 Objective

Sea ice work included three separate parts: (i) installation of buoy for measuring sea ice mass balance (ICE-T — provided by LOCEAN to DTU/NTNU for deployment); (ii) installation of two remote sensing systems on board the ship; and (iii) ground-based (*in-situ*) ice sampling of deformed ice (pressure ice ridges) during the summer period. Due to difficult sea-ice conditions deployment of the buoy was not possible (see explanation below).

On the cruise, two remote sensing systems were mounted and used to collect data and test out methods for mapping sea ice properties with remote sensors onboard the ship. The main purpose was to develop passive systems that can gather data about sea ice conditions when ships operate in icy waters. Close to real-time locally sourced information about Arctic ice will be useful in development and validation of models to predict ice drift and long-term changes in the ice.

The objective of the ground-based work was to sample ice pressure ridges during the summer. Few observations are available of pressure ridges in general, but even fewer during the summer period. Pressure ridges account for about 50% of the Arctic sea ice pack, but they are poorly understood and captured by models and remote sensing applications. It is therefore crucial to collect more observations of ice ridge geometries, morphologies and physical properties. Such work will help improve our understanding and knowledge of pressure ridges in the Arctic during summer consolidation processes.

10.2 Equipment and Methodology

10.2.1. Optical/lidar/GPS/IMU system - remote sensor platform

Two duplicates of a sensor platform were created for the cruise. They were designed to handle the harsh Arctic climate with a waterproof container and heating elements to avoid condensation and freezing. The main payloads were a lidar (3D laser scanner) and camera (Figure 47). In addition to this, the system was equipped with an inertial measurement unit (IMU) and a global navigation satellite system (GNSS) receiver. One of the systems was mounted on the helicopter deck railing, facing forwards from the bow of the ship. The second one was placed outside the bridge facing starboard direction down on the ice. They were connected to the ship network so that the sensors could be controlled by a web application hosted by two Intel NUC computers from the control room (Figure 48). In addition to recording data from the sensors, drivers were created to collect data from the ship's navigation system. This can be used to validate and improve estimates for the trajectory and geopositioning of the system. The systems were also synchronised to the ship clock with millisecond accuracy via a NTP server available on board. This makes it possible to compare measurements across platforms with the ship navigation.



Figure 47. (Left) Inside view of the sensor platform. On the left side, from bottom to the top is the lidar (Livox Mid-70), camera (Blackfly GigE) and navigation module (Aceinna OpenRTK). On the right side is all supporting equipment including a small fan, heating element, network switch and a 12V power transformer. (Center) sensor mount points on the front of the bow, and (Right) sensor mount pointing outside the bridge (on starboard side).

10.2.2. Camera System for Droplet Dataset Formation

Modern ships are equipped with optical cameras for collection of ice observations. The CCTV camera facing the bow of RV Kronprins Haakon also serves as an ice observation camera, images from which are exported for archival purposes.

Bridge
10.3.64.220
August 01, 2023 - 23:53:05

Camera (10.3.64.206): Connected Submit changes

Parameter	Server value	Update value
Acquisition	False	---
Frame rate [fps]	1.00	---
Resulting frame rate [fps]	1.00	---
Auto exposure	True	---
Exposure time [us]	140	---
Throughput limit [bps]	2500024	---
Current throughput [bps]	1612440	---
Device temperature [C]	51.38	---
PTP status	True	---

Reset Camera

Lidar (10.3.64.224): Connected Submit changes

Parameter	Server value	Update value
Lidar mode	2	---
Lidar return mode	2	---
Acquisition rate	100.00	---
Temperature warning	0	---
Voltage warning	0	---
Motor warning	0	---
Dirty warning	0	---
Heater status	False	---
PTP status	True	---

Reset Lidar

Openrtk (10.3.64.241): Connected Submit changes

Parameter	Server value	Update value
Acquisition active	True	---
Unit temperature [deg]	48.37	---
Board temperature [deg]	34.68	---
Temperature reference [deg]	20.00	---
Heating active	False	---
Duty cycle [0-1]	0.20	---
IMU rate [Hz]	100	---
PTP rate [Hz]	0	---
Use NTP synchronization	True	---
NTP connection status	2	---

Reset RTK

August 01, 2023 - 22:41:09

July 14, 2023 - 19:53:33

Data from GNSS:

- Last longitude registered -3.3610970894562033
- Last latitude registered 81.37909782516213
- Last position update at: August 01, 2023 - 23:53:05

Data from IMU:

- Roll angle: 154.88235468200126
- Pitch angle: -0.23768354017984966
- Last angle update at: August 01, 2023 - 23:53:05

Figure 48. Screenshot from web application to control the sensors and record data. Since this is hosted on the ship network, anyone with access to the IP address could potentially run the application. This was luckily never a problem.

Condensation and rain on cameras observing ice conditions lead to occlusions in the ice images. Such occlusions adversely affect the image processing pipelines trained on clean images. A couple of examples are shown in Figure 49.

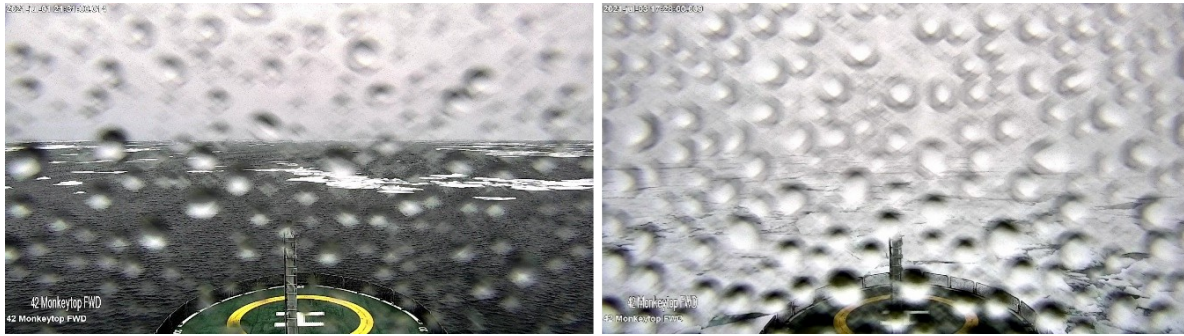


Figure 49. Examples of images with occlusions due to water droplets on the camera lenses.

Drops on the lens of cameras, as seen above can be removed with the help of deep learning algorithms. However, these droplet removal algorithms need training pairs, i.e., one image with droplets, and one image without droplets on the lens. To create such a novel dataset, a stereo camera system was designed. The system consists of two GoPro cameras, fixed on top of each other, inside a dark box, with a polycarbonate shield at the front. The polycarbonate sheet was sprayed with water such that the droplets cover the field of view (FOV) of one of the cameras, while the FOV of the other camera was kept droplet-free, at all times. This setup (see Figure 50A) allows for collection of image pairs, one with droplets, and another without. Figure 50B presents the number of images and videos collected with this setup.

