Operational river ice monitoring: from earth-observation satellite imagery to in-situ measurements

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Introduction

Many northern rivers developing ice cover during the winter season are prone to ice-related flooding. In order to assess flood risk and mitigate its impact, it is imperative to monitor the river throughout the ice season, with particular emphasis on the freeze-up and break-up events. Operational monitoring is being undertaken on the Lower Churchill River in Labrador, Canada.

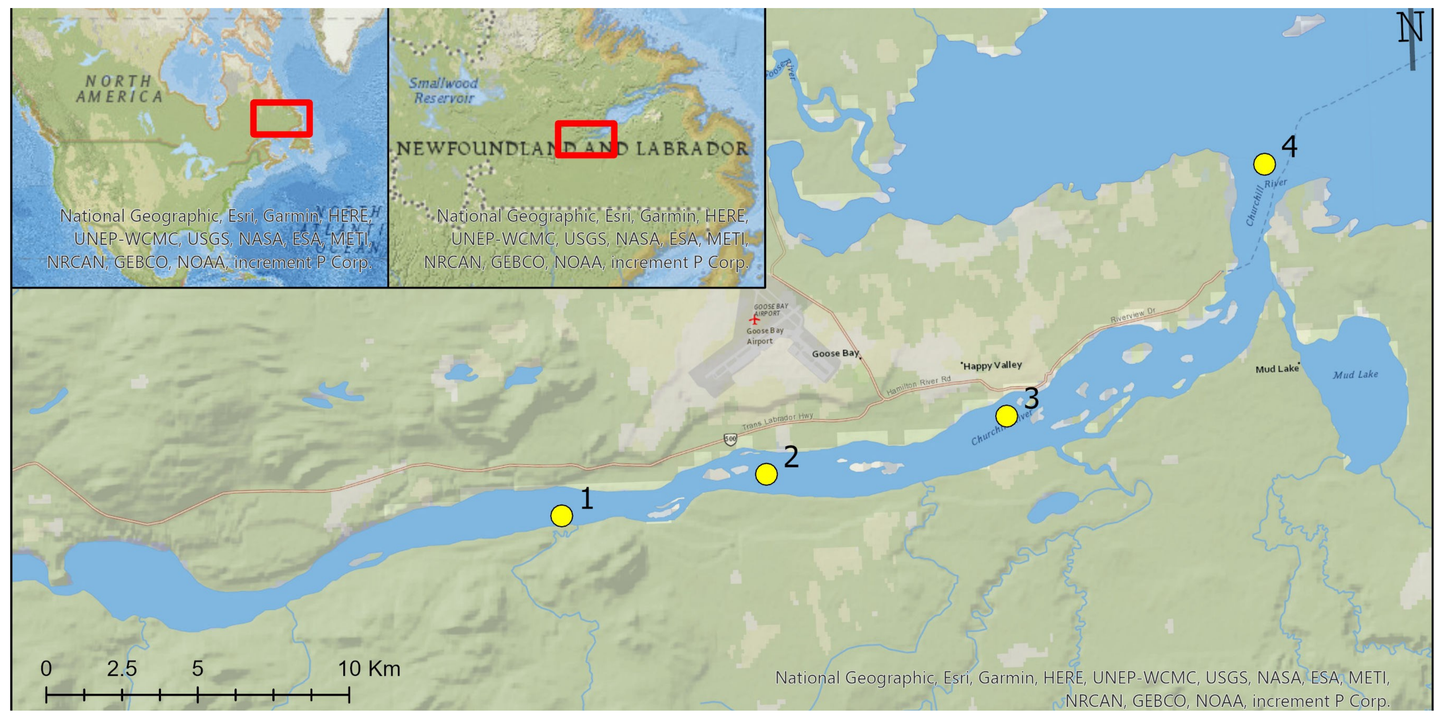

Figure 1. Location map of the Lower Churchill River in Labrador. The yellow dots indicate the locations of the ice monitoring units.

