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Cover photo: View of Quukinniq from the *RV Nuliajuk*, near the northern extent of the survey. NRCan photo 2022-432.

Publications in this series have not been edited; they are released as submitted by the author.

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Acknowledgements

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1. Background and objectives

The Baffin Bay activity of NRCan's Public Safety Geoscience Program conducts research to improve the understanding of geological processes and hazards (geohazards) in Baffin Bay to support stakeholder decisions on the use of offshore areas and provide northern communities with better knowledge for improving public safety. Despite efforts to conduct seabed mapping in Baffin Bay, there remain large knowledge gaps in the region regarding seabed composition and marine geohazards, which are both important for hazard assessment and for marine spatial planning. These hazards assessment and seabed mapping are particularly critical near Nunavut communities since they can help promote coastal and nearshore infrastructure and provide the knowledge necessary for emergency planning.

Grise Fiord is a long, flooded valley with steep walls above the water line that was formed by glaciers that once occupied the valley before retreating landwards. Because the valley walls are no longer supported by ice, they can be inherently unstable. Landslides that occur in fiords may run out into the water of the inlet, or can occur subaqueously, both possibly resulting in tsunamis (e.g., Higman et al. 2018; Gallotti et al. 2022). Communities in eastern Nunavut are typically at or near sea-level in fiord or fiord-like environments, and as such, consideration of these risks are important (Gosse et al. 2020). Aujuittuq is located at the mouth of Grise Fiord (the inlet), southern Ellesmere Island. It is one of several north-south oriented fiords that empty in to northern Jones Sound. It is 45 km long and 1 – 4 km wide. Fiord sidewalls rise to 820 m above sea level and are generally steeper up tributary river valleys.

The main objective of the RV Nuliajuk *2022Nuliajuk* expedition was to provide seabed mapping and surficial geology assessment in Grise Fiord and near the community of Ausuiituq. Specifically, the aims were to:

1. Consult with community members, the Hunters and Trappers Organization (HTO), and hamlet to: a) determine what areas in their offshore are important for seabed mapping, b) where there is a risk of interference with hunting and fishing activities, and c) where their observations and knowledge suggests geologically important features that could represent nearshore hazards;
2. Conduct seabed mapping using a multibeam echosounder in Grise Fiord and in front of Ausuittuq using the feedback provided in (1). These seabed surveys will allow us to provide an overview of seabed composition and hazards;

3. Assess the stability of the seabed and sediment transport processes near Grise Fiord based on the analysis of newly-collected sediment cores. This stability analysis will allow us to better characterize the seabed for the creation of surficial geology maps and hazards maps.

Figure 1. The RV Nuliajuk upon arrival off Ausuittuq. NRCan photo 2022-434.

2. Participants

Scientific participants of the *2022Nuliajuk* cruise consisted of one Geological Survey of Canada researcher (Eamer) and one M.Sc. student (Stancu) from the Université du Québec à Rimouski (UQAR). Two watchkeepers (Kiguktak and Pijamini), hired from the community of Ausuittuq, performed 24 hour lookout duties for marine mammals (Figure 2). Alexandre Normandeau (GSC-A) unfortunately had to cancel his participation at the very last minute but planned the cruise and provided instrumental shore-based support.

Table 1. Scientific participants of the *2022Nuliajuk* expedition

First name	Last name	Affiliation	Role
Jordan	Eamer	Geological Survey of Canada (Atlantic)	Chief Scientist
Charlotte	Stancu	UQAR	M.Sc. Student
Nolan	Kiguktak	Community of Ausuittuq	Marine mammal watch
Silas	Pijamini	Community of Ausuittuq	Marine mammal watch

Figure 2. Crew and science participants of the 2022Nuliajuk scientific cruise, pictured in front of Ausuittuq. From left to right:, Alfred Burton, James Giesbrecht, Mitchell Deering, John Cabot, Silas Pijamini, Nolan Kiguktak, and Charlotte Stancu. Not pictured: Doriana Malliki and Jordan Eamer (who took the photo). NRCan photo 2022-433.

3. Summary of activities

Activities integral to the cruise began upon arrival in Ausuittuq on Tuesday, August 16 2022. Consultations with the HTO and Hamlet on shared objectives, permissions, and community hires were initiated. On August 17, the planning of the cruise in collaboration with the HTO and the hamlet was finalized, the RV Nuliajuk arrived off Ausuittuq (Figure 1), and initial community visits to the vessel were attempted but aborted due to bad weather conditions. Setup and troubleshooting of the survey equipment aboard the RV Nuliajuk began that evening. Thanks to the excellent preparation of the vessel by Kirk Reguklar (Marine Institute of Newfoundland), the multibeam echosounder was ready to survey on that evening. On August 18, the remainder of the crew (Stancu, Kiguktak, Pijamini) joined the vessel, and several hours of successful vessel visits from community members were completed.

On the evening of August 18, a CTD cast for multibeam echosounder calibration was completed, and surveying commenced with a mapping campaign in front of Ausuittuq. This mapping seamlessly integrated with mapping data collection in Grise Fiord, which continued until late in the evening of August 21.

Submarine landslide targets were selected on August 20 based on the previously collected multibeam echosounder data, and coring took place August 21. Ten cores were collected on 11 attempts (i.e., only one core attempt yielded no recovery). Following coring operations, several holes were filled in the mapping data on the return transit to Ausuittuq, and in the morning of August 21, additional mapping data was collected in front of the community. The science crew disembarked around noon on August 21.

The remainder of August 21 and 22 were dedicated to processing data and sharing preliminary results with community members.

