Using Traditional Inuit Knowledge and Scientific Methods to Characterize Historical Climate Change Impacts to Sea Ice in Resolute Bay, Nunavut

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Submitted under the supervision of

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Abstract

One of the most visible impacts of climate change in Arctic environments is declining sea ice. Due to an absence of spatially coarse quantitative data, there is a lack of understanding on declining sea ice on a community scale. This study seeks to document historical trends in air temperature, sea ice thickness (SIT), break-up dates (BUDs) and freeze-up dates (FUDs), correlate sea ice behaviour to air temperatures, and document the socio-economic impacts of sea ice change in Resolute Bay Nunavut, using traditional Inuit knowledge (TIK) and scientific methods.

During the scientific portion of this study linear regression, statistical significance, anomaly analysis, and change point detection were used on time series of sea ice concentration (SIC), SIT, and air temperature. Two SIC datasets were accessed to characterize BUDs and FUDs, Canadian Ice Services archived sea ice charts from 1982-2022 and Copernicus Climate Change Services (C3S) gridded satellite derived SIC from 1979-2015. The BUD was defined when SIC fell and stayed below 20%, and the FUD was when SIC returned and stayed above 50%. By applying a statistically significant linear regression to both datasets, the BUD was shown to occur 37.5 days earlier and the FUD occurred 23.4 days later in 2022 than in 1979. This study accessed two SIT datasets, Environment and Climate Change Canada fast ice measurements from 1947-2022 and C3S satellite derived sea ice freeboard measurements from 2002-2020 at four locations in the Barrow Strait. After applying change point detection algorithms, this study found annual maximum fast ice thicknesses increased 32.5 cm from 1948-1981 and decreased 33.2 cm from 1981-2021. Fast ice decreased most substantially in the months of April and May. Sea ice freeboard decreased by 260.8 cm on average from 2002-2020 in the Barrow Strait. Freezing degree days (FDDs) were used to correlate sea ice behaviour to air temperature. As FDDs decrease, sea ice freeboard was the most rapidly changing sea ice parameter and fast ice thickness was most strongly correlated to FDDs. Both these results indicate that air temperature has a greater effect on SIT than the BUD and FUD.

During the TIK investigation of this study, seventeen community members from Resolute Bay, Nunavut, ranging from age 19-81 were interviewed about their perception of changes in SIT, BUD, FUD, and seasonal weather patterns. Participants were interviewed about the socio-economic impacts of sea ice change, traditional Inuit methods of determining thickness, and asked to indicate typical areas of thin and thick ice, areas that break-up and freeze-up first, and hunting and travel routes on printed maps. The interviewees described a decline in sea ice thickness, areas of thin ice in the Barrow Strait, north of Cornwallis Island, and between Bathurst and Devon Island, less frequent use of the sea ice, less traditional food available in the community, increased vessel traffic, a decrease in seal population, new species and birds in the area, and detailed traditional methods of determining ice thickness through observation of color and use of the harpoon.

Agreement between traditional knowledge and the scientific data was present in typical break-up and freeze-up patterns, and annual maximum thickness decreasing over time. While most respondents indicated FUD was later and BUD earlier, more participants responded there have been changes to the FUD than the BUD, whereas the scientific data showed more severe changes to the BUD than FUD. During interviews, there was consensus that summer temperatures are getting warmer but there was variability in responses when asked about winter temperatures. The scientific results showed less warming in the summer (Jun-Aug) than winter months (Jan-Mar) with the most warming in the fall (Sept-Nov). The lack of agreement between these results could be attributed to local perceived changes to winter weather referring to storminess rather than strictly temperature. TIK provided small scale information about the sea ice that the current state of scientific observation can not. In conclusion, a more holistic understanding of sea ice behaviour can be achieved by including Inuit traditional knowledge in partnership with scientific methods.

Acknowledgements

This study was done with the utmost collaboration with the Hamlet of Resolute Bay, Nunavut. I am eternally grateful for the people I met in Resolute Bay for their participation and knowledge. The interview participants were so eloquently able to express their connection to the sea ice, as well as remain in well humoured spirits when describing changes to their environment and any fears they experience due to climate change. Thank you, Devon Manik, for the guided sled dog tour on the sea ice, for sharing his love of traditional methods of hunting, and making his every day my once in a lifetime. Thank you to Ian Dudla for coordinating many portions of this project, your support contributed heavily to its success. Thank you to the Tudjaat Co-op for housing us during the community interviews and providing the space for community interactions and connections to be made.

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List of Inuktitut Words

Quasuitturmiut	Resolute Bay residents name for themselves
Ilagiit Nunagivaktangit	Nomadic lifestyle
Inuit Quajimajatuqangit (IQ)	Inuit knowledge
Inuit Nunangat	Homeland of Inuit people of Canada, includes regions of Nunavut, the north part of Quebec, Northwest Territories and Newfoundland and Labrador. Settled land claim region
Siku	Sea ice
Qamutiik	Sled used during hunting
Qimmiit	Sled dogs

List of Symbols

Quantity		**SI Unit**	
Name	**Symbol**	**Name**	**Symbol**
Freezing Degree Day	FDD	temperature	ºC
Air Temperature	T	temperature	ºC
Sea Ice Concentration	SIC	unitless	m^2/m^2
Break-up Date	BUD	days	86 400 s
Freeze-up Date	FUD	days	86 400 s
Sea Ice Thickness	SIT	meters	m
Snow Depth	SD	meters	m
Ice Draft Depth	D	meters	m
Total Sea Ice Concentration	Ct	unitless	m^2/m^2
Sea Ice Concentration of Thickest Ice	Ca	unitless	m^2/m^2
Sea Ice Concentration of Second Thickest Ice	Cb	unitless	m^2/m^2
Sea Ice Concentration of Third Thickest Ice	Cc	unitless	m^2/m^2
Sea Ice Concentration of Fourth Thickest Ice	Cd	unitless	m^2/m^2
Total Ice Stage of Development of Thickest Ice	So	meters	m
Stage of Development of Second Thickest Ice	Sa	meters	m
Stage of Development of Third Thickest Ice	Sb	meters	m
Stage of Development of Fourth Thickest Ice	Sc	meters	m
Sea Ice Form of Thickest Ice	Fa	meters	m
Sea Ice Form of Second Thickest Ice	Fb	meters	m
Sea Ice Form of Third Thickest Ice	Fc	meters	m
Sea Ice Form of Fourth Thickest Ice	Fd	meters	m
Sea Ice Form of Fifth Thickest Ice	Fe	meters	m

List of Acronyms

ATLAS	Advanced Topographic Laser Altimetry System
AIS	Automatic Identification System
ALS	Automatic Landing System
AMSR	Advanced Microwave Scanning Radiometer
ATVs	All Terrain Vehicles
BUD	Break-up Date
C3S	Copernicus Climate Change Service
CBC	Canadian Broadcasting Company
CDR	Climate Data Record
CDS	Climate Data Store
CIS	Canadian Ice Services
CMIP	Coupled Model Intercomparison Project
CP	Change Point
DL	Data Location
ECCC	Environment and Climate Change Canada
ECMWF	European Centre for Medium-range Weather Forecasts
ESA CCI	European Space Agency Climate Change Initiative
FDD	Freezing Degree Day
FUD	Freeze-up Date
GLAS	Geoscience Laser Altimeter System
GPS	Global Positioning System
HPAIED	Harvard Project on American Indian Economic Development
HTA	Hunters and Trappers Association
ICDR	Interim Climate Data Record
ICESat	Ice Cloud and Elevation Satellite
ICESat-2	Ice Cloud and Elevation Satellite
IPCC	International Panel on Climate Change
IQR	Inter Quartile Range
ITK	Inuit Tapiriit Kanatami
LIDAR	Light Detection and Ranging
NASA	National Aeronautics and Space Administration
NCEI	National Centers for Environmental Information
NEMO	Nucleus for European Modelling of the Ocean
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NRI	Nunavut Research Institute
NSIDC	National Snow and Ice Data Center
OSI SAF	Ocean and Sea Ice Satellite Application Facility
PELT	Pruned Exact Linear Time
QIA	Qikiqtani Inuit Association
RCMP	Royal Canadian Mounted Police
SAO	Senior Administrative Officer
SIC	Sea Ice Concentration
SIMIP	Sea Ice Model Intercomparison Project
SIRAL	Synthetic Aperture Interferometric Radar Altimeter
SIT	Sea Ice Thickness
SSM/I	Special Sensor Microwave/Imager
SSMIS	Special Sensor Microwave Imager and Sounder
SSMR	Scanning Multichannel Microwave Radiometer
VHF	Very High Frequency
WMO	World Meteorological Organization

1 Introduction

Green house gas emissions and increased average global temperatures are the most common metrics of global climate change. The rise in global temperatures in the last few decades has had significant environmental impacts on Arctic Canada. Arctic amplification refers to the phenomenon of temperatures rising within the Arctic at nearly four times the rate of the global average (NSIDC, 2010.). These increases in temperature are causing severe fluctuations in the coastal Arctic environment which impact coastal communities, and the Inuit people who rely on the environment for their way of life. One of the most visual impacts of climate change on Arctic environments is that of declining sea ice (Government of Canada, 2013.). Sea ice is declining in its extent, thickness, and duration of the ice-covered season. Historical trends in sea ice change have been well documented on an Arctic wide scale (Moon, 2021; Thoman et al., 2020; Ford et al., 2009). Studies that focus on small community scale historical trends in sea ice change are less common due to remoteness of communities leading to a lack of spatially coarse quantitative data. However, the Inuit communities who rely on the sea ice for a traditional way of life have extensive knowledge on sea ice behavior that has been passed down through oral history (Nickels & Knotsch, 2011). Often scientific research conducted in Arctic environments is completed with little to no involvement of Inuit communities. Without meaningful partnership, and the centering of Inuit values, and community priorities, Arctic scientific research can be exploitative and inequitable (Biermann, 2011).

1.1 Research Objectives

This study seeks use both scientific methods as well as Inuit traditional knowledge to identify:

- Historical trends in sea ice break-up and freeze-up timing as well as sea ice thickness in Resolute Bay, Nunavut.
- How sea ice change (break-up timing, freeze-up timing, and thickness) relates to air temperature and climactic change.
- The socio-economic impacts the changing sea ice conditions are having on the community of Resolute Bay.

Motivation for Study

- Lack of understanding on a regional scale of climate change impacts to Arctic sea ice and Inuit communities.
- Lack of involvement of Inuit people in scientific research about their environment, despite their deep ties to the land and rights to self govern.

This study was done in partnership with the hamlet of Resolute Bay, it seeks to offer a practical application of two-eyed seeing to combine the strengths of Western and Indigenous knowledge to characterize the historical sea ice and climactic behaviour in Resolute Bay. During the scientific portion of this study, five long term datasets were accessed on sea ice concentration (SIC), sea ice thickness, and air temperature. Change point detection algorithms were applied to these datasets to detect the timing of statistical parameter change. Linear regression was performed to identify trends over time. Finally, the break-up timing, freeze-up timing and sea ice thickness were correlated to air temperature data in Resolute Bay. During the traditional knowledge portion of this study, the candidate, together with her academic supervisor, conducted community consultation to develop the goals and scope of this study, as well as conducted traditional Inuit knowledge interviews on perceived change in the sea ice, detailed spatial knowledge of the sea ice, and the impacts of the changing sea ice to the community.

1.2 Novelty of this Study

This study is the first of its kind done in Resolute Bay. Traditional Inuit or Indigenous knowledge has been incorporated into scientific studies using two-eyed seeing in other studies seeking to understand the physical and natural environment (Abu et al., 2019, Michie et al., 2018). This study is the first application of these methods to characterize climate impacts to sea ice in an Arctic Inuit community. Not only does this study document the correlation between air temperature and sea ice behaviour and linear trends over time, but it also goes further to include the knowledge of the Inuit stewards of the sea ice and centre Inuit values, knowledge, and priorities, while doing so.

1.3 Scope of this Study

This study strictly seeks to characterize historical trends in sea ice behaviour and air temperature using scientific knowledge and traditional Inuit knowledge. From these historical trends, this study identifies correlation between air temperature in the form of freezing degree days to sea ice behaviour. This study does not use methods such as numerical modelling or predictive neural networks to predict sea ice behaviour in Resolute Bay. The correlation made between air temperature and sea ice behaviour is done through linear regression. This study does not address ice thermodynamics, wave ice interaction, or ice dynamics, or ice response to ocean or wind driven currents.

1.4 Limitations of this Study

As stated in Section 1.1, one of the motivations for this study is a lack of understanding of specific climate change impacts to sea ice on a community scale in the Canadian Arctic. This lack of understanding comes in part from a lack of spatially coarse quantitative data or of the data that does exist there are large temporal data gaps. This lack of data poses a challenge to developing historical linear trends. This limitation was mitigated within this study by testing the statistical significance of all the trends developed. For example, the two sea ice concentration data sets were used in this study were intended for use on an Arctic wide scale. In this study however, only one spatial point from the large-scale data sets were used to characterize sea ice concentration only in Resolute Bay. When using one point from a large data set, there is a risk of inaccuracy or misrepresentation of the exact sea ice concentration at one point as sea ice concertation is averaged over a 25 km by 25 km spatial scale. To develop linear trends in break-up and freeze-up dates, a quantitative limit was applied to the sea ice concentration time series. These quantitative limits do not capture the nuances and complexities of break-up and freeze-up timing defined by Inuit people by when it is safe to or no longer safe to walk or drive on the sea ice. Despite these limitations, a strength of this study was the inclusion of traditional Inuit knowledge to supplement scientific data gaps and provide detailed community scale knowledge of the sea ice in Resolute Bay.

This thesis is organized as follows:

Section 1: Introduction

Section 2: Background and Literature Review

Section 3: Methodology

Section 4: Results

Section 5: Discussion

Section 6: Conclusions

2 Background and Literature Review

The following section will provide a summary of the literature reviewed for this thesis and background information on historical trends in sea ice decline on an Arctic wide scale, the type of quantitative data available on sea ice concentration and thickness, and the processes of predicting and simulating sea ice change through numerical models and machine learning. This section also provides an overview of previous studies conducted on how changing sea ice affects Inuit communities in Canada, as well as the effects declining sea ice has on other aspects of Arctic environments and ecosystems. This background and literature review also discusses the current and historical governance of Nunavut and the community history of Resolute Bay. Finally, this section presents the literature on how to ethically include traditional Indigenous knowledge into scientific studies.