Key parameters required to assess the danger of flooding due to ice jams include location, extent and thickness of the ice cover. Satellite Earth Observation is a valuable tool to collect ice cover extent and surface roughness on river ice development over large areas, repeatedly and consistently throughout the ice season. Ice thickness is measured using two methods; ice thickness monitoring units installed in the ice provide frequent (every six hours) measurements at four locations and Ice (Ground) Penetrating Radar (GPR) mounted to a helicopter provides a complimentary ice thickness track along the length of the river. Combining these three-ice monitoring methods provides information to government and the public and serves as input to an active river ice forecasting tool

Ice monitoring units

Four key locations were identified on the Churchill River where ice thickness measurements are required as an input into a river forecasting tool. Scottish Association for Marine Science Research Services LTD ice mass balance array units were installed at each of these locations where air, snow, ice, and water temperatures are measured every six hours and transmitted via satellite. From these data, ice thickness is derived. The units are deployed and recovered from helicopter. Site visitations are not required between installation and removal of the units.

Figure 2. The photograph is of an ice monitoring unit installed at site number 3 (see Figure 1). The yellow case contains the hardware (Battery, CPU, GPS, Iridium transmission etc.). It is mounted on a raised pallet to reduce the risk of it being buried by a heavy snowfall. A string of thermistors is connected to the yellow case and attached to the vertical white pipe (in the foreground) that is installed into the ice through a borehole. The thermistor string subsequently freezes in situ such that a temperature profile of the air/snow/ice/water environment can be derived (see Figure 3).The system is usually recovered at the end of the season once the thermistor stings melts out but whilst the ice is still safe. It the unit cannot be recovered it has flotation such that it can be recovered from boat, if it survives the break-up.