Table 2. Summary of activities

Date	JD	Location	MBES	GC	Notes
17 Aug	229	Ausuittuq			Community meetings, ship arrival and visits, mobilization
18 Aug	230	Ausuittuq / Grise Fiord	X		Community visits, mobilization, MBES surveys in front of community
19 Aug	231	Grise Fiord	X		MBES surveys in Grise Fiord
20 Aug	232	Grise Fiord	X		MBES surveys in Grise Fiord
21 Aug	233	Grise Fiord / Ausuittuq	X	X	Grise Fiord coring, MBES surveys in front of community, demobilization

4. Preliminary results

4.1 Cruise statistics

The *2022Nuliajuk* cruise allowed the collection of:

1. 10 gravity cores
2. 96 km^2 of new multibeam data

4.2 Key preliminary results

The mapping of Grise Fiord revealed water depth reaching more than 400 m in front of Ausuittuq (Figure 3). Towards the fiord-head, water depth progressively diminish from 390 m to less than 150 m. The mapping of the fiord was limited to south of Quukinniq, where two deltas partly infill the fiord (Figure 3). Backscatter from the multibeam echosounder shows varied locations of high and low-intensity backscatter, which probably reflects variations in surficial grain-size and texture of the seabed. Notably, high backscatter on fresh-looking iceberg pits and mass transport deposits suggest their recent formation and initiation (Figure 4). Many of these mass-transport deposits were mapped throughout the fjord and are particularly visible near deltas entering the fiord. Some of the mass-transport deposits appear to originate at or close to iceberg pits. The largest visible mass-transport deposit is visible in front of the Ikpiugalik delta, measuring 1 km wide by 1 km long (Figure 4). Future analysis of these mass transport deposits will provide a hazard assessment of the fjord, and will be combined with subaerial landslide susceptibility assessment previously completed (Eamer et al., 2022). A total of 10 gravity cores were collected from 4 landslides in Grise Fiord, their locations shown in Figures 5, 6, 7, and 8.

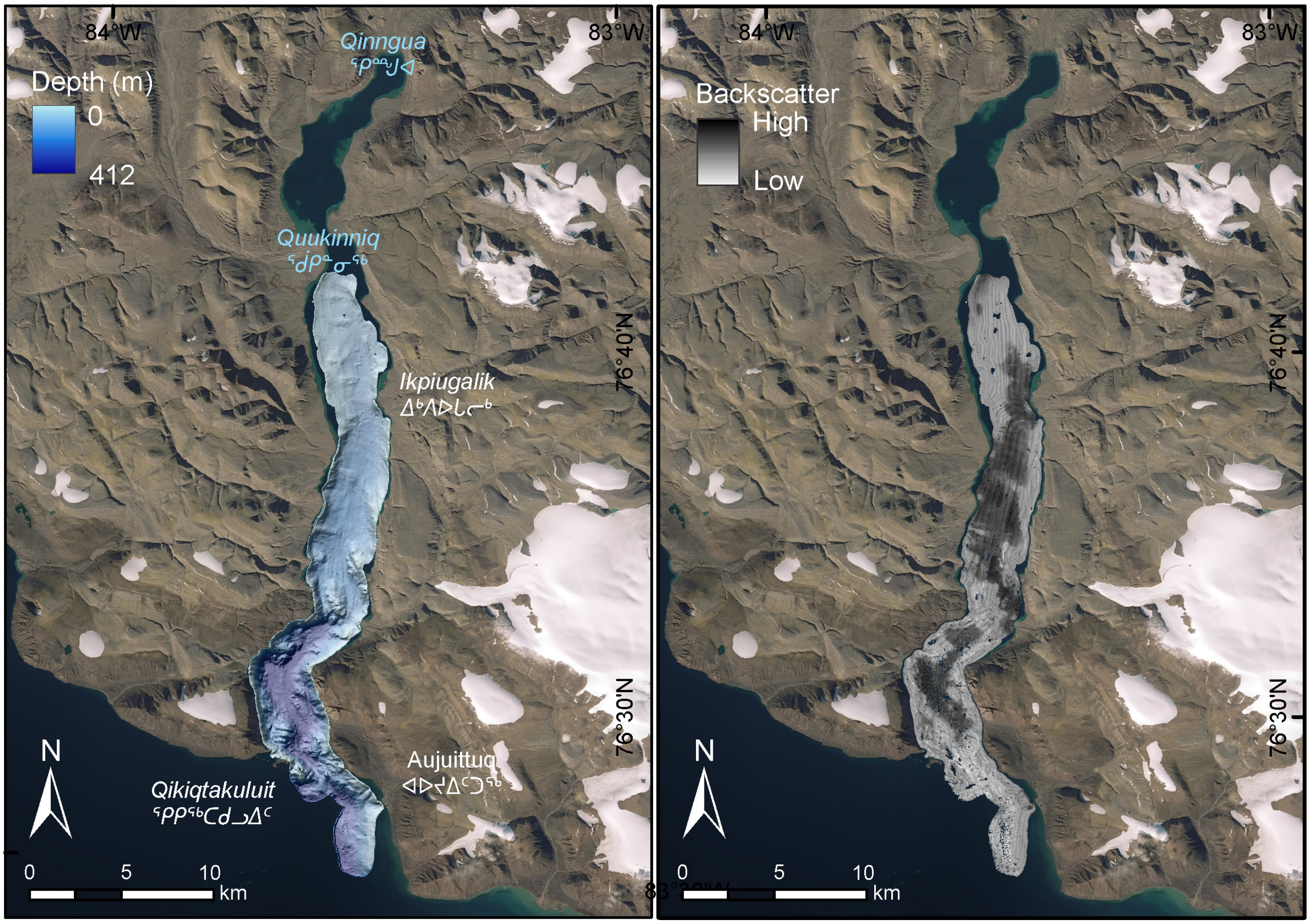

Figure 3. Overview of the bathymetry (left) and backscatter (right) of Grise Fiord.

