SEA ICE MONITORING SERVICES AT DECEPTION BAY, SALLUIT AND KANGIQSUJUAQ

KRG - Contract #: 2330

Final progress report 2019-2020

Report submitted to

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MINE RAGLAN UNE COMPAGNIE GLENCORE

KATIVIK

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TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

1. Project background and objectives

The project "ICE MONITORING IN DECEPTION BAY" was initiated in 2015 through a technical and administrative agreement between the Kativik Regional Government (KRG) and Raglan Mine, a Glencore company. INRS (under the leadership of Professor Monique Bernier) acted as a consultant to KRG and as a partner to the project. The work was also funded over 2015-2018 by Polar Knowledge Canada (Safe Passage Project). "SEA ICE MONITORING SERVICES AT DECEPTION BAY, SALLUIT AND KANGIQSUJUAQ" is a two-year extension of the project under a technical and administrative agreement between the Kativik Regional Government (KRG) and Raglan Mine, with INRS being contracted as a consultant by KRG.

The general objectives are:

- To improve our understanding of the diverse conditions of coastal ice with direct observations of snow, ice, oceanographic and meteorological parameters in real time, and indirect observations (satellite images, photographs, and traditional knowledge).
- To better understand the impact of icebreakers on the local ecosystem and the activities of northern communities by comparing ice formation and its structural features in Deception Bay with ice conditions in two other fjords without winter navigation (Figure 1).
- To maximize the impact of research for communities.

Figure 1: Location of the study area.

2. Project activities and deliverables

The planned activities are:

- Maintenance of the instruments (cameras, sonars) until 2020
- Continuation of the field measurements
- Installation of a Weather Station in Deception Bay
- Data analysis
- Involvement of local resources
- Installation of new real-time cameras
- Development of a website
- Development of an information tool

The expected deliverables are:

Table 1 : Deliverables for the contract extension

1. Real-time weather station in Deception Bay;	Installed in 2019.
2. Real-time cameras in Salluit and Kangiqsujuaq;	Installed in 2018.
3. Operational sonars and cameras in Deception Bay until the summer of 2020;	Still operating.
4. Deception Bay sonars and autonomous cameras removed in the summer of 2020 (if the project ends);	Removed in September 2020.
5. Freezing and melting dates and sequences and ice thickness measurements for the three sites up to the summer of 2020;	2017-2018 and 2018-2019 seasons were analysed in previous reports. **2019-2020 season presented in the present report.**
6. Local resources trained;	Local resources were involved during each maintenance or installation.
7. Operational website;	Website operational and up-to-date.
8. Information tool on ice conditions;	Dashboard operational
9. Annual report on the status of the project and the main results.	**This report is the last annual report for the contract.**

3. Project publications

Since the beginning of the project, three main reports were produced:

Gauthier, Yves; Poulin, Jimmy; Bernier, Monique (2016). Rapport de recherche (R1679). INRS, Centre Eau Terre Environnement, Québec. http://espace.inrs.ca/id/eprint/4846/

Gauthier,Yves; Dufour-Beauséjour,Sophie; Poulin,Jimmy; Bernier,Monique (2018). *Ice Monitoring in Deception Bay : Progress report 2016-2018* Rapport de recherche (R1792). INRS, Centre Eau Terre Environnement, Québec. http://espace.inrs.ca/id/eprint/7538/

Gauthier,Yves; Dufour-Beauséjour,Sophie; Poulin,Jimmy; Bernier,Monique (2019). *Ice Monitoring in Deception Bay : Progress report 2018-2019* Rapport de recherche (R1892). INRS, Centre Eau Terre Environnement, Québec. http://espace.inrs.ca/id/eprint/9674/

Two papers related to the project were published in 2020:

Dufour-Beauséjour, S., Wendleder, A., Gauthier, Y., Bernier, M., Poulin, J., Gilbert, V., Tuniq, J., Rouleau, A., and A. Roth (2020). **Combining TerraSAR-X and time-lapse photography for seasonal sea ice monitoring: the case of Deception Bay, Nunavik.** The Cryosphere, 14, 1595–1609, https://doi.org/10.5194/tc-14-1595-2020.

Dufour-Beauséjour, S., and Plante Lévesque, V.: **Our Practice of Outreach during the Ice Monitoring Project in Nunavik: An Eary-Career Researcher Perspective**, FACETS | 2020 | 5: 123–137 | DOI: 10.1139/facets-2019-0021 123.

A third paper has been submitted:

Dufour-Beausejour S, Bernier M, Simon J, Homayouni, S. Gilbert V, Tuniq J, Wendleder A, Roth A (2021). **RADARSAT-2 and TerraSAR-X signatures from snow-covered sea ice in Salluit, Deception Bay, and Kangiqsujuaq.** Submitted to *Remote Sensing* in December 2020.

Another paper is in preparation:

Dufour-Beausejour S, Gauthier, Y., in preparation. Monitoring ice cycles from satellite images in Deception Bay. To be submitted in 2021.

A PhD thesis has also been completed:

Dufour-Beauséjour, Sophie. **Suivi de la glace de mer par imagerie satellitaire radar, photographie automatique et mesures directes aux fjords de Salluit, de la baie Déception et de Kangiqsujuaq au Nunavik**. Thèse présentée pour l'obtention du grade de Philosophiæ Doctor, Ph.D. en sciences de l'eau, 2020. Soutenue le 30 octobre 2020 et acceptée.

The present report is the annual report covering the activities conducted between **September 2019 and December 2020 (The last year of the extension contract)**.

4. Schedule of Works

Table 2 : Planned schedule of works

Aug-Dec 2018	Jan-Apr 2019	May-Aug 2019	Sept-Dec 2019	Jan-Apr 2020	May-Dec 2020
Maintenance of instruments; data retrieval;	installation of new instruments		Maintenance of instruments; data retrieval; installation of weather station.		Maintenance or removal of instruments; data retrieval;
Training of local resources	Field measurements; training of local resources; activities with schools.		Training of local resources	Field measurements; training of local resources; activities with schools.	Final presentation to communities
Data analysis					
Website development			Development of the information tool		
		Annual report			Annual report
Travels to the sites (DB = Deception Bay; K = Kangiqsujuaq; S = Salluit)					
Visit DB – 1^{rst}	Visit BD – 2nd Visit K-S – 1^{rst}		Visit DB – 3rd	Visit BD – 4th Visit K-S – 3rd	Visit DB – 5th
			Visit K-S – 2nd		Visit K-S – 4th

5. Summary of achievements and results

5.1. Maintenance of the instruments (cameras, sonars) until 2020

- The September 2019 maintenance visit was described in detail in the previous report.
- The 2020 maintenance visit was conducted from September 26 to 28, conforming to complex rules and restrictions due to the pandemic.
- The camera present at Black Point and in front of Moosehead Island (paid for by Transport Quebec), were still operational and 2019-2020 photos were retrieved. With the maintenance contract between INRS and Transport Quebec coming to an end, the systems were removed. The real-time camera present at the Deception Bay Raglan Mine facility (paid for by Raglan) is still operational and has been left in place.
- In accordance with the end of the last phase of the ice monitoring project in Deception Bay, we have also removed the two underwater sonars (SWIP and IPS) during the September 2020 maintenance visit. Data were retrieved.

5.2. Continuation of the field measurements

- The May 2020 field visit was cancelled due to the COVID-19 pandemic. It was also impossible for our local collaborators to get on the ice and measure ice thicknesses.

5.3. Data analysis

5.3.1. Analysis of time-lapse photos for freeze-up and breakup processes

The dates presented here are determined through interpretation of the photos from the Panasonic camera near the port facilities and from the Reconyx cameras in front of Moosehead Island and at Black Point. It is not always clear when ice is moving or not and when water leads are frozen or not. Therefore, there may be some uncertainties when determining the exact freeze-up and breakup dates and interpretation may differ slightly from one interpreter to the other. It nonetheless gives a good qualitative portrait of the ice cycles in Deception Bay. However, in 2020, there was a problem with the server at INRS and we lost all photos of the Panasonic camera from March 3 to July 10. The breakup sequence in the bottom end of the bay is therefore unknown.

Table 3 summarizes the key moments of freeze-up and breakup for the 2019-2020 ice season in Deception Bay for three general areas illustrated in Figure 2. Freeze-up happens early December in the bottom of the bay (C) and progresses to Moosehead Island (B) and beyond (A) where freeze-up is complete in mid-December (Figure 3). Breakup started on June 20 and ended on June 26 (Figure 4).