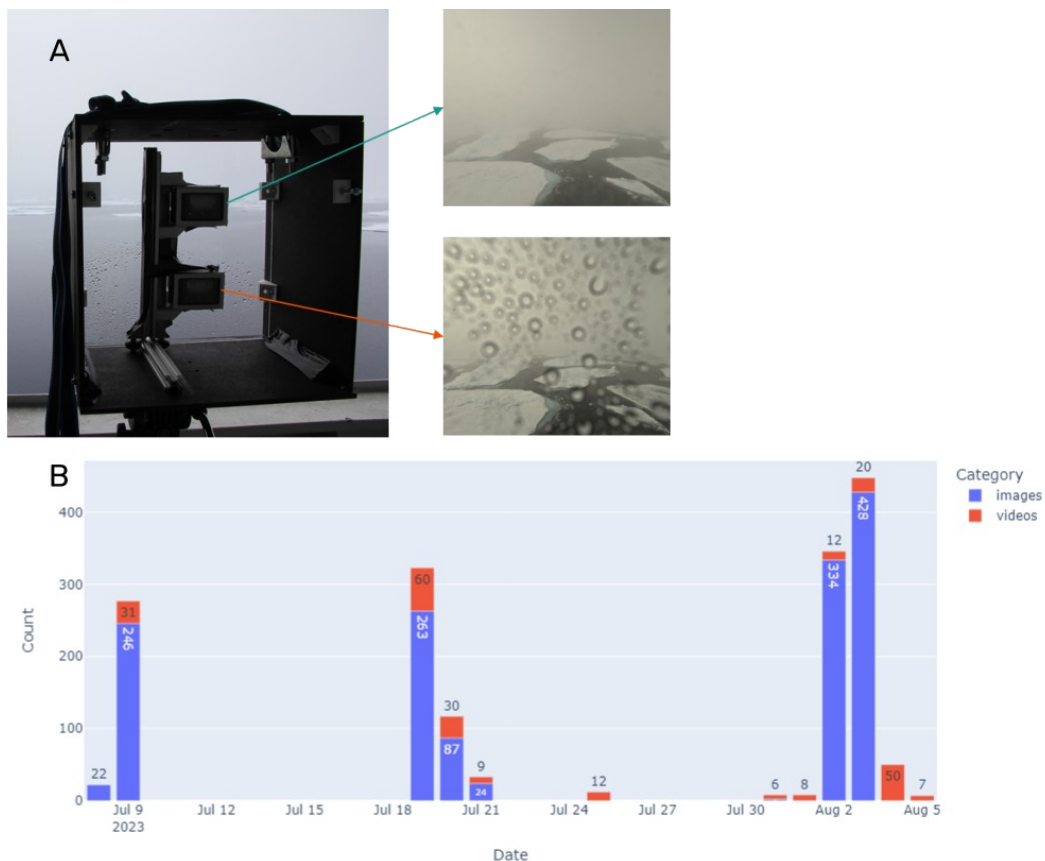


Figure 50. (A) The camera setup (left), and the outputs from the two cameras (right). (B) Statistics on collected images and videos show the number of images (blue) and videos (red) captured while transiting through ice.

10.2.3. Ground-based observations of pressure ridges

Pressure ridges are formed when floes of ice are pressed together, causing them to raft and later break off in blocks that are pushed either on top of the ice/water level (creating the sail of the ridge), or below the ice/water level (creating the keel of the sail). Due to this formation through blocks of ice, ridges are more porous (macroporosity) than surrounding ice floes, and therefore melt differently than level ice. However, due to the heterogeneity that they provide to the ice pack, they also play a large role in the dynamics and drift of the ice. Furthermore, ridges present a large risk to ships navigating in ice covered waters or offshore structures. Thus, it is important to better understand ridges and ridge processes, so that we can better model and estimate ridge creation, consolidation and loads. We aimed to measure pressure ridges through mechanical drilling and coring, which would provide information about the ridge structure, morphology and properties. We used the following equipment for in situ measurements of ice pressure ridges:

- Kovacs thickness kit: 2-in mechanical drill (up to 9.5 m worth of extensions), measurement band
- 7.5-cm Kovacs core barrel (up to 5 m worth of extensions (full length))
- Meter sticks
- 2 Makita drills
- Termometer
- Salinometer YSI
- Salinometer Mettler Toledo
- Saw
- Density set: scales KERN EMB-V with KERN YDB-02
- Kerosene/paraffin (for density observations)

First, the aim was to make a cross-section by drilling across the ridge and record any changes that occur to the drill while drilling to get the ridge structure. First, locations of drill holes were selected by 2-m intervals (and later, a denser sampling of 1 m or less was obtained at the thickest parts of the ridge). For each location, snow depth should be recorded before drilling. When drilling, a meter stick was placed next to the 2-in Kovacs drill — here, one person would drill while another would make observations off the meter stick. Extensions were applied when necessary. Once the hole was drilled, the total thickness and depth to the water level were measured using a measurement band (or thickness gauge). If the water level could not be recorded from the bottom of the ice and up using the measurement band, a meter stick was used to measure the freeboard (from the top of the ice and down to water level). At times where many voids are apparent in ridges, the thickness gauge would get stuck in the voids. In such cases we relied on observations from the meter stick to provide the total thickness. After drilling, we measured the water salinity at the top of the water layer in each drill hole using YSI salinometer.

For core sampling, we used a 7.5-cm Kovacs core barrel. Once a core was sampled, it was taken out of the barrel and put in a halved plastic tube on the ice. Therefore, it was either saved for further sampling and analysis in the cold lab, or drilled for temperature observations (every 5 cm) and cut on the ice for salinity sampling. For density cores, it was important to pack the ice immediately after extraction, note down top+bottom and date/place/hole number on the core, and then put it in the freezer (-20°C) on board the ship for freezing all brine liquid inside the

core. This approach would prevent losing brine liquid, which could be measured for salinity later.

After the ice station, salinity observations were recorded once the ice melted (in either containers or bags, depending on how the ice was stored). Preparation of ice for salinity could be done in two ways: (a) after temperature measurements on the ice the core could be cut into 5-cm pieces and stored in plastic containers, or (b) melt the ice samples once density had been measured in the cold lab (5-cm pieces). All salinity observations of ice were measured using a Mettler Toledo salinometer.

In the cold lab (-15°C), the core was cut the ice into 5-cm pieces and density was measured before salinity observations. Density is measured by weighing the 5-cm pieces of ice on a scale to provide the mass in air, and when covered by kerosene (mass in kerosene). By knowing the density of kerosene (which is also measured in the lab), the density of ice could be computed from:

$$\rho_{ice} = \frac{m_{air}}{m_{air} - m_{kerosene}} \cdot \rho_{kerosene}$$

Once density had been recorded in the cold lab, the ice samples were left for melting and salinity measurements following the methodology outlined above.

10.3 Preliminary Results

10.3.1. Buoy Deployments

Due to unforeseen circumstances and heavy ice conditions, we were not able to go as north as we would have liked. Potential deployment sites for the ICE-T buoy close to Aurora (south-west (SW) and south-east (SE) points on Figure 51) were investigated for potential buoy deployment. Through a simple advection model, the drift path of a floe with the ICE-T buoy moored was simulated (provided by LOCEAN). Using those provided points, and the last 10 years of daily drift observations from passive microwave observations, the last active date of the buoy (before the ice parcel would have left ice concentration >15% or come in contact with land/coast) was simulated assuming a deployment date of 30 July 2023. Based on the simulations, buoy deployment would at best have a lifetime of 4–5 months at SE deployment site (70% probability for 4-month survival, 20% for 5 months). SW deployments rarely survives past a few months. Due to these limitations, it was decided to not deploy the ICE-T buoy during this cruise. Through collaboration between the partners on the GoNorth 2023 expedition, we were able to secure placements of buoys on cruises later the season. Here, the ICE-T buoy will be deployed at the North Pole ice station by AWI during leg 2 of Le Commandant Charcot's 2024 cruise with expected deployment around mid-August 2023. Other buoys to have been deployed in the ice (by NPI and LOCEAN) were also not deployed, and other arrangements have been made for these as well to ensure as successful deployments as possible.

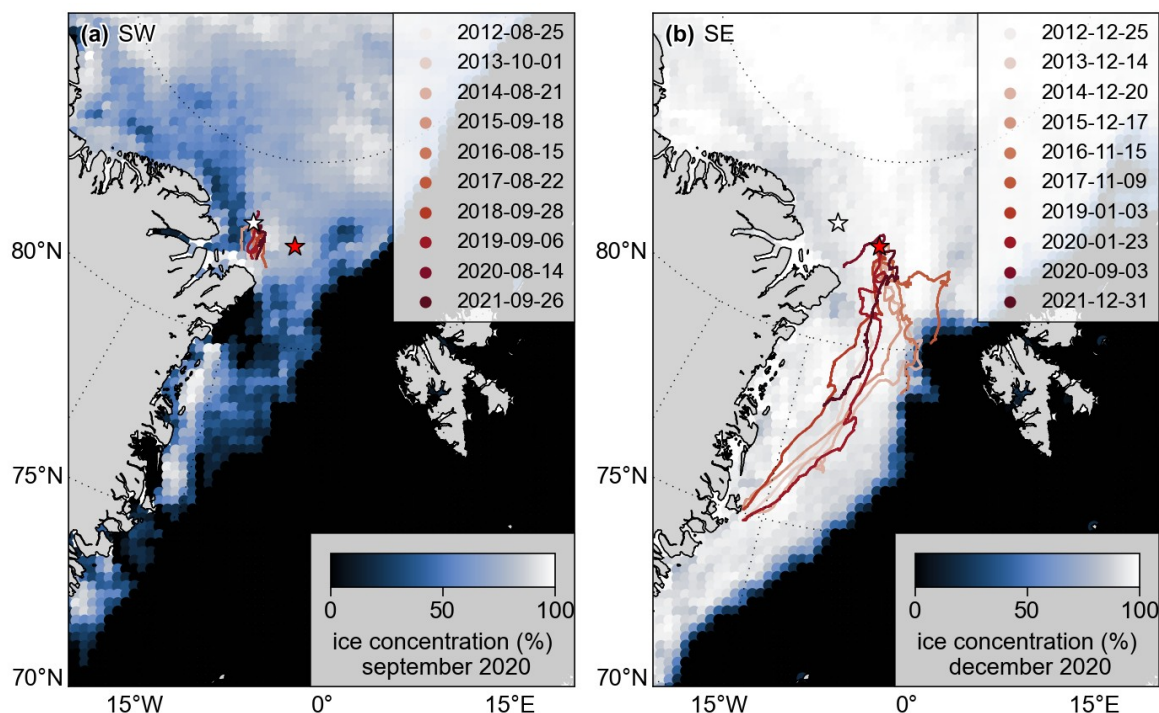


Figure 51. Simulations of buoy trajectories assuming deployment date of July 30 for the past 10 years (2012–2021). (a) trajectories with deployment at SW point, and (b) trajectories with deployment at SE point. Labels of each point denote the last date where the buoy would have been in ice/active. Ice concentration (from OSI SAF Global Sea Ice Concentration using AMSR2, identifier: OSI-408-a) for 01 September 2020 is shown in (a) and for 01 December 2020 in (b). The white star denotes SW point, and the red star is SE point. Trajectories provided by Frederic Vivier, LOCEAN.