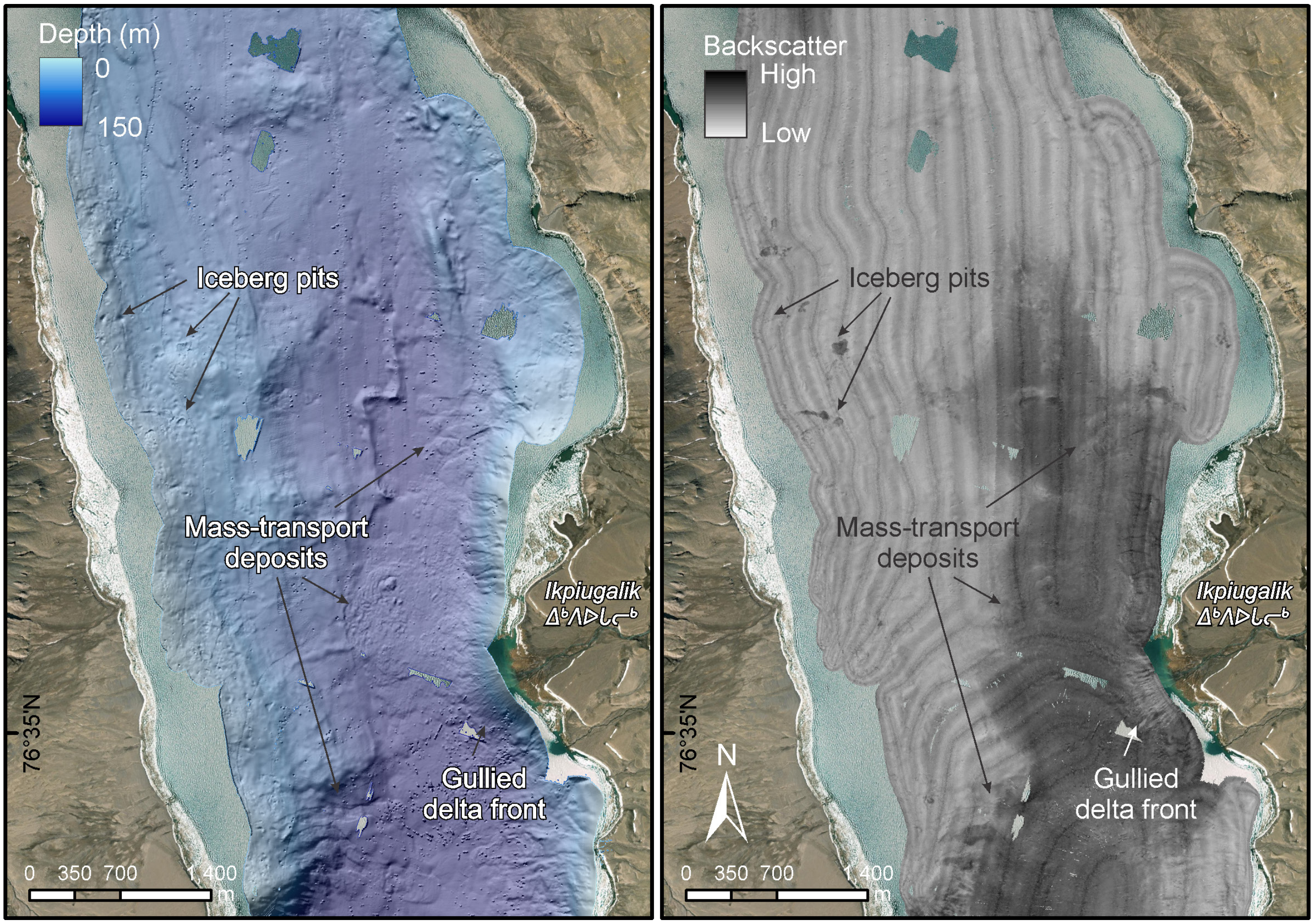

Figure 4. Geomorphological features on the seabed of Grise Fiord illustrating mass transport deposits, iceberg pits and a gullied delta front.

5. Daily narrative

5.1 JD 229 – Wednesday, August 17 - Ausuittuq

The day was spent in community meetings with members of the HTO and hamlet, to plan research and community visits to the RV Nuliajuk, which arrived in the afternoon and anchored offshore. An initial attempt to ferry community members to the vessel was abandoned due to weather conditions, but chief scientist took the opportunity to board the Nuliajuk and begin mobilization. Following Kirk Regular's detailed instructions (Appendix C), a new GPS antenna was installed and all hardware/software was calibrated and tested, with no significant issues noted.

5.2 JD 230 – Thursday August 18 – Ausuittuq/Grise Fiord

On the morning of August 18, we hired a local boat to ferry visitors to and from the Nuliajuk. The sea state was not appropriate for the vessel zodiac to be used – local knowledge proved very important for landings in Grise Fiord and is recommended for future work in the area. Once all those who wanted to visit the vessel were back on shore, the remaining science crew were ferried to the ship and work began with a CTD cast to correct the multibeam echosounder data. This was done at 2152 UTC in 70 m of water depth at 76.41559 N, -82.90500 W. The multibeam was turned on at 2215 UTC and good data collection was immediately observed. Seventeen lines were completed in front of Ausuittuq into JD 231.

