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Churchill River Ice Thickness from Ground Penetrating Radar

2024-2025 Ice Season

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Table of Contents

List of Tables

List of Figures

Executive Summary

On February 13, 2025, a river ice thickness survey was conducted over the Churchill River in central Labrador using a helicopter mounted Ground Penetrating Radar (GPR). The survey data were processed to determine ice thickness measurements along the flight path from Rabbit Island to Muskrat Falls.

Ground Penetrating Radar (GPR) is a geophysical remote sensing technique that uses high frequency electromagnetic waves to penetrate the shallow subsurface. The GPR operates by transmitting and receiving a high frequency radio wave that is reflected at the boundary of materials having different permittivities (the measure of resistance a medium has to an electric field), in our case, air to snow (if present) to ice (if present) to water. For river ice we could potentially see up to four interfaces: top of snow, top of ice, top of water and, depending on water-depth, the surface of the river bed. To undertake the river ice survey the GPR must be flown as close to the surface of the ice as possible.

The survey consisted of a pass upstream following the approximate center of the river. The length of the survey was almost 52 km. For the survey, only 436.56 m of 51,774.79 m (0.84%) could not be interpreted to provide ice thickness due to higher helicopter altitude. Of the 436.56 m of survey that could not be interpreted for ice thickness, 176.87 m was lost because the helicopter had to increase altitude to fly over the bridge, and the remaining 259.69 m was due to mistaken altitude increase, leaving 51,338.23 m (99.16%) of the survey with interpreted ice thickness data.

1 Introduction

A river ice thickness survey was conducted over the Churchill River in central Labrador, on February 13, 2025, using a helicopter mounted GPR. Figure 1 shows the section of river that was surveyed. The survey data were processed to collect ice thickness measurements along the flight path between Rabbit Island and Muskrat Falls on the Churchill River. The survey was conducted upstream following the approximate center of the river while attempting to avoid sandbars. The length of the survey was almost 65 km.

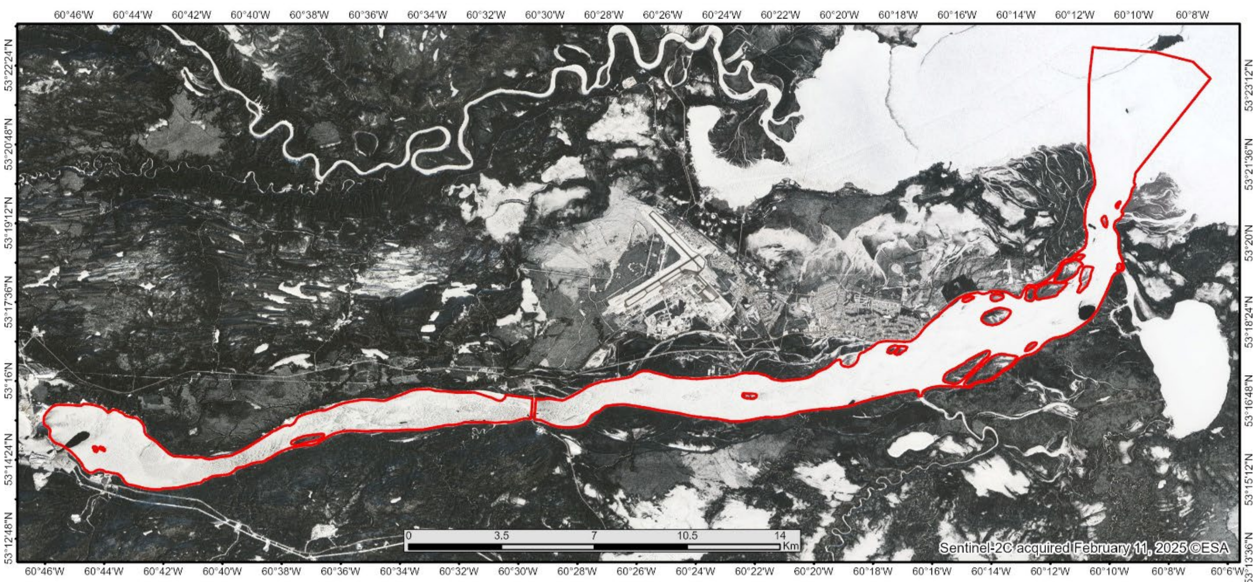

Figure 1. Churchill River between Muskrat Falls and Rabbit Island. The background image was acquired by Sentinel-2[1] on February 11, 2025 (Sentinel-1 European Space Agency (ESA) (2025)).