Table 3: Summary of the 2019-2020 ice cover season in Deception Bay from the Panasonic camera

	First appearance of ice	**Final complete ice cover**	**First appearance of water**	**First water free of ice**	**Last ice observation**	**Ice duration* (days)**
Mouth of the bay (A)	Unknown	December 15, 2019	June 19, 2020	June 27, 2020	July 13, 2020	195
Middle of the bay (B)	December 2, 2019	December 14, 2019	June 20, 2020	June 26, 2020	July 12, 2020	195
Bottom end of the bay (C)	November 13, 2019	December 4 to 8, 2019	Unknown	Unknown	Unknown	Unknown

**Ice duration is the number of days between the final complete ice cover and the first day of water free of ice.*

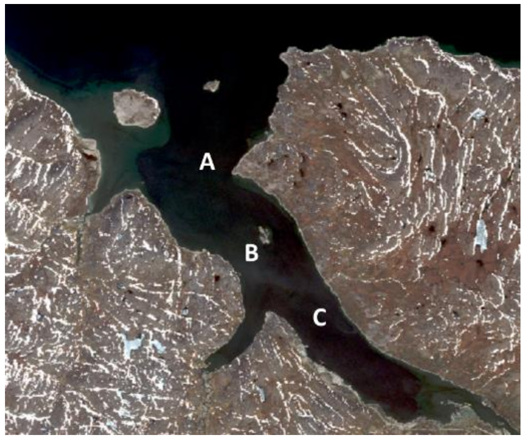
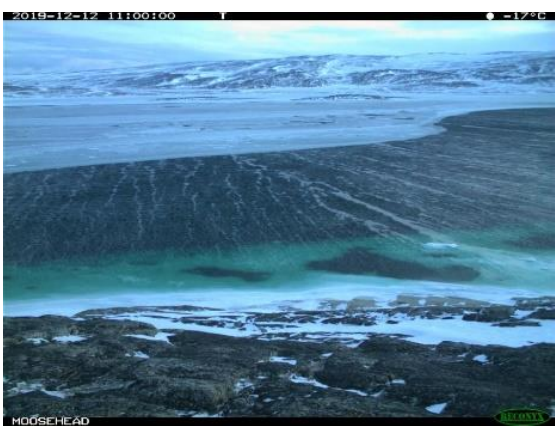


Figure 2: Deception Bay: Mouth (A), Middle (B), Bottom (C)

#1 – December 4

#2- December 8



#3 – December 12

#4 – December 14

Figure 3: Freeze-up sequence in Deception Bay in 2019. 1) Bottom end, 2) Bottom end to Middle, 3) Middle of the bay, 4) Mouth of the bay.

#1- June 20

#2- June 22

#3- June 25

#4- June 27

Figure 4: Breakup sequence in Deception Bay in 2020 in front of Moosehead Island.

In Figure 5 to Figure 7, we updated the year-to-year variation of the freeze-up date, breakup date and ice duration as determined from the time-lapse cameras. The year 2019 showed the latest freeze-up date of all observation years (Figure 5). Even with a late breakup (Figure 6), the 2019-2020 is still the second shortest ice season of our records with 195 days (Figure 7).

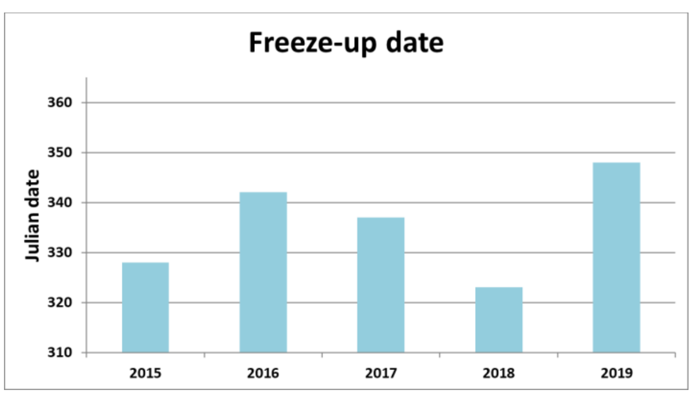


Figure 5: Year-to-year variation of the freeze-up date in Deception Bay

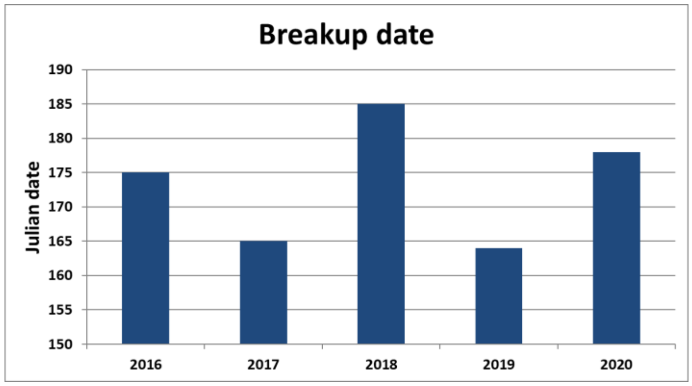


Figure 6: Year-to-year variation of the breakup date in Deception Bay

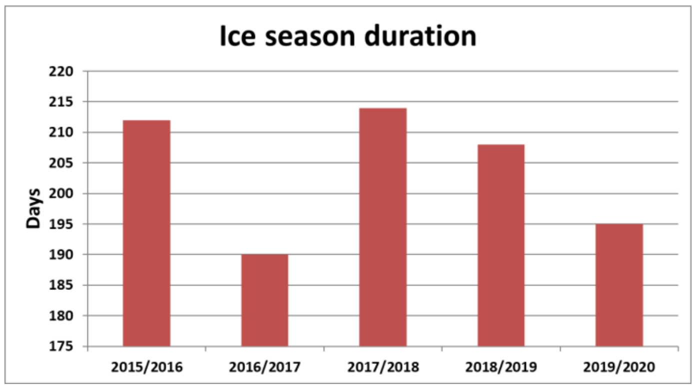


Figure 7: Year-to-year variation of the ice duration in Deception Bay

5.3.2. Snow/ice thicknesses

In last year's report, we presented graphs of the mean snow/ice thicknesses measured every year during the late April/early May field campaign (near maximum ice thickness) (Figure 8). As we were not able to access Nunavik in 2020 (COVID-19), no field measurements were performed in May and so we cannot update the graphs with the 2019-2020 season.

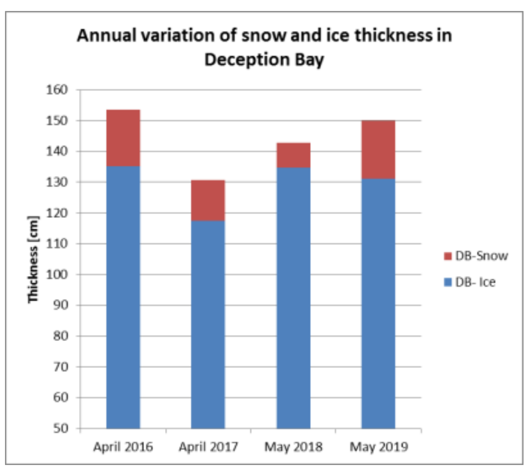


Figure 8: Year-to-year variation of the snow/ice thickness in late April/early May

5.3.3. Analysis of sonar data (2015-2019)

As fully described in previous reports, we have installed two underwater sonars to measure continuous ice thickness in Deception Bay. The shallow water ice profiler (SWIP) was installed in 2015 near Moosehead Island and the ice profiling sonar (IPS) was installed in 2016 in the area were the icebreakers manoeuver to turn around when approaching and exiting the docks. We retrieve the instruments every year for maintenance and data transfer and then put them back into the water.

The sonars acquire measurements every few seconds, which produces a tremendous amount of data, with a lot of noise. Processing the data is also complex, taking into account several parameters such as pressure, temperature, salinity, density and snow cover to calculate the ice draft and infer the total ice thickness. In "*Progress report 2016-2018*", we explained the theory and the data processing steps that we used and the results obtained for 2015-2016 and 2016-2017.

For the 2017-2018 and 2018-2019 data, the processing steps have changed. The instrument provider (ASL) has changed its processing software, enabling simpler and faster processing. It assumes a fixed atmospheric pressure and a sound speed correction. The software also use a predefine range of values for certain parameters. Figure 9 shows the range of values inputted to the processing software.

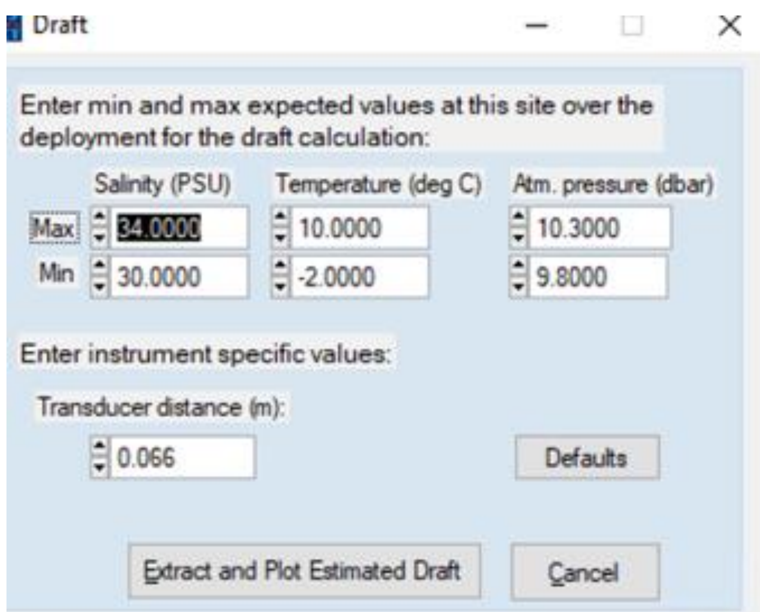


Figure 9: Range of values used for the processing of the sonar data

There is an enormous gain in processing time and lower complexity when using this software version but there is probably a trade-off in accuracy. The software produces ice draft estimates, and a graph with error bars reflecting how much the draft could change from the fixed case estimate (Figure 10). Before freeze-up and after break-up, the signal is extremely volatile and of no interest for us. When the ice cover is complete, the signal is more stable, but nonetheless containing some significant noise.