5.3 JD 231 – Friday August 19 – Grise Fiord

After a few lines to create seamless coverage between the community bathymetry and the fiord, lines 20 onward were in Grise Fiord. A few large grounded icebergs meant there were a few holes in the data that had to remain unmapped. We decided to separate the lower fiord (the surveyable area) into 4 sections for efficient line surveying. After Charlotte took over, she determined that lowering the frequency of the echosounder to 210 kHz (e.g., not all the way down to 200) resulted in a significant reduction of noise when surveying in water depths close to 400 m. However, the swath width was reduced as well so water deeper than 350 m result in fairly narrow swaths (and lots of lines). While inefficient, it is largely the result of surveying at the outer bounds of the specifications of the EM2040. The first section was completed by line 65 at 1300 UTC. Line 81 included a safety drill, so there was

no new line and the track deviated from the planned trajectory. The third section of the fiord was started on line 86.
Spare time during the day shift was spent preparing the coring equipment for deployment. Everything was found in good working order and well packed, except for the wype-all paper towels which were exposed on deck and the majority soaked. On crew change, the science crew went through the coring procedure, where all the equipment was located (BIO and Nuliajuk-owned), and cleared space for processing and storing of cores.

5.4 JD 232 – Saturday August 20 – Grise Fiord

A few icebergs left some other holes in the data that were later filled when the icebergs moved. At 0400 UTC, the navigation started to lose satellite fixes, and this manifested itself as "red" on the SIS interface. Chief scientist was woken up to troubleshoot, but it was simply due to shadow from being adjacent to a fiord wall – it soon remedied itself (and was still producing valid data, just with a higher uncertainty). We went over this part again to re-collect multibeam data and develop a better bathymetry model with no GPS issues. By 0645 UTC, we were starting the fourth section of the fiord (the final, northernmost section). Mid-day Saturday, we had some time to discuss the plans for the rest of the survey. Although we had originally planned to collect data until JD 234 (Monday), boarding the vessel in Ausuittuq proved to be sea-state conditions- and tide-dependent that we didn't want to leave it to a single high-tide cycle as originally planned. So, because progress was good, we planned to return to Ausuittuq a day early (JD 233) to make sure we had enough opportunity to get everyone off the vessel safely. This was particularly relevant considering the extended shifts the crew of the RV Nuliajuk had agreed to in order to enable this work.

5.5 JD 233 – Sunday August 21 – Grise Fiord and Ausuittuq

Coring began early on JD 233. Four landslides were targeted based on preliminary interpretation of the bathymetric data collected on this expedition. Targets for three of the slides were in the depositional lobe and downstream of the lobe, and the fourth slide, a complex slide with multiple glide planes, was targeted on two different depositional lobes, the glide plane, and downstream of the slide in the basin. Coring operations were generally smooth, with the hauler and handling of the rope being used for deployment and retrieval of the core (rather than simple rope friction on a cleat for deployment, which has been used previously). Following the successful recovery of 10 cores (Appendix A), we transited back to Ausuittuq. We used the transit back to fill holes in the bathymetric surface and also to increase coverage in front of the community. By noon Sunday we were demobilized and off-ship.

6. Equipment and procedures

6.1 EM-2040 multibeam echosounder

The Kongsberg EM2040 is a single head hull-mounted system (Table 3). It was run at various frequencies between 210 and 400 kHz during the entire cruise with HD equidistant, meaning that 400 beams were separated by equal distance. The swath width used was 120°. Throughout the *2022Nuliajuk* expedition, the EM2040 multibeam echosounder proved to be a functioning system up to a limit of approximately 400 m water depth. Between 350 and 400 m data started to get noisy, however reducing the frequency as low as 210 kHz (and not all the way to 200 kHz) proved to be helpful in reducing noise. Beyond 400 m, no bottom tracking was possible.

Table 3: Specifications of the EM2040

Beams	400 (HD Equidistant)
Frequency	200 kHz – 400 kHz, frequently varied at increments of 10 kHz
Swath	Greater than four times water depth
Max Swath Angle	120 degrees
Depth Range	10 m to ~400 m

6.2 Coring

The coring device used was a mooring system gravity corer with a 1.5 m long barrel. This system performed better than the larger diameter Geological Survey of Canada built gravity corer previously used on the vessel (see Normandeau et al., 2019). The main reason for its better performance is probably the smaller diameter of the barrel. Unlike the GSC-built corer, the liner that is used has an inside diameter of 2 5/8” and an outside diameter of 2 7/8”. The gravity coring system head and barrel are made of galvanized steel and can hold up to six lead weights. On the *2022Nuliajuk*, we used 6 lead weights (four “gravity corer” weights at 20 kg each and two “piston corer” weights at 25 kg each) which totaled 130 kg. The core head includes stabilizing fins which help with penetrating the seabed at the correct upright angle. A one way-valve is located inside the core head and barrel which allows the water pressure to escape through the top of the core head while the gravity core is being lowered into the seabed. When the gravity core is retrieved and winched out of the seabed and back to the ship the one way valve closes and keeps the sediment intact.

A small DMW marine knuckle crane on the top deck was used to position the samplers over the side and had a hydraulic winch with wire running through a small block that provided the lift point. A 5/8” poly rope was used through a hydraulic net hauler to provide the deployment and recovery means for each sampler and run through the crane block. A minimum of 2 vessel crew and 1 science crew were required on the deck during the operations. An additional crew member on the upper deck was useful when available for providing signals to the crane operator who did not have direct visual contact with the primary deck crewmen below.