2.1 Historical Trends in Sea Ice on an Arctic-Wide Scale

The scientific community has developed methods of monitoring sea ice behaviour on a long-term time scale. These methods include observation via satellite remote sensing. This section will present findings from the long-term monitoring of Arctic-wide sea ice.

2.1.1 Sea Ice Extent

Arctic-wide sea ice extent has been steadily and substantially declining from the 1970's to the 2020's. Particular change has been observed in the sea ice extent in summer months (June-September) (Thoman et al., 2020). Figure 2-1 from the National Oceanic and Atmospheric Administration (NOAA 2020) Arctic report card depicts the decreasing trends in September and March sea ice extent compared to the 1981-2010 average.

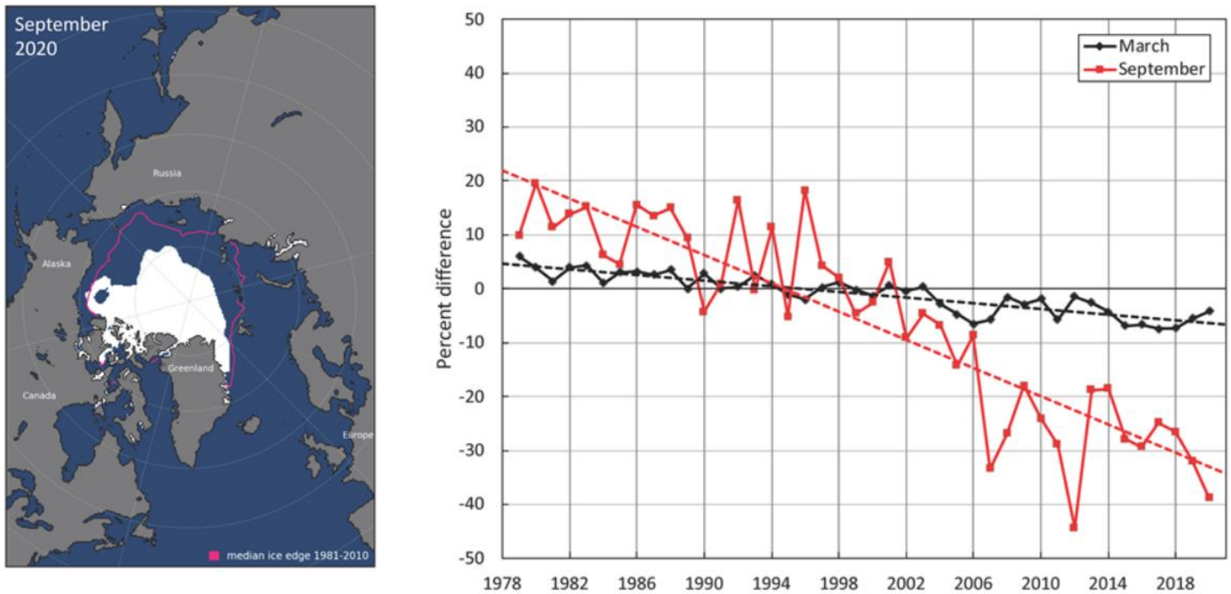


Figure 2-1: NOAA 2020 Arctic Report Card Decrease of Sea Ice Spatial Extent from 1981-2020 (Thoman et al., 2020).

The rate of sea ice extent decrease is 13.1% per decade from 1979-2020 relative to the 1981-2010 average, which corresponds to a decrease of 82,700 km^2 per year (Thoman et al., 2020). September 2020 had the second lowest sea ice extent in the 42-year record (Thoman et al., 2020).

With far less sea ice extent within Arctic oceans and bays, coastlines are left exposed to larger fetch driven waves causing an increase of storm surge as well as coastal erosion (Vermaire et al., 2013). The decreased spatial extent of sea ice has captured global attention for its potential to allow for increased resource development, transportation, and tourism (Johnston et al., 2019). Aspects of sea ice change and its impact on communities is further discussed in Section 2.3.

2.1.2 Sea Ice Thickness

Sea ice thickness is a much more challenging metric to measure than sea ice extent (Ramsayer, 2020). National Aeronautics and Space Administration (NASA's) land Elevation Satelite-2 (ICESat-2) data suggests that sea ice has thinned up to 20% between 2003-2009, however, other studies have described contradictory conclusions of sea ice remaining constant (Ramsayer, 2020). The 2020/21 sea ice was thinnest in the full CryoSat-2 record (2010-2020) (Moon, 2021). The intensity of change in sea ice thickness depends on coastal and atmospheric conditions as well as the shoreline of area. Sea ice measurement techniques are constantly being improved and used along side calculations, models, and traditional knowledge. More about current sea ice measurement techniques can be found in Section 2.2.

2.1.3 Sea Ice Age

When the Arctic Ocean freezes, the thin layer of ice is called first-year ice, which thickens throughout the winter. Most of the first-year ice melts when areas of the Arctic Ocean become ice free in the summer. Multi-year ice refers to ice that has grown thicker year by year, either by layers of ice, driven by ocean currents, piling on top of each other, waves overtopping the ice and freezing, or snow accumulation weighing the ice down below the sea surface height causting flooding and freezing. Multi-year ice is significant to Arctic environments due to its increased thickness and resilience to changes in sea surface, and air temperatures (Thoman et al., 2020). Multi-year ice also provides habitat for many species of marine mammals in the Arctic (NSIDC, 2018). The age of ice within the Arctic Ocean greatly impacts the dynamics of the system. First-year ice is more easily manipulated by winds, ocean currents and waves, and can be cleared from the Arctic much faster than multi-year ice contributing the decreases in sea ice extent.

In 1985 33% of Arctic sea ice consisted of ice aged four years or older, in 2019 that number had decreased to 1.2% (NOAA, 2019). Figure 2-2 is from the NOAA 2019 Arctic report card and depicts sea ice age and dynamics in the Arctic.

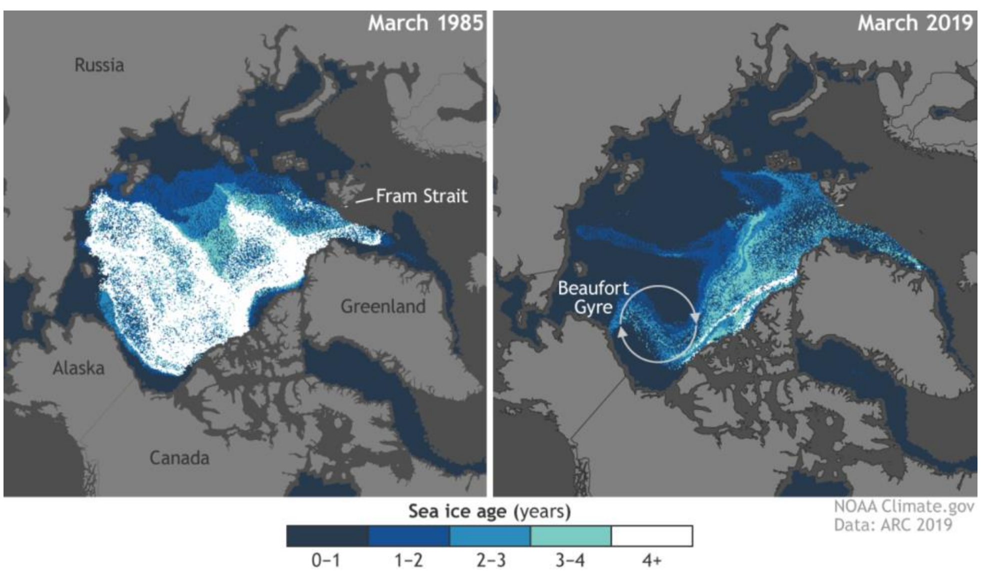


Figure 2-2: NOAA 2019 Arctic Report Card Sea Ice Age in March 1985 and March 2019 and Sea Ice Interaction with Ocean Dynamics (NOAA, 2019).

Historically, young ice recirculated in the clockwise eddy in the western Arctic called the Beaufort Gyre. While recirculating this ice could increase in thickness into multi-year ice. Today the southern part of the Beaufort Gyre has become too warm for sea ice to stay frozen. Sea ice is exiting through the Fram Strait and not being rebuilt (NOAA, 2019).

2.1.4 Open Water Season

Along with the thickness, extent, and age changes to Arctic sea ice, the time in which the Arctic Ocean is covered with ice is also declining (Crawford et al., 2021). Rising air temperature and sea surface temperature are causing sea ice freeze-up to occur later and break-up to occur earlier causing a longer open water season. Regional variation of trends in open water season length occur in different areas of the Arctic but researchers found a two week per decade increase (Polyakov et al., 2012).

2.2 Scientific Analysis Techniques to Evaluate Sea Ice

In addition to analyzing historical trends of sea ice behaviour Arctic-wide, climate scientists and researchers can also project and predict sea ice loss based on Representative Concentration Pathways (RCP) emission scenarios with numerical models and neural networks. Calibration and validation of these prediction techniques relies on measurements of sea ice characteristics. The following section details current sea ice prediction and measurements techniques.

2.2.1 Quantitative Data Availability and Measurement Techniques of Sea Ice

This section describes quantitative data sources that give scientists and researchers information about sea ice characteristics (temporal coverage, spatial extents, and thickness).

2.2.1.1 Measurement of Sea Ice Concentration (SIC)

Sea ice concentration is a valuable variable for both climate science and marine navigation. It is defined as the fraction of a given spatial area that consists of sea ice compared to open water for any point in the ocean.

Sea ice concentration can be determined via passive microwave satellite measurements. The difference between active and passive microwave measurement is, passive measurements receive the naturally emitted microwave frequencies from Earth's surface, where active measurement sends microwave signals out and measures the response time and scattering to determine the range and size of a specific object. Passive microwave measurements are done with radiometers to measure Earth's sea ice. The first radiometer attached to a satellite to measure sea ice extent was implemented in 1972. All objects on Earth emit some level of microwave energy, however microwave energy is emitted in very low magnitudes from Earth's surface (Serreze & Stroeve, 2015). Due to the crystalline structure of ice compared to the sea around it, sea ice emits a higher microwave energy and can be read by radiometers on satellites (N. R. Canada, 2008). The benefit of measuring microwave energy is the larger wavelengths of 1 cm to 1 m are able to penetrate cloud cover, fog, dust, and most rain. However, due to microwave energy emission levels being quite low, a large area must be within view of the radiometer to pick up a signal. This renders microwave measurement only possible over large areas with low spatial resolution. The resolution of these measurements is usually 1 km or more (Cavalieri & Parkinson, 2012). Measuring small areas in detail with this method is not possible but microwave satellite measurement is beneficial when measuring global or Arctic-wide range change over time.

Passive microwave satellite measurements of sea ice report sea ice concentration. When determining sea ice extent, it is common practice to count a grid cell as an ice grid cell, instead of a water grid cell, if the sea ice concentration is above 15%. A limitation of using sea ice concentration to assess trends in sea ice behavior, is when a cell is counted as an ice cell it does not distinguish between 15% or 100% sea ice concentration (Stroeve et al., 2014). Therefore, conclusions cannot be made on the quality of the sea ice.

Two sources of sea ice concentration data used in this study are defined below, Copernicus Climate Change Service (C3S) Sea Ice Concentration and Canadian Ice Services (CIS) weekly and regional archived sea ice charts.

2.2.1.1.1 Copernicus Climate Change Service (C3S) Sea Ice Concentration (SIC) Determined with Satellite Observation

A sea ice concentration daily gridded dataset (Copernicus Climate Change Service, 2020) was accessed during the scientific portion of this thesis. This dataset is produced by Copernicus Climate Change Services (C3S), Copernicus Eyes on Earth European Commission and implemented by the European Centre for Medium-Range Weather Forecasts (ECMWF). The data are derived from satellite passive microwave brightness and temperatures and is composed of two products. Both products are global sea ice concentration Climate Data Records (CDRs). CDRs are a format developed by the NOAA and the United States National Research Council. CDRs are calibrated and quality controlled long term satellite records for the purpose of developing trends on the effects of climate change (National Centers for Environmental Information (NCEI), 2021.). The first CDR data product within this dataset is produced by the European Organization for the Explorations of

Meteorological Satellite Ocean and Sea Ice Satellite Application Facility (OSI SAF). It is made up of coarse resolution (25 km) measurements based on the following three sensors, the Scanning Multichannel Microwave Radiometer (SSMR) was used from 1979-1987, the Special Sensor Microwave/Imager (SSM/I) from 1987-2006, and the Special Sensor Microwave Imager and Sounder (SSMIS) from 2006 onward. The second product is produced by European Space Agency Climate Change Initiative phase 2 (ESA CCI). This data are medium resolution measurements based on the Advanced Microwave Scanning Radiometer- Earth observing system (AMSR-e) sensor from 2002-2011 and its successor AMSR2 (2012-2017). The AMSR CDR has the spatial resolution of about 15-25 km vs the 30-69 km of the SSMIS product. AMSR provides a more detailed view of sea ice cover especially along marginal ice zone and the transition zone between ice and water. However, the SSMIS provides over a 40-year record for the development of long-term trends. These two datasets can be used together due to their shared algorithm baseline for SIC development.

After 2015 in both datasets, the CDR switch to Interim Climate Data Records (ICDR). CDRs have sufficient length, consistency, and continuity to be used to assess climate variability and change. ICDR are regular temporal extensions of the CDRs. Consistency of ICDR with the CDR are checked for an overlapping period but cannot be guaranteed during the live production of ICDR. CDRs spanning from 1979-2015 were used in the scientific portion of this thesis. The temporal resolution is every second day from prior to 1987 and daily after 1987. Only the period of 1979-2015 were used to develop long term trends for this analysis. The methods of obtaining and analyzing these data are found in Section 3.1.1.1 and the results of this analysis are presented in Section 4.1.2.1 Both the SSMIS and AMSR CDRs from January 3rd, 2015, are presented in Figure 2-3.