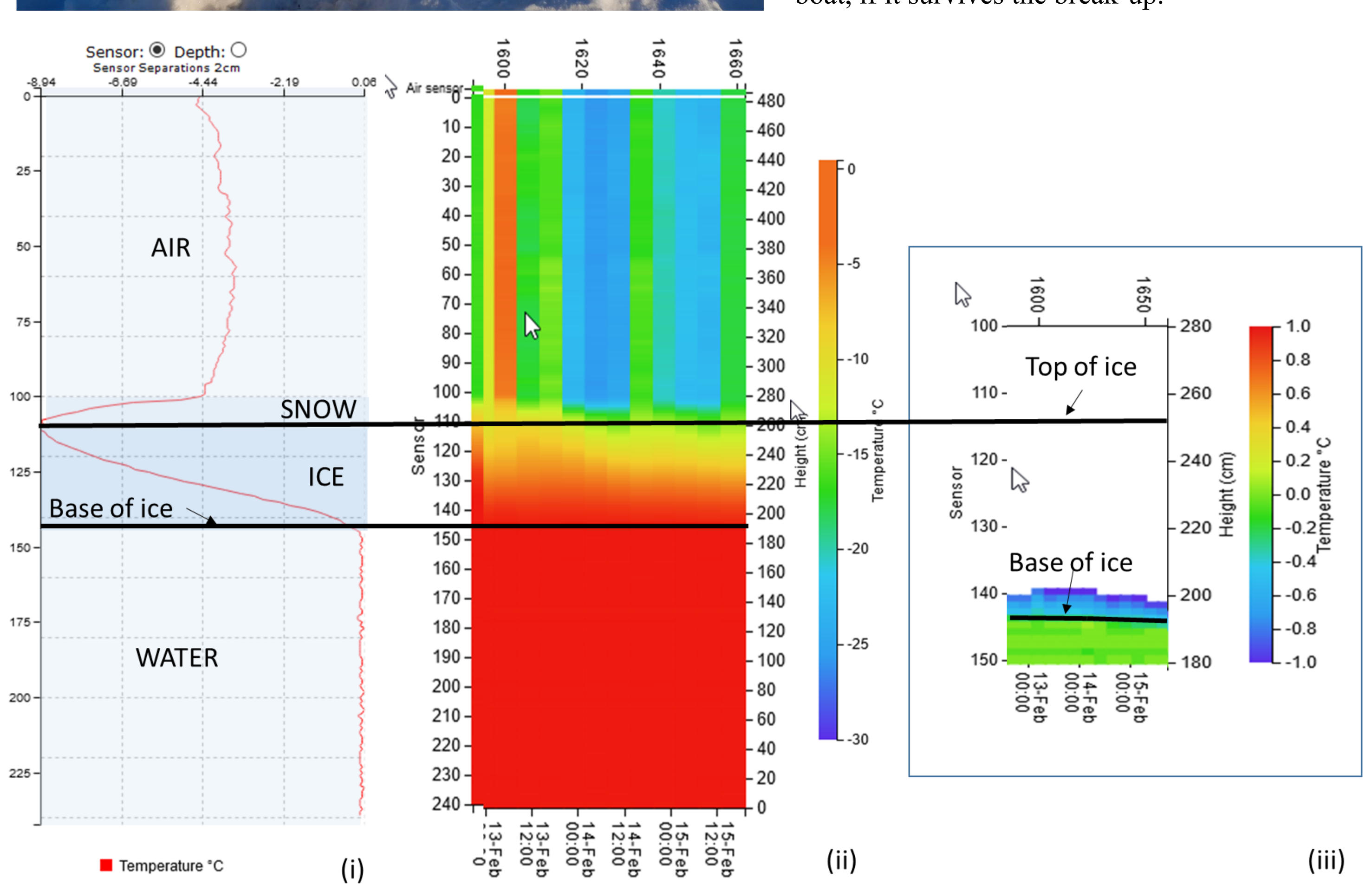

Figure 3. Interpretation of the temperature data from the ice monitoring buoy to estimate ice thickness. (i) A single temperature profile from 13FEB (2020) at 0700, with air/snow/ice/water environment labeled. The water is at freezing point. The air temperature is about -4.5°C. The temperature decreases from the top of the snow pack until the signal is inflected at the top of the ice. The top of the snow is at sensor #100 and the bottom of the snow/top of the ice is 10 sensors lower at #110 (sensor #110 was also known to be at the top of the ice upon installation of the buoy on 14JAN.) The sensors are spaced 2cm apart; the snow depth is therefore 20cm. The bottom of the ice is at about sensor #145, 35 sensors below #100; the thickness of the ice is therefore estimated to be about 70 cm. (ii) the individual profiles can be adjoined to create a time series, but this can be difficult to interpret due to the large range of temperatures caused by the diurnal cycles. The plot in (iii) has been zoomed-in to sensors #100 to #150 and the temperature display range shrunk to 1 to -1°C thus expanding the colour scale to aid in identifying the base of the ice.

Satellite products

Satellite river ice monitoring service uses methods of visual interpretation, automated image classification and change detection to generate products custom-tailored to user requirements. Image data sources include RADARSAT-2 and RADARSAT Constellation Mission provided by the Government of Canada and Sentinel-1 provided by the European Space Agency. These satellites combined, acquire images up to two times per day using synthetic aperture radar (SAR) C-band which is ideal for ice discrimination. SAR systems do not require daylight to operate and imagery is acquired in all weather conditions (in contra-distinction to optical sensors)