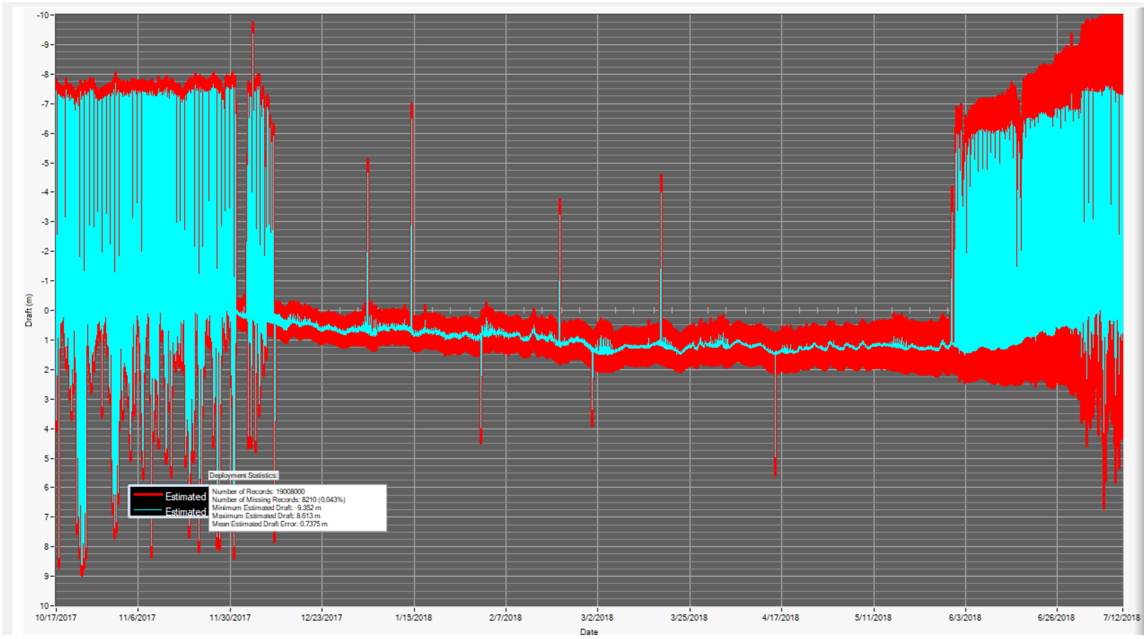


Figure 10: Example of the output from the processing software for the 2017-2018 SWIP data.

To reduce this noise, we have tested eight different filters on the ice draft time series: Daily average, Daily median, Daily max, Daily 95th percentile, Hourly average, Hourly median, Hourly max and Hourly 95th percentile. We consider that hourly or even daily ice thickness would be sufficient for the study. The filtered ice drafts were then transformed into total ice thicknesses using isostatic equilibrium theory. This requires information on snow-on-ice density and thickness and ice density. Those values were determined from the field measurements of 2018.

Here we present the ice thickness results for the SWIP and IPS data, from 2015 to 2019, using the simplified processing steps and the daily filters.

SWIP data

First, for each field campaign, we compare the ice thickness measurement nearest the instrument, with the SWIP ice thickness estimation on the same day, for the four daily filters (Figure 11). In case there was no measurement near the SWIP, we used an average of all measurements in the bay. The median filter provides the best results with a root mean square of 0,925, with a slight overestimation of the ice thickness. The maximum and 95th percentile filters tend to overestimate the ice thickness more significantly while the mean filter produce a lower R^2. These results indicate that the simplified processing steps, with a daily median filter, seem to produce realistic ice thicknesses.

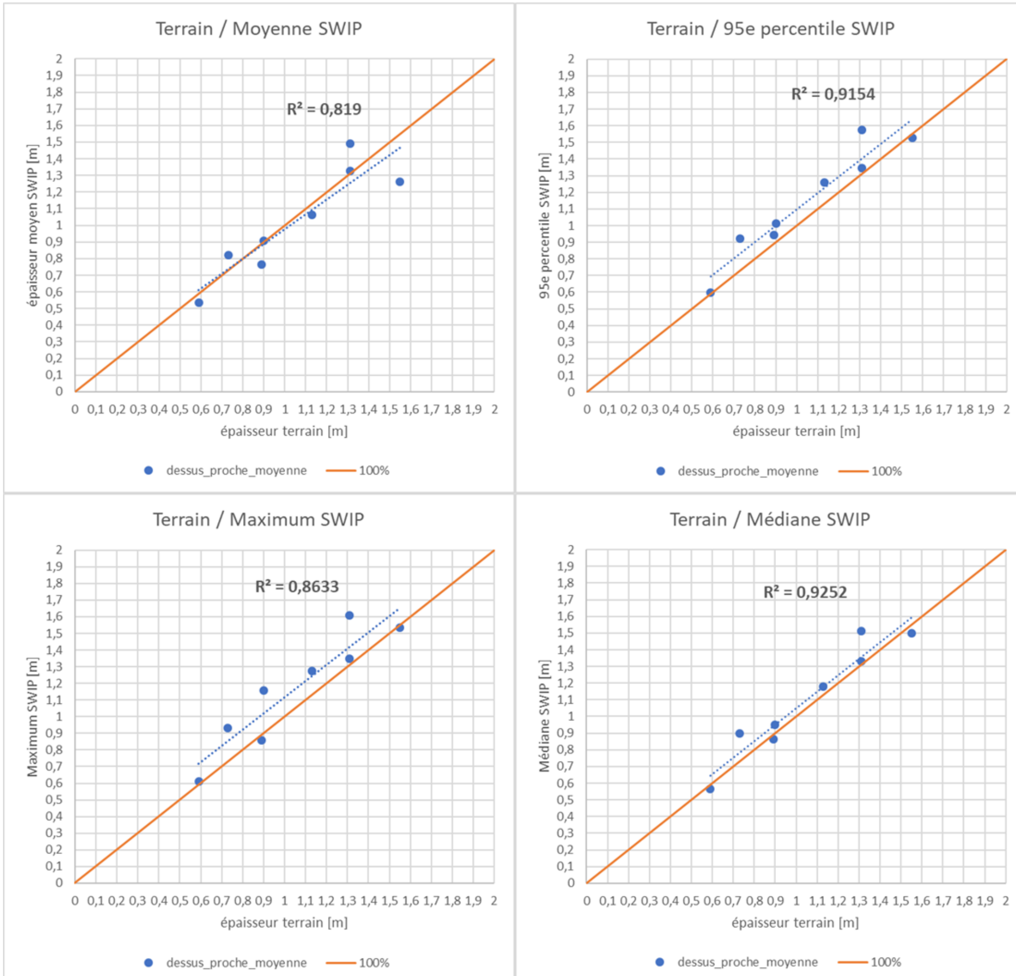


Figure 11: A plot of field measurements with SWIP estimations over 2015-2019 for different filters. Values on the X-Axis are field measurements of ice thicknesses, which depending on the campaign, could have been taken over the instrument, near the instrument or from an average of the area.

Hence, we will focus on the results with the daily median filter (Figure 12). Each graph shows the time series for ice thicknesses estimated from SWIP data for an ice season. Orange and yellow dots represent freeze-up and breakup dates previously identified from the cameras. Red dots represent field measurements (same values as X-axis of Figure 11).

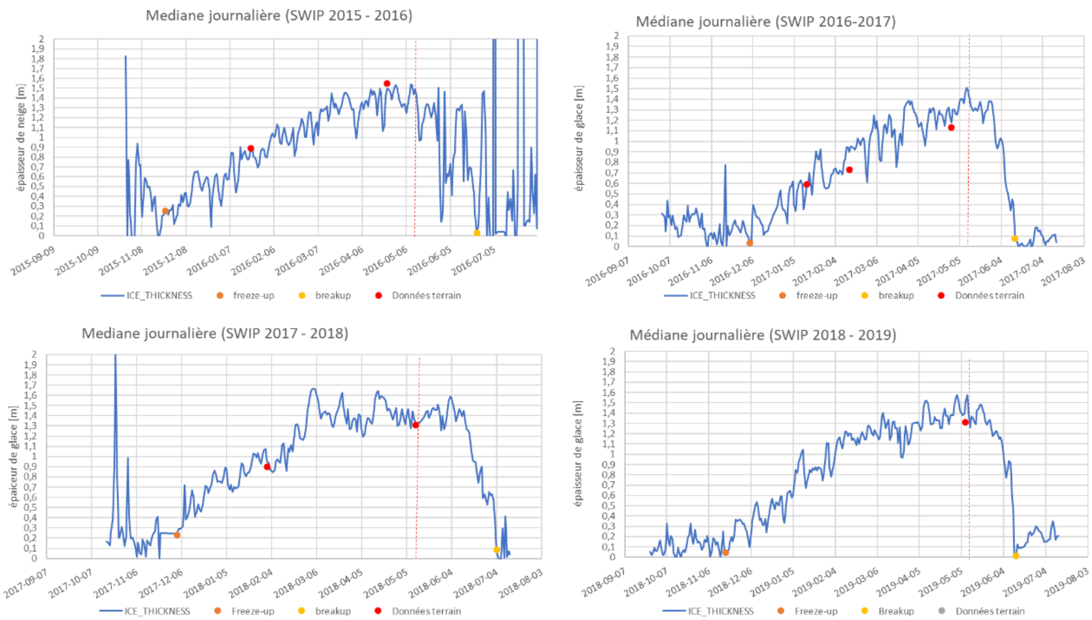


Figure 12: Ice thickness time series (SWIP) for 2015-2019 using the daily median filter

Before freeze-up and after breakup, the water is ice-free and hence, ice estimates are irrelevant. The graphs shows that the values starts to make sense and climb more steadily after the freeze-up date. The thicknesses do not start at 0 cm but rather around 10-20 cm. The ice growth is gradual and is at its maximum around May 10 (dotted red line in Figure 12). Once ice thickness starts to decrease, it takes between 1 and 2 months before the area around the SWIP is free of ice.

As can be seen in Figure 13, the hourly median filter shows a similar behavior with simply more noise. Therefore, we only used the daily median filter for the analysis.