[1] https://sentinel.esa.int/web/sentinel/missions/sentinel-2

2 Ground Penetrating Radar

2.1 Overview

Ground Penetrating Radar (GPR) is a geophysical remote sensing technique that uses high frequency electromagnetic waves to penetrate the shallow subsurface (meters through to tens of meters). A schematic of a GPR system is shown in Figure 2. The transmitter emits a pulse of high-frequency electromagnetic waves into the ground or ice below the GPR. As the wave propagates down it is distorted due to the electromagnetic properties of the material it is passing through. At the interface between different materials, where the electromagnetic properties change abruptly, the signals may undergo transmission, reflection and/or refraction. A receiving sensor records the reflected waves. The GPR system then processes the transmitted and received signal and computes the amplitudes and travel times (Jol 2008).

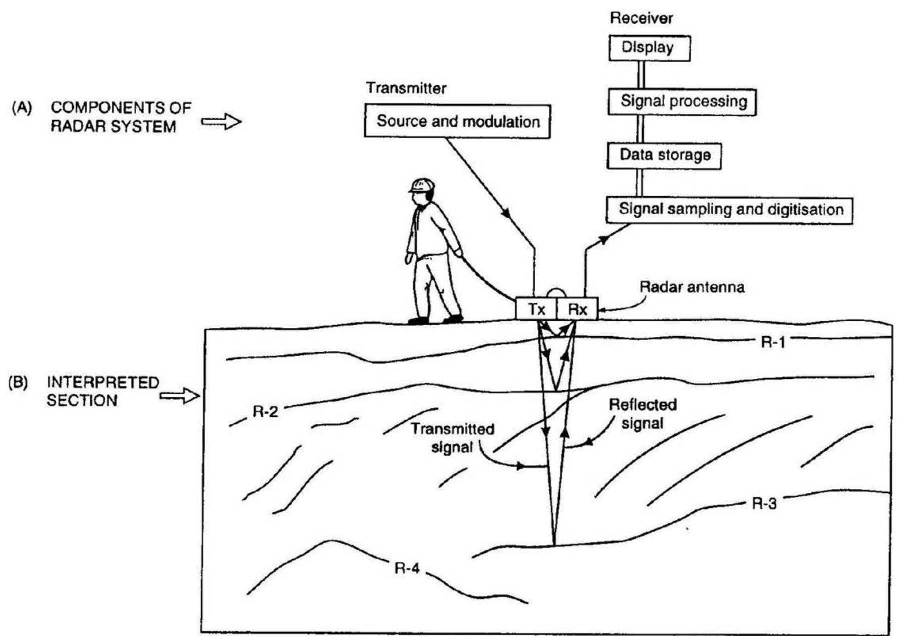

Figure 2. Schematic of GPR setup.

2.2 Noggin 500 System

The GPR that was selected to be used in this project was the Sensors and Software (S&S)[2] Noggin 500 GPR system. S&S GPR systems have been used in previous snow and ice studies, both over sea ice (Lalumiere and Prinsenberg 2009; Lalumiere 2006) and freshwater ice. This system has been used for river ice surveys for five seasons.

[2] Sensors and Software Inc. are a Canadian company that has been providing subsurface imaging solutions commercially since their formation in 1989. They develop and provide GPR based technologies enabling a worldwide client base to visualize and understand what lies beneath a range of materials such as rock, rubble, pavement, concrete, water, snow and ice.

The Noggin 500 system, shown in Figure 3, comprises:

1. The GPR unit;
2. Power/Data cable that connect the GPR to the battery and the DVL;
3. A handheld computer – Digital Video Logger (DVL) - for configuring and operating the GPR and for saving and exporting the data; and
4. Battery box (and charger) which powers the GPR and the DVL.