10.3.2. Ground-based observations of pressure ridges

In total, three ice stations (IS) were held during this expedition (see Figure 52), where the ice team (consisting of Alexandra Pliss, Renée Mie Fredensborg Hansen, Christian Katlein, Oskar Veggeland, and Nabil Panchi) would venture onto the ice (either via gangway, zodiac workboat, or by crane) to measure ice pressure ridges.

Four ridges were measured: one at IS1, two at IS2 (IS2a and IS2b) and one at IS3. At each ridge the following was done:

- Ridge thickness was measured by drilling a cross-section (using 2-in mechanical drills), where full thickness, freeboard, snow depth, and ridge structure were recorded.
- Ice cores (either from the surrounding level ice, to be used as a baseline, or from the ridge) were collected to measure salinity, temperature, and density of the ridge. The salinity observations were taken at different conditions: (a) the ice core was cut and prepared on ice, and (b) the ice core was frozen and cut in the lab, with the aim of keeping the brine liquids inside the core as best as possible. These observations will be compared to investigate the accuracy of preparation of ice samples when measuring salinity during summer conditions.

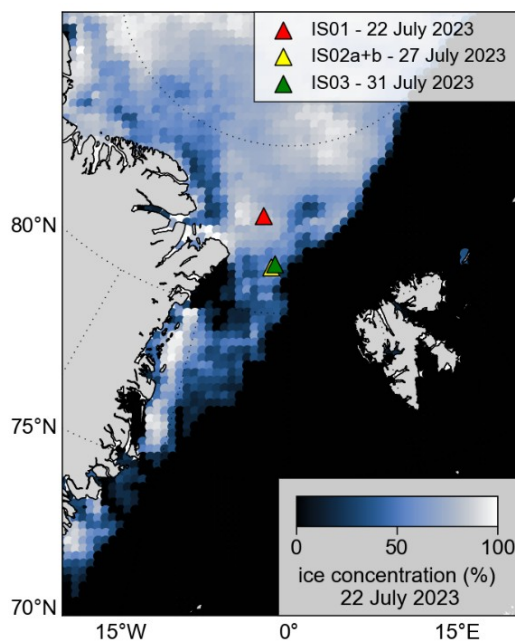


Figure 52. Map of ice station locations with ice concentration map from 22 July 2023 overlaid, derived from spaceborne passive microwave data (OSI-408-a).

In total, 53 drill holes were made, salinity from 9.5 cores were measured on the ship, five temperature profiles were captured on the ice, and four density profiles were measured in the cold lab on the ship. The distribution of measurements at each site are presented in Table 2, and example of an ice station is shown in Figure 53.

Table 2. Measurements from each ice station.

Ice station	Drill holes	Salinity core	Temperature core	Density core
IS1	16	3	1	1
IS2a	14	3	1	1
IS2b	8	1.5*	1	1
IS3	15	2	2	1

*We had to stop halfway through cutting and preparing the ice core on the sea ice due to limitations in time.



Figure 53. Pressure ridge at IS2b where sticks denote drill holes. Photo by Alexandra Pliss, NTNU.

Preliminary results from one of the ice stations are shown in Figure 54. First, a full cross-section with thickness (freeboard — the ice above local water level, and draft — the ice below local water level), provides a combined total thickness with potential voids, snow depth (whenever available), position of a melt ponds and locations of ice cores, as well as water salinity in drillholes. Here, we see a relatively small sail (freeboard, if we assume the water level to be the zero-level) with the highest value of 0.58 m (P5), and a large keel with the highest value of 3.50 (P6). The thickest keel is slightly skewed compared to the sail, and we observe additional blocks to the right of the thickest keel, showing an example of how ridges do not necessarily follow the ideal triangular/trapezoidal geometry that is commonly expected of ice-pressure ridges. It is also worth mentioning that the water salinity drops almost to 0 at the drilling sites in melt ponds, which we would expect.

Most previous work on remote shipborne sea ice analysis has been based on camera images. This provides rich detailed information about a wide area in front of the lens, but this comes at some costs. For one thing, images do not provide any information about the scale of the scene. Another issue is that it is often dependent on lighting conditions and other visibility constraints. For this reason, it is often beneficial to fuse (combine) the camera with complementary sensors, such as a lidar. This is a popular combination because the lidar can extract depth information from the scene and is not affected by poor visibility, making it a good complement to the camera. Figure 55 and Figure 56 show some examples of processing we have performed during the expedition, including a curious visitor that came close to the ship one day.

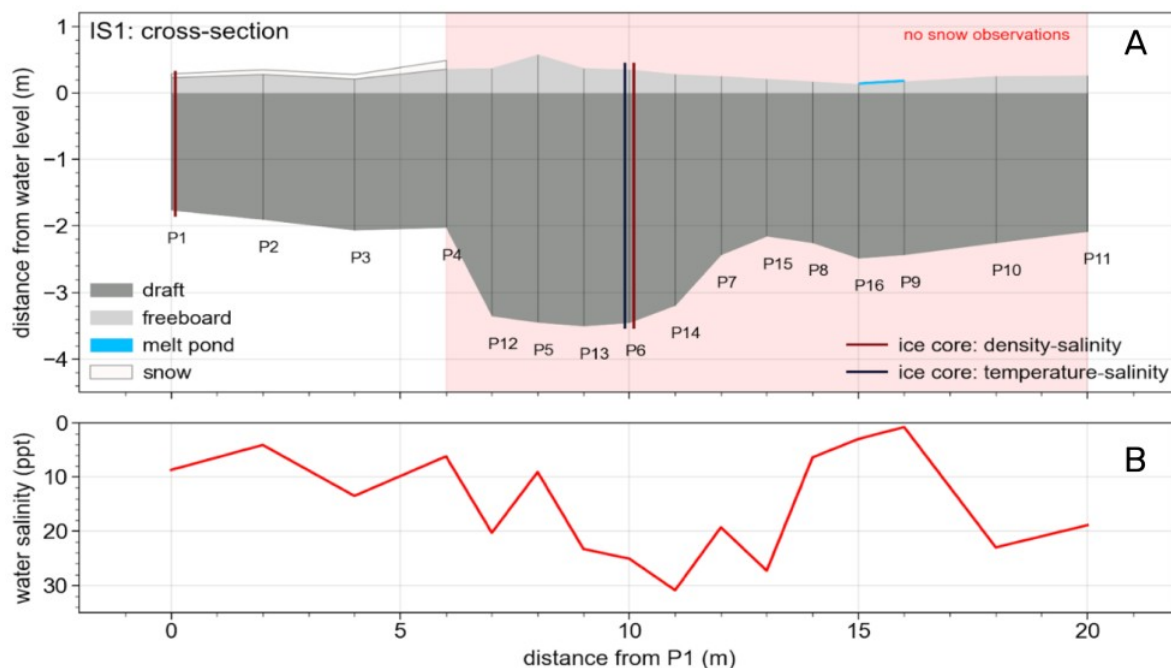


Figure 54. (A) cross-section of pressure ridge at IS1 with measured draft (provided in dark gray) and freeboard (provided in light gray) using total thickness and thickness until water level observations obtained from thickness gauge from the 16 drill holes (2-in drills) conducted. Note the melt pond (blue) at P9 and P16, both at which measured 3-cm depth. Locations of cores (approximate, they are expected to provide similar information as where the drill hole is) and type of core (what type of analysis to be performed) are provided. (B) salinity of top water is shown in red — note the clear decrease in salinity over the melt pond.