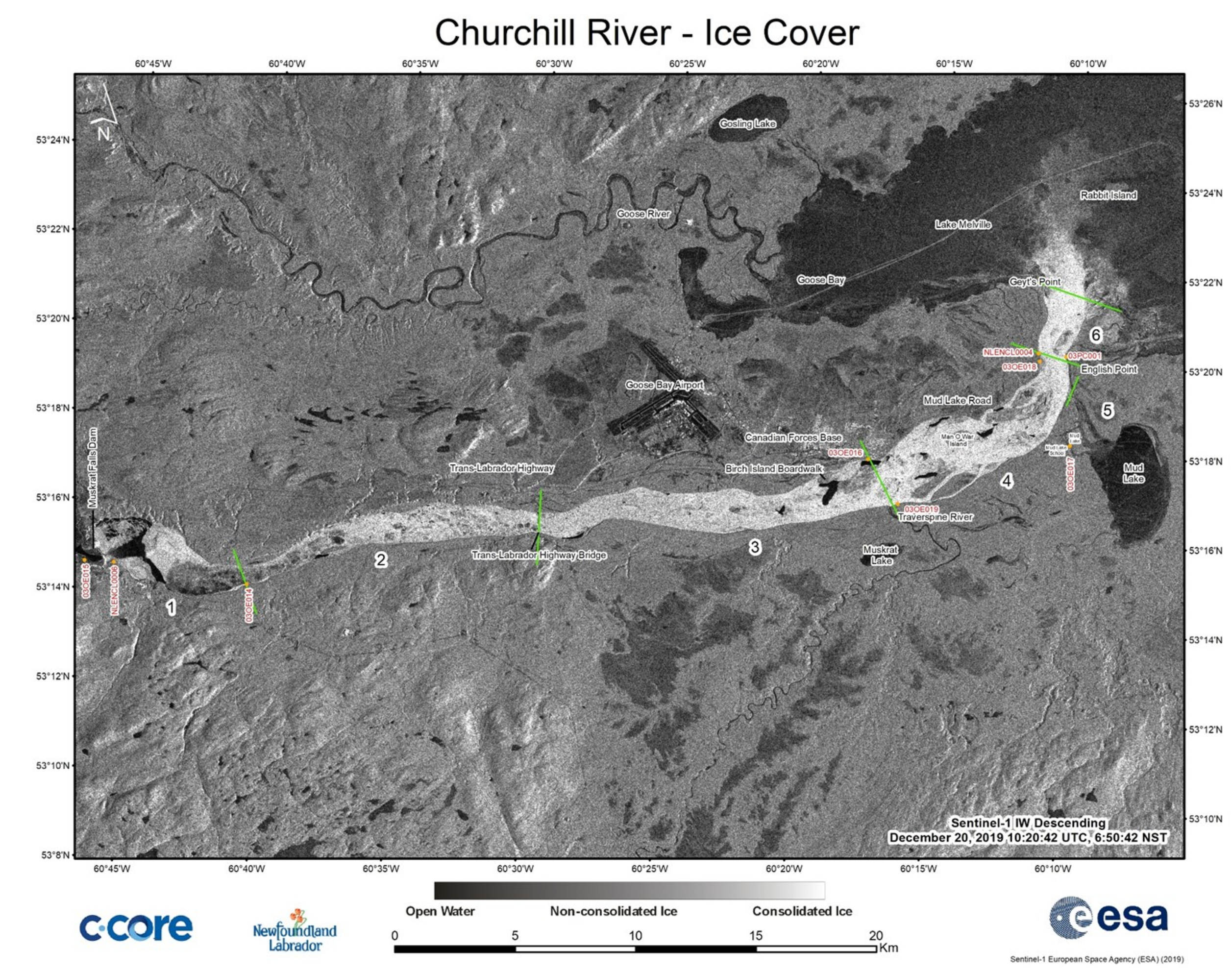

Figure 4. Ice Cover: The SAR ice cover product consists of a preprocessed SAR image enhanced to provide detailed ice cover conditions prior to ice classification and change detection analysis.