The DVL used does not carry an onboard system for acquiring positional data. As such, an external Global Positioning System (GPS) receiver was connected via an RS232 serial link to record positional data. The handheld GPS used in the survey was a Garmin GPSmap 65s. The GPR data are recorded, exported and processed as projects and lines; one project can have one or many lines. The data are managed in a database file structure.

Figure 3. The Noggin 500 system and external GPS used for the helicopter survey. Clockwise from top left, Noggin 500 GPR, power-data cable, Digital Video Logger (DVL) handheld GPS receiver with GPS serial data cable, battery charger and battery pack.

2.3 GPR Parameter Configurations

The GPR system is highly configurable so that it can be used for a variety of different applications. The configuration is defined by the operator changing various parameters and/or employing different modes through the DVL interface. The choice of those parameters and modes is a function of the type of survey to be undertaken (e.g., searching for deeper targets vs. shallower targets; performing a small [tens of meter square] grid-like survey vs. a long-distance track [many kilometers] survey) and the technical characteristics of the GPR. For example, the GPR has a limit on how fast it can gather data based on certain parameter configurations; if the operator is moving the GPR faster than that limit the target becomes under sampled. Under sampling was not an issue with the 2025 GPR survey.

A critical step in using the GPR system is to determine the optimal configuration for the survey being undertaken. There can be multiple optimal configurations depending on the altitude/speed that can be flown given the weather conditions. For the purpose of this helicopter-borne river ice survey, the optimal configuration shown in Table 1 maximizes the resolution at which the data can be collected while ensuring that the helicopter can fly at a speed that allows the proposed survey route to be covered within the available flight time and at an altitude and speed that is safe to operate.

Table 1. GPR settings.

GPR Parameter	Setting
Scan depth	10.0 m (124.4 ns)
Velocity	0.16 m/ns
Trigger	Free run (continuous, 58.525 km/hr)
Step size	1 m
Stacks	4
Traced interval	Continuous
Travel speed	58.525 km/hr
Gain	1

2.4 Helicopter Mounted GPR System

2.4.1 Helicopter

To undertake the river ice survey the GPR must be flown as close to the surface of the ice as possible; in general, a target altitude of 5 m is used. Custom Helicopters were contracted to perform the required low-level river survey using a Bell 407 helicopter.

Figure 4. Custom Helicopters Bell 407 at the Goose Bay hanger. The grey box on the front is the GPR mount enclosure.

2.4.2 GPR Hardware Mounting

The GPR must be mounted on the helicopter in such a way as to ensure there are no large metallic objects obstructing the antenna, which would block the radar signal. Mounting it similar to an external camera system was determined to be the most efficient manner to achieve this. The GPR mounting hardware attached to the helicopter is shown in Figure 5. The GPR is secured in a commercially available enclosure. The enclosure is attached to the helicopter using an Airfilm G1 nose-mounted utility bracket (G1). The G1 mount is a certified (with a Special Flight Operating Certificate) mounting system used for aerial videography that can be used on either the Bell 206L and the Bell 407 Helicopters.

Tests were performed to ensure that the enclosure did not interfere with the GPR signal (C-CORE 2019). These tests confirmed that there was no degradation or interference to the GPR signal due to the enclosure.

Figure 5. The GPR hardware is mounted inside the enclosure (grey box) using the G1 mount (black angled bracket), to the nose of the helicopter.

2.5 Processing the GPR Signal Data

Extracting ice thickness information from the GPR data is a labour intensive process. The GPR operates by transmitting and receiving a high frequency radio wave that is reflected at the boundary of materials having different permittivities (the measure of resistance a medium has to an electric field), in our case, air to snow (if present) to ice (if present) to water. The GPR receives and processes the signal, specifically the two-way travel time, from these reflections to produce a GPR trace of the interfaces of the materials that are below it. An analyst can then view the trace and make inferences about the material underneath.

The reflections from the interfaces between the different mediums are rendered as a white-black-white set. The number of interfaces below the GPR will dictate the number of reflection sets. For river ice we could potentially see up to four interfaces: top of snow, top of ice, top of water and, depending on water-depth, the surface of the river bed. The upper reflection is the top of the medium that is closest to the GPR, i.e., the first reflection the signal sees, so, in this case snow, ice or water, depending on the medium(s) below the GPR at that location.