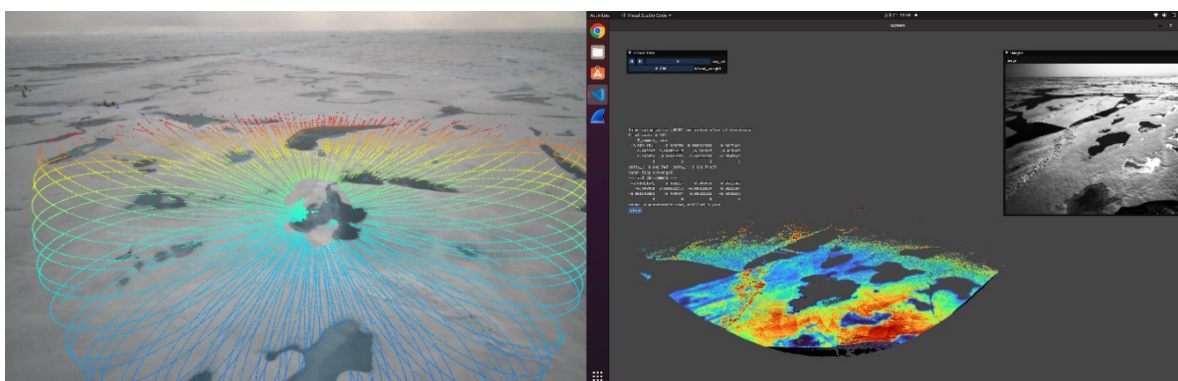


Figure 55. (Left) point cloud projected onto the image plane. We can predict where in the image points would appear if they were photographed. This image shows the points collected at the same time as the image. The points are colored based on their distance from the camera. This means that we can derive the image depth from the lidar. (Right) visualization of the lidar point cloud next to a synchronised image (top right). We can see that the lidar only detects sea ice, and not sea water or melt ponds. This can be useful when creating models with the purpose of segmenting ice from water.

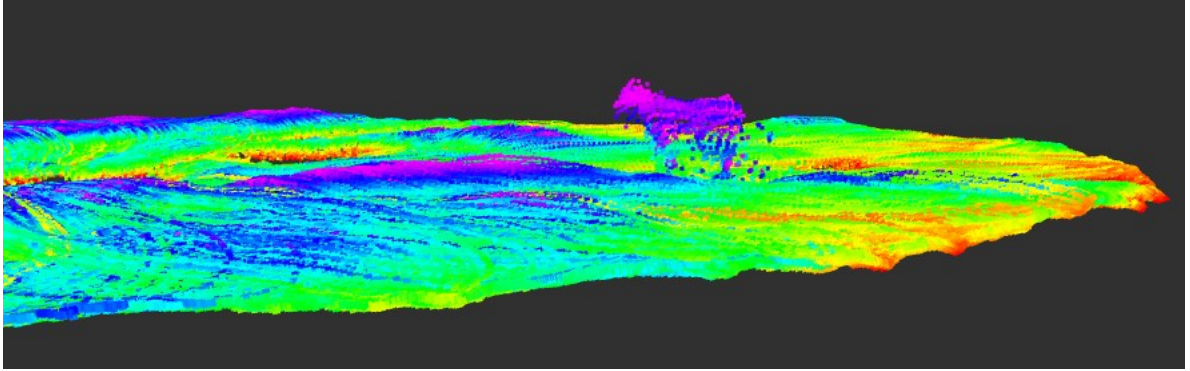


Figure 56. 3D-scan of a curious visitor close to the ship.

11. Sediments

11.1 Planktonic and benthic biodiversity

by S. De Schepper and K. Häkli

11.2 Objective

A Genetic View into Past Sea Ice Variability in the Arctic | ERC AGENSI | www.agensi.eu

In the AGENSI project (ERC Consolidator Grant #848339, PI De Schepper; 2019–2024), we collect sediments and sea ice samples for DNA analyses, palynology, and organic biomarkers. The collected sea floor sediment samples recovered by the boxcorer and/or multicorer will be added to the Arctic Surface Sediment DNA Database that is being built within AGENSI. This database is essentially mapping planktonic (after sinking to the seafloor) and benthic biodiversity in the Arctic Ocean and can provide us a state-of-the-art assessment of Arctic biodiversity before the Arctic summer sea ice disappears, as expected within the next few decades. One application of the database that we explore in the AGENSI project is the development and establishment of sedimentary DNA as a sea ice proxy. The recovered multicores and push cores will also be used to reconstruct the Arctic Ocean sea ice history over the past thousands of years.

ERC-AGENCI has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No 818449). In addition, sediment samples were collected to study Pharmaceuticals (SINTEF), Foraminifers (NPI), Meiofauna and Macrofauna (UiT).

11.2.1. Equipment and methodology

Box cores, multicores and push cores were used to recover sediment samples from the sea floor.

Table 3. Summary table of sediment sampling for DNA, pharmaceuticals, forams, meio- and macrofauna.

Station	Core type	Latitude (dd)	Longitude (dd)	Water Depth (m)
669	PushCore	82.89680	-6.21550	3955
13	Box Core	82.07033	-7.77211	3327
14	Box Core	82.05692	-7.71186	3330
15	Box Core	81.40438	-4.11388	3823
16	Multicore	81.38768	-4.11519	3794
674	PushCore	81.38309	-4.10095	3809
17	Box Core	81.45438	-2.91005	4098
18	Multicore	81.46131	-2.83544	4051

11.3 Geomicrobiology of deep-sea sediments

by I. H. Thorseth and S. L. Jørgensen

11.3.1. Objective

The objective was to investigate the processes and function of the microbial ecosystem in ice-covered Arctic deep-sea sediments.

11.3.2. Equipment and methodology

One push core (KH23-249-ROV07-PC-J) and one gravity core (KH23-249-GC01) were collected for DNA and porewater extraction. The gravity core was cut in three sections (A-C). Oxygen was first measured in both sediment cores through holes drilled in the liner at specific depths. The same holes were used to extract porewater by rhizon samplers connected to syringes, after sediment samples for DNA analyses were taken by cut syringes through separate drilled holes. The DNA samples were immediately frozen at -80°C. The extracted porewater samples were divided in aliquots for analyses of pH and alkalinity (onboard), nutrients (frozen at 20°C), major and trace elements (acidified by concentrated, ultrapure HNO₃ and stored at 4–6°C) and anions (stored at 4–6°C).

11.4 Sedimentary petrology

by R. Portner, E. Valdar, E. Siira

11.4.1. Objective

A series of cores from the Aurora and Lena Trough vent fields as well as surrounding areas were taken to characterise the lithology of the sediment. Later lab work will aim to identify fluctuations in hydrothermal and/or volcanic activity in the recent geologic past.

11.4.2. Equipment and methodology

Subsamples taken from the bottom of all box cores and one gravity core were sieved at sea with a 250 µm sieve. The medium grained sand components were then dried for petrographic analysis. Approximately 10 ROV sediment push cores and one multicorer were taken, cleaned and capped at sea for later lab work. Later analysis will involve geochemical and geophysical core scanning, splitting and visual observations.

11.4.3. Preliminary results

Nearly all sediment recovered from the Lena Trough was completely devoid of volcanic glass implying volcanic activity has for the most part been inactive on this part of the ridge in recent geologic past. A small proportion of mafic volcanic ash was recovered from the first core west of the Lucky Ridge, but most of the sample was <250 µm deep sea mud.

12.CTD and water samples

by Y. Kern, M. Bratrein, K. Häkli

Contact: Paul Dodd and Agneta Fransson, NPI.

12.1 Objective

With this year's heavy ice conditions, it was not possible to resample some of the CTD stations from the Arctic Ocean cruise (July–August 2022) transect across the Amundsen Basin as originally planned. Instead, given that a lot of multiyear ice seems to have been flushed out of the western Arctic, there might also be a large Pacific water contribution in the water column with an anomalously large fraction of water from the Canadian Basin. Hence, a CTD transect across the outflow from the Arctic Ocean north of Fram Strait was conducted to test this hypothesis (Figure 57).