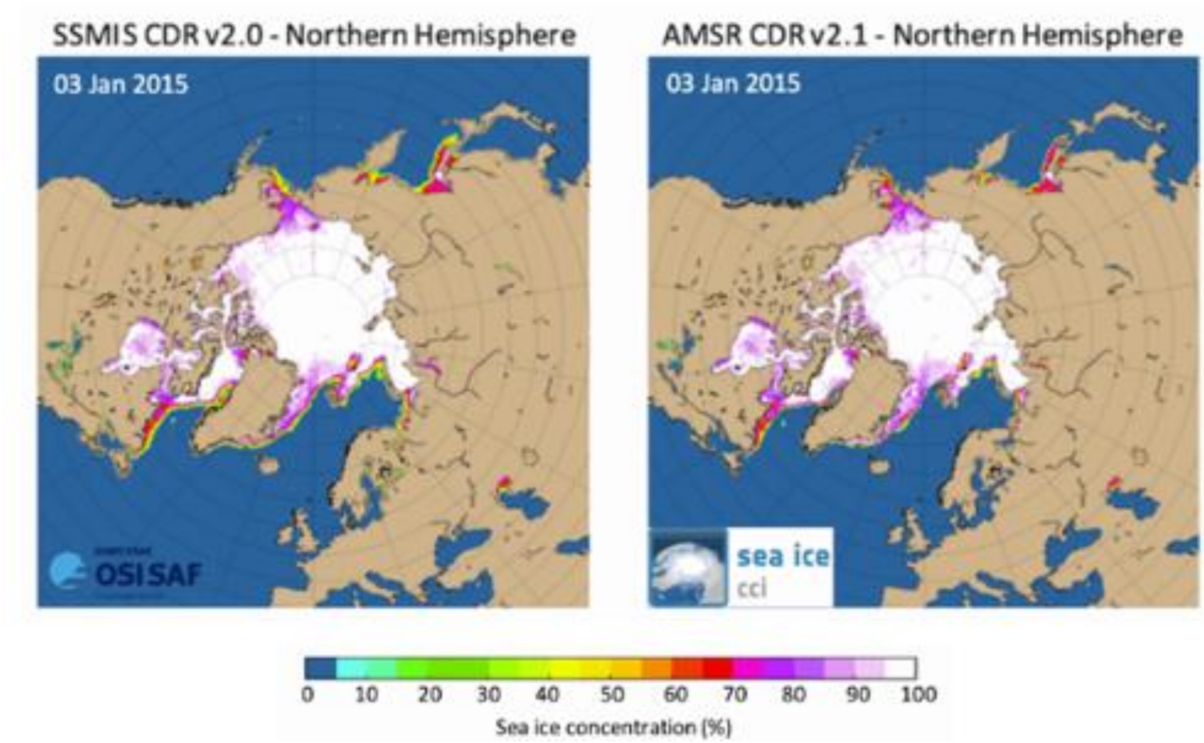


Figure 2-3: Copernicus Climate Change Services (C3S) Sea Ice Concentration (SIC) Climate Data Records Data Products on January 3rd, 2015. SSMIS (left) and AMSR (right) (Copernicus Climate Change Service, 2020).

2.2.1.1.2 Canadian Ice Services (CIS) Archived Weekly Regional Sea Ice Charts

The Canadian Ice Services (CIS) publish regional weekly and daily ice charts (E. and C. C. Canada, 2010). These charts are meant to be used for marine navigation and climate science. CIS also maintains archives of sea ice conditions for five regions in Canada dating back to 1960 in some areas. The five regions are shown below in Figure 2-4.

Figure 2-4: Canadian Ice Services (CIS) Archived Weekly and Regional Archived Sea Ice Charts, Five Data Regions (E. and C. C. Canada, 2009a).

The weekly generated sea ice charts are based on various sources of data, primarily satellite imagery in addition to visual observation from marine and air transport. Several days of data are combined to achieve complete spatial coverage of the area.

Resolute Bay is included in the western most part of the eastern Arctic, and the eastern most part of the western Arctic. The eastern Arctic charts were accessed for this study as the area of interest on the southern shores of Cornwallis Island were fully included within the spatial extent of eastern Arctic maps. An example of an archive map from May 15th, 2004, is shown in Figure 2-5.

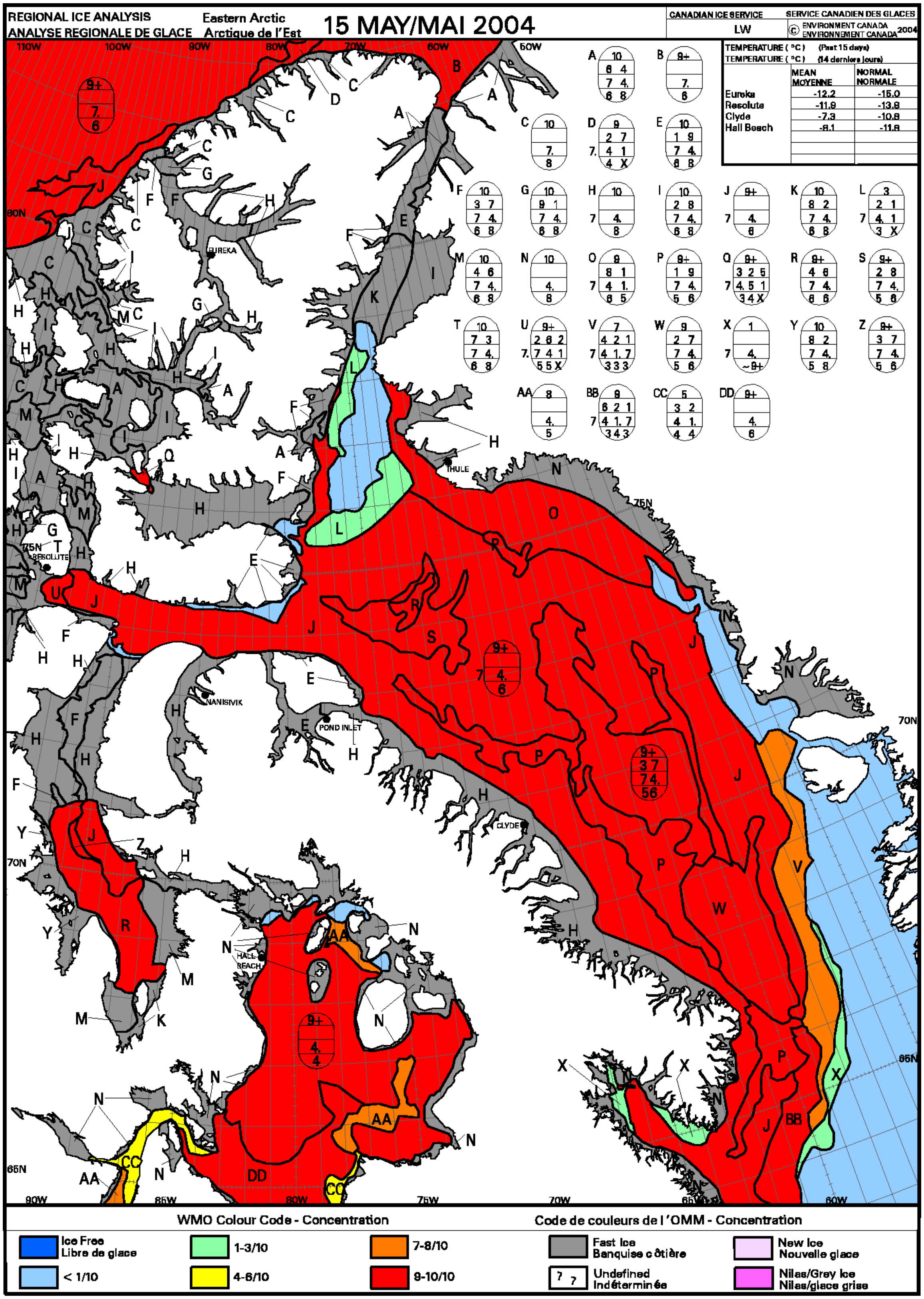


Figure 2-5: Canadian Ice Services (CIS) Eastern Arctic Archived Sea Ice Chart Week of May 15th, 2004 *(E. and C. C. Canada, 2010)*.

The World Meteorological Organization (WMO) colour coding refers to the sea ice concentration in the format of a fraction out of 10. The May 15th, 2004, chart indicates there is break-up beginning and open water within Baffin Bay. However, near Resolute Bay there is still fast ice (ice that is still frozen to the shoreline) on the southern shores of Cornwallis Island and 90-100% ice concentration in the Northwest Passage. In addition to sea ice concentration, historical ice charts also report on the form and stage of development of sea ice via the egg code. An inset on the May 15th, 2004, chart of the area near Resolute Bay and an example of how to interpret the egg code is shown in Figure 2-6.

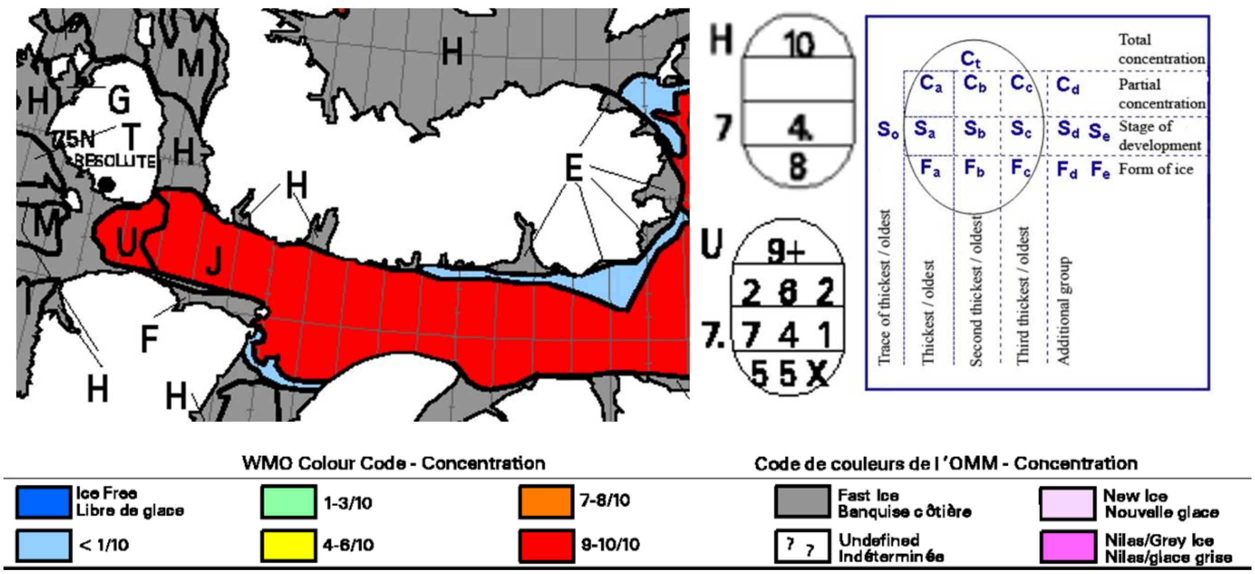


Figure 2-6: Canadian Ice Services Eastern Archived Sea Ice Chart Week of May 15th, 2004. Inset of area near Resolute Bay (left), Associated Alphabet Egg Code per Spatial Area (center), Reading Instructions (right) *(E. and C. C. Canada, 2009a)*.

The egg code reports the concentration, stage of development, and form of the ice. The concentration is reported in the top two rows, stage of development in the third row from the top, and the form (floe size) of sea ice is reported in the bottom row. The egg code is used internationally to report sea ice conditions. In Canada, additional parameters have been added So, Cd, Sd, Se, Fd, and Fe. Concentration (C) is reported with Ct total concentration, and partial concentration of the thickest (Ca), second thickest (Cb), third thickest (Cc), and fourth thickest (Cd) in tenths. The stage of development (S) is recorded in a similar fashion. (So) represents the stage of development of the thickest ice, (Sa) second thickest, (Sb) third thickest, (Sc) fourth thickest, and thinner ice (Sd and Se). The stage of ice development also refers to the thickness.

Table 2-1 below dictates the number code and the corresponding ice thicknesses and ice stage (E. and C. C. Canada, 2009b).

Table 2-1: Canadian Ice Services Archived Weekly Regional Ice Chart Coding for Stages of Development and Ice Thickness.

Description	Thickness	Code
New ice	<10 cm	1
Nilas, ice rind	<10 cm	2
Young ice	10-30 cm	3
Grey ice	10-15 cm	4
Grey-white ice	15-30 cm	5
First-year ice	>= 30 cm	6
Thin first-year ice	30-70 cm	7
First stage thin first-year	30-50 cm	8
Second stage thin first-year	50-70 cm	9
Medium first-year ice	70-120 cm	1•
Thick first-year ice	>120 cm	4•
Old ice	-	7•
Second year ice	-	8•
Multi-year ice	-	9•
Ice of land origin	-	▲•
Unknown or undetermined	-	X•

Ice form or floe size is reported as (Fa, Fb, and Fc) as predominate floe sizes. Fa refers to the thickest, Fb the second thickest and so on as above. Table 2-2 below defines the codes associated with floe width.

Table 2-2: Canadian Ice Services Archived Weekly Regional Ice Chart Coding for forms of Sea Ice.

Description	Floe Size	Code
Pancake Ice	-	0
Small ice cake, brash ice, agglomerated brash	<2 m	1
Ice cake	2-20 m	2
Small floe	20-100 m	3
Medium floe	100-500 m	4
Big floe	500-2000 m	5
Vast floe	2-10 km	6
Giant floe	>10 km	7
Fast ice	-	8
Icebergs, growlers, or floe icebergs	-	9
Undetermined, unknown, or no form	-	X

CIS began using the egg code in the eastern Arctic ice chart archives on May 15th, 1982. Prior to this date the historical ice charts used a different coding system. The old system was used from 1967-1981 and gave information about both sea ice concentration and stage of development (thickness). Sea ice chart archive records from before May 15th, 1982, were disregarded for the purposes of this thesis. The methods of using sea ice charts to determine the changing trend in the sea ice break-up and freeze-up timing are described in Section 3.1.1.2 and the results of this analysis are presented in Section 4.1.1.2.

2.2.1.2 Measurement of Sea Ice Thickness

There are various methods of measuring sea ice thickness and change over time, each with its advantages and limitations. One of the most common methods is through satellite observations, using sensors that can measure the height of the sea ice above the ocean surface. Another method is airborne surveys, which use radar or LIDAR to measure ice thickness from above. Ground-based measurements can also be taken using specialized tools such as ice-penetrating radar or electromagnetic sensors. In addition, scientists can collect ice cores, which provide a record of past ice thickness and can be used to reconstruct historical trends. This section will discuss sea ice thickness measurement techniques including satellite imagery, hot wire measurements, and newly developed SmartICE sensors. Each type of sea ice thickness data is described in the sections below however, two sources of sea ice thickness data were used in this study, a C3S gridded sea ice thickness dataset and an Environment and Climate Change Canada (ECCC) dataset of fast ice thickness near Resolute Bay.