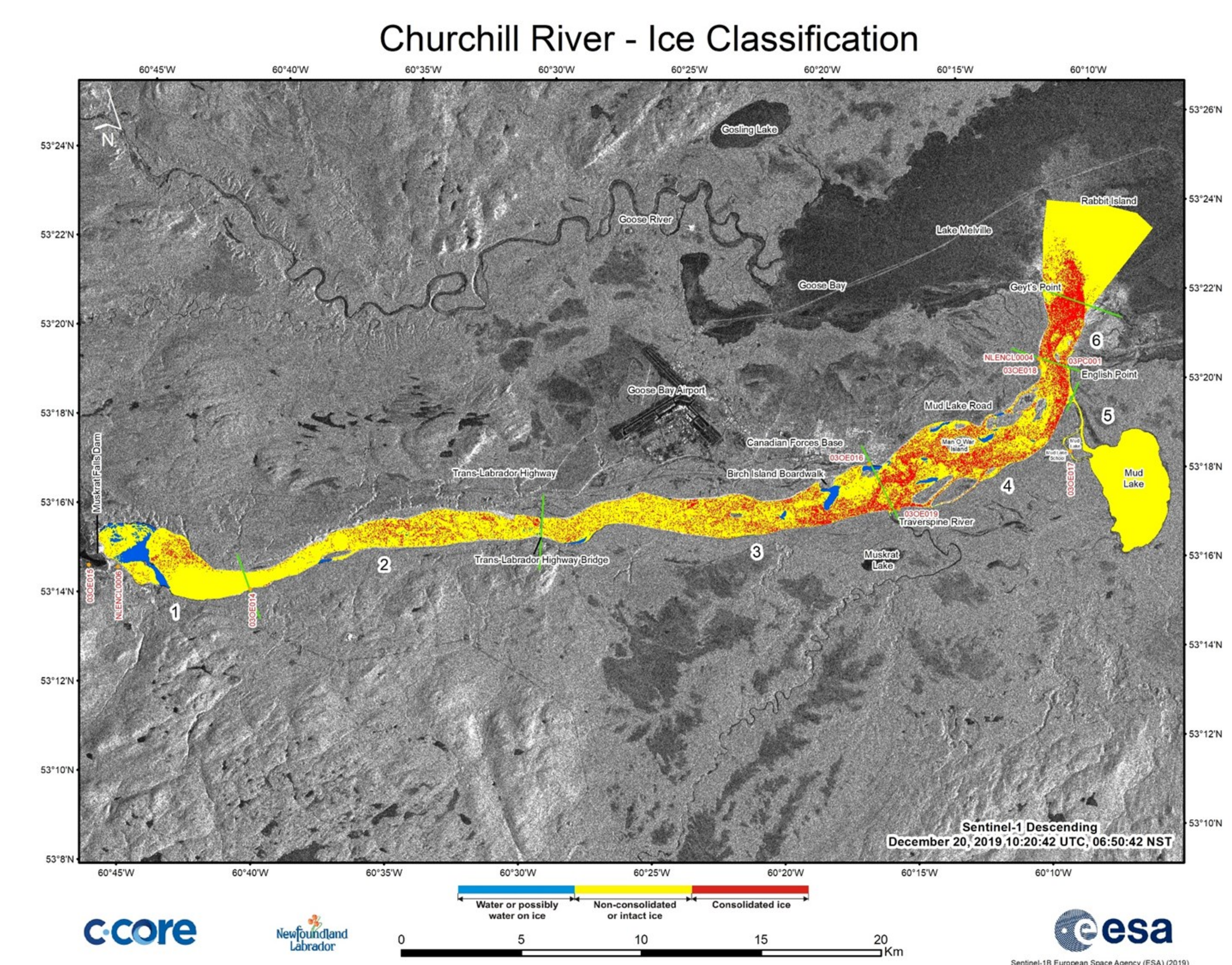

Figure 5. Ice Classification: SAR satellite image ice classification consists of three classes; open water, smooth ice and rough ice. These are measures of backscatter where low backscatter represents open water and increasing amounts of backscatter represent smooth to rough ice.