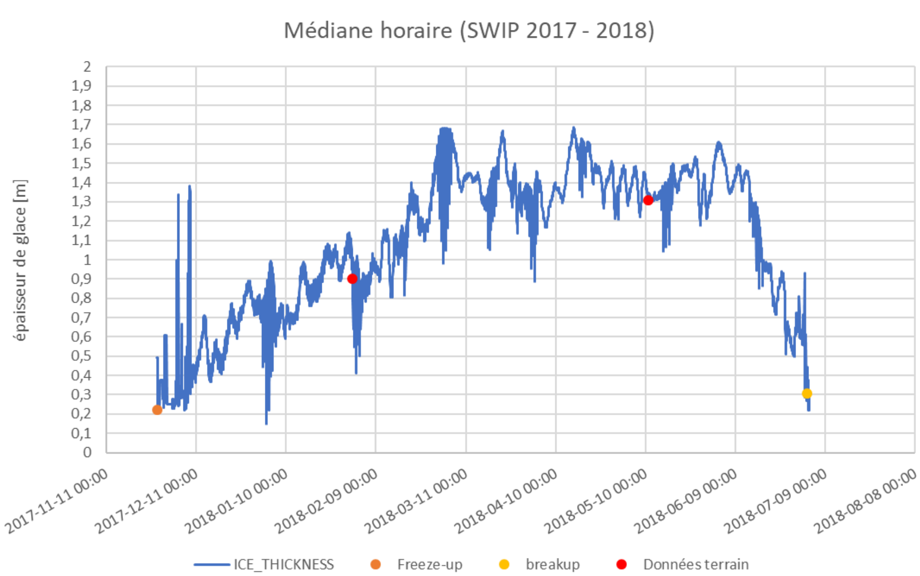


Figure 13: Ice thickness time series (SWIP) for 2017-2018 using the hourly median filter

In Figure 14, we have superimposed the new SWIP estimated ice thickness time series for 2015-2016 to the one published in "*Progress report 2016-2018*", which was using the complex processing. There is no major discrepancy between the two, which tends to show that both approaches give similar results, with the simplified approach with median daily filter reducing the noise. Therefore, we consider that we can use the simplified approach for our study.

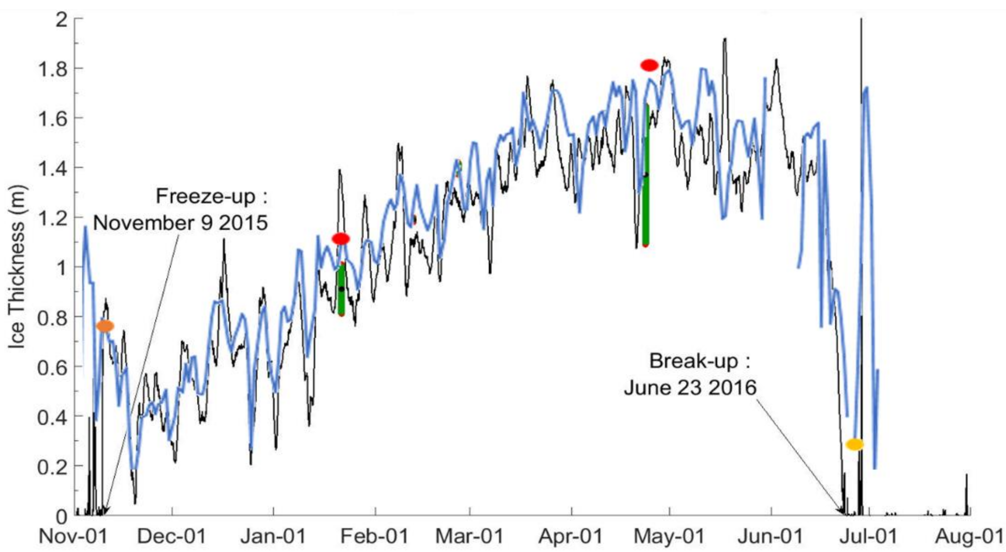


Figure 14: Comparing ice thickness time series (SWIP) for 2015-2016 from complex processing (black line) and simplified processing with daily median filter (blue line)

IPS data

We have applied the same processing to the IPS data for the 3 seasons available: 2016-2017, 2017-2018 and 2018-2019. The data interpretation is however different from the SWIP, as the instrument is submerged in an area where the movements of the icebreakers have an impact on the ice cover. Their passage can create or break ice accumulations along their path, suddenly changing the ice thickness seen by the IPS. These features were clearly identified in "Progress report 2016-2018". Furthermore, the field measurements are not made over such pressure ridges but on a smoother ice cover. This is why there may be a discrepancy between the two datasets spreading the points in the regression (Figure 15).

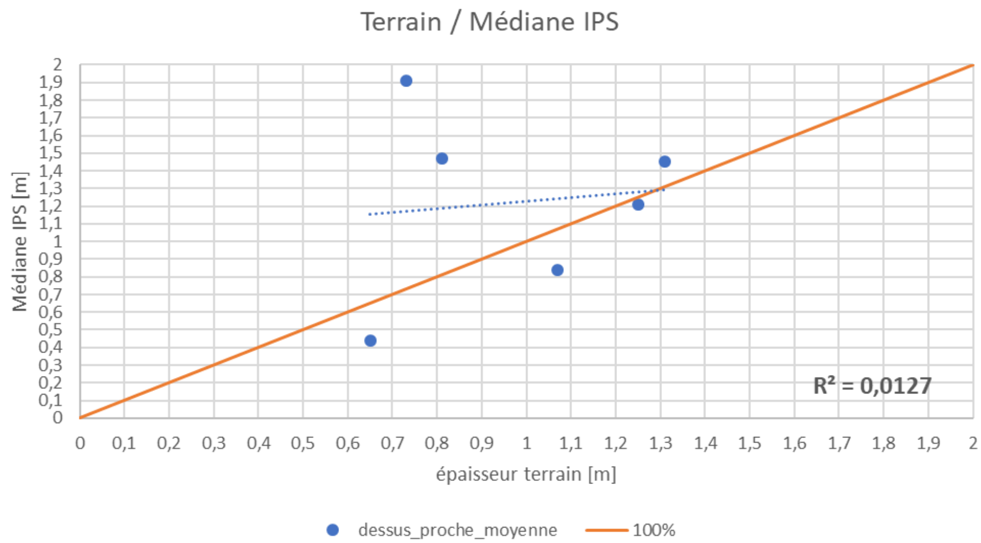


Figure 15: A plot of ice thickness field measurements with IPS estimations over 2016-2019 with the median filter.

The two points astray are those of February 14, 2017 and February 1, 2018 (red arrows in Figure 16). This figure presents the IPS time series using the median filter for the three ice seasons. For the two points astray, the field measurements of ice thickness were made in a period where the IPS was probably under a pressure ridge, hence the overestimation. On February 2017, the measurements were made just before the Nunavik icebreaker (Canadian Royalties) left the Bay on the same day, breaking the ice ridge previously created by the Arctic icebreaker (Raglan) in mid-January. On February 1 2018, the field measurements were made the day after the passage of the Arctic icebreaker and the appearance of the new ice ridge. If those two points were not considered in Figure 15, the root mean square would be 0.93.

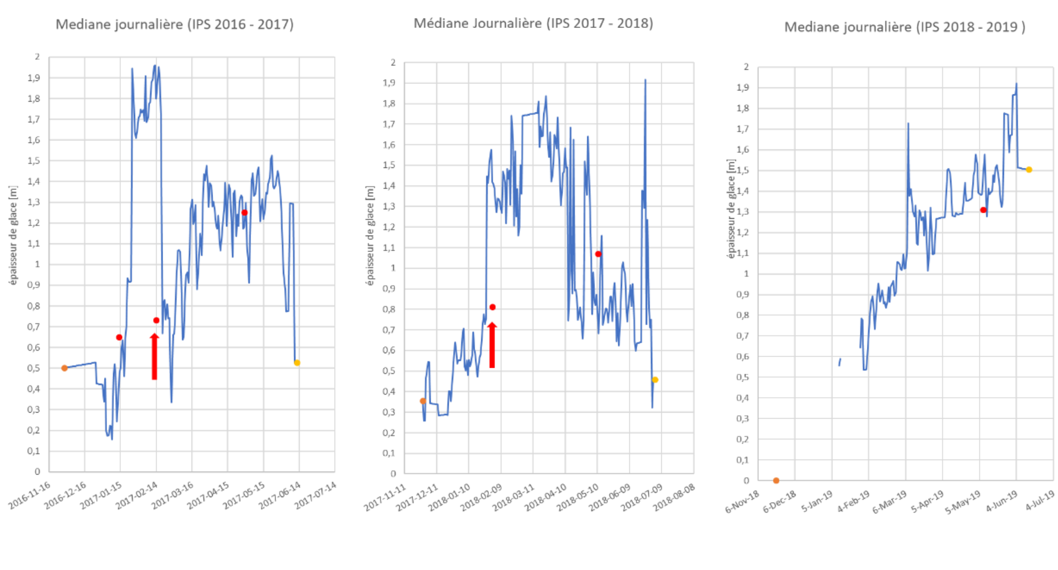


Figure 16: Ice thickness time series (IPS) for 2016-2019 using the daily median filter

Another factor influencing the IPS estimations may be that the instrument is anchored but floating above the water bottom and we hypothesize that movements can change the tilt angle and cause more variations in the estimation of the ice thickness with the IPS. Finally, in 2018-2019, all ice thickness estimations prior to the end of January were either negative or erroneous (ice thickness inferior to the ice draft). We could not identify the cause.

Analysis of SWIP and IPS data of the 2019-2020 season

The SWIP and IPS data were retrieved during the maintenance visit of September 26-28, 2020. We processed the data with the simplified approach and applied the daily median filter. In Figure 17, we present the ice draft and ice thickness calculated from the 2019-2020 SWIP data. The dataset shows a lot of noise, as in previous years. Again, freeze-up and breakup dates (from time-lapse cameras) correspond with a drastic change in the signal. The maximum thickness stands around 1.5m, if we ignore the short peak of early April. This is higher than the previous years but we have no field measurements to validate the 2020 numbers.