In general, the coring operations were successful. Only one attempt resulted in a lack of recovery. However, it should be noted the large discrepancy between apparent penetration and sediment recovery (Appendix A). This, along with the lack of sample recovery in the cutter and catcher, suggests that the coarse sediment generally caused a great deal of liner friction when filling the liner, and despite apparently sinking the full 150 cm barrel in 7 of 10 attempts, no more than 110 cm of sediment was ever recovered.

Deployment speeds were varied as well, but difficult to measure and keep consistent as we were not using a real oceanographic winch or wire. Continuing the practice of vertical core extrusion discussed on the *2019Nuliajuk* cruise report (Normandeau et al. 2019) was successful – the setup on the Nuliajuk is quite conducive to this method. This was done in order to preserve the orientation of the sediment and worked very well.

A total of ~7.6 m of sediment was obtained from 10 gravity cores. All cores were processed according to standard GSC Atlantic core procedures. The section ends were carefully capped to minimize disturbance to the sediment surface. The top end cap was labelled with the cruise number, station number, section label and as top. The base of the core is designated with the letter A and the top of the base section is designated as B. Each section was taken into the Wet Lab and stored vertically. Each core was processed using the following procedure. The core liner was labelled with an up arrow, cruise number, station number, section label and the top and base of the section were labelled with the appropriate letter. The section length was measured and recorded. The ends were then waxed with beeswax and secured to the lab bench.

The sealed core sections were stored upright in the WetLab. The WetLab is temperature controlled and the cores were kept at ~10°C. All station location information, core section lengths, extruded pieces and cutter/catcher lengths, core performance information and all relevant field information were documented (Appendix A). The core sections were stored in the below-deck bow section of the ship, kept above freezing due to the proximity to the engines.

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Appendix A: Station summary

Table 4. Summary of core stations in Grise Fiord, Nunavut. Note the lack of seismic control (none collected) and that no core catcher/cutter samples were recovered.

Station No.	Sample Type	J Day	UTC at Bottom	Lat Bottom	Long Bottom	Water Depth (m)	Corer length (cm)	App. Penetration (cm)	Core length (cm)	Comments
0001	GC	233	1:33	76.62908	-83.25692	101	230	200	87	LS_1_Downstream in section 4 (east side of the fiord)
0002	GC	233	2:20	76.62968	-83.25355	97.5	230	57	41	LS_1_Lobe in section 4 (east side of the fiord)
0003	GC	233	2:57	76.63664	-83.30589	108.71	230	70	88	LS_2_Downstream in section 4 (more up north on the east side of the fiord)
0004	GC	233	3:29	76.63768	-83.30356	105.53	230	200	71	L2_2_Lobe in section 4 (more up north on the east side of the fiord) Big lobe
0005	GC	233	4:21	76.58223	-83.1888	180.76	230	150	59	LS_4_Downstream in section 3 (Big double landslides on the west side of the fiord)
0006	GC	233	5:01	76.58352	-83.1949	179.43	230	150	98	LS_4_Lobe in section 3 (Big double landslides on the west side of the fiord)
0007	GC	233	5:30	76.58277	-83.21924	151.95	230	75	49	LS_4_GlidePlane in section 3 (Big double landslides on the west side of the fiord) The boat was moving while the coring
0008	GC	233	5:54	76.58285	-83.22316	136.73	230	150	117	LS_4_SubLobe in section 3 (Big double landslides on the west side of the fiord)
0009	GC	233	6:22	76.58587	-83.18459	174.16	230	150	75	LS_5_Downstream in section 3 on the east side of the fiord (Boat has drifted a little bit, might have been coring a the limit of the lobe)
0010	GC	233	6:43	76.58684	-83.18382	171.82	230	150	82	LS_5_Downstream in section 3 on the east side of the fiord