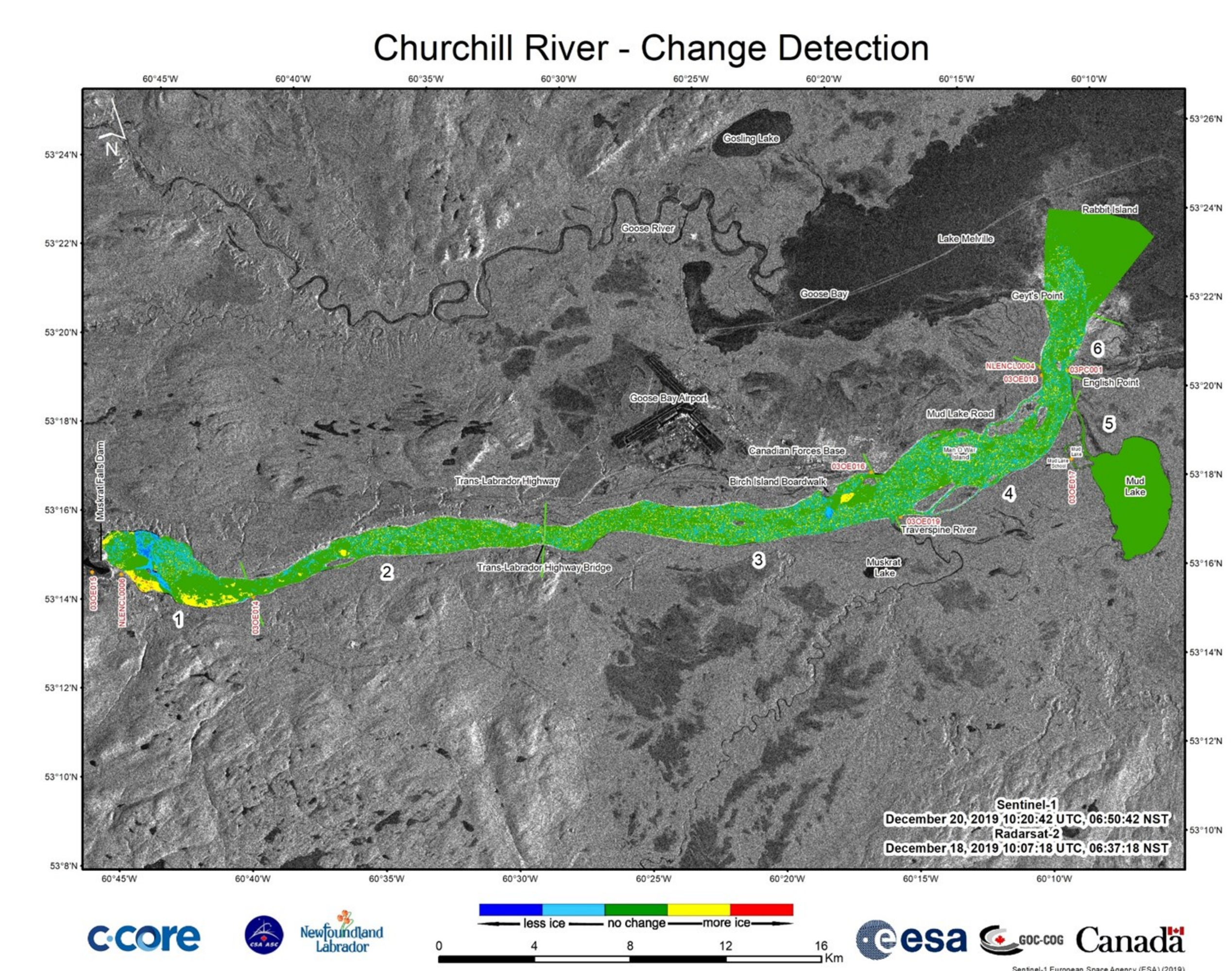

Figure 6. Change Detection: Change detection analysis is a subtraction between two consecutive ice classification products. It enables a user to visual the change in ice conditions.

Ice (Ground) Penetrating Radar

Ice thickness measurements are also derived from airborne ground penetrating radar surveys (GPR). GPR is a geophysical remote sensing technique that uses high frequency electromagnetic waves to penetrate the shallow subsurface (meters through to 10's of meters). At the interface between snow/ice and ice/water the electromagnetic properties change abruptly, the signals may undergo transmission, reflection and/or refraction. These boundaries are identified and the distance between them are determined to derive snow and ice thicknesses. Approximately 50 km of the Churchill River is surveyed in a 1.5–2 hr flight.

Figure 7. (i) Universal Helicopters Bell 206L, with floats, on the apron at Universal Helicopter's Goose Bay hanger. The grey box on the front is the GPR mount enclosure. (ii) GPR transmitter/receiver (yellow box) mounted inside the enclosure (grey case) attached, using a G1 camera mount, to the nose cowling of the helicopter (a side panel is attached to seal the enclosure prior to flight).