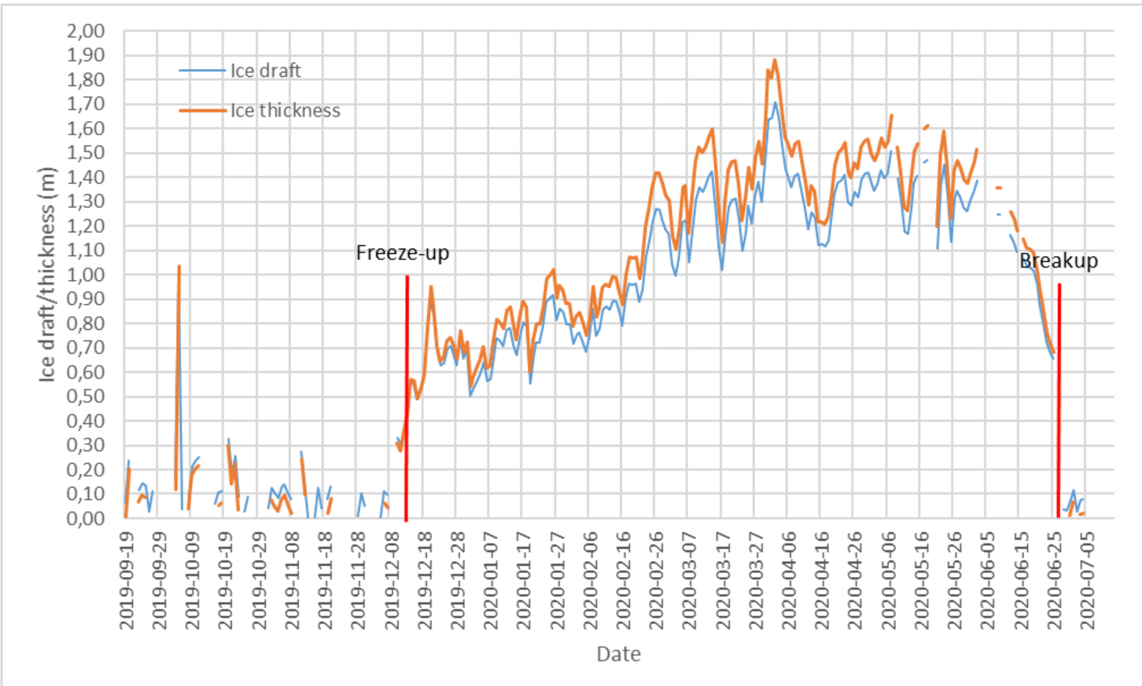


Figure 17: Estimated ice draft and thickness from SWIP data in Deception Bay for 2019-2020

In Figure 18, we present the ice draft and ice thickness calculated from the 2019-2020 IPS data. Same variability as in previous years. The blue arrow indicates the arrival of the icebreaker at the Raglan port facilities (Feb.5), as it probably broke the ice cover over the IPS. From March to July, we do not have the dates of arrival or departure of the ships because of the loss of the photos from the camera at the port facilities. However, looking at the sharp drop of thickness in early June, we can hypothesize that it corresponds to the arrival of the icebreakers at the end of the blackout.

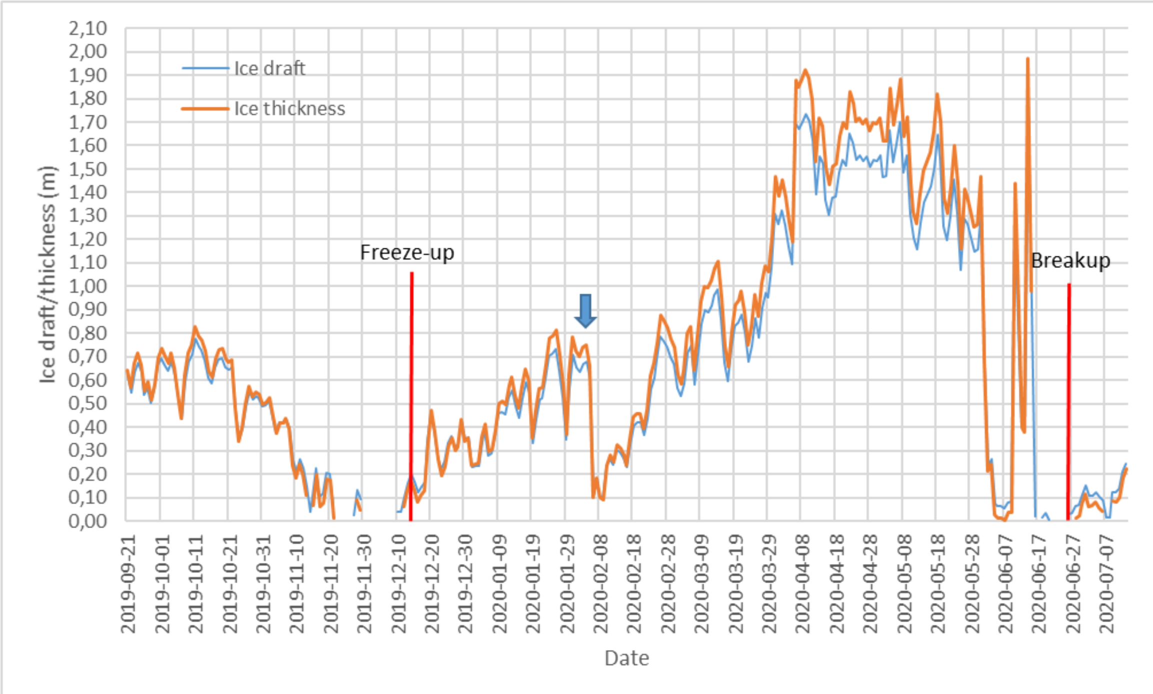


Figure 18: Estimated ice draft and thickness from IPS data in Deception Bay for 2019-2020

In Figure 19, we compare the estimated ice thicknesses from the SWIP over the five seasons. For clarity purposes, the values shown are the weekly median. The form of the ice growth curve is rather similar, with a plateau of maximum ice thickness (1.3 to 1.5m) in April-May. 2016-2017 would be the lower end and 2019-2020 the higher end.

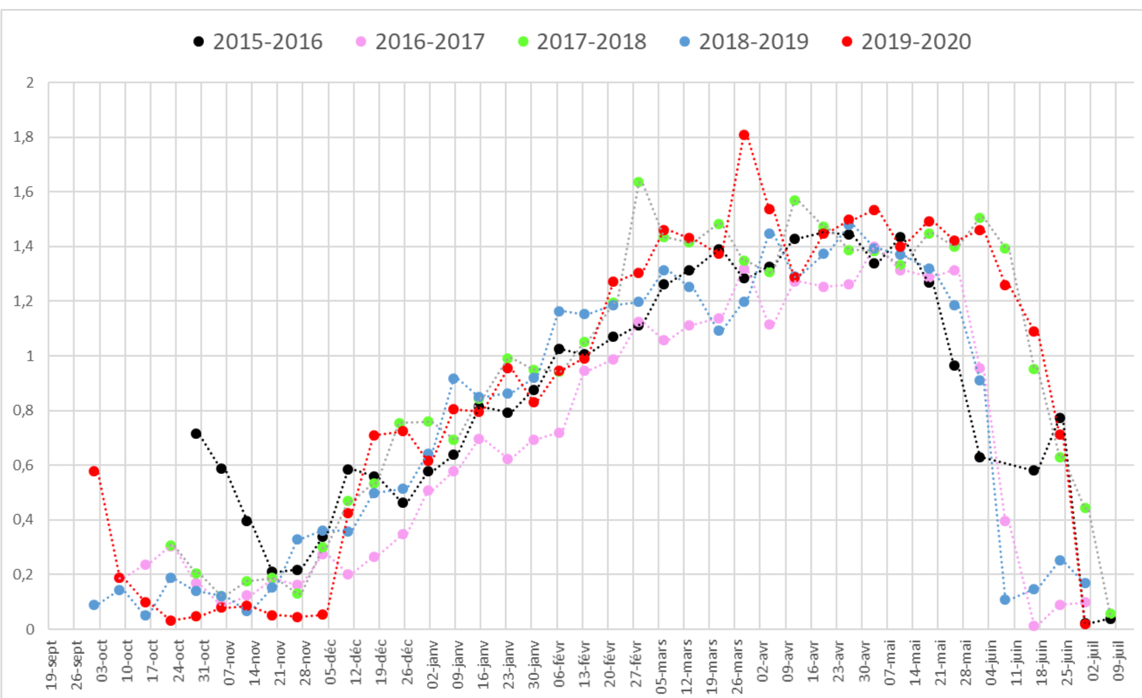


Figure 19: Annual comparison of estimated ice thickness from SWIP data in Deception Bay for 2015-2020 (weekly median).

5.3.4. Analysis of satellite images

As described in previous reports, we analyzed a series of optical and radar images since 1984 to extract the following information:

- Estimated freeze-up date: Between the last image with <100% ice and the first image with 100% ice.

- Estimated breakup date: Between the first image with <100% ice and the first image with 0% ice.