2.2.1.2.1 Copernicus Climate Change Service (C3S) Sea Ice Freeboard Thickness Determined with Satellite Observation

Similar to the dataset described in Section 2.2.1.1.1, C3S also provides a monthly gridded dataset of sea ice thickness (Copernicus Climate Change Service, 2018). These sea ice thickness data represent sea ice freeboard (the difference between the sea ice height and the sea surface height) rather than the entire sea ice thickness. The following schematic (Figure 2-7) demonstrates the difference between sea surface height, snow depth, ice draft, ice freeboard, and ice thickness.

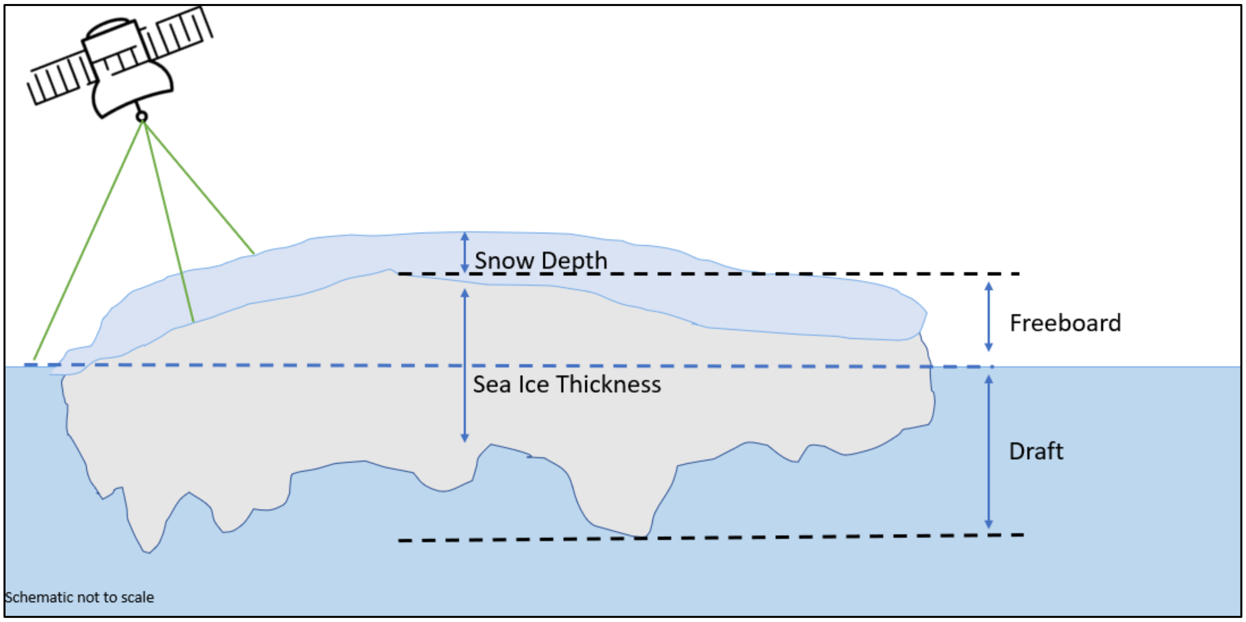


Figure 2-7: Copernicus Climate Change Services (C3S) Sea Ice Freeboard Data Collection Schematic.

The C3S sea ice thickness dataset has a 25 km spatial resolution, monthly temporal resolution, and is based on satellite radar altimetry observations from Envisat and CryoSat-2. This dataset has combined measurements from both satellites into one CDR from October 2002 to April 2020. ICDR data were available beyond April of 2020 but excluded from this analysis in order to ensure data quality. Envisat uses the RA-2 altimeter from October 2002 to October 2010 and CryoSat-2 uses the SIRAL SAR (Synthetic aperture Interferometric Radar Altimeter) from November 2010 to April of 2020.

These data only include measurements from winter months (October to April) to avoid bias from melting snow or open melt ponds for the remaining months. Although CDR's are of sufficient length, consistency, and continuity to develop long term trends, the data from CrySat-2 is of higher quality and accuracy (Copernicus Climate Change Service, 2018). An example of the sea ice thickness climate data record from both Envisat and CryoSat-2 satellites in April of 2003 and 2020 is presented in the Figure 2-8.

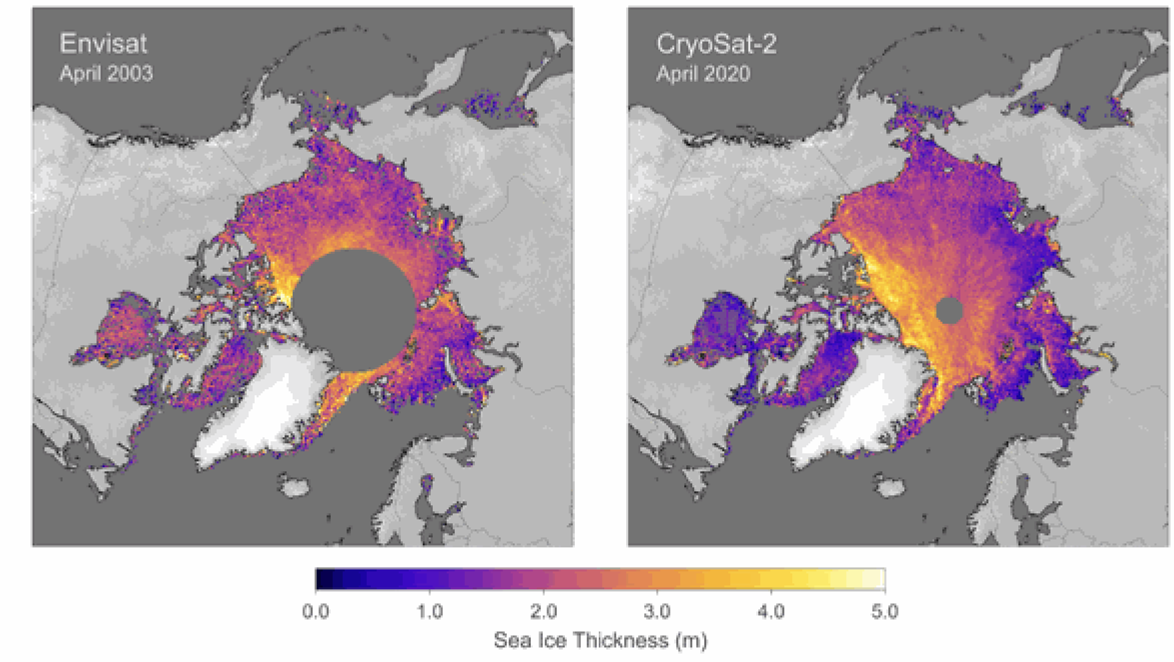


Figure 2-8: Copernicus Climate Change Services (C3S) Sea Ice Freeboard Thickness Climate Data Records Data Products on April 2003. Envisat (left) and CryoSat-2 (right) (Copernicus Climate Change Service, 2018).

The methods used to obtain and evaluate this data are presented in Section 3.1.2.1 and the results are presented in Section 4.1.2.1.

2.2.1.2.2 National Aeronautical and Space Administration (NASA) ICESat and ICESat2 Derived Sea Ice Thickness

NASA has conducted three missions that have remotely measured sea ice thickness between 2002 and 2021 via altimeter. The first was Ice, Cloud, and Elevation Satellite (ICESat). The ICESat mission was from January 13th, 2003, to August 14th, 2010 (Neumann, 2017). The second generation of the laser altimeter ICESat Mission was IceSat2 launched in 2018 and is still collecting data (Ramsayer, 2020). The IceBridge mission collected data between the first (ICESat) and second (ICESat2) satellite missions. ICESat collects data with a Geoscience Laser Altimeter System (GLAS). The original mission goal was to measure ice sheet balance to identify the difference and reduction of snow melt, ice melt, ablation, or calving through measurement of the elevation of an ice sheet.

IceBridge was designed to bridge the gap in Arctic observation between ICESat and ICESat2. IceBridge flew specialty aircraft to conduct surveys with equipment such as radar sounder, gravimeters, magnetometers, and mapping cameras. While IceBridge mapped ice sheet and glacier elevation, it also documented seasonal growth and melt of sea ice, including tracking interannual variations in sea ice extent and thickness. IceBridge continued to fly after ICESat2 was launched to validate the satellite measurements. The primary area that the IceBridge mission covered was Greenland and Antarctica. However, there are a few datasets that have Arctic-wide coverage.

ICESat2 was derived from the advanced topographic laser altimeter system aboard the Ice Cloud and land Elevation Satellite-2 (Khalsa et al., 2022)). This mission measures the height of Earth's surface by measuring the time it takes for a laser pulse to reach Earth's surface and return to the satellite. The altimeter system aboard the ICESat2 is the ATLAS (Advanced Topographic Laser Altimetry System). It fires a green laser at a frequency of 10,000 pulses /second (McGarry et al., 2021). The time it takes the laser pulse to leave the instrument then return after rebounding off the surface gives information about elevation and consequently the sea ice thickness.

Although NASA's sea ice thickness measurement program offers valuable information when combined on an Arctic-wide scale, the amount of data from these missions near Resolute Bay was not sufficient to develop long term trends. ICESat and ICE-Sat2 data were not used during the scientific portion of this study.

2.2.1.2.3 Environment and Climate Change Canada (ECCC) Weekly Auger Fast Ice Thickness Measurements

Environment and Climate Change Canada (ECCC) provides sea ice thickness measurements for various communities in Inuit Nunangat (E. and C. C. Canada, 2007). These measurements were taken in the fast ice with an auger. An auger is used to measure sea ice like a large drill, and only gives sea ice thickness measurement at one point. Figure 2-9 demonstrates the measurement techniques with an auger.

Figure 2-9: Drilling into Sea Ice (left) (Hartley, 2022) and Augur Fast Ice Measurement Schematic (right) (Mahoney & Gearheard, 2008).

The ECCC fast ice data incorporate two data collection programs, the original ice thickness program collection from 1947 to 2002 and extended ice thickness program collection from fall 2002 to summer 2021. The 1947-2002 dataset has ice thickness measurements for 195 sites. Some of the data sites also have Environment Canada hourly weather monitoring stations to give paired ice and weather measurements for atmospheric, oceanographic, and cryospheric modelling. The original data gathering from 1947-2002 are downloadable and contain the data fields station ID, station name, date, ice depth, snow depth, measurement technique, surface topography, and cracks and leads. Limited metadata were available with the downloadable data. The updated program from 2002-2021 is downloadable and contains snow depth, ice depth, surface code, water feature, and method of observation.

The following communities have data present in both the first phase (1947-2002) and the second phase (2002-2021) Alert, Baker Lake, Cambridge Bay, Coral Harbour, Eureka, Sanirajak (Hall Beach), Inuvik, Iqaluit, and Resolute Bay. Figure 2-10 shows the temporal coverage of sea ice thickness measurements at the above communities.

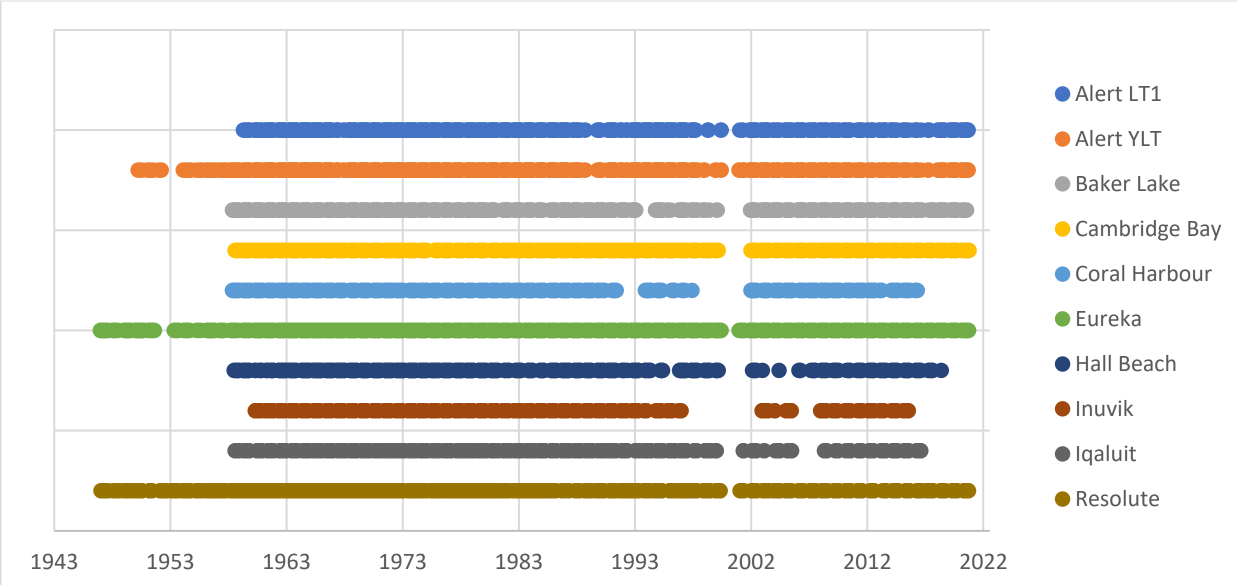


Figure 2-10: Environment and Climate Change Canada (ECCC) Fast Ice Measurements Temporal Coverage at All Locations.

There are a few missing years of data within some of the communities specifically when the measurement program changed from the former to current. However, most communities have about a 70-year record of weekly ice thickness measurements. Of the communities with long period ice thickness data available, Resolute Bay was selected for the purposes of this study. Resolute Bay was selected based on many factors including the amount of data available, lack of previous studies, and accessibility from the home university in Ottawa. Alert and Eureka are military bases rather than habitable communities. Baker Lake is not a coastal community, Iqaluit was eliminated because as the capitol of Nunavut and largest community, many studies have already been done on this community. Between Coral Harbour, Cambridge Bay, Sanirajak (Hall Beach), and Resolute Bay, Resolute Bay was selected based on flight logistics for community visits.