The strongest reflection is usually from the ice/water or air/water interface, i.e., when the signal is reflected back from the water surface. The top of smooth ice is also a relatively strong reflector. Rougher ice is still a strong reflector but, depending on the spatial resolution and the surface roughness, the signal can become smeared. Snow can also be seen but, again, depending on the snow (age, moisture content, temperature etc.) it can produce a blurred interface. The oscillating vertical flow of the trace and reflections is an artifact of the helicopter changing altitude, even slight changes [< cm's] have a significant impact on the time it takes for the signal to travel from the GPR to the reflecting interface and back to the GPR. The more rapid the changes in altitude, the steeper the peaks and troughs, which in turn can increase the error in interpreting the data. As such, vertical stability of the airborne platform is of primary importance for acquiring good GPR traces.

The scale along the X-axis is the position in meters from when the survey/trace was started. This can be correlated to the GPS signal to give a thickness at a particular geographic position. On the left-hand Y-axis, the scale is in meters. In reality this scale is the two-way travel time (right hand X-axis). However, because the velocity of the radar signal through different mediums is known, the scale is usually converted to a distance/thickness. In this case, the conversion factor is 0.16 ns/m, the speed of the signal in ice. The spacing between the vertical ticks equates to 20 cm ice thickness. By identifying the top of the ice and the top of the water the ice thickness can be estimated.

To extract the ice thickness data from the GPR data, an analyst, using the EKKO software, must identify and trace a polyline along the interfaces that are the upper (top) and lower (bottom) surfaces of the ice Figure 6. This identifies the depth of the interfaces from the GPR data. Once the polylines have been created along the length of the survey, they can be exported out of the EKKO software and, using Geographic Information Software (GIS), the ice thickness can be computed by subtracting the depth of the upper interface from the depth of the lower interface.

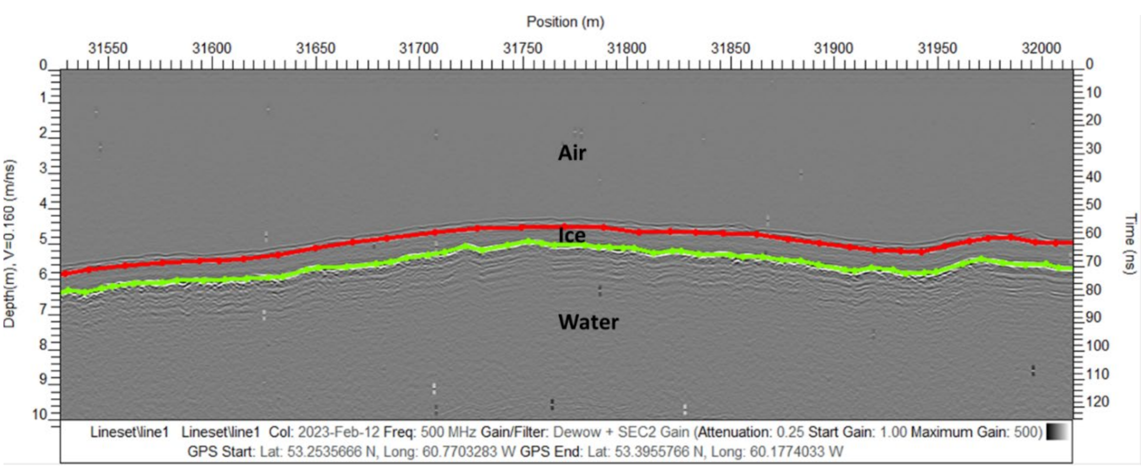

Figure 6. Radargram of a section of the Lower Churchill River ice cover.

Interpretation of the upper and lower ice interfaces depends on a number of factors:

- Presence or absence of open water along the survey track: stretches of water do not need to be analyzed;
- Presence or absence of snow cover and, if snow is present, the depth and type of snow;
- Surface roughness of the top of the ice;
- Sub-surface roughness of ice;
- Vertical stability of the helicopter as a platform, i.e., the speed and magnitude of unintentional vertical displacement. This is predominantly a factor of wind speed and direction and the required helicopter speed (to some degree it is assumed that pilot skill must be a factor also); and
- Specific to the Churchill River, presence of sandbars merging with the ice base.