The number of cloud free observations is much greater during winter and spring than during fall. This increases the uncertainty for the freeze-up date. The number of satellites, sensors and images available increased dramatically since 2010, also increasing the chance to get an image near the exact freeze-up or breakup date. Particularly with the availability of SAR radar images which see through clouds. The radar images are however harder to interpret and sometimes require complementary information. The available images that were used for this study are: 1) Optical satellites: MODIS, Sentinel-2, Landsat-8 and 2) Radar satellites: Sentinel-1, TerraSAR-X, Radarsat-2. We focused our analysis over the bay area (Figure 20). Freeze-up of the bay is completed when the ice sheet has reached the Neptune and Arctic Islands. Breakup is achieved the first day the bay (south of the Islands) is free of ice.

Figure 20: Extract from a Sentinel-2 image over Deception Bay

This report presents the updated historical trends, from the addition of the analysis of the 2015-2020 images. In Table 4, we present the freeze-up and breakup date ranges extracted from satellite imagery. In addition, we compare these ranges with those inferred from cameras at center and at the mouth of the Bay. The ice season duration is then calculated. Since 2015, the freeze-up date uncertainty from satellite ranges from 4 to 15 days (1-2 days from cameras). The breakup date uncertainty from satellite ranges from 1 to 3 days (1-4 days from cameras). The ice duration uncertainty therefore ranges from 5 to 18 days from satellite imagery (2-6 days from cameras).

Table 4: Freeze-up and breakup dates from satellite images - Deception Bay

	Freeze-up date			Breakup date		Ice season duration range	
	From Satellite images	**From cameras**		**From Satellite images**	**From cameras**	**From satellite**	**From cameras**
2015	Nov-17- Dec-3	Nov-23-25	**2016**	Jun-28-30	Jun-26-30	208-226	214-220
2016	Nov-29-Dec-9	Dec-6*	**2017**	Jun-18-19	Jun-16 *	191-202	192*
2017	Dec-12-18	Dec-15	**2018**	Jul-3-5	Jul-4-7	197-205	201-204
2018	Nov-18-24	Nov-19-21	**2019**	Jun-11-14	Jun-13-15	199-208	204-208
2019	Dec-10-14	Dec-14-15	**2020**	Jun-26-27	Jun-26-27	195-200	194-196
2020	Dec-12-22	Dec-17-18					

** From the camera in the middle of the bay only*

In Figure 21 we show an example of the 2018 breakup analysis. Breakup date was estimated somewhere between July 3 and 5.

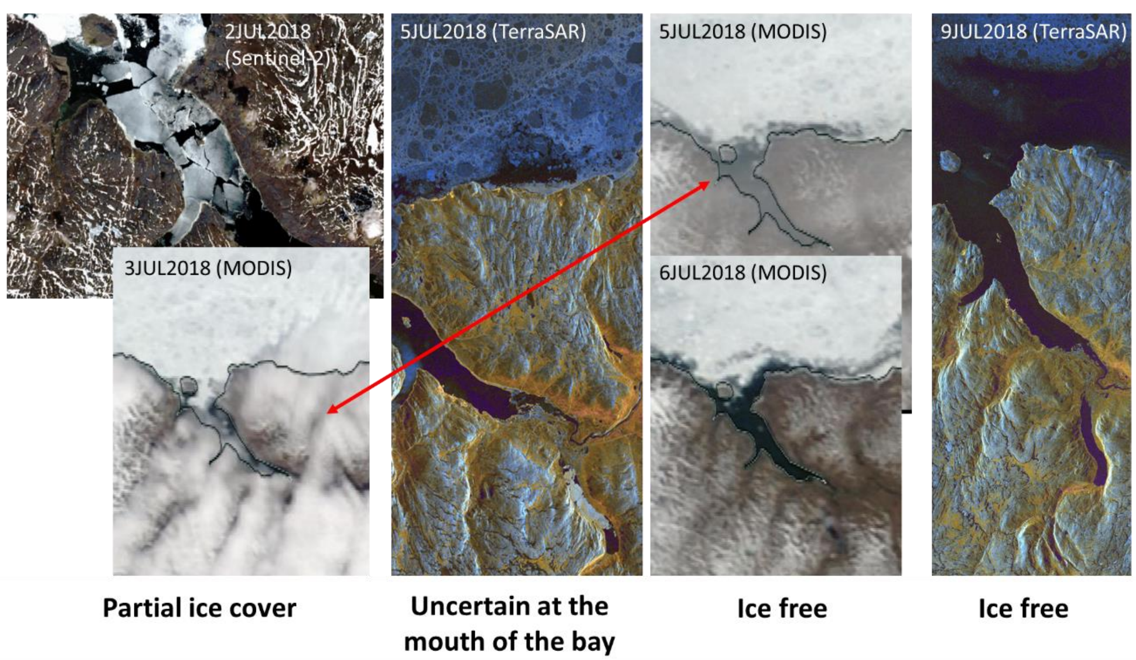


Figure 21: Estimation of the breakup date in Deception Bay for 2018.

We performed the same analysis on the fjords of Salluit and Kangiqsujuaq (Figure 22) and present results in

Table 5 and 6. Note that no time-lapse camera were monitoring those bays.

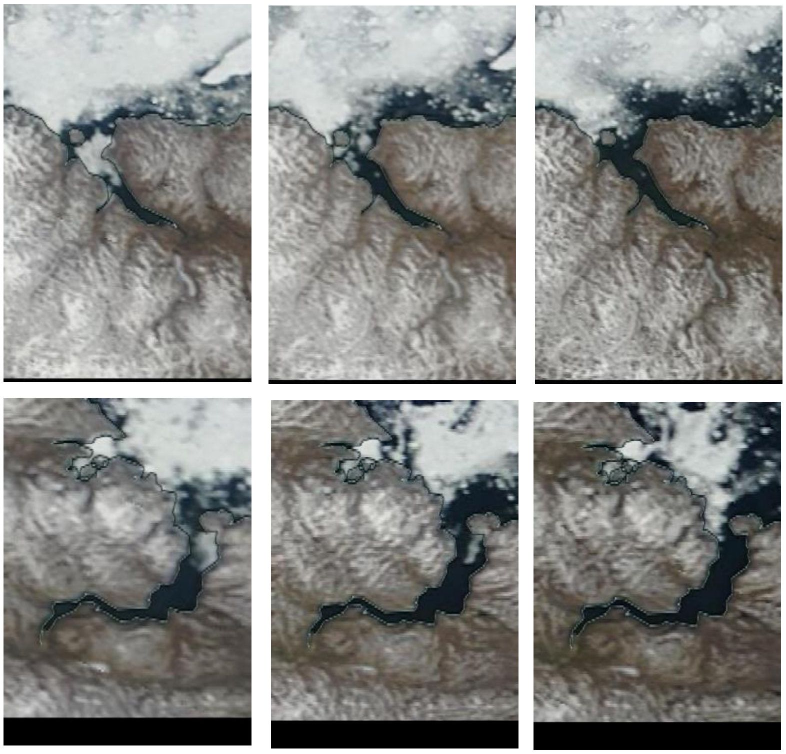


Figure 22: Example of MODIS images over the Salluit and Kangiqsujuaq fjords during breakup 2020 (June 25, 26, 27)

Table 5: Freeze-up and breakup dates from satellite images - Salluit

	Freeze-up date		Breakup date	Ice season duration
	From satellite images		From satellite images	From satellite images
2015	Nov-13-Dec-3	**2016**	Jun-27-28	207-228
2016	Dec-4-10	**2017**	Jun-18-21	190-199
2017	Dec-13-17	**2018**	Jul-4-5	199-204
2018	Nov-19-27	**2019**	Jun-18-19	203-212
2019	Dec-10-14	**2020**	Jun-26-27	195-200
2020	Dec-7-17			

Table 6: Freeze-up and breakup dates from satellite images - Kangiqsujuaq

	Freeze-up date		Breakup date	Ice season duration
	From satellite images		**From satellite images**	**From satellite images**
2015	Dec-8-Dec-13	**2016**	Jun-29-Jul-1	208-231
2016	Dec-6-10	**2017**	Jun-22-23	194-199
2017	Dec-9-11	**2018**	Jul-3-5	204-208
2018	Nov-13-19	**2019**	Jun-23-24	216-224
2019	Dec-14-21	**2020**	Jun-26-27	188-196
2020	Dec-7-18			

As for Deception Bay, satellite coverage enables a good estimation of the freeze-up and breakup dates in Salluit and Kangiqsujuaq, with uncertainties similar to Deception Bay (around a week range for freeze-up since 2016). Here also, the range for breakup is only 1 to 3 days. The uncertainty on ice season duration is 5 to 9 days since 2016, slightly better than for Deception Bay.

Next, we look at the freeze-up and break up ranges over an extended period of time (1984-2020). As explained before, there were fewer satellites in the past and therefore, less images to estimate a precise freeze-up or break date. Due to the persistent cloud cover in November-December and the small number of images available, freeze-up date could not reliably be estimated from satellite before 2012. As weather is more favorable in June-July, break-up date could be estimated but only within a two weeks range. In the last ten years, there has been a growing number of satellites (optical and radar), which now provide enough images to pinpoint the freeze-up date within a week or so and the breakup date within a couple of days.

Figure 23 shows the 2012-2020 ice freeze-up date estimated from satellite imagery in Deception Bay and in the fjords of Salluit and Kangiqsujuaq. Apart from 2018, which has seen a very early freeze-up, there seem to be a general tendency towards a later freeze-up over the last 9 years. The blue line is only a visual and qualitative expression of this tendency. The three bays show a similar behavior, but generally, freeze-up in Deception Bay seems to happen a few days earlier than in Salluit and Kangiqsujuaq.

For breakup, Figure 24 shows data over a much longer period of time but with a large uncertainty prior to 2012. Here, the blue lines generally encompass the upper and lower limits of the breakup dates, which highlight that there is no obvious trend towards an earlier or a later event.