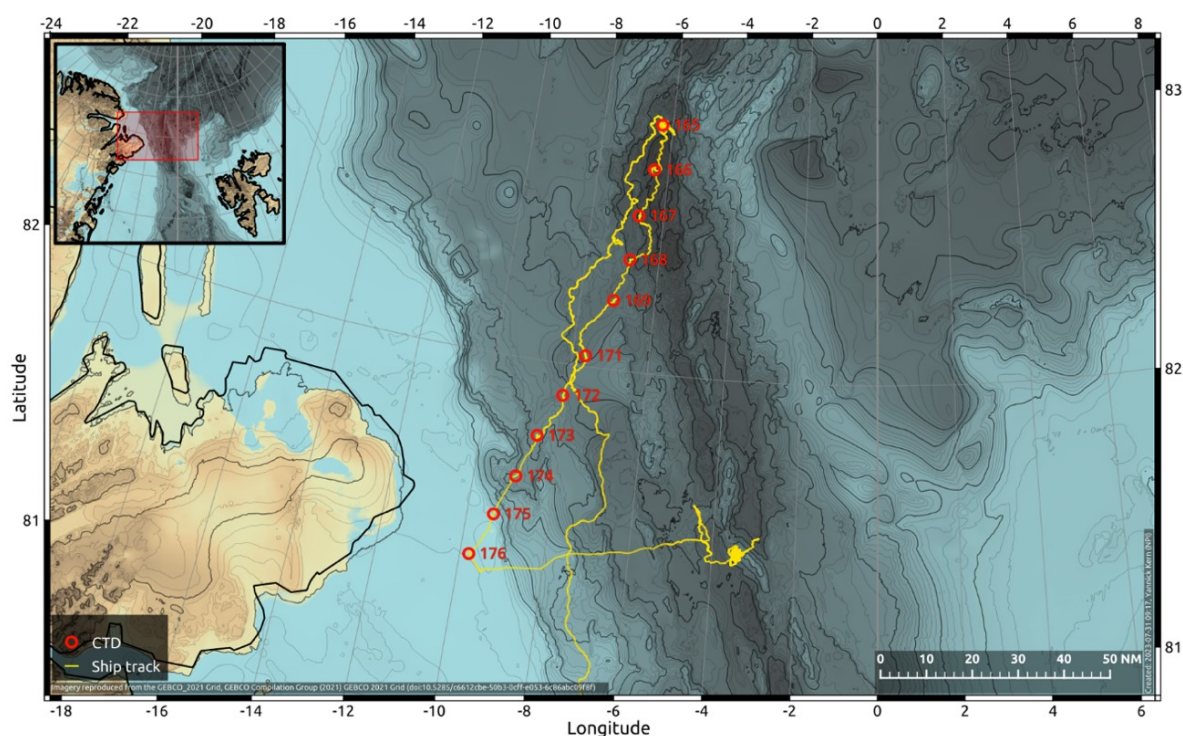


Figure 57. CTD stations for oceanographic purposes completed during GoNorth 2023.

12.2 General approach

The CTD used was an SBE911+ unit with a 12-bottle rosette. The T, S and O₂ ducts were neither flushed with Triton-X nor freshwater between stations but were sometimes blown out by mouth just before deployment, to avoid problems with icing. At the beginning of stations, the CTD was lowered to 20 dbar and allowed to soak until the pump started and sensors stabilised. The CTD was then brought to the surface and then lowered to 1000 m for the first 5 stations and within 10 m of the seabed as determined using the altimeter for the last 6 stations. Data acquisition was generally initiated just before deployment with the CTD on deck and allowed to run until the CTD was back on deck at the end of the cast.

During GoNorth 2023 the CTD was always lowered over the side of the ship in the conventional way, the moon pool was not used. Niskin bottles were closed using the bottle fire command within the SeaBird acquisition software so that a .bl file was created for each cast when bottles were fired. NMEA time and position information was fed to the acquisition computer and added to each scan line of the data files. Cast positions and starting times were also automatically added to the header of all data files.

Note that the first station completed during GoNorth 2023 has the number 165 and not 001 and station 170 was used for geological purposes and is thus not included in this description. The vessel operators specify numbers assigned to CTD stations. The first cast each year has the number 1 and subsequent casts are numbered sequentially.

During the cruise a paper log sheet was completed for each CTD cast listing the depths at which bottles were fired and the serial numbers of water samples taken from each bottle. Scanned images of these paper log sheets are included in Appendix Error: Reference source not found at the end of this report.

12.2.1. CTD package configuration

Table 4. CTD package configuration during GoNorth 2023. The CDOM fluorometer FLRCTD-4531 has an internal gain setting (AsV) which can be varied between 1, 2 and 4. AsV was set to 1 during GoNorth 2023.

Channel	Sensor	Serial Number	Last Calibration
1. Frequency	Temperature 1	5884	14-Oct-2022
2. Frequency	Conductivity 1	2860	18-Oct-2022
3. Frequency	Pressure	141612	19-Dec-2017
4. Frequency	Temperature 2	6504	12-Oct-2022
5. Frequency	Conductivity 2	3123	18-Oct-2022
6. A/D Voltage 0	Oxygen SBE43	3785	29-Nov-2022
7. A/D Voltage 1	Altimeter	73084	24-Dec-2017
8. A/D Voltage 2	Chl. Fluorometer	FLRTD-6506	18-Sep-2020
10. A/D Voltage 4	Transmissometer	CST-2003DR	01-Jan-2019
11. A/D Voltage 5	CDOM Fluorometer	FLCDRTD-4531	12-May-2023

12.2.2. Salinity sensor validation

Water samples for laboratory salinity measurement were collected along the section at standard depths where tracer samples were collected: 5, 15, 25, 50, 75, 100, 150, 200, 250, 400, 750 and 1000 dbar. Salinity samples were analysed on board using Guildline Portasal portable salinometer (serial number 74176), which was standardised after every 24 measurements using IAPSO P-series standard seawater. The salinometer performed well for the duration of the cruise. The air temperature in the laboratory remained at $19 \pm 2^\circ\text{C}$ for the duration of the cruise and the bath temperature was set at 22°C for the entire cruise. Samples were stored next to the salinometer for at least 24 hours before analysis.

Comparison of laboratory salinity measurements and CTD salinity measurements revealed offsets of +0.005 and +0.003 practical salinity units for the primary and secondary sensor respectively (Figure 58). The errors were not normally distributed, featuring a tail to the right-hand side of both histograms (Figure 58).

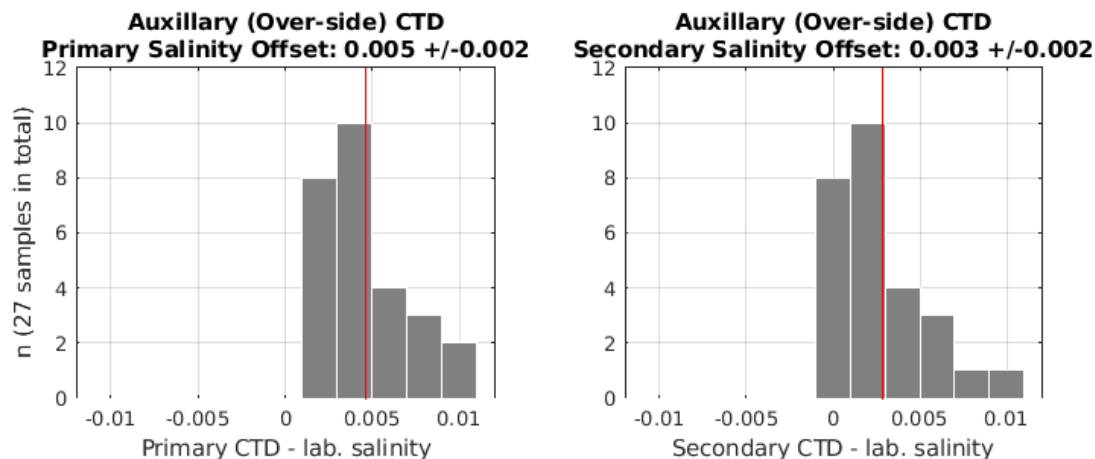


Figure 58. Histograms showing the difference between the primary (left) and secondary (right) sensor on the CTD and laboratory salinity measurements. Only points deeper than 400 m are considered for salinity validation, due to steep salinity gradients close to the surface.

12.2.3. Temperature and salinity sensor cross-validation

The temperature sensors showed a linearly increasing difference with depth of up to $\sim 1.5 \times 10^{-3} \text{ }^{\circ}\text{C}$ (Figure 59). The conductivity sensors show a maximum difference of $\sim 2 \times 10^{-4} \text{ S/m}$ closer to the surface, which linearly decreased with depth to $\sim 1 \times 10^{-4} \text{ S/m}$. With 11 stations in total, taken within the time span of 2 days there were no obvious drifting differences of the sensors over the course of the cruise.