Measurements for this dataset are taken on the fast ice at approximately the same location every year with weekly time resolution, starting after freeze-up and continuing until break-up. The ECCC fast ice thickness measurements were taken in Resolute Bay approximately 100 m offshore, within the bay nearest the community. The measurement location is close to shore but over a depth of water which exceeds the maximum ice thickness. Figure 2-11 depicts the measurement location relative to the community.

Figure 2-11: Environment and Climate Change Canada Fast Ice Thickness Measurement Location Relative to Resolute Bay, Nunavut.

Data from this period of record extended from 1947 to 2021. The measurements were taken at a weekly frequency. However, the number of measurements varies per year. The number of measurements taken in each year are displayed in Figure 2-12. The measurement location is in about 20 m of water depth.

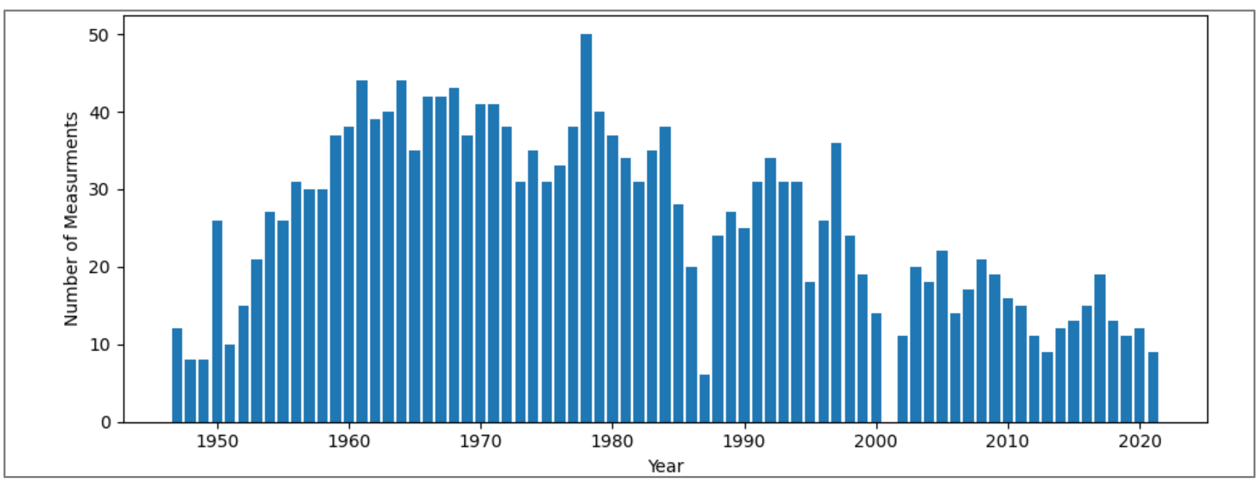


Figure 2-12: Environment and Climate Change Canada (ECCC) Fast Ice Measurements Number of Measurements Per Year in Resolute Bay.

As the program spun up after 1947, the number of measurements per year increased from 10 to about 40 in 1960. The number of measurements then stayed around 40 in the 1960’s, 70’s, and

80’s. After 1984 the number of measurements per year declined to about 30 in the 80’s and 90’s and between 10 and 20 in the 2000’s and 2010’s. There are many factors that may influence the number of measurements per year, including personnel availability or safety standards of the institution maintaining the measurement stations. For example, a year with fewer measurements could be indicative of a year where there were fewer staff available to take measurements rather than fewer ice covered days to measure. Additionally, a change in number of measurements over time could be determined by new safety standards or other operational changes for measurement of the sea ice rather than fewer days of sea ice coverage to measure. Environment and Climate Change Canada (the maintainers of these data) were contacted to clarify why some years have fewer measurements than others. The candidate and her academic advisor spoke with Wayne Davidson of ECCC in May of 2023. He has been living in Resolute Bay for the past 40 years and has been responsible for either taking the fast ice thickness measurements or overseeing the measurement program. Wayne explained that these data were collected by ECCC from 1970-1998. In 1998 the collection switched to a contractor. In 1997 there was a policy change in ECCC to wait until the sea ice reached a thickness of at least 50 cm to begin taking measurements and stop taking measurements when it thinned to 50 cm. He also shared there was a policy change in 2012, to take measurements bi-weekly until March, then take measurements weekly after March. This information was not provided in the data and is helpful for understanding it’s availability.

These data were further broken down into the months in which each measurement occurred in the Figure 2-13.

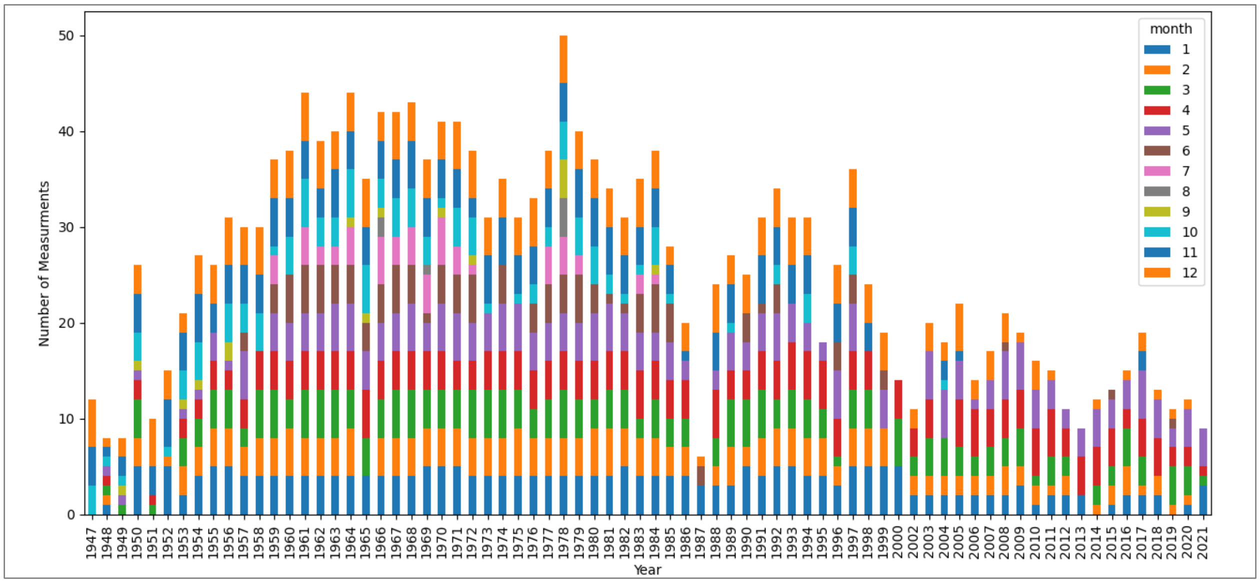


Figure 2-13: Environment and Climate Change Canada (ECCC) Fast Ice Thickness Number of Measurements per Year Broken Down by Month.

As expected, throughout most of the measurement years, the measurements occurred mainly in winter and spring months (December, January, February, March, April, and May). To demonstrate the higher occurrence of measurements in winter and spring, the above plot was further broken down into the number of measurements filtered by season. Winter is defined as measurements taken within a given year in December, January, or February. Spring being March, April and May, Summer is defined as June, July, and August, and Fall September, October, and November. The seasonal occurrence of fast ice thickness measurements is shown in Figure 2-14.

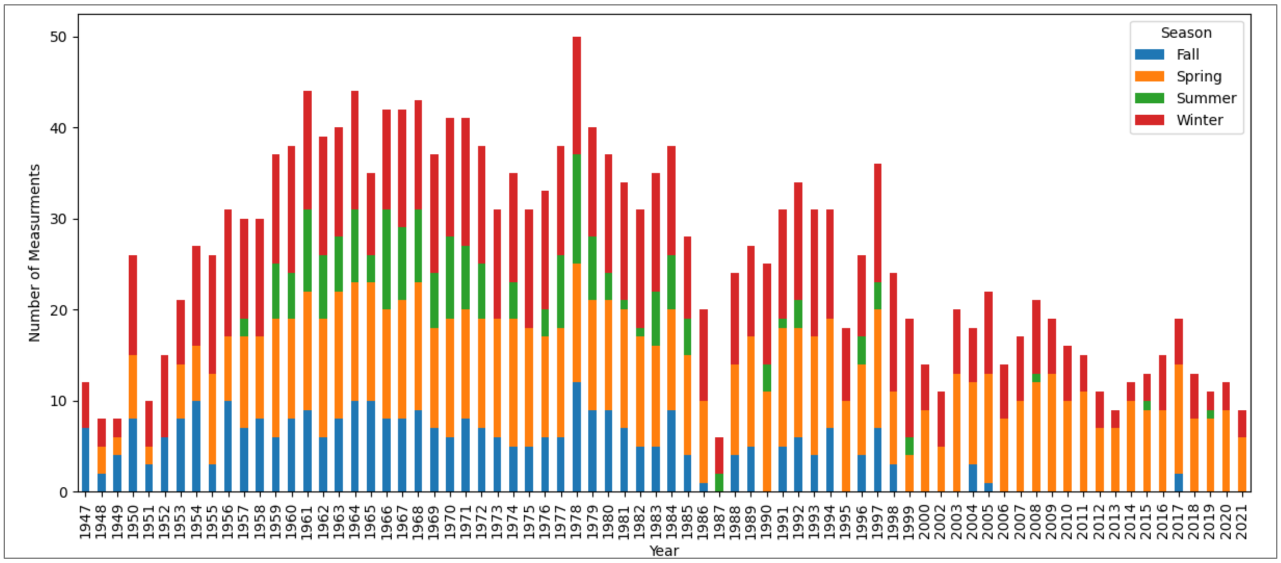


Figure 2-14: Environment and Climate Change Canada (ECCC) Fast Ice Thickness Number of Measurements per Year Broken Down by Season.

Most measurement points were taken in either the spring or the winter, which coincides with the ice-covered season. However, the number of summer measurements decreased significantly after 1985 and fall measurements decreased after 1998. Before 1985, 12.3% of all measurements were taken in the summer and after 1985 that percentage fell to 3.5%. Similarly, before 1998, 25.6% of measurements were taken in the fall which decreased to only 1.3% after 1998. From 2006 onward only 2.2% of measurements have occurred in the fall or summer months. These changes are likely due to a combination of the procedural changes in the measurement program, safety standard changes, or a decrease of ice presence during these seasons.

The figures presented above were done to gain a better understanding of this dataset. The methods used to access the fast ice thickness measurements themselves are described in Section 3.1.2.2 and 3.1.4.2. The results of these analysis are presented in Section 4.1.2.2.

2.2.1.2.4 Other Sea Ice Thickness Measurement Techniques

The methods of measuring sea ice thickness presented above are not an exhaustive list. Other measurement techniques are presented below.

Sea Ice Thickness Measurement Through Community Initiatives

SmartICE is a Canadian not for profit organization that has developed two sensors the SmartBUOY and the SmartQAMUTIK ("SmartICE - Sea Ice Monitoring and Information Inc.," 2021). The SmartQAMUTIK is towed behind a snowmobile during traditional hunting on the ice and the SmartBUOY is an autonomous sensor that is deployed post freeze-up and recovered before ice break-up where the sensor would be lost to ocean currents. The SmartQAMUTIK sensor transmits a signal through Global Positioning System (GPS) back to a main data base. SmartICE trains local Inuit operators to deploy and use the sensors. SmartICE is also Inuit owned and currently operates in 15 communities in Nunavut, including Resolute Bay. The partnership between SmartICE and the Hamlet of Resolute Bay is in its early stages and no sensors have been deployed near the community yet. Unfortunately, data from any SmartICE sensors will not be available to access within this study but may be available for future work. SmartICE is a revolutionary and innovative solution that provides significant contribution to a field lacking in recorded data while valuing community participation and cooperation.

Siku is the Inuktitut word for sea ice, it is also an Indigenous knowledge social network and mobile app (SIKU - The Indigenous Knowledge Social Network, n.d.). It is created by and for Inuit people and values the preservation of traditional knowledge, hunting practices and language. It provides a platform for information about weather, the sea ice, marine mammals, tides, marine forecasts, and satellite imagery. SIKU allows hunters to document dangerous and changing conditions as well provides new ways for Inuit knowledge and science to work together. SIKU partners with SmartICE and all sensor data is available alongside traditional knowledge on the combined platform.

Sea Ice Thickness Measurement Through Sonar and ADCP

Sea ice thickness can be measured with sensors, upward looking Acoustic Dopler Current Profiler (ADCP)s, or sonar. During sonar measurements, an upward looking ice profiler sends an ultrasound pulse up through the water through a layer of ice and returns an echo from the ice liquid interface (*Monitoring Sea Ice in Tasiujaq*, n.d.). Sonar measurements are valuable for predicting difficult to measure parameters such as sea ice draft thickness.

2.2.2 Numerical Modelling of Sea Ice

There are many existing numerical models that are either stand alone sea ice models that determine the thickness and extent of sea ice, or coupled sea ice, atmospheric, and ocean models that work together to determine the effects of ocean and atmospheric forces on sea ice. The stand-alone models also have the capability to be coupled with separate atmospheric and ocean models. The results of these models are highly dependant on the initial conditions, so are difficult to validate when simulating future predictions. Sea ice thickness and extent is influenced by many factors to be considered within numerical models including cloud cover, albedo, air temperature, winds, sea surface temperature, and hydrodynamic conditions such as waves and currents.

The world climate research program has two ongoing model comparison projects Coupled Model Intercomparison Project (CMIP) and Sea Ice Model Intercomparison Project (SIMIP) (*CMIP*, n.d.). CMIP is a group of scientists and projects who register their coupled sea ice models with CMIP. Model results are used in international negotiations and International Panel on Climate Change (IPCC) reports (*CMIP6/ESGF*). There are many phases of CMIP which have 40-60 sea ice models registered that are evaluated and compared. The objective of CMIP is to better understand past, present, and future climate change and to make this data widely available. CMIP6 is the current phase and has three main participant groups. The three groups being modelers carrying out the CMIP6 simulations, data mangers responsible for input data, and data users analyzing the CMIP6 data output.