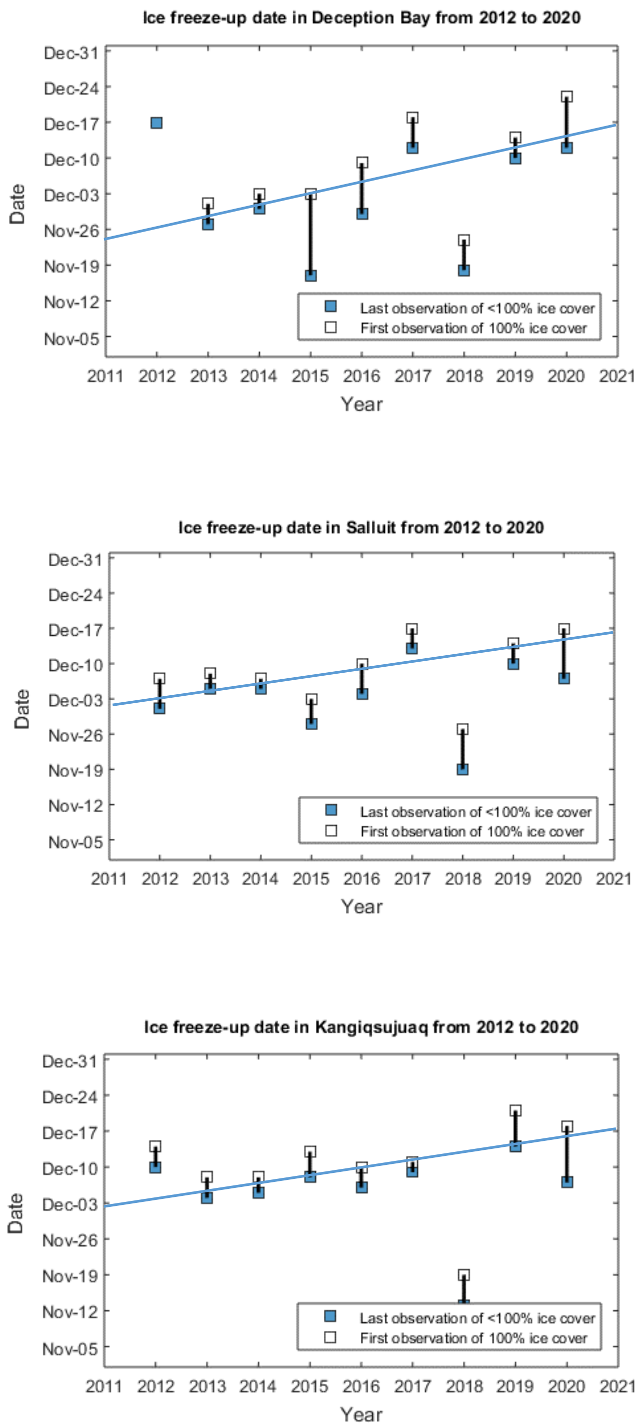


Figure 23: Historical ice freeze-up date from satellite imagery in Deception Bay and in the fjords of Salluit and Kangiqsujuaq – 2012-2020.

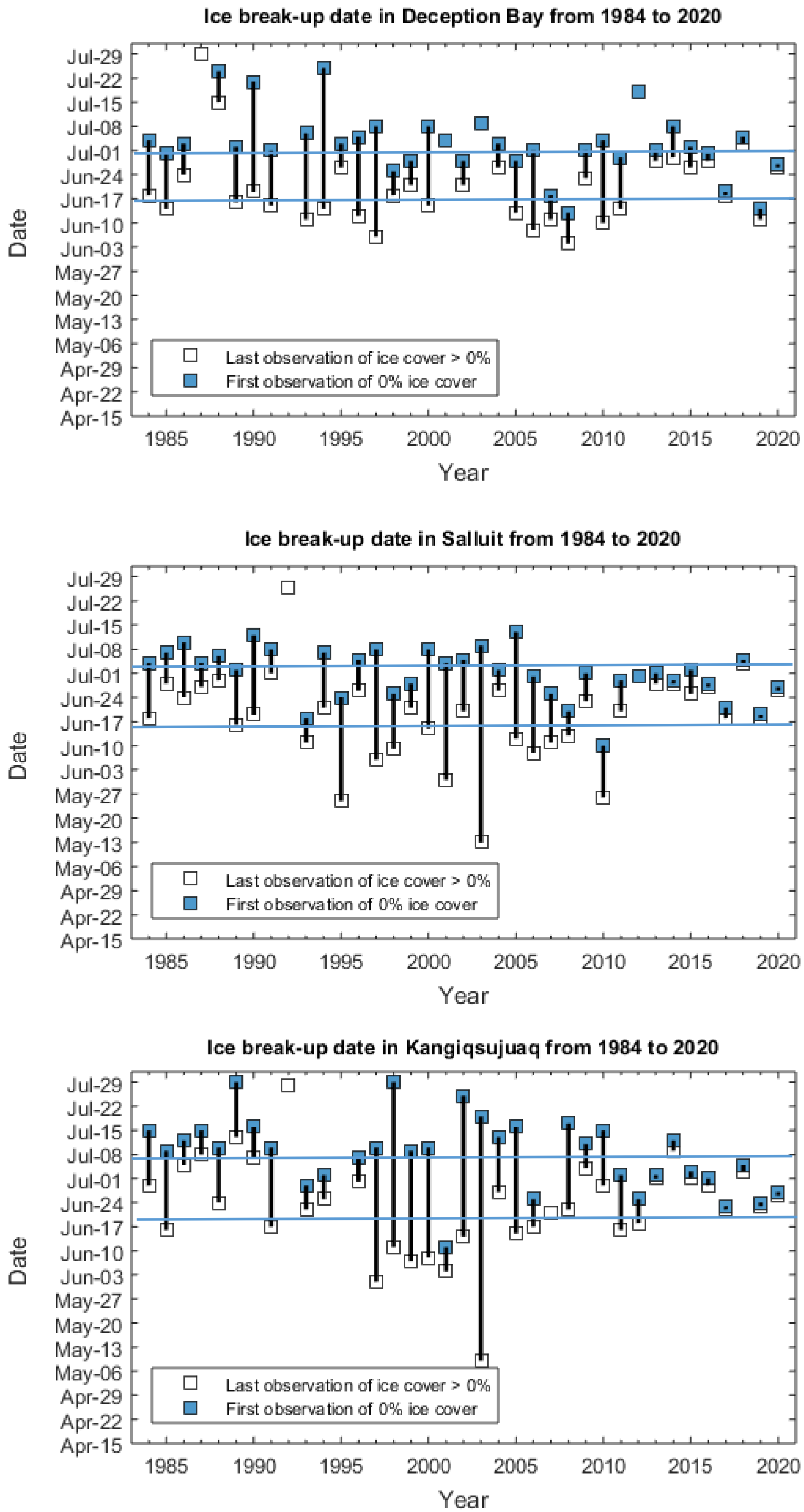


Figure 24: Historical ice breakup date from satellite imagery in Deception Bay and in the fjords of Salluit and Kangiqsujuaq.

5.4. Operation of the new real-time cameras and weather stations

Table 7 shows a list of the camera systems installed during the project. As mentioned in section 5.1, the two onsite-recording systems (Reconyx cameras) were removed as the maintenance contract with Transport Quebec ends. The real-time transmission systems are up and running. However, a server problem at INRS caused the loss of all real-time photos acquired between March and July 2020.

Table 7: List of cameras related to the project

Location of the camera	Type	System status	Working period
DB (at Black Point)	Onsite recording	Removed	Sep2015-Jan2016 Sep2016-Sep2020
DB (facing Moosehead Island)	Onsite recording	Removed	Sep2015-Sep2016 May2018-Sep2020
DB (Raglan port facilities)	Real-time transmission	Working	Sep2015-Mar2020 Jul2020-Dec2020
Ujararjjuak (West of DB)	Real-time transmission	Working	May2019-Mar2020 Jul2020-Dec2020
Tasialutjuak (South of DB)	Real-time transmission	Working	May2019-Mar2020 Jul2020-Dec2020
Niaqurnaq (Kangiqsujuaq area)	Real-time transmission	Working	May2019-Mar2020 Jul2020-Dec2020
Kangirsuapik (Kangiqsujuaq area)	Real-time transmission	Working intermittently	May2019-Apr2020 Oct2020-Dec2020

In January 2020, the system installed in Kangirsuapik stopped transmitting. People from Kangiqsujuaq went to the site in April and removed the camera and the satellite antenna in order to send them to the INRS. When they were received, the camera was damaged and no longer working. It did not appear in this condition in the photos taken before disassembly. The satellite antenna was working. It was then difficult to find the cause of the transmission problems at the site. After the camera reparation, we found that it had worked until it was removed in April and was probably not the cause of the initial problems. During the maintenance visit in October 2020, the camera and satellite antenna were put back in place. During the reinstallation, it was noted that a relay present in the system was probably the cause of the transmission problems in winter 2020. This relay closed by the camera in order to turn on the antenna for transmitting the photos. The relay was no longer closing so the antenna was no longer turning on. Since we did not have a replacement relay, it has been removed and the antenna should always stay on. As it goes to sleep between transmissions, we were hoping that the power consumption would not be too high for the system. Unfortunately, this was not the case and the low sunshine of late autumn was no longer sufficient to keep the batteries charged. The system then turns off when the battery level is too low. It should resume normal functioning when the days get longer or when a new relay is put in place. For the moment, the ice does not allow access to the site. The system works occasionally on sunny days when there is enough sun to momentarily recharge the system.

New mini weather stations

During the maintenance visit in October 2020, small weather stations have been installed at the Kangirsuapik and Niaqurnaq camera sites (Figure 25). This had been previously planned for in the system set up.