Because of the manual aspect of analysis, the degree of interpretation is both a judgement call from the analyst and a cost-benefit exercise of detail required against the labour that must be consumed to produce the results, i.e., the analyst can perform a quick estimate to capture the general trend (smoothing the roughness) or a highly accurate tracing of the reflection. This will determine the amount of time required to analyze the survey line.

3 February 13, 2025, GPR Survey

On February 13, 2025 a GPR survey was conducted over the Churchill River between Rabbit Island and Muskrat Falls. Weather conditions on the day of the flight were partly cloudy, with temperatures ranging from -20 °C to -14 °C, and 12 to 21 km/hr winds from the southwest. Daytime maximum temperatures were below freezing seven days prior to the survey. Figure 7 shows the hourly temperature data from February 6 to February 13, 2025.

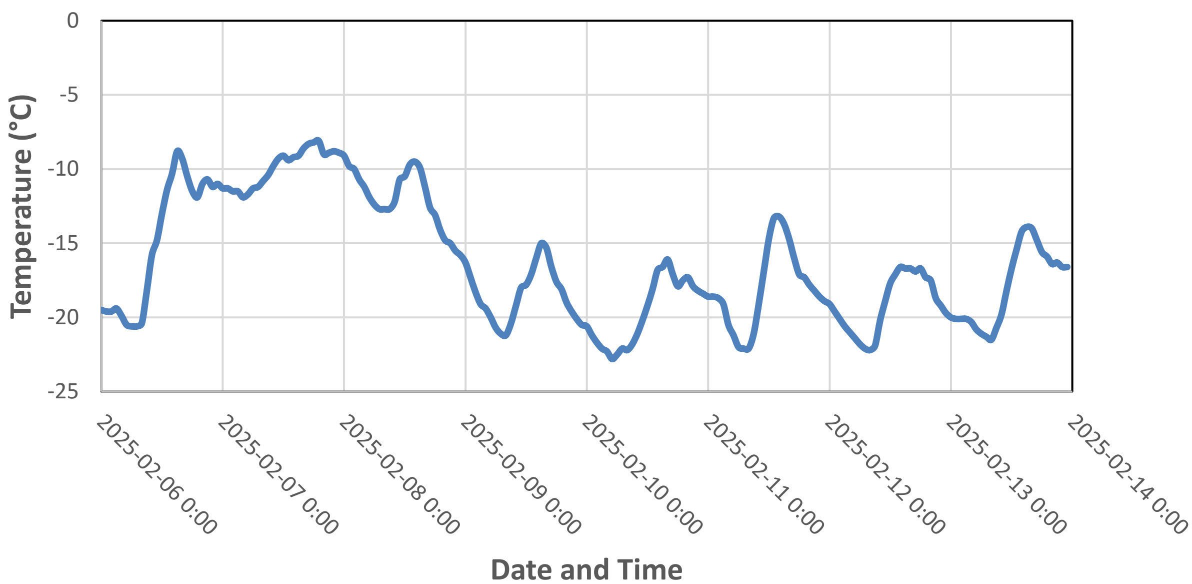

Figure 7. Hourly temperatures recorded at Goose Bay Airport, Labrador between February 6 and February 13, 2025.

The GPR survey started near Rabbit Island and continued to the Muskrat Falls Hydroelectric dam. The flight path is shown in Figure 8. The background image is from Sentinel-2 which was acquired February 11, 2025. The red outline indicates the section of the river being monitored for ice conditions.

Details of the survey are provided in Table 2. The helicopter pilot attempted to maintain a flight speed of 50 km/hr and an altitude of five meters during GPR data recording. The survey route was designed to avoid many of the sandbars. These sandbars were identified during a sandbar analysis using optical satellite image from Sentinel-2 conducted prior to the ice cover formation (CCORE 2024).

Table 3 contains snow and ice thickness measurements from the GPR data extracted from the locations where there SIMBA units had been installed in previous years (C-CORE 2023). Ice thickness measurements from the SIMBA locations are used with the Churchill River Flood Forecasting System[3].