CMIP compares coupled sea ice models where SIMIP compares only the sea ice components of models. Sea ice numerical models are generally spatially gridded with varying grid resolution from 1.5-150 km scale per grid cell (Blockley et al., 2020). Individual calculations within each grid cell are completed on ice concentration. For grid cells that have an ice concentration of at least 15% sea ice, will contribute toward the sum of total sea ice area (Thoman et al., 2020). Sea ice models generally model two components, thermodynamics, and ice dynamics. Thermodynamic simulations include the ocean-ice interaction and air-ice interaction such as the freezing and melting of ice when in contact with an above 0 °C interface (*Studying: Modeling | National Snow and Ice Data Center*, n.d.) where the ice dynamic processes are ocean currents and ice deformation. Incorporating highly complex interactions and mechanisms is a large challenge in sea ice modelling. Such complexities include wave-ice interaction, individual ice floes on a sub grid scale, melt ponds on sea ice, and high-resolution ice dynamics (Feltham, n.d.).

Two models included in the world climate change research program are Nucleus for European Modelling of the Ocean (NEMO) a coupled model and CICE a stand-alone model. The NEMO model has three components, NEMO-OCE models the ocean thermodynamics and solves equations such as the Navier-Stokes equation (*Primitive Equations*), NEMO-ICE models the sea ice thermodynamics, brine inclusion, and sub grid scale thickness variation, and NEMO-TOP in ocean paradigm models the oceanic tracers transport and biogeochemical processes (Rousset et al., 2015). CICE is a stand-alone model that simulates growth, melt, and movement of sea ice. It is developed by United States Department of Energy and maintained by CICE consortium. It is one component of a coupled atmosphere-ocean-land ice global climate models (*1.1. About CICE — CICE Documentation*, n.d.). CICE has been successfully used in a regional study to model sea ice in Labrador with a 10 km gird resolution (Zakharov et al., 2016). The NEMO model was used by Hu et al. to simulate the spatial distribution of sea ice thickness in the Canadian Arctic. Their model was compared to ECCC's new ice thickness monitoring program at seven sites (Cambridge Bay, Coral Harbour, Sanirajak (Hall Beach), Iqaluit, Resolute Bay, Eureka, and Alert) between 2002-2016. Their model performed well at some stations but not at others. Although a CMIP numerical model was used to simulate sea ice thickness at a regional scale across the Canadian Archipelago, the spatial scale was not granular enough to make conclusions on a community scale.

Data availability is crucial for the calibration and validation of numerical models. Science and engineering have the capability to model complex ice, ocean, and atmosphere interaction and there is potential to use this capability to better understand and help communities adapt to the changes in sea ice that may affect their daily lives. There are many existing global sea ice models covering the entirety of the Arctic and global models of both the Arctic and Antarctic. Limited studies, particularly in Arctic Canada, have been done with a regional sea ice model. Many qualitative vulnerability studies exist for community assessments done in Nunavut however, data availability is the main inhibitor of quantitative sea ice studies.

2.2.3 Neural Networks to Predict Sea Ice Change

Numerical models are powerful tools for simulating sea ice behaviour. However, they are dependant on physical phenomenon. Neural networks are a type of machine learning algorithm that can trained on historical data and be used to predict sea ice decline based on RCP scenarios. These networks can learn complex patterns and relationships in large datasets, such as sea ice extent and thickness measurements. These models can be used to project sea ice decline, estimate the probability of different outcomes, and identify the key factors that influence sea ice dynamics. The use of neural networks can improve the accuracy and reliability of sea ice predictions, particularly in regions where direct measurements are limited or unavailable (Nichol et al., 2021). Neural networks also have the potential to improve the speed and efficiency of sea ice predictions, as they can process large amounts of data quickly and can be run on parallel computing systems

(Andersson et al., n.d.). However, neural networks also have limitations, such as the need for high-quality data and the potential for overfitting or underfitting the model. Combining neural networks with other modeling approaches and observation methods can provide a more comprehensive understanding of sea ice behavior and improve predictions of future sea ice decline.

2.3 Changing Sea Ice Impacts to Arctic Environments and Inuit Communities in Nunavut

The reduction of sea ice has been drastic within Nunavut over the last few decades. These changes have potential to severely impact communities in Nunavut but also provide opportunity to improve standard of living through emerging opportunity for sustainable economic development.

2.3.1 Changing Sea Ice Impacts to Arctic Environments

Arctic ecosystems including the atmosphere, ocean, and cryosphere are complex and interdependent systems. Changes to one portion of the system will cause cascading effects to the other portions. A positive feedback loop occurs when change in one variable leads to change in a second variable. The change in the second variable then reinforces and further amplifies change in the first. A positive feedback loop is present in Arctic ecosystems when sea ice melts, the albedo value of the Earth's surface decreases. This decrease in albedo further exacerbates melting sea ice. Albedo is defined as the ratio of sun reflected off a surface compared to the radiation absorbed by that surface. The Arctic generally has high albedo values meaning more sun is reflected from bright surfaces, where a dark surface with a low albedo absorbs more radiation from the sun. The Arctic snow- and ice-covered surfaces typically have high albedo values and reflect more heat back into space than is absorbed, effectively cooling the earth. As surface air temperatures rise and snow and ice cover deplete, albedo values lower, causing further melting of sea ice (Gunnarsson et al., 2020).

As presented in Section 2.1, Polyakov et al. found an average decrease of two weeks per decade in ice covered time Arctic-wide. Sea ice acts as a physical barrier between the atmosphere and the ocean surface limiting exchange of heat between the two. In the absence of sea ice, the ocean surface is able to absorb more incident solar radiation (Barnhart et al., 2014). Sea surface temperature is driven mainly by the amount of solar radiation absorbed. Increased sea surface temperature further contributes to the decline in sea ice. Longer open water seasons are also causing an increase to permafrost degradation and coastal erosion (Thoman et al., 2020). The severity and frequency of Arctic storms have increased due to climate change. A storm that makes landfall during the ice-covered season does not bring severe waves and storm surge with it. Less sea ice causes longer fetch for wind driven waves. A lack of sea ice leaves coastal shores exposed to warmer waters with more intense waves. The warmer water interacting further inland on Arctic coastlines contributes to the thawing of permafrost and causes severe coastal erosion up to 7 m per year in highly exposed regions such as Tuktoyaktuk. The most severe Arctic storms occur in November to February, therefore open water present later into the fall causes greater ocean swells (Crawford et al., 2021). Longer open water season increases the occurrence of algae blooms (*Chapter 3: Polar Regions — Special Report on the Ocean and Cryosphere in a Changing Climate*, n.d.). Changing sea ice within the Arctic does not only have impacts to Arctic environments but global weather patterns as well. Declining sea ice causes changes to ocean currents, and the jet stream due to smaller differences in air temperatures. This will impact Arctic climates as well as global weather patterns.

2.3.2 Impacts on Communities

Sea ice decline severely impacts Inuit communities that rely on the sea ice for their traditional ways of life including sustenance hunting and travel on the sea ice.

2.3.2.1 Loss of Hard and Soft Infrastructure

A vulnerability assessment in Arctic Bay, Nunavut was conducted (Ford et al., 2010) to define the climate change effects on both hard and soft infrastructure within the community. It defined the current and future vulnerability as well as adaptive capability of infrastructure in the community. Their study outlines defining characteristics of the community including population, current weather and environment, existing infrastructure, and typical community activities.

Soft infrastructure refers to the semipermanent trails on land, ice, and at sea used during hunting and fishing activities (Ford et al., 2010). Climate change is rendering Artic storms to be more frequent and intense. The increased unpredictability of Arctic storms affects the ability of traditional knowledge to understand the environment and evaluate risks when using soft infrastructure. Due to inconsistent and changing conditions year to year, Elders are no longer able to pass on traditional knowledge through gained experience to young hunters and fishers. Arctic Bay residents have observed changes in weather patterns (wind and wave) and open water becoming harder to predict, leaving hunters stranded on land waiting safe conditions (Ford et al., 2010). Traditional knowledge transfer of ice conditions has also become less predictable with later ice freeze-up, earlier ice break-up, thinner ice, more snow on the ice and new ice-free areas. Changes in ice conditions leave hunters and fishers exposed to risks such as being stranded on ice sheets that have detached from fast ice, falling through ice that is thinner than expected, and more snow camouflaging areas of thin ice and open water. Adaptation to these risks can be achieved in the form of transition of traditional knowledge from Elders to youth, shortening of hunting seasons to occur during safe conditions, and purchase of equipment such as personal GPS equipment and Very High Frequency (VHF) radios to communicate and locate individuals during an emergency. Although the hunting seasons have been affected by changing ice in a negative way, the longer open water season allows for longer fishing seasons.

Coastal erosion is the main factor affecting hard infrastructure in Arctic Bay. Construction has occurred on permafrost soil, thawing of this ice rich terrain has potential to cause subsidence of the ground which causes structural damage to buildings. Erosion events have been witnessed by community members from large storm events including the community breakwater which suffered damage during a storm event (Ford et al., 2010). Current adaptive capability relies on piled structures and gravel beds underneath buildings to prevent thermal conduction from thawing the permafrost underneath. Conditions promoting coastal erosion have been predicted to increase in the future. Future adaptability is reliant on understanding of the local climate variability and landscape response, which in many Arctic communities including Arctic Bay, is not readily available.

Arctic Bay is not the only community being affected by coastal erosion. The Hamlet of Tuktoyaktuk is severely at risk of losing culturally significant historic sites to coastal erosion such as the community graveyard as well as hard infrastructure such as community homes on the shoreline (Lantz et al., 2022). The current adaptive strategy is to construct shoreline erosion mitigation structures to protect the community in the short term. Eventual relocation is a long-term option to protect the hamlet of Tuktoyaktuk from coastal erosion.

2.3.2.2 Decreased Trust in Traditional Knowledge

Typically, in Inuit culture, knowledge of hunting and traveling on the sea ice is passed down through oral knowledge. However, with climate change causing rapidly evolving sea ice conditions, traditional knowledge may not be applicable to the evolving sea ice. Indigenous communities using the water and ice to fish and hunt have had to adapt to the increased length of the ice-free season and decreased sea ice thickness. Changes in the floe edge or land ice have changed species migration patterns and therefore the hunting of those species for Indigenous communities (Laidre et al., 2012).

2.3.2.3 Increase in Food Insecurity

Food security is defined as “all people at all times having access to sufficient, safe, and nutritious food to meet dietary needs and food preferences for an active and healthy lifestyle” (Ford, 2009). Food security contains many different components such as food availability which deals with the question of sufficient food being available to meet a population demands. Food access is the ability of households and individuals to access adequate food even if it is available. Food quality refers to the food being sufficiently safe, nutritional and in some cases culturally significant. When any of these components fail to be met food insecurity can occur. Rates of Inuit food insecurity are far higher than Canadian average due to high prices of available food, limited unreliable access to income, and climate change effects on traditional food sources (Ford, 2009). Food insecurity is linked to negative health outcomes such as chronic illness and stress. Food insecurity is well documented in Inuit communities in Canada.

Due to the remote northern nature of Arctic communities, there is little opportunity for reliance on locally harvested products. Inuit food systems are particularly vulnerable to climate change due to the remoteness of communities and reliance on traditionally sourced food. All communities in Nunavut have both waged and sustenance economies. Harvesting of marine and terrestrial animals supplies and important part of nutritional intake as well as cultural significance. Ice conditions are particularly important for the hunting of walrus and polar bear as well as transportation and access to the mainland for caribou hunting. The lack of roads makes the condition of land trails important.

A study in Igloolik, Nunavut found the consumption of traditional food has fallen especially in younger generations. A survey indicates 41% of respondents obtained more than half of meat and fish they consume from traditional sources (Ford, 2009). Another study found Inuit people obtain 6-40% of their daily energy from traditional foods (Kuhnlein & Receveur, 2007).

Sea ice has been thinning all over the Arctic posing challenges to communities that use sea ice as an important platform for transportation and hunting (Cooley et al., 2020). Migration patterns of typical species being hunted have changed as well as the safety and ability of hunters to use and travel on the ice (Prno et al., 2011). A study by Ford et al. (2009) produced Figure 2-15 defining factors affecting food insecurity in Inuit communities.

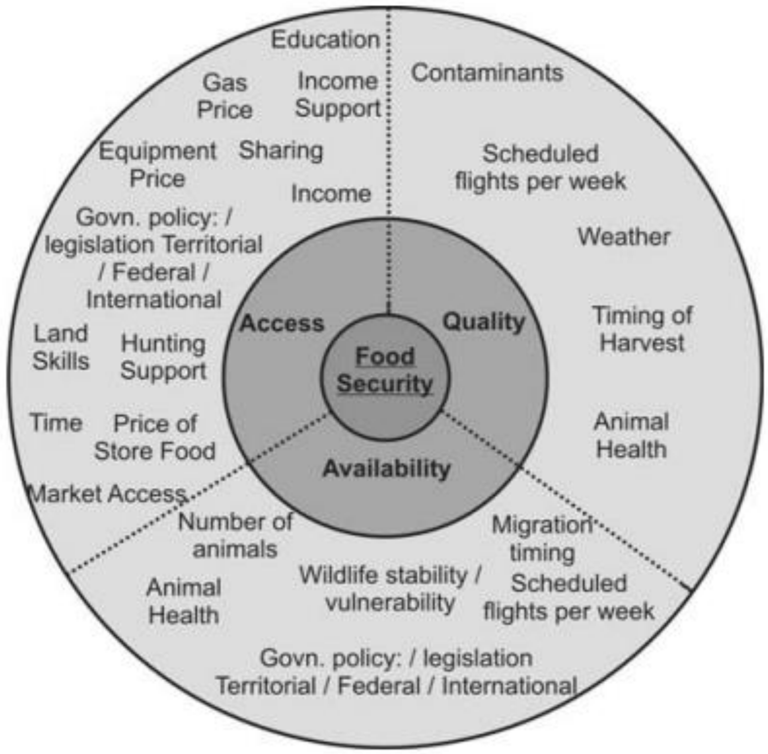


Figure 2-15: Factors Affecting Food Insecurity in Inuit Communities (Ford et al., 2009).

Traditional foods historically relied on by Inuit people vary slightly depending on the community. However, they can be generally defined by hunting and fishing of local non domesticated species such as seal, caribou, polar bear, Arctic char, beluga whales, narwal, and wild berries.