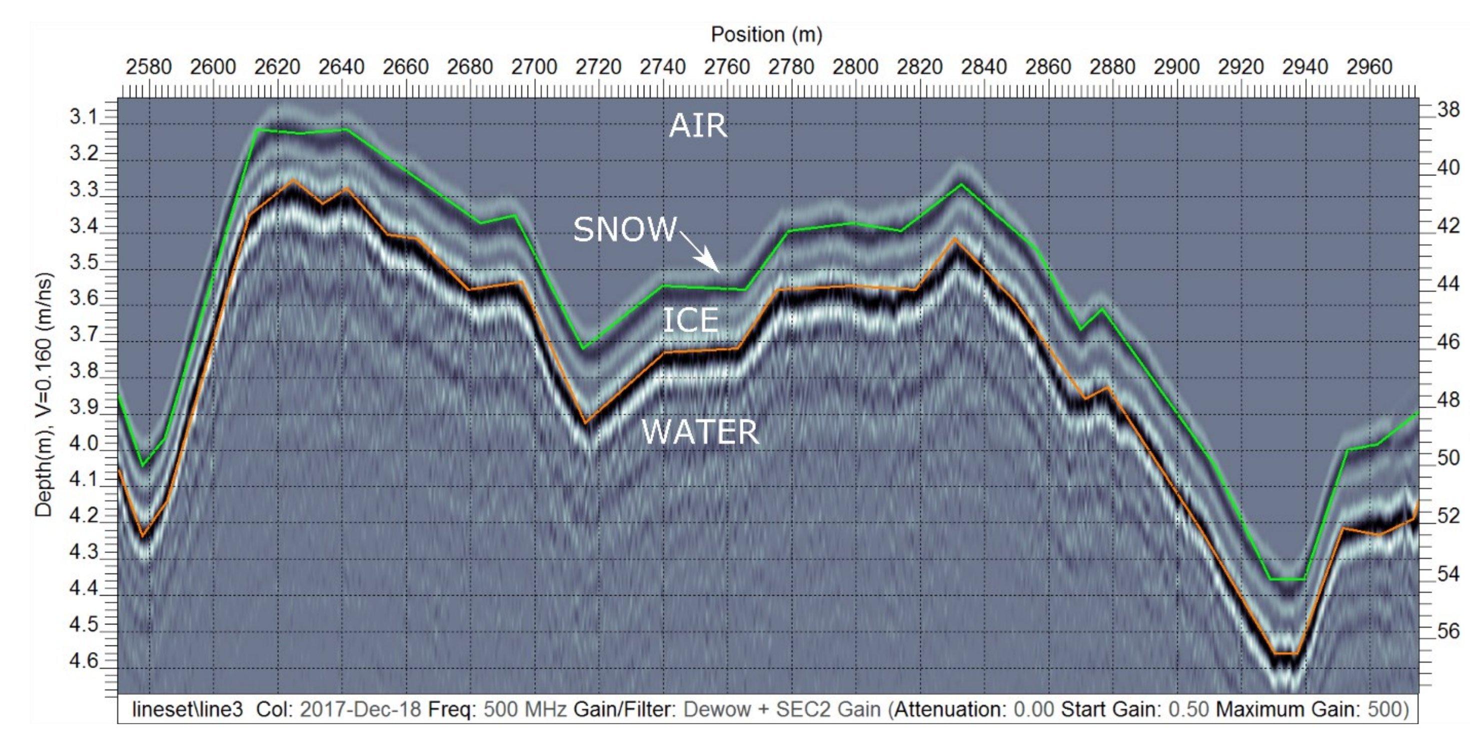

Figure 8. GPR data segment with interpretations delineating the interfaces. The green polyline indicate the top of the ice and the brown polyline indicates the bottom of the ice. Knowing the speed of the signal thorough the ice allows the ice thickness to be computed by calculating the travel time between the two interfaces.