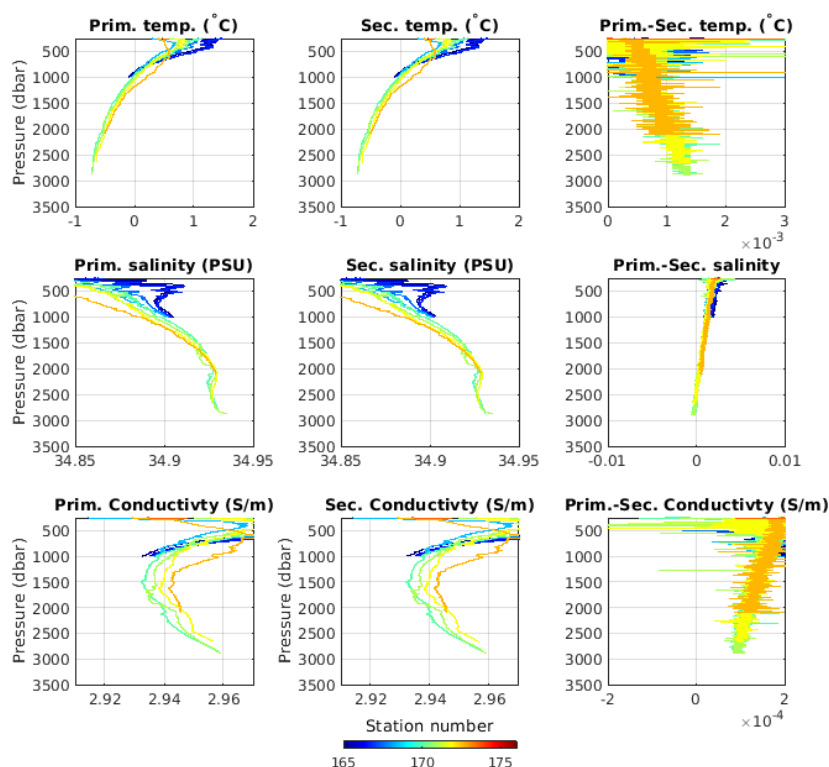


Figure 59. Profiles of temperature, salinity, and conductivity from the primary (left) and secondary (center), as well as their differences (right). Colors indicate the station number of individual profiles.

12.2.4. Biogeochemical Program

Table 5 lists the sample types that were collected from Niskin bottles. Only salinity analysis was carried out on board as described above. All samples were preserved for further analysis ashore as described in Error: Reference source not found. The position coordinate and times are given in Table 6.

Table 5. Summary of water samples taken from CTD during GoNorth 2023 including a description of the parameter and information about specific sampling and/or preservation methods.

Sample type	Description	Sampling/Preservation
Laboratory salinity	Laboratory salinity measurements are used to validate and (if necessary) calibrate conductivity sensors on the CTD.	Samples were analysed on board after they adjusted to room temperature.
Nutrients	The parameter inorganic nutrients include measurements of nitrate, nitrite, phosphate and silicate in seawater. Used to investigate nutrient cycling in Arctic Ocean and to trace Pacific Water.	The samples were preserved with 200 μ L chloroform and kept cool (4°C) and dark for post cruise analysis.
Dissolved inorganic carbon (DIC) and total alkalinity (AT)	The parameter dissolved inorganic carbon (DIC) describes the sum of dissolved CO ₂ , carbonic acid, bicarbonate and carbonate ions in seawater. It is used to investigate carbon chemistry to study ocean acidification.	The samples were taken first from the CTD rosette, preserved with 50 μ L mercury chloride and stored in the cool and dark for post-analysis at IMR in Tromsø.
Stable oxygen isotopes ($\delta^{18}\text{O}$)	The parameter $\delta^{18}\text{O}$ describes the ratio of ^{18}O to ^{16}O isotopes in the H ₂ O molecule. $\delta^{18}\text{O}$ is a tracer for water which has at some point evaporated and is useful to separate sea ice meltwater from river input and precipitation.	Vials were sealed with parafilm and stored cool for post cruise analysis.
Colored (or chromophoric) dissolved organic matter (CDOM)	Dissolved organic matter (DOM) is a ubiquitous component of aquatic systems, present in all natural waters, representing a major carbon reservoir. CDOM is the DOM fraction that is colored (i.e., absorbs light) and can be often used as a proxy to describe the amount of DOM in a given natural water sample.	Samples for DOM analysis were directly gravity filtered through 0.22 μ m pore size membrane filter cartridge into 40 mL acid-washed, pre-combusted amber glass vials and kept cool (4°C) and dark for post cruise analysis.

Table 6. Summary of CTD casts.

CTD #	Cast depth (m)	Echo depth (m)	Latitude (dd)	Longitude (dd)	Time (UTC)
165	1002	3984	82.901	-6.307	23-Jul-2023 06:24
166	1000	4513	82.737	-6.402	23-Jul-2023 11:48
167	1001	4283	82.566	-82.566	23-Jul-2023 15:09
168	1001	5115	82.403	-6.798	24-Jul-2023 00:16
169	1002	3326	82.251	-7.102	24-Jul-2023 02:48
171	2862	3305	82.039	-7.656	24-Jul-2023 15:02
172	2896	2905	81.886	-8.097	24-Jul-2023 19:39
173	2661	2650	81.729	-8.596	25-Jul-2023 00:06
174	2099	2032	81.572	-8.964	25-Jul-2023 02:56
175	268	286	81.424	-9.359	25-Jul-2023 05:20
176	151	151	81.268	-9.786	25-Jul-2023 06:43

12.3 Preliminary Results

Some preliminary data results of the CTD transect are presented in Figure 60 and 7.

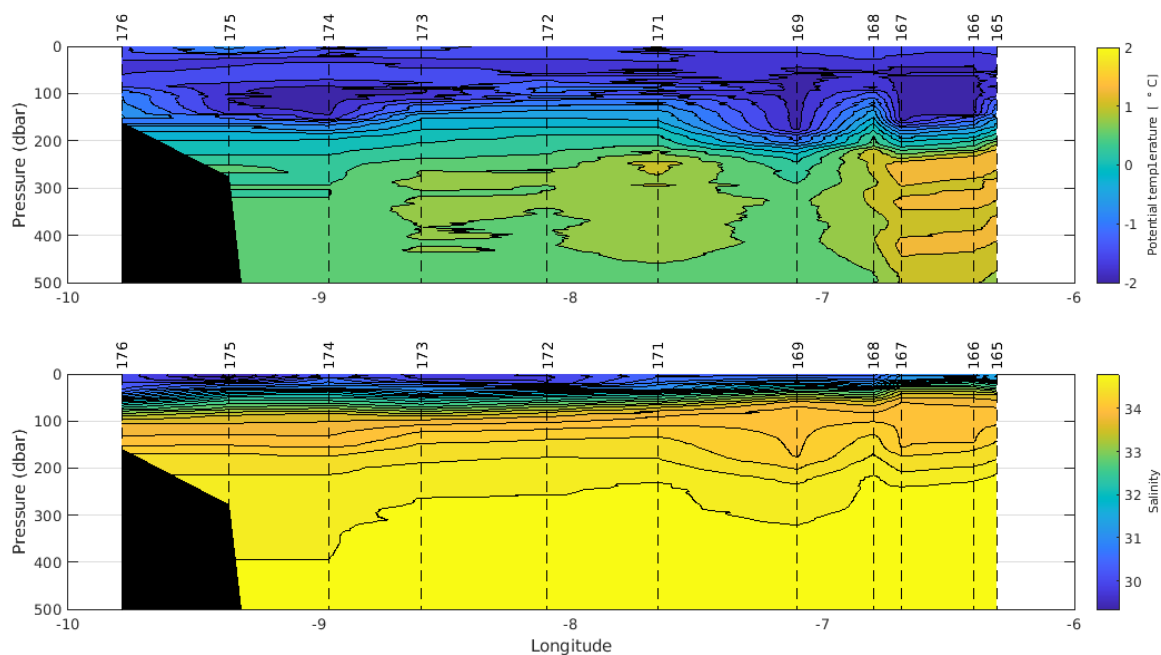


Figure 60. CTD measurements along the main transect; Measurements are from the primary temperature (top panel) and primary salinity (bottom panel) sensors. Station numbers are indicated above the sections.