The link between climate change and food insecurity is prominent. Climate change represents the physical changes in the environment affecting the availability of food. However, there are other social and political factors causing stresses on the food system. Climate change may affect food security by altering migration patterns of typically hunted species or rising temperatures altering the likelihood and frequency of food poisoning (Ford, 2009). Food delivery during storms and open water season needs a reliable predictable schedule. The act of hunting has cultural and historical significance to Inuit life affecting their spiritual, mental, and physical health. Large portions of the Inuit diet is made up of traditionally sourced nutrient rich foods.

2.3.3 Potential for Economic Development

There are many studies that describe the adverse effects of the reduction in sea ice on communities, including those cited above. However, there is potential for these changes to positively impact communities. One potential development opportunity is marine tourism. Current tourism in Nunavut is centred around July-August tourism involving outdoor activities such as hiking, mountaineering, and rock climbing (Johnston et al., 2019). The greatest obstacle to further development of the tourism industry is the cost of travel for inbound tourists due to the remote nature of the communities, as well as the short summers of most communities. Arctic cruise and yacht tourism has already increased across all Arctic regions as sea ice declines. Commercial cruise ships increased by 200% from 2005 to 2010 (Johnston et al., 2019) and pleasure craft travel in Nunavut has increased 400% over the last decade (2009 – 2019) (Johnston et al., 2019).

Many companies are marketing either "last chance tourism" or "first chance tourism". Last chance tourism refers to the marketing strategy that pulls on climate change shortening the remaining years possible to view polar bears and encourages customers to experience the Arctic before it is gone. First chance tourism refers to the marketing strategy drawing upon sea ice melt exposing brand new opportunities to see the Arctic like never before (Johnston et al., 2019).

External investment, tourism, and resource development may lead to improved infrastructure for those living in remote coastal communities whose main food source comes from marine transport (Carlson et al., 2017). Tourism development has the opportunity to draw awareness to Inuit culture, issues facing communities, and an opportunity to showcase local artists and entrepreneurs. If executed properly, the expansion of this sector in Nunavut has the potential to enhance living conditions, and meet community, regional, and government goals.

Another avenue for climate change to positively impact economic development is increased shipping through Arctic Canada. Northern sea routes could become a viable commercial shipping alternative to the Panama Canal, as ice coverage may diminish sufficiently to allow for transit of larger vessels. A dramatic increase in pleasure craft, commercial shipping, and fishing vessels has already increased in Arctic waters. Further decreases in ice coverage may also allow for future development of oil and gas deposits and lengthen the summer fishing season.

While climate change could improve economic development, it should be done with caution, and an understanding of the historical context of the region. Specifically, Nunavut has a long history of colonization, forced settlement, assimilation, and residential schools. There is a fear and historical reality of external economic development leading to detrimental consequences for communities. Success differs from community to community, and sustainable economic development requires involvement with the Arctic communities.

According to the Harvard Project on American Indian Economic Development (HPAIED), the key factors that determine nation building success are the need for self-determination or governance, capable institutions with a cultural match, and human capacity that puts community needs ahead of personal gain (Cornell et al., 2007). While the framework was established mainly through studies of Indigenous communities in the United States, its effectiveness and transferability to Canadian communities was reinforced through a 2015 study in Pond Inlet, Nunavut, demonstrating that the framework have effective economic self determination (Ritsema et al., 2015). This study also sites further case studies may be needed to reinforce the usefulness of framework at a community level. However, in another study done in 2017, the framework was used at regional level to examine the nature of goals and intentions of the Nunavut economic development strategies (Carlson et al., 2017).

Concerns with these types of economic development include cultural implications, profit leakage, and environmental issues. Profit leakage is the concern that the businesses and transient workers will benefit from economic development rather than local workers and entrepreneurs (Johnston et al., 2019). Moreover, cultural implications can arise if community members become more reliant on a waged economy, such as the loss of traditional hunting and fishing knowledge (Ford, 2009). Environmental concerns naturally arise, as the development of infrastructure and resource extraction may have adverse effects on the land, flora, and fauna that are important to an Inuit way of life (Johnston et al., 2019). For all of these reasons it is imperative to involve members of the community as employees and decision makers. Activities that directly impact the local community should be focused on developing human capacity, entrepreneurship, and business skills.

2.3.4 Increased Vessel Traffic

As the sea ice coverage time declines in Nunavut, more shipping routes are becoming available for longer periods of time. Resolute Bay is situated in the Canadian Archipelago, on Cornwallis Island in the Northwest Passage. The declining sea ice in the Northwest Passage has drawn specific interest due to an ice-free passage would allow for vessel transport and connection of the Pacific an Atlantic Ocean. Vessel traffic has almost tripled from 1990-2015 in Arctic Canada (Dawson et al., 2018). There is interest in increasing vessel traffic to strengthen tourism, increase global shipment, and strengthen economic development within communities. However, increased vessel traffic has adverse effects such as interrupting species migration and hunting locations directly surrounding the community, air and water pollution, increased risk of collision incidents or contamination via oil spills. The Canadian Federal Government has developed policy under the Ocean Protections Plan to identify low impact shipping corridors in Canada's Arctic (F. and O. C. Government of Canada, 2021). These policies will protect culturally significant and ecologically sensitive areas with consultation of Inuit communities in Canada. The Arctic corridors research project at the University of Ottawa headed by Dr. Jackie Dawson, has been conducting research with many Inuit communities to identify these culturally significant hunting areas, as well as identifying trends in increased vessel traffic with Automatic Identification System (AIS) data (Johnston et al., 2019).

Resolute Bay is located directly on the Northwest Passage. Which used to be unnavigable due to severe ice conditions. In current times, this route is being explored and used for naval shipment, tourism. It is a large area of research, and many resources are being poured into this area. Many studies are being done without consulting the local residents. This study intends to generate a method to categorize the changes in sea ice on a small community scale using technical scientific principals as well as involving the community. Seeking to better understand the changing ice for the benefit of local Inuit hunters, not companies looking to profit off the use of the Arctic environment.

2.4 Community Background and History of Resolute Bay

Resolute Bay is an Inuit Hamlet located on Cornwallis Island within the Qikiqtaaluk region of Nunavut, Canada. The Inuktitut name is Qausuittuq meaning 'place with no dawn' or Quarnartakuj 'place of the ruins' referring to the whale bones found in the area. Quasuitturmiut is the Inuit word the residents of Resolute Bay refer to themselves as. Resolute Bay is the second most northern community in Nunavut after Grise Fiord. The population of Resolute Bay as of 2021 is 183 residents, 83% of which are Inuit, 65.6% are Inuktitut speaking (Resolute Bay (Qausuittuq) | The Qikiqtani Truth Commission, n.d.). Resolute Bay is in an area within continuous permafrost zone, mean annual high temperature is -12.7 °C. Resolute Bay experiences seasonal thaw depths of 0.65 m, and is considered a polar dessert climate with mean annual precipitation of 150 mm and has minimal vegetation cover. The landscape is dominated by gravel vegetation restricted to lichen mosses and sparse grasses in areas fed by ponding of snowmelt (O. of the A. G. of C. Government of Canada, 2018).

Figure 2-16 shows Resolute Bay's location on Cornwallis Island and the surrounding Islands.

Figure 2-16: Map of Resolute Bay and Surrounding Islands (Statistics Canada, 2018).

The Tlingit and Thule people lived nomadically in the area surrounding Resolute Bay thousands of years ago (*Community Histories 1950 - 1975 | The Qikiqtani Truth Commission*, n.d.). After this there were no Inuit people living on Cornwallis Island in the 19th century. Resolute Bay experienced early contact by European exploration in the Northwest Passage. The community is located on the south shore of Cornwallis Island, named after a British Royal Navy Admiral. Resolute Bay was named after the vessel HMS Resolute Bay in 1850. Although there is archeological evidence of Inuit Dorset and Thule people having lived near the area surrounding Resolute Bay pre-contact, there were no permanent inhabitants until the 1950's. In 1953 and 1955 the Canadian Federal Government forcefully relocated Inuit families from both Pond Inlet and Inukjuak to Resolute Bay. Resolute Bay was chosen as a relocation destination due to its assumed abundance of wildlife for hunting. However, no wildlife studies were ever preformed, and no Inuit had lived there for centuries (*Community Histories 1950 - 1975 | The Qikiqtani Truth Commission*, n.d.). The families relocated or, "exiles" as people refer to them in the community today, were forced to adapt to their new home and keep hunting practices alive by reinventing them in a new environment. Prior to the relocations multiple institutions such as the government in the form of weather stations, military and royal Canadian air force had established bases in the area. Once Inuit people arrived in Resolute Bay, they were exposed to foreign, laws, ways of life, customs, and poor communication and mistreatment by the existing establishments. Inuit being exposed to these foreign ways of life became reliant on hunting for trade rather than traditional hunting practice and supporting family members. When the price of furs for trade fell after the Second World War, government perception was that Inuit people were susceptible to starvation. The relocations to Resolute Bay were also motivated by the governments belief that Inuit would be less reliant on government support in their new environment. Additional goals of the relocation were Arctic sovereignty in the area. The following is a direct quote from the Qikiqtani Inuit Association (QIA) community histories "evidence firmly points to the fact that Inuit were never fully informed of option or potential consequences when making decision about relocations." Many Inuit people were reluctant to move due to fear of losing their significant ties to their homelands. The Royal Canadian Mounted Police (RCMP) claims that the families relocated were volunteers of strong hunting and trapping abilities, however evidence shows that those who were most reliant on government support were relocated to Resolute Bay. The families that were moved to Resolute Bay were done so during September, six weeks prior to the dark season in Resolute Bay with no familiarity of the land or local wildlife. They were moved with inadequate and non-existent shelter in Resolute Bay. Between 1955-1970 the people of Resolute Bay were introduced to foreign ways of life living in communities to access government programs rather than live nomadically on the land. The RCMP invoked laws that allowed them to kill Inuit sled dogs, restricting Inuit ability to continue their traditional way of life. There were no hospitals or health care facilities in Resolute Bay. If Inuit needed medical care, they were taken to facilities in other communities and in some instances not returned to Resolute Bay. There was no ability to communicate with medical evacuees and notice of their death was not given to their families. Children in Resolute Bay were taken from their families and forced to attend residential schools in Churchill Manitoba or Pond Inlet, Nunavut. Residential schools attempted to extinguish Inuit culture by disallowing the use of traditional language and hunting. Many children faced mental, physical, sexual, and spiritual abuse at the hand of residential schools. Decades of mistreatment of Inuit lead to hopelessness and sadness. Coping with these horrors lead to high instances of substance abuse of drugs and alcohol.

These substances were never a part of Inuit culture before the introduction by missionaries. Communities suffered with the typical issues that surround substance abuse, like childhood neglect, physical and emotional abuse. These communities did not have the social infrastructure to support the substance abuse issues like cities in the south (southern Canada).

Today Resolute Bay is a well established and culturally vibrant community. Many Elders will speak of the years between 1955-1970 with great sorrow. Resolute Bay today is a dry community that restricts access to alcohol, and many people hunt and fish on the land. Typically hunted species include polar bear, ringed seal, bearded seal, caribou, walrus, and beluga. Residents of Resolute Bay use either snowmobile, dog sleds, and All Terrain Vehicles (ATVs) to hunt on the land and access remote cabins for multiday trips. More about what was learned in the community when speaking to locals can be found in the community visit reports in Appendix A. Inuit have always been incredibly resilient and adaptive to changes in their environment, they have fought to keep their traditional ways of life through attempted cultural genocide and assimilation. Climate change is once again calling on Inuit resiliency and forcing Inuit hunting practices to evolve.

2.5 Historical and Current Governance of Nunavut

To work with and conduct scientific research impacting Indigenous communities, it is important to understand the complex history Indigenous that populations have with the Federal Government of Canada, institutions, scientific research, and how they are governed today. The following section will give a brief nonexclusive history of settlement within Canada and some important documentation and agreements that occurred throughout the process, some of which still exist today.

Indigenous people of Canada lived in Canada far before any colonization by European nations occurred. There are theories within the scientific community of how Indigenous people came to inhabit North America including the land bridge theory, that Indigenous people migrated to North America from Asia 10,000-12,000 years ago (Joseph & Joseph, n.d.). However, many cultures, including Indigenous cultures, believe in creationism and creation history that their people came from the land, which contradicts the land bridge theory (Joseph & Joseph, 2019). The arrival of Christopher Columbus in 1492 is widely accepted as the beginning of colonization of North America. But, dependant on the geographic location in Canada interaction with arriving Europeans happened at different times and had varying levels of impacts some catastrophic and some successful (Joseph & Joseph, n.d.). Settlement continued in Canada by both the English and French throughout 1500-1700 (Joseph & Joseph, n.d.).

The Royal Proclamation of 1763 assured Indigenous people that they would not be disturbed in their territories beyond the settled colonies. In the Royal Proclamation, Indigenous people were referred to as the owners of the land with Europeans using and occupying it (Joseph & Joseph, n.d.), although in many Indigenous cultures the land is not believed to be owned by anyone, but a mutual relationship and respect exists between people and the land (Spirits, 2021). The Royal Proclamation is often used as evidence of early recognition of Aboriginal rights including hunting and harvesting of the land in Canadian law.

Following the Royal Proclamation, many land and peace treaties were signed. As settlement moved west, the numbered treaties were negotiated from 1871-1921 ("What Are Treaty Rights?," 2017). Many of the numbered treaties still exist today in communities that haven't reached final settlement agreements through negotiation with the Federal Government. Slight differences exist between the numbered treaties depending on when they were signed and what areas they cover. The Figure 2-17 depicts the numbered treaties that exist in Canada today.