The Churchill River near Goose Bay was experiencing lower snowfall accumulation this year as opposed to previous years. Figure 9 shows variation of the snow thickness on the ice.

Overall, the data collected during the February 13, 2025, GPR survey clearly showed the top and bottom ice boundaries. The moisture content of the ice was low, which allowed the GPR signal to penetrate through the ice over the majority of the survey. It was learned from previous surveys that it is important to conduct surveys in cold weather and prior to when water begins to flood the ice surface.

Only 436.56 m of 51,774.79 m (0.84%) was not interpreted due to higher helicopter altitude leaving 51,338.23 m (99.16%) of the survey with interpreted ice thickness data. The results of the GPR ice survey can be found on the Churchill River Ice Monitoring Application[4] as shown in Figure 10.

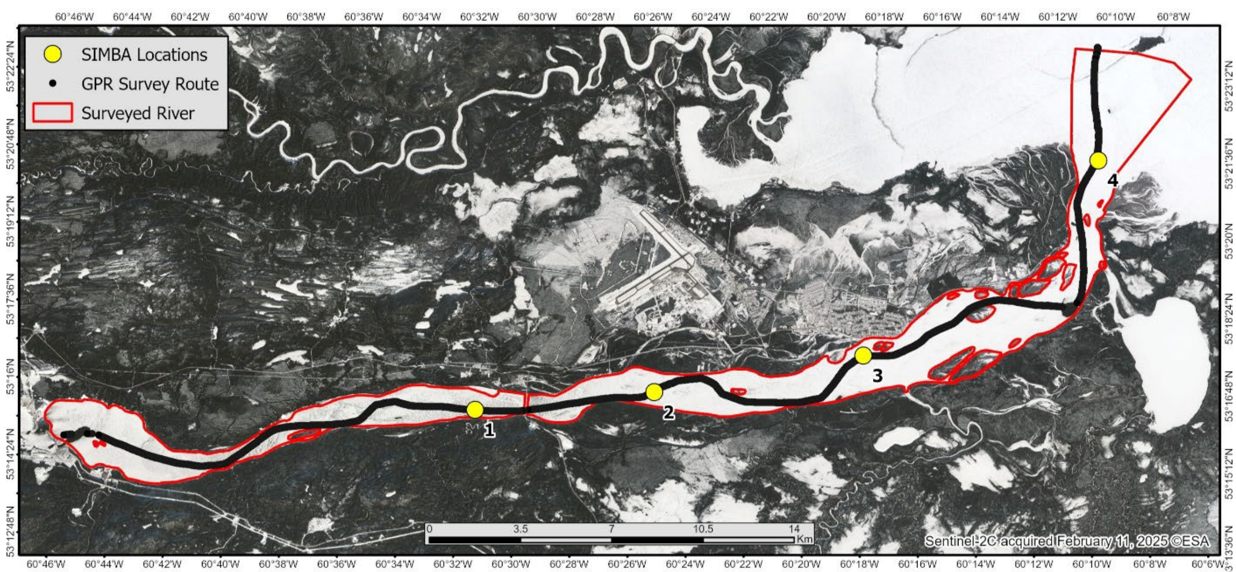

Figure 8. February 13, 2025, GPR survey flight path.

[3] https://www.gov.nl.ca/ecc/files/Churchill-River-Flood-Forecasting-System-1.pdf
[4] https://www.churchillriver.app

Table 2. February 13, 2025, GPR survey flight details.

Survey Details	
Date	February 13, 2025
Start Time (local)	10:00
End Time (local)	12:30
Weather	Partly cloudy skies, -20 °C to -14 °C, wind SW 12 to 21 km/hr
Survey Plan	Forecast was for partly cloudy skies. Survey began 1.25 km west of Rabbit Island and proceeded upstream to Muskrat Falls.
Helicopter speed	Approximately 50 km/hr
Helicopter altitude	4-6 m above the ice surface
Total length of collected GPR data	51,774.79 m

Table 3. Field and GPR snow and ice thickness measurements.

SIMBA Site Number	Distance between SIMBA location and GPR track (m)	GPR Snow Thickness (cm)	GPR Ice Thickness (cm)
1	13.6	0	63.9
2	41.1	0	52.6
3	28.8	0	70.5
4	96.6	0	77.7

Figure 9. The photo on the left shows the variation in the snow thickness and the photo on the right shows dark ice with virtually no snow.