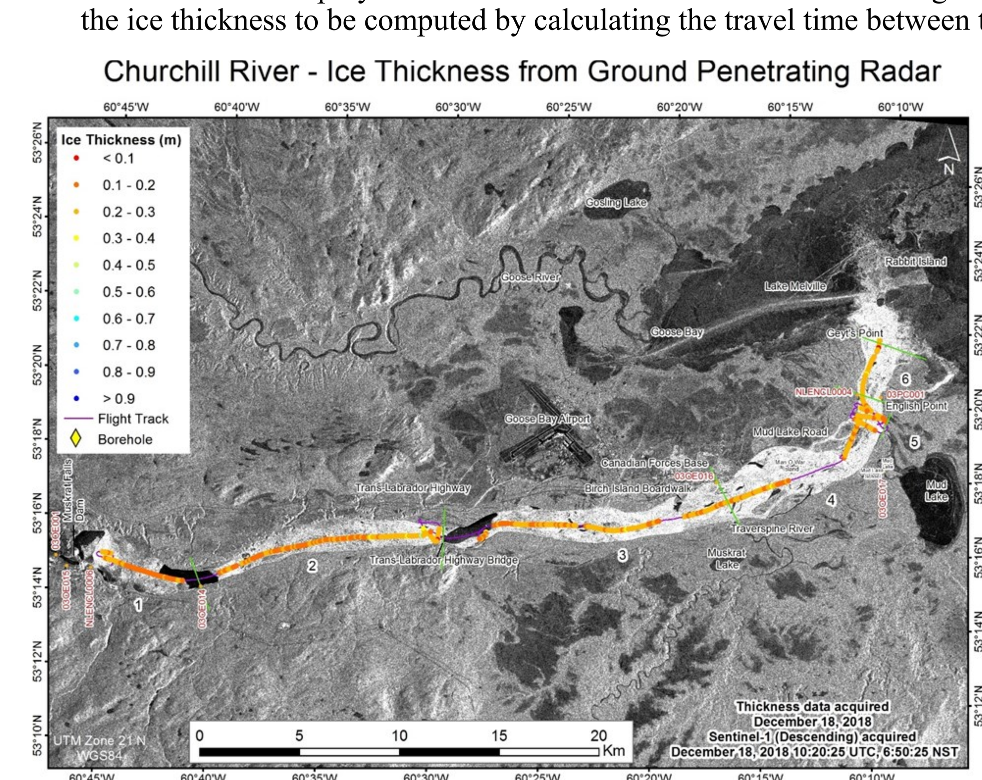

Figure 9. Ice thickness transect from the helicopter GPR survey performed on 18DEC (2018). The reds, oranges and yellows indicate that the ice thickness is around 0.1 to 0.3 cm. The black areas where there is no ice thickness data along the transect are patches of open water. Later in the season, once the snow becomes wet, or when there is pooling on the surface of the ice, it becomes challenging to recover ice thickness data from the GPR.

Product Delivery

The Churchill River Ice Monitoring project started in 2008 with the SAR products. They were made available to the public as linked files via a government website[1]. This delivery mechanism is still in place.

Since 2019, as the historical dataset has grown and the thickness datasets have come online, the river ice products have been added to the stream of services being offered thought the CORESIGHT system; an in-house developed geospatial platform that enables clients and stakeholders to better visualise and analyse their data. Visit churchillriver.app on any browser on any platform to view the live service and investigate the data (also shown in Figure 10). Note: this is a browser based service, an app does not need to be installed.

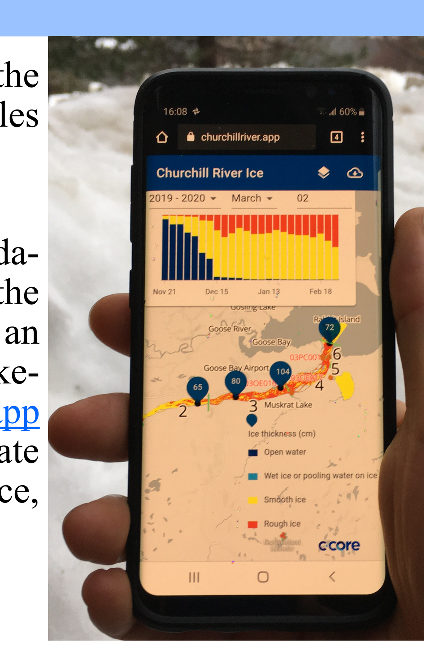

Figure 10. churchillriver.app being used in the field

The work has been made possible thanks to funding from the Water Resources Management Division of the Department of Municipal Affairs and Environment, Government of Newfoundland and Labrador

[1] https://www.mae.gov.nl.ca/waterres/flooding/lc_flood_warning.html