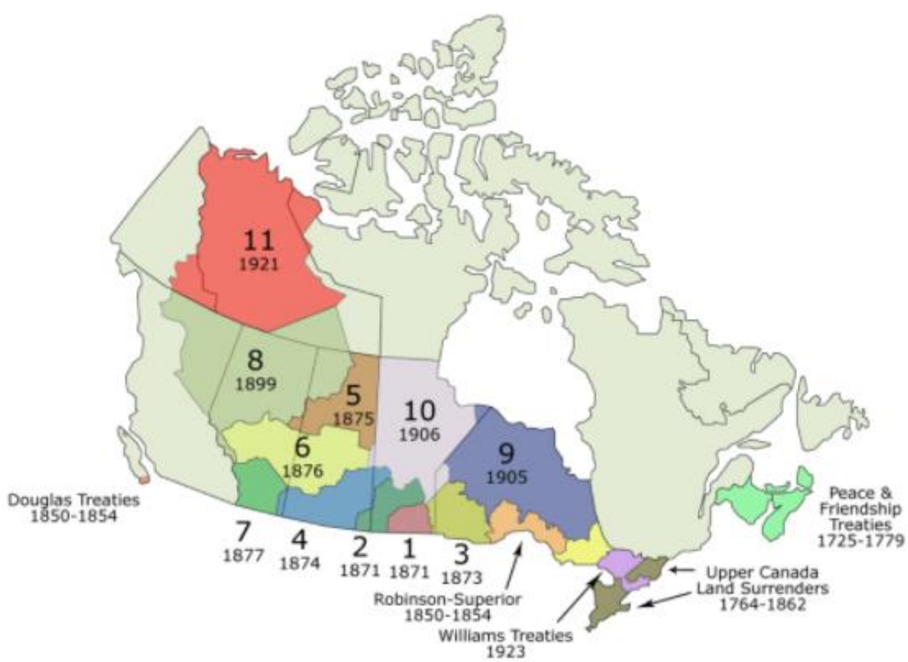


Figure 2-17: Canada's Numbered Treaties Spatial Extent and Date Signed *("What Are Treaty Rights?," 2017)*.

The numbered treaties were meant to serve as peace agreements and outline rights to ancestral land (“What Are Treaty Rights?,” 2017). Eventually, after Canadian Confederation in 1867, the Indian Act of 1867 was put into place. The Indian Act defined the bounds of the reserves as well as Indian status on band lists. The Indian act no longer recognized Indigenous people as independent nations and had assimilation as a goal, prohibiting ‘Indians’ from participating in cultural ceremonies and requiring communities to abandon traditional governance structures and adopt new imposed governance. Under the Indian Act, the Indian agent of each reservation needed to give Indian status members permission to leave their reserve. Reserves made up an extremely small portion of previously inhabited ancestral land often in desolate areas that were unsuitable for agriculture (Joseph & Joseph, n.d.). As part of the Indian Act, the first residential school in Canada opened in 1844 and the last one did not close until 1996. Compulsory attendance was added to the Indian act in the early 20th century. Residential schools promoted the forced removal of Indigenous children from their families to assimilate and extinguish Indigenous people and culture. Disturbing accounts of children being intensely mistreated by employees of the Catholic Church, who ran the schools, resulting in many of whom died. In cases of survival, there are long lasting generational impacts of trauma (Wilk et al., 2017). Knowledge of Indigenous and institutional relations such as residential schools, the harm they caused, and communicating effectively and respectfully are imperative when working with Indigenous communities.

The Canadian constitution was signed in 1982 amending Confederation of 1867. Within the Canadian Constitution Act of 1982 section 35 recognized Indigenous people have an inherent, constitutionally protected right to self-governance (Branch, 2020). The Canadian Constitution acknowledges original treaty agreements made between Indigenous communities and the Canadian Government many of which honour the right to hunt and fish on traditional land. The Indian act from 1876 continues to govern most Indigenous and non-Indigenous relationships. Many nations seek to negotiate “final settlement agreements” and many have successfully negotiated these agreements which take place of historical agreements many of which claim rights to self governance.

There is no one successful model for self governance of Indigenous communities because all communities have different needs. These community and region-specific self governance structures help meet the needs, priorities, and goals of different groups.

Nunavut was officially separated from the Northwest Territories on April 1st, 1999, via the Nunavut Act and the Nunavut Land Claims Agreement Act making it Canada's youngest territory. This separation held great cultural significance as Inuit people were able to have a territory in which they were the majority, to use their language and practice their culture (Branch, 2020). It was signed in 1993 but didn't become its own province officially until 1999 making Nunavut the largest province in Canada and the largest land claims settlement in history (Branch, 2020).

Some highlighted changes at the time of the Nunavut act include commitments to capitol transfers, land and mineral land rights, and the act aims to keep Inuit interests central, allowing the Inuit population participate in decision making when developing wildlife management system and harvesting rights (Indigenous Corporate Training Inc., 2013). Royalties of oil and gas and mineral development on crown land are shared with the Inuit people who inhabit Nunavut. In all Indigenous self governance structures, the Canadian Charter of Rights and Freedoms, Canadian Human Rights Act and Canadian Criminal Code continue to apply.

When participating in any research involving Indigenous communities, the cultural sensitivities and complex relationship between Indigenous people and science, institutions in the past must be considered along with their constitutionally affirmed rights to self governance.

2.6 Incorporating Traditional Knowledge into Scientific Studies

This section will review literature on methods of incorporating traditional Indigenous knowledge in scientific studies. The Truth and Reconciliation Commission of Canada found that current governing structures of northern areas emerged under colonial regimes often excluding Indigenous peoples. However, land claim agreements have affirmed rights to self governance in recent years. Canada signed the universal declaration of rights of Indigenous people which further supports Indigenous right to self governance. In 2018, the Inuit Tapiriit Kanatami (ITK) released a strategy on Inuit involvement in research (Inuit Tapiriit Kanatami, 2018). This document outlines the colonial approaches to research that endure in Canada that omit Inuit from making decisions about research. Inuit people should determine how data is collected, stored, used, and shared. In research, Indigenous knowledge does not receive the same recognitions as traditionally accepted Western knowledge systems (Biermann, 2011). Due to systemic factors of exclusion, Inuit people are underrepresented among Western academics. 86% of Canadians aged 25-64 have earned a high school diploma compared to the 34% of Inuit (Inuit Tapiriit Kanatami, 2018). These numbers continue to drop at the post-secondary level. Ethical inclusion of Inuit communities requires partnering with Inuit organizations, respecting cultural differences, and maintaining the integrity of cross-cultural epistemologies.

Throughout history, the relationship between Inuit people and Western-based research has been incredibly problematic, involving racism and exploitation. Inuit people were dehumanized and used as test subjects, in the Canadian Federal Governments attempts to improve Arctic sovereignty. If Inuit people were not the test subjects of research, they played the roll of observer with no involvement. Research is often conducted with methods that limit Inuit involvement and often benefits the researcher or institution through data and information availability, access to funding, and career progression. These methods and approaches are still present in research today. Specifically in research in the Arctic, many scientific studies are completed on the environmental changes due to climate change with no consultation, involvement, or consent of the people who live on the land being most impacted. It is becoming more common to conduct research through partnerships with Inuit communities, but these partnerships can be sporadic and short lived. Research is a powerful tool to increase advocacy and social equity, but only if it is done through meaningful partnership and involvement of Inuit people with the priority of keeping Inuit goals and benefiting Inuit people.

2.6.1 Methods of Bridging Knowledge Systems

Researchers from many fields have advocated for the involvement of Indigenous knowledge systems in academic research. Many have developed techniques for respecting multiple ways of knowing as equal and valid sources of data. The term “two-eyed seeing” was developed by Mi’kmaw Elder Albert Marshall. It refers to “learning to see from one eye with the strengths of Indigenous knowledge, and from the other eye with the strengths of Western knowledge, and to use both eyes and ways of knowing together.” (“The Learning Process and Two-Eyed Seeing,” n.d.). It is used to bridge scientific and traditional knowledge, to fill gaps, provide strategies for checking accuracy, while maintaining the integrity of both knowledge systems. Many researchers have implemented this approach when researching natural, environmental, and physical science (Michie et al., 2018). Abu et. al (2019) uses two-eyed seeing to assess the social-ecological change of the Saskatchewan River delta with plural and diverse knowledge systems (Abu et al., 2019b).

Although many researchers have attempted to bring Indigenous knowledge into environmental studies, Western knowledge is still valued over Indigenous knowledge to the detriment of Indigenous peoples. In response Tango et al., (2014) propose that two knowledge systems be brought together on equal footing proposing a multiple evidence-based approach. Where, Indigenous and local knowledge as well as scientific knowledge systems are both valid and useful and contribute to a more holistic understanding that identifies complementariness, synergies, and contradictions (Spierenburg et al., 2014). Epistemology refers to the way in which a culture or society comes to knowledge, for example how beliefs become truths. Epistemological pluralism, or plural existence of knowledge is a cross cultural research strategy that acknowledges and respects both Indigenous and non-Indigenous knowledge (Zanotti & Palomino-Schalscha, 2015). This approach leads to more flexibility with methods and approaches to research. A study done at Utah State University found multiples ways of knowing in a given research context can be equally valuable and the integration of plurality results in more thorough understandings (Miller et al., 2008).

This current study seeks to incorporate the methods of two-eyed seeing to study long term environmental change to the sea ice, and the socio-economic impact of those changes. Inuit knowledge will be used along side Western knowledge to strengthen the understanding of historical sea ice behaviour in Resolute Bay. Both knowledge systems will be used to fill gaps in the other without subsuming either way of knowing.

2.6.2 Differences and Strengths in Scientific and Traditional Knowledge

Scientific research often has positivist ontology. Where, knowledge can only be acquired from scientific and empirical methods (Luby et al., 2021). There is one objective truth to be found, proved, and validated through quantitative and empirical methods. However, Indigenous knowledge and research has a more nuanced and flexible version of the truth (Brook & McLachlan, 2005). There can be more than one truth through lived experience and oral history. Arctic scientific research and Inuit research often have different methods, scopes, validation techniques as well as goals. Arctic scientific research is mainly conducted remotely from institutions in southern Canada. Strictly scientific research tends to focus on large scale phenomenon and long-term trends either historical trends, or future predictions of sea ice change. Inuit knowledge studies are often done on a small community scale. The goals of Inuit research are generally to determine the daily impact of changing sea ice to Inuit life and the implementation of climate mitigation. Inuit research is done with Inuit values in mind, to protect traditional ways of life, and the safety and resiliency of Inuit communities (Nickels & Knotsch, 2011). The validation of findings differs in the scientific and Inuit research communities. Inuit culture values storytelling and valued evidence that supports findings favors oral histories. Within scientific research there are multiple fields including social science and natural science. The findings of quantitative research in social and natural science are validated with repeatable experiments or numerical datasets. The power imbalance in academia leads to the celebration of Western ontology and methods as correct within colonial institutions.

Evaluating one knowledge system with the validation methods from another, sacrifices the integrity, quality, and potentially eliminates the latter knowledge system. The methods of one knowledge system should not be used to validate another (Bishop, 2020). Allowing for different knowledge systems improves broader understanding of a research subject without prioritizing one knowledge system over another and sacrificing the integrity and validity of each knowledge system. Using multiple knowledge systems within a study leads to a more holistic understanding of environmental behavior from both scientific and Inuit perspectives.

2.6.3 Traditional Inuit Language for Sea Ice

The Inuit knowledge of ice is so vast while, in English there is only one word for ice the same word describes the small cubes we non-Inuit put in drinks to the vast 100's of km surface that covers the Arctic ocean for many months of the year. The Inuit language has over 100+ different words to describe the ice depending on the conditions present (Igloolik Terminology, n.d.). Whether the ice is rough or smooth, broken, thick or thin. This emphasis of oral communication of conditions and passing down generation of knowledge and experience with the ice is one of the main reasons community members were involved in this study.

3 Methodology

This study developed a mixed methodology that uses both traditional Inuit knowledge and scientific methods to gain a deeper understanding on the trends in sea ice and air temperature change over the last 50 years in Resolute Bay. Section 3.1 describe the methods used during the scientific portion while Sections 3.2 and 3.3 outline the methods used for the traditional Inuit knowledge portion of this study.

3.1 Scientific Methods

The types of quantitative data and analysis tools available to researchers in the Arctic sea ice field are described in detail in Section 2.2. The objective of this study is to identify long term trends in sea ice and climactic behavior in Resolute Bay. These trends are identified with both traditional Inuit knowledge, and scientific methods. Five sources of data were accessed during the scientific portion of this study. This section will describe the data sources and methods of analysis used to identify historical trends in sea ice thickness, break-up timing, freeze-up timing, and air temperature in Resolute Bay. The five data sources used in the scientific portion of this thesis are listed below.

1. Environment and Climate Change Canada, weekly fast ice thickness measurements,
2. Canadian Ice Services Weekly and Regional Archived Sea Ice Concentration Charts,
3. Copernicus Climate Change Services Daily Sea Ice Concentration,
4. Copernicus Climate Services Daily Sea Ice Freeboard Thickness, and
5. Environment and Climate Change Canada, Daily Air Temperature.

The schematic in Figure 3-1 demonstrates the five sources of data and which variables each dataset contributed to the development of trends.

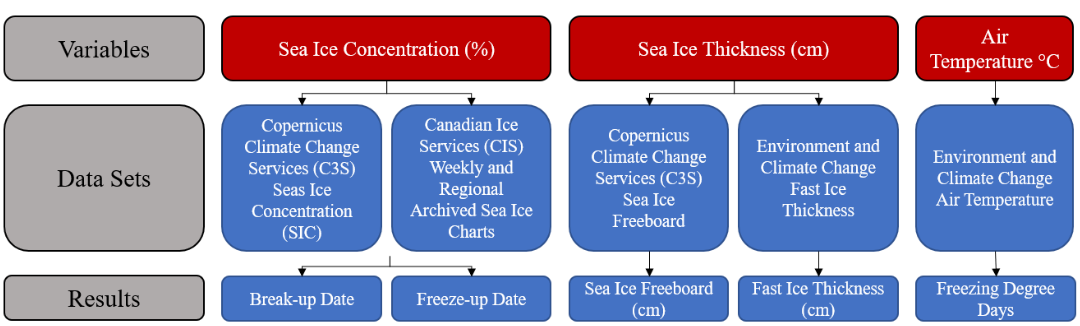


Figure 3-1: Scientific Data Source Schematic.

The above five data sources, their temporal span and measurement frequency are described further in Table 3-1.

Table 3-1: Scientific Data Source, Temporal Coverage and Measurement Frequency Summary.

Data Source	Temporal Coverage	Measurement Frequency
C3S Sea Ice Concentration	1979-2015	Daily
CIS Sea Ice Charts	1982-2023	Weekly
C3S Sea Ice Freeboard	2002-2020	Daily
ECCC Fast Ice Thickness	1947-2021	Weekly
ECCC Air Temperature	1947-2023	Daily

3.1.1 Sea Ice Concentration (SIC) Methods

The following section describes the methods used to access the two sea ice concentration datasets, Copernicus Climate Change Services Sea Ice concentration and Canadian Ice