Appendix B: Core location

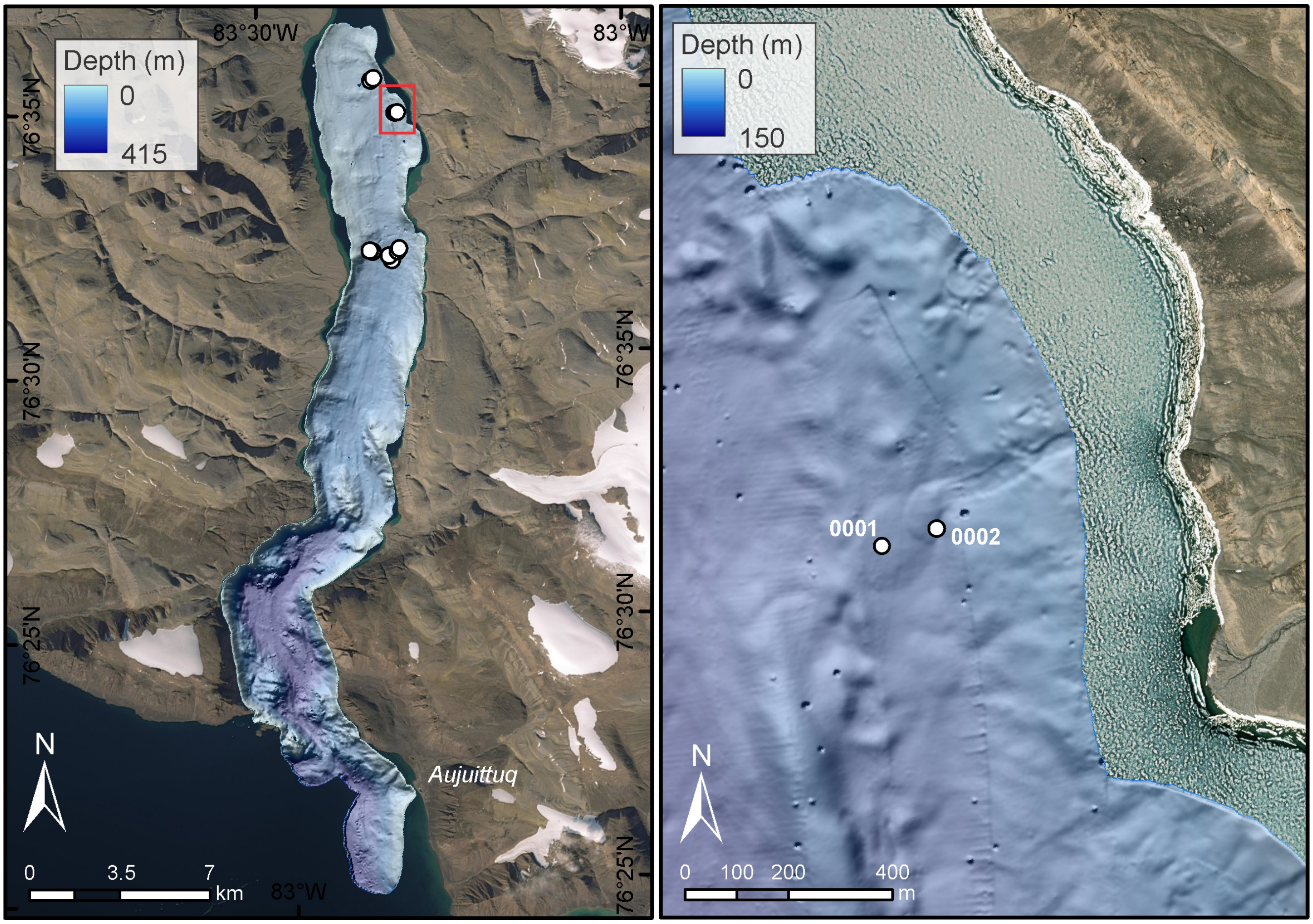

Figure 5. Location of cores 0001 and 0002

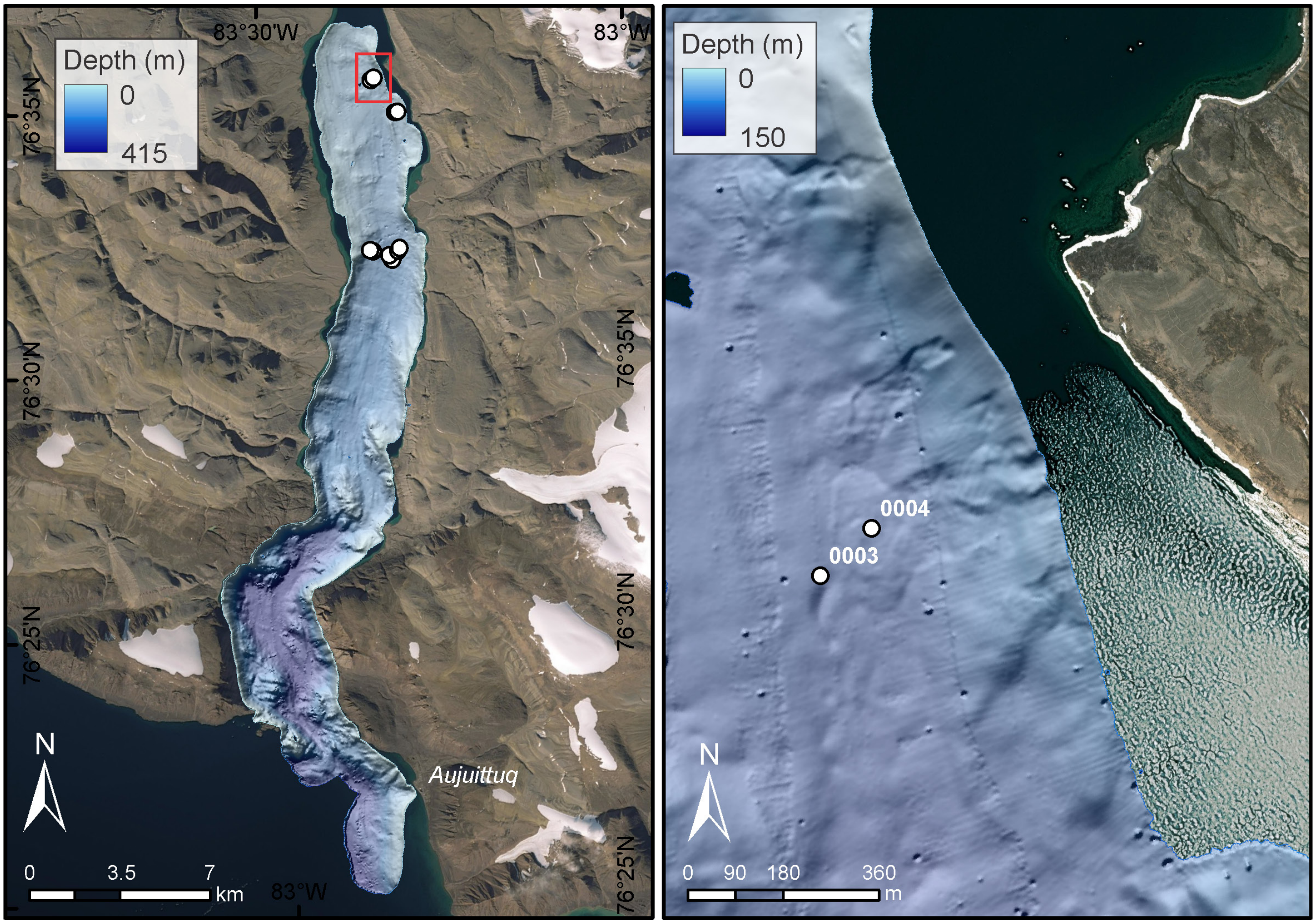

Figure 6. Location of cores 0003 and 0004

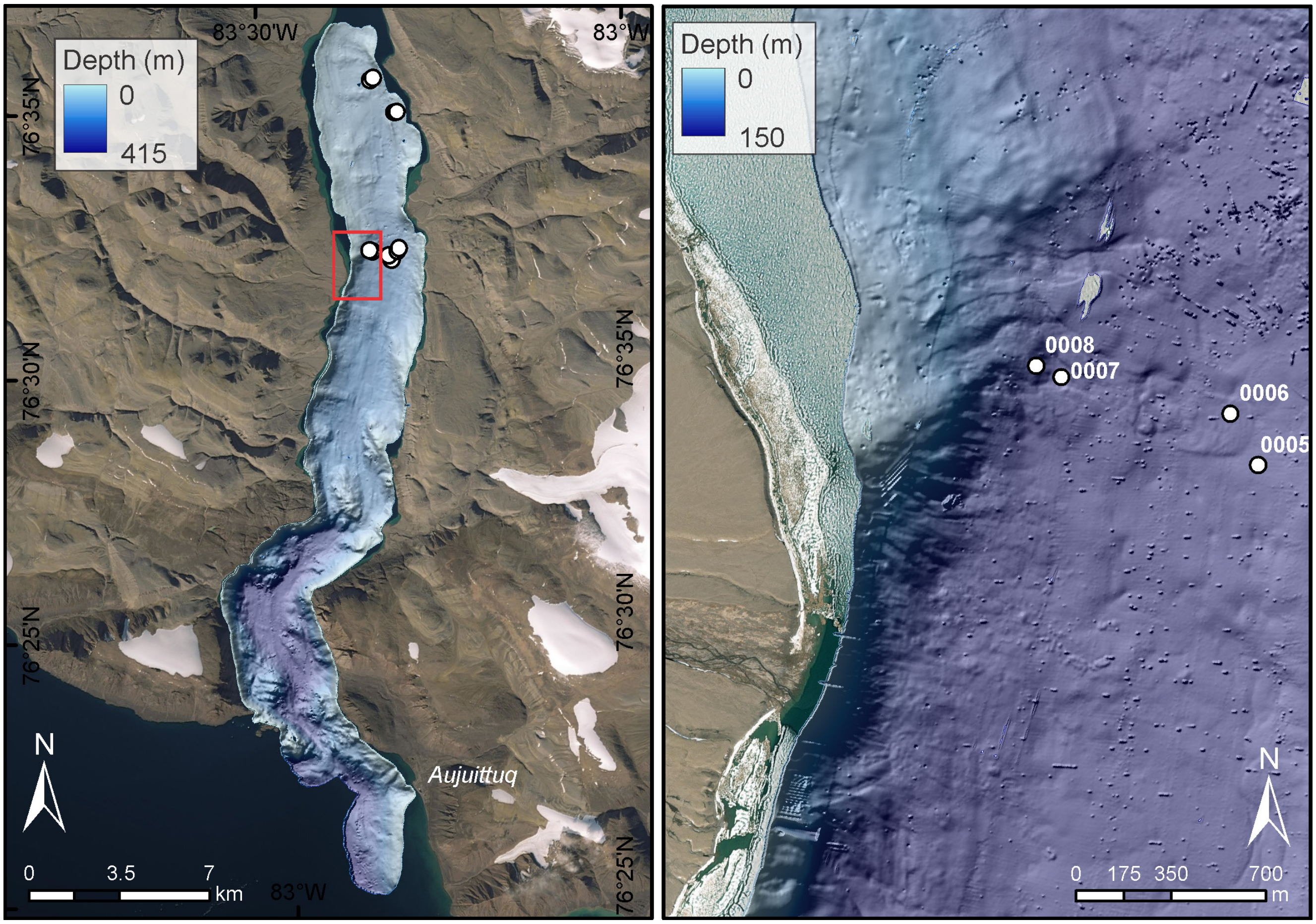

Figure 7. Location of cores 0005, 0006, 0007 and 0008

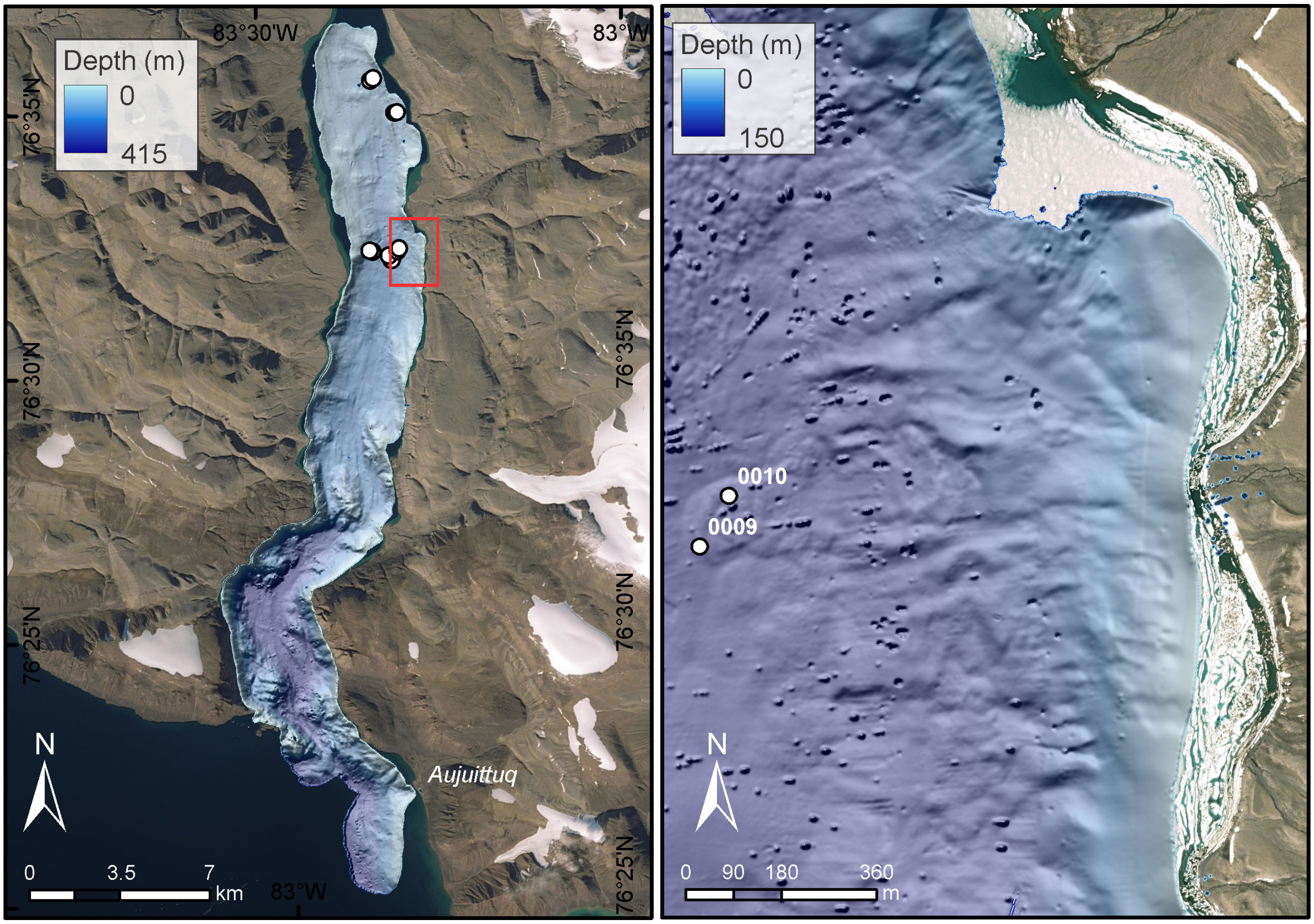

Figure 8. Location of cores 0009 and 0010

Appendix C: Nuliajuk equipment setup

The following, from Kirk Regular, is a bootup procedure for the scientific equipment aboard the Nuliajuk. This worked very well prior to 2022Nuliajuk. Note that equipment and software changes may render this outdated on future expeditions aboard the RV Nuliajuk.

- Turn on the C-Nav3050 GNSS sensor and ensure the antenna is plugged into the front of the unit.
- There are 3 computers at the Hydrographic workstation. Below left is the MBES computer, right is SBP and behind the right monitor is the navigation computer. Turn on each.