WEST END OPEN WATER OPEN WATER OPEN WATER ICE ICE ICE ICE ICE ICE ICE ICE ICE EAST END

Station #	11	10	9	8	7	6	5	4	3	2	1	Station #
Type	A	A	A	B	A	B	A	B	A	B	A	Type
Latitude	81° 16.093' N	81° 25.473' N	81° 34.367' N	81° 43.750' N	81° 53.190' N	82° 1.841' N	82° 15.081' N	82° 24.205' N	82° 33.950' N	82° 44.234' N	82° 54.080' N	Latitude
Longitude	9° 47.162' W	9° 21.507' W	8° 57.740' W	9° 35.692' W	8° 5.876' W	7° 37.393' W	7° 5.986' W	6° 47.874' W	6° 41.251' W	6° 24.139' W	6° 18.480' W	Longitude
Approx depth	154	286	2032	2650	2904	3324	3325	3505	4283	4512	3984	Approx depth
Cast #	176	175	174	173	172	171	169	168	167	166	165	

5 dbar	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	5 dbar
15 dbar	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	15 dbar
25 dbar	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	25 dbar
50 dbar	SAL, OXY, NUT, CDOM	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	50 dbar
75 dbar	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	75 dbar
100 dbar	SAL, OXY, NUT, CDOM	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	100 dbar
150 dbar	SAL, OXY, NUT, AT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	150 dbar
200 dbar	Seabed	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	200 dbar
250 dbar	Seabed	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	250 dbar
400 dbar	Seabed	Seabed	SAL, OXY, NUT, CDOM	SAL, OXY, NUT	SAL, OXY, NUT, CDOM, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	400 dbar
750 dbar	Seabed	Seabed	SAL, OXY, NUT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	750 dbar
1000 dbar	Seabed	Seabed	SAL, OXY, NUT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	SAL, OXY, NUT	SAL, OXY, NUT, AT	1000 dbar

Comment	All casts over-the-side due to ROV occupying moonpool Some CDOM bottles reused from earlier stations and rinsed 3 times	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool Some CDOM bottles reused from earlier stations and rinsed 3 times	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool Some CDOM bottles reused from earlier stations and rinsed 3 times	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool Some CDOM bottles reused from earlier stations and rinsed 3 times	All casts over-the-side due to ROV occupying moonpool	All casts over-the-side due to ROV occupying moonpool	Other Activities
---------	--	---	--	---	--	---	---	---	---	--	---	---	------------------

Totals	7	9	12	12	12	12	12	12	12	12	12	12	Totals
124	7	9	12	12	12	12	12	12	12	12	12	12	124
124	7	9	12	12	12	12	12	12	12	12	12	12	124
60	3	9	0	0	12	0	0	0	12	0	0	0	60
51	4	9	10	0	10	0	9	0	9	0	0	0	51

Illustration 1. CTD transect and water sampling plan.

12.4 Additional Water Sampling

In addition, there was three CTD stations where water was collected for eDNA analysis (method responsible: Sabine Cochrane, Akvaplan niva). Shortly, water samples (three replicates of 1.5 L per depth) were collected close to the surface, below thermocline and close to the sea floor.

Table 7. CTD eDNA stations. Samples were taken at three depths in each station (depth 1–3), close to the surface, below the thermocline and close to the seafloor.

CTD #	Depth 1 (m)	Depth 2 (m)	Depth 3 (m)	Latitude (dd)	Longitude (dd)	Time (UTC)
170	10	250	3362	82.07575	-7.8265444	24.07.2023 08:35
177	10	300	3805	81.41237	-4.2101763	26.07.2023 09:03
178	10	300	4113	81.4296	-3.0047077	31.07.2023 07:24

12.5 Water Sampling During Transects

To analyse pharmaceuticals and other contaminants from the water, pre-conditioned LV-SPE capsules were used to filter approximately 500 L of water (each) during transects (method responsible: Ida Beathe Øverjordet, SINTEF). Between Tromsø and the beginning of the sea ice, three transect samples were collected. As sea water intake must be closed when on ice, sampling was not possible after that point.

Table 8. Transect water stations.

Trans. #	Start latitude (dd)	Start longitude (dd)	Start time (UTC)	End latitude (dd)	End longitude (dd)	End time (UTC)
1	73.06871153	18.6840033	15.07.2023 14:10	74.97204775	13.46510043	16.07.2023 07:30
2	75.5588342	11.29123503	16.07.2023 12:45	77.86916617	1.831828433	17.07.2023 05:15
3	77.98255168	1.323346417	17.07.2023 06:05	80.1053937	-5.7588124	18.07.2023 00:35

13. Heat flow measurements

by E. Valdar and B. R. Olsen

13.1 Objective

The main objective was to determine the heat flow based on the data collected on the thermal gradient and the thermic conductivity in sediments within the spreading ridge of the Fram-strait area. The heat being produced from a spreading ridge is likely to show a different thermal gradient and conductivity signature than that of a continental shelf and will give an insight to how the heat being generated on spreading ridges travels up through the sediments on the seafloor. In the Fram-strait the spreading rate of the ridge is considerably low, and the heat being produced is likely to show a different thermal gradient than that of other faster spreading ridges, making this locality great for thermal heat flux studies. We aim to gather data from two localities in the vicinity of the ridge. Penetration of the sediments should take place on a flat seabed with no more than 15° angle of dip. Therefore, the most favourable location would be in a basin located within the ridge area.

13.2 Equipment and Methodology

The probe is a CTM-1030 equipped with 22 high sensitivity sensors which are able to record minimal temperature variations in sediments. The software utilised to visualise and process the data is called SST Standard Data Acquisition rev. 2.18. The data is to be collected from the probe when it is back on the ship with a converted usb-c to a micro circular inline.

The probe was calibrated to initiate measuring below the depth of 900 m to limit the amount of power being used. For the second measurement this depth was set to 1100 m. In preparation of the heat flow measurements, the probe was tested with a 12-V power supply to check that it was working correctly and to export the data. A stick with a magnet attached on the end acted as a start/stop tool for the probe and is utilised by holding the magnet close to a switch, which activates a red light, indicating that the probe has been turned on. Repeating this maneuver turns the probe back off. During mounting of the probe, the contacts on the three cables were smeared with silicon to prevent seawater from damaging the connections. A power unit and the probe were mounted into a weight stand which was attached to a six-metre-long sensor string.

On the first measurement, the probe was lowered to a depth of 1701 m and held in a steady position for 30 min before being raised. The measurement was taken at 79°22.250 N, 4°30.096 W at 10:22 UTC (Figure 61). The second measurement was completed at a depth of 1305 m on the position 79°00.600 N, 5°01.264 W at 16:07 UTC (Figure 62) and held in a steady position for the same amount of time as the previous measurement. The first 15 min no temperature data is recorded as the probe is programmed to give the instrument time to get in a steady position.

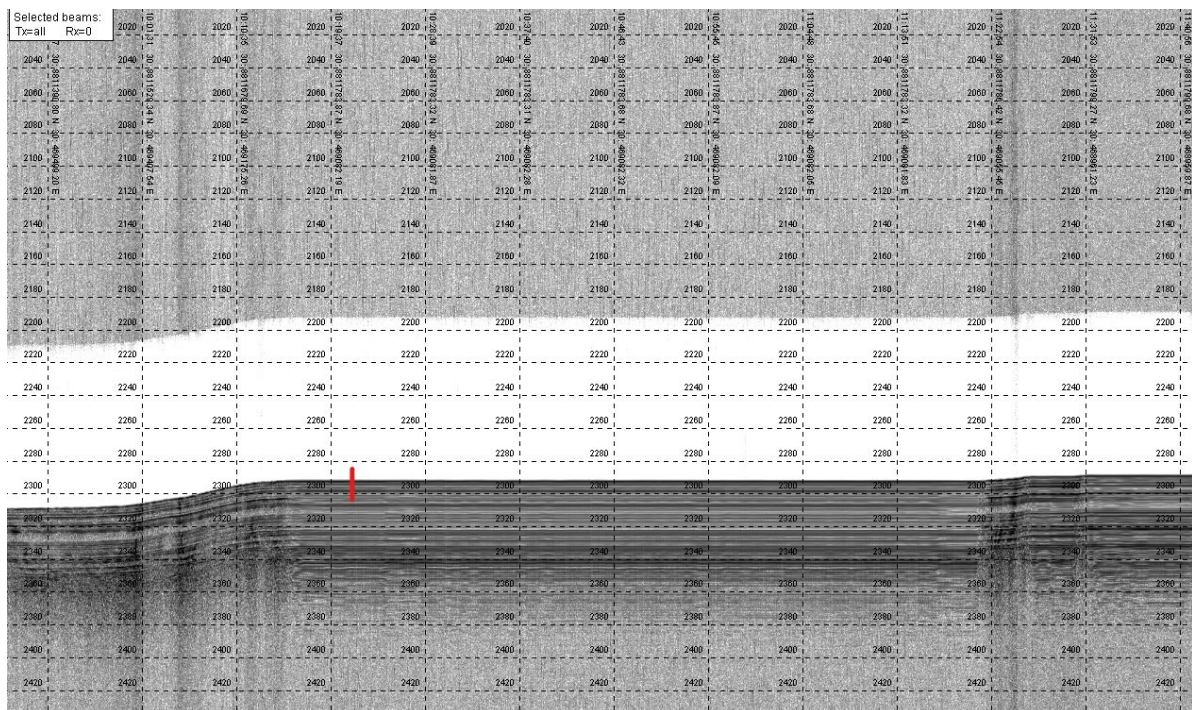


Figure 61. Image showing the approximate position of where the first heat flow measurement was completed.