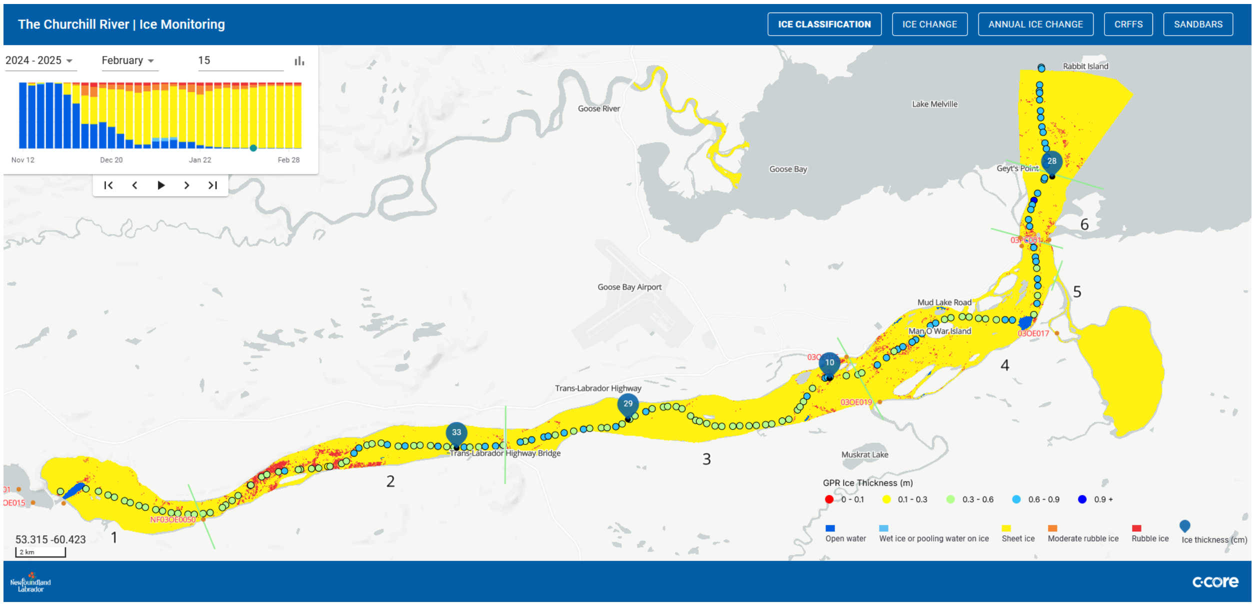

Figure 10. Results of the GPR ice thickness survey on the Churchill River Ice Monitoring Application (https://www.churchillriver.app).

4 Conclusions

Almost 52km of GPR data was collected over the Churchill River on February 13, 2025, using Ground Penetrating Radar mounted to a helicopter. The general trajectory of the flight track was along the center of the river from Rabbit Island upstream to Muskrat Falls. The survey route intercepted four SIMBA installation sites from past ice thickness measuring projects (C-CORE 2023).

The flight parameters required to survey using the GPR is to fly low altitude (about 4 to 6 m elevation) and at relatively slow speed (50 km/h). Custom Helicopters operate a Bell 407 was chosen to perform the GPR survey. In addition, because of the low altitude, the survey cannot be flown during cloudy conditions which make it difficult for the pilot of the helicopter to differentiate between the surface of the river and the horizon. Low wind speed is essential during GPR surveys because the helicopter is susceptible to vertical motion caused by windy conditions. The smoother the dataset, the easier it is to interpret and the more accurate the results. Cold, dry snow and ice conditions are essential to collecting useful GPR data. The quality of the GPR is significantly impacted as the moisture content of snow and ice increases.

The helicopter mounted GPR is an effective, safe field tool to quickly gather river ice thickness data over large areas. The Churchill River GPR ice thickness program should continue focusing on lessons learned from previous seasons, such as identification of grounded ice, sandbars, pooling water. It is expected that further experience in gathering and processing the data will improve the accuracy of generating the GPR thickness estimates.

5 References

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