- The MBES computer runs SIS and controls the left 2 monitors. The top monitor is duplicated on the monitor to the right of the Helm. The SBP and Nav computers are both plugged into the lower right monitor because the top one is broken. You will have to toggle between computers using the monitor menu buttons (digital & analog connections).
- The mouse and keyboard are used for all computers and is switched at the box on the wall next to the door (behind the monitor). The buttons are actually covered by the labels for each computer.
- Power up the MBES and SBP processing units in the pelican case rack in the workshop next to the engine room. MBES will take a few minutes to boot and the LED should list EM2040C, Tx and RX ok and the IP address.
- The MRU/INS should already be turned on. It is in the crawl space next to the cabin and is powered up by the UPS on the wire track near the ceiling (this should be already powered on).
- You should be able to start SIS with everything working ok.
    - Select the EM2040C_10024 from the pull-down list at the middle top of the SIS interface.
    - Once connected the 3 lights to the right should all be green.
    - Check that all values in the numerical display look ok.
    - During the survey you would move the SIS display to the top monitor which will also display at the helm monitor
    - Use the View>Tear off menu to open “New Survey”
    - Run a BIST test from a tab of the View>Tear off “Installation parameters” dialogue box
    - The top left pull down has pre-defined display settings. Choose the one you like.
- Run EchoControlClient on the Sub-bottom Computer and make sure the GPS location is being updated
    - This is our 4 channel processing Unit but you can only run the 3.5 kHz
    - The coax cable to sync this PU to the MBES is not attached. If there is a lot of interference you will have to pull the rack down to the floor and check the back connections for sync out from the MBES to sync in on the Sub-Bottom.
- The Navigation should be running ok if you are getting all green lights on the SIS interface. To check the navigation you will have to switch the monitor to the Nav computer display.
    - Run C-Nav3050 software and connect the computer to the C-Nav box in the cabinet under the helm. You will have to run a USB cable across the floor to the cabinet as the IP connection will not work.