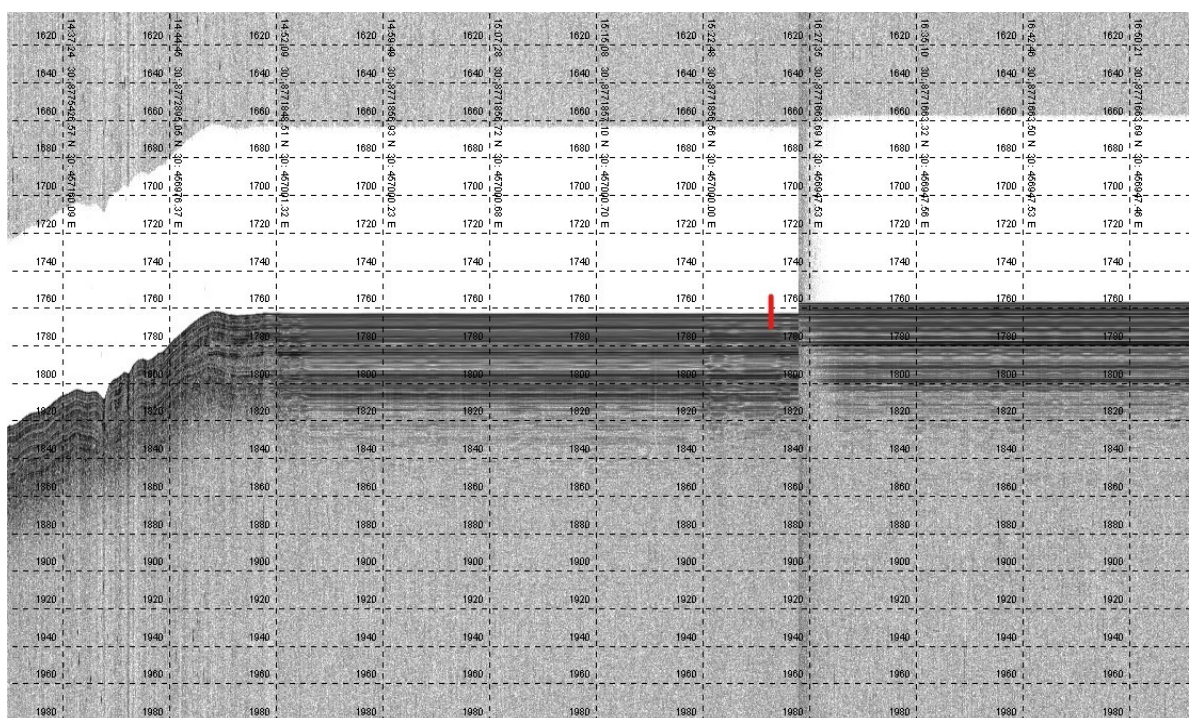


Figure 62. Image showing the second approximate location of the heat flow measurement.

On both attempts the full length of the sensor string penetrated the sediments. On deck the probe and battery package were detached from the weight stand and washed with water. The probe was then connected to a laptop and the data exported. The data was converted to ASCII files and then visualised in the software FELLOW.

13.3 Preliminary Results

The results obtained from the two heat flow measurements can be observed as plotted graphs on Figure 63 and Figure 64. Each one of the curves represents a sensor at different lengths of the sensor string. It is possible to interpret from the data that the temperature is ascending with depth, which is shown in the interval 100 to 110 in Figure 63 and 50 to 60 on Figure 64. Sensor 1 records the deepest measurement, while sensor 22 measures the shallowest measurement. One major error can also be distinguished from both the heat flow measurements, and that is that there was no heat pulse being transmitted after the initial 15 min had been completed.

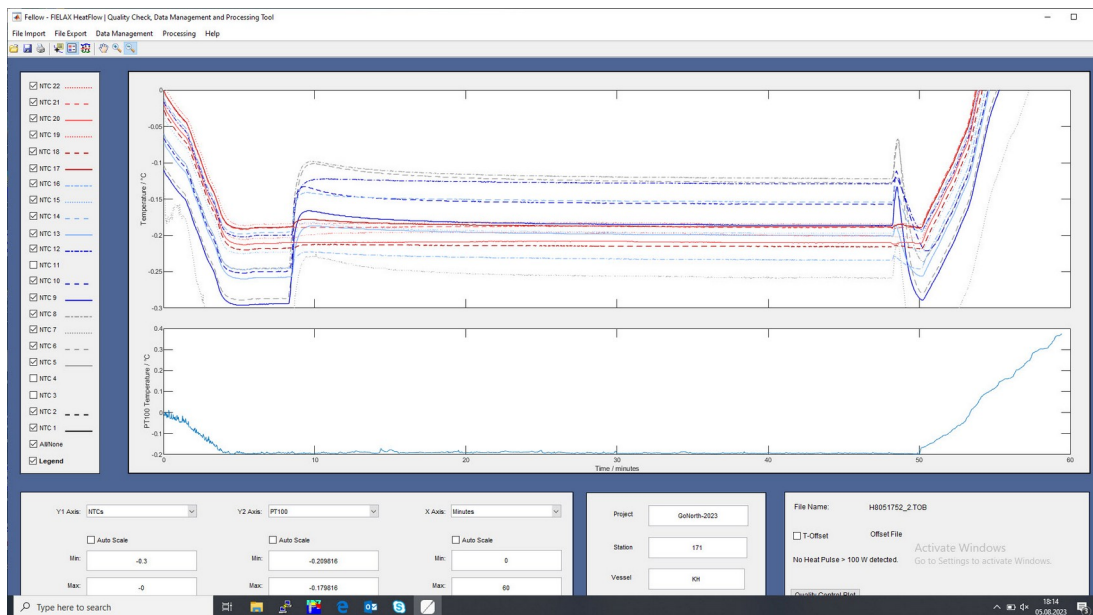


Figure 63. Image showing a plot of the first heat flow measurement. Each one of the plotted lines represents a sensor measurement. The Y-axis is temperature, and the X-axis shows minutes.

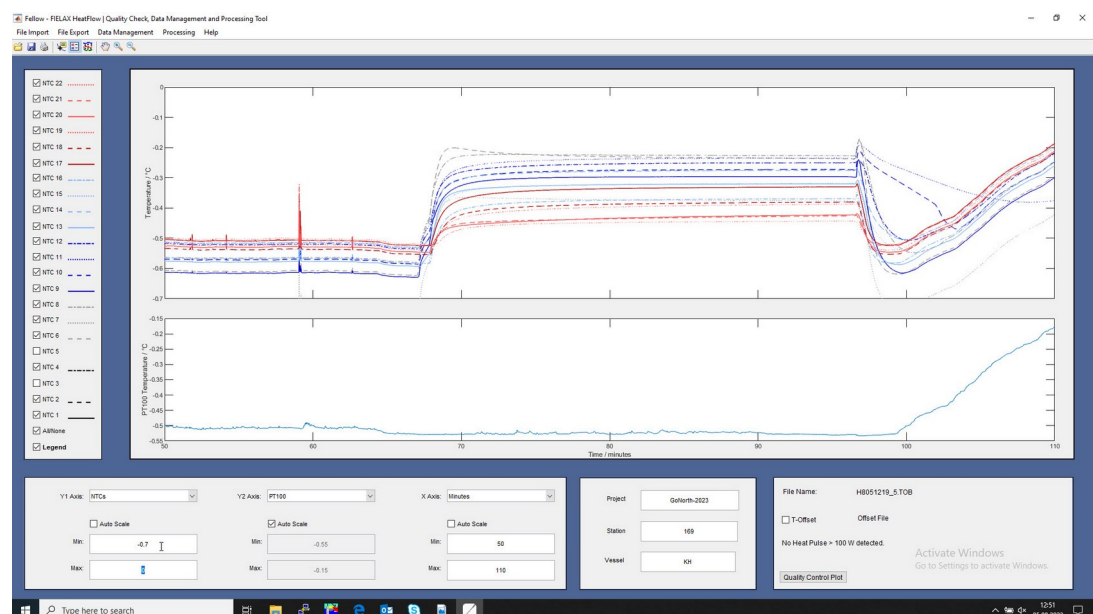


Figure 64. Image showing the graph of the second heat flow measurement.

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Appendices

Appendix 0: paper log sheet for each CTD cast (12 pages)

Appendix 1: Rock sample description (53 pages)

Appendix 2: Maps (10 pages)

Appendix 3: Survey log (7 pages)

Appendix 4: ROV log (11 pages)

Appendices will be available after a 2-years post-cruise moratorium. Contact Rolf Birger Pedersen (UiB) for more information.