Figure 25: Camera system with weather station at Niaqurnaq near Kangiqsujuaq

These weather stations measure:

- Air Temperature
- Relative Humidity
- Barometric Pressure
- Vapor Pressure
- Wind Speed
- Wind Direction
- Solar Radiation
- Precipitation
- Tilt
- Lightning Strike Count
- Lightning Average Distance.

The weather stations have not been installed at the Ujararjjuak and Tasialutjuak sites in October because these sites are only accessible by snowmobile. Their installation was scheduled last spring but the COVID pandemic did not allow the planned work to be carried out. Those weather stations were funded by KRG.

Main weather station in Deception Bay

In 2019, a new weather station has been installed at Deception Bay at the end of the bay a few hundred meters behind the Canadian Royalties camp. The site has been selected to be relatively far from natural obstructions such as mountains and human constructions. In addition, without being far from the bay, the selected site is closer to the airstrip present at Deception Bay and to Lake Duquette, an area favored by the people from Salluit. A flyer produced for the people from Salluit shows the components of the system (Figure 26).

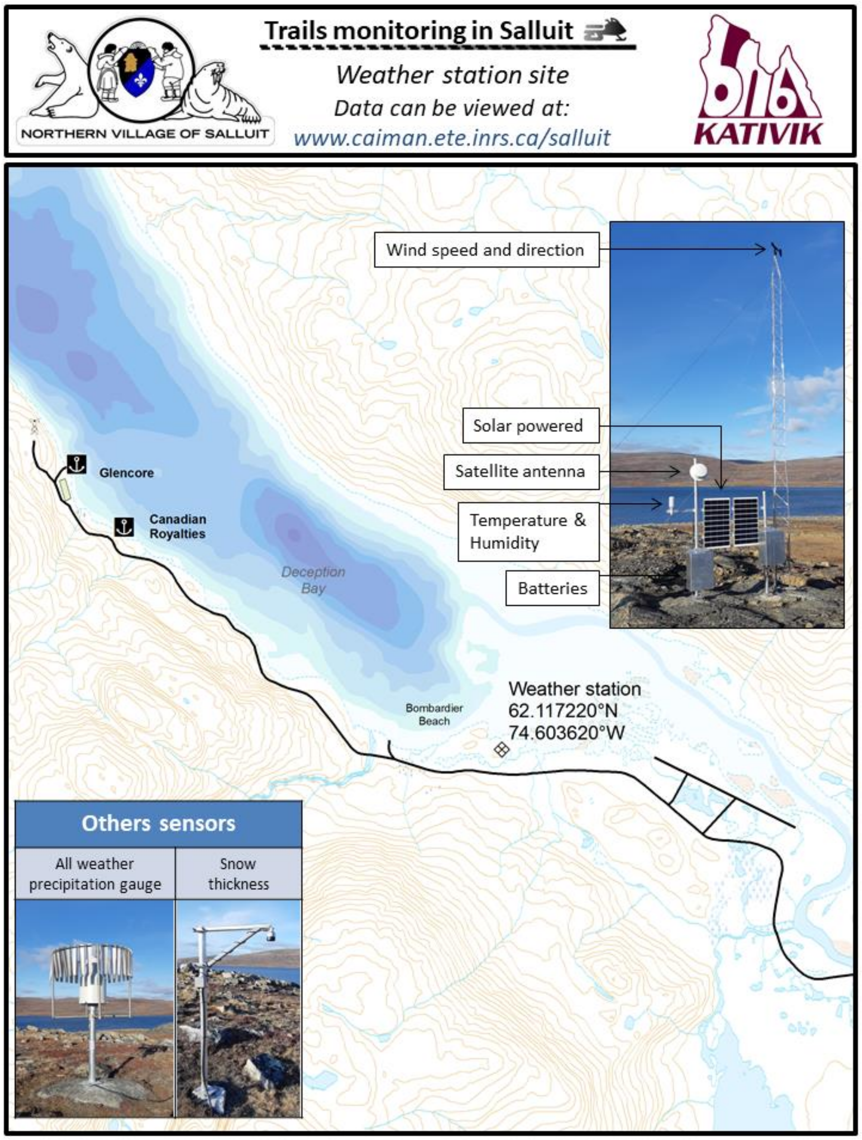


Figure 26 : Components of the main weather station in Deception Bay

In November 2019, problems occurred with the satellite transmission. At the beginning, some transmissions were missing then the communication was interrupted completely. The Ministry of the Environment had provided the equipment for satellite data transmission. The initial hypothesis was that another transmitter was transmitting on the same channel and interfering with the one installed at Deception Bay. At the end of November, the targeted transmitter was replaced, but this did not correct the problem. The Ministry then gave us new equipment in February 2020. It would have been possible to obtain the equipment before but we were waiting for the planning of a site visit to recover it but this was slow to be achieved. In February 2020, we received an offer from the Raglan Mine Environmental Department staff to help us with the repair. The material was therefore sent to the coordinator Évangéline Rivest. She was not able to go to Deception Bay in her run in March, she returned on May 16. In the meantime, the data was again being transmitted by the station. Mme Rivest nevertheless proceeded to the replacement of the satellite transmitter. Since we were not receiving data from the new transmitter, the original transmitter was put back in place the same day. At some point, some parts of the all weather precipitation gauge were damaged, others had fallen (Figure 27). The fallen pieces were put back in place. The damaged ones were not a problem. After that, the situation was corrected with the new transmitter and Ms. Rivest carried out a new replacement on July 30, 2020.

Figure 27: Problems observed with the all weather precipitation gauge in May 2020

When we visited in September 2020, the equipment was still functional. The windbreak blades of the all weather precipitation gauge had moved again (Figure 28). They have been put back in place. The all weather precipitation gauge was also emptied and prepared for winter.

Figure 28: Problems observed with the all weather precipitation gauge in Septembre 2020

5.5. Development of a website (portal) and of an information tool (dashboard)

The purpose of the website is to make all information collected during the project, available to the local communities and to any person interested by ice and climate change in Nunavik. The cameras in Deception Bay and Kangiqsujuaq are integrated into the CAIMAN Network, which include 30 time-lapse or real-time cameras distributed over seven Nunavik communities and around Deception Bay. The Network was gradually implemented since 2009 to support ice and climate change studies for the Quebec's ministry of transports. The photo database is now comprised of close to 500 000 photos (132 000 from DB), which can be viewed through the CAIMAN Portal (www.caiman.ete.inrs.ca). This Portal is therefore the platform chosen to disseminate the Deception Bay ice monitoring information.

The objective of the dashboard is to regroup all relevant information for real-time decision support relative to safe travel on the ice. It is primarily intended for people travelling in the area of Salluit-Deception Bay-Kangiqsujuaq. The tool is part of the CAIMAN Portal and includes photos from real-time cameras, data from weather stations, the most recent satellite images over the area and comments and photos from land users about the state of the trails. Land users can therefore get a sense of the weather, snow and ice conditions of the monitored trails. However, because of the pandemic, it was not possible to get comments and photos from users.

In a future phase, the dashboard could also include: 1) Schedule of the icebreakers in Deception Bay, 2) the most recent snow/ice thickness measurements, 3) statistics about historical freeze-up and break-up dates and historical snow/ice thicknesses and 4) an ice thickness model.

From September 2019 to December 2020, the following related activities were performed:

- Maintenance of the Portal and Dashboard
- Minor corrections/modifications;
- Addition of the photos recorded onsite and downloaded during the September-October 2020 visit;
- Creation of a link to display the real-time weather data from the main weather station in Deception Bay and from the newly installed mini-stations at Ujararjjuak, Tasialutjuak;
- Creation of the interface for land users to add comments and photos
- Production of training material (under review at KRG). Due to the pandemic, there was no opportunity to hold a training session onsite with land users;
- Investigation of an ice growth model to implement in Deception Bay;

6. Conclusion

The project is now concluded and all activities and deliverables have successfully been completed except for the in person training session for the dashboard due to the pandemic. The training and evaluation of the dashboard with the users have been postponed for a future phase.

Through this contract, we have installed a complete weather station in Deception Bay and two new real-time cameras (with mini weather station and emergency system) for trail monitoring (west of Deception Bay and North of Kangiqsujuaq) (Deliverable #1 and #2). We have also maintained all other cameras and instruments to ensure data acquisition up to the fall of 2020 and beyond (Deliverable #3). As planned, the underwater sonars were removed in September 2020 (Deliverable #4). From data analysis, we have determined the ice freezing and melting cycles and measured ice and snow thicknesses for the three sites up to the summer of 2020 (Deliverable #5). The only gap is the fieldwork of May 2020 due to the pandemic. On each visit on the sites, local collaborators were involved and trained on the methodology for the measurements being performed and on the installation and maintenance of instruments (Deliverable #6). All archived and new data are available through the operational CAIMAN website (Deliverable #7) and real-time information has been integrated into a useful dashboard (Deliverable #8). Also due to the pandemic, the training and evaluation of the dashboard with the users have been postponed. Finally, we have produced progress reports annually, three scientific publications (a fourth is in preparation) and a doctoral thesis (Deliverable #9).

Therefore, we consider that the objectives of the contract have been achieved. We have successfully gathered and shared an extensive environmental dataset from various technologies and documented the spatial and temporal variability of the ice cover in Deception Bay (main site) and to some extent, in Salluit and Kangiqsujuaq (comparison sites). The real-time instruments and information tools that were set in place during this contract should continue to sustain decision-making and safe access to the territory for the communities of Salluit and Kangiqsujuaq in the future. To ensure long-term maintenance, relevance and usefulness of the system, we recommend that all partners work towards local awareness, training and empowerment, with a recurrent support and collaboration from interested partners, including a support for the involvement of INRS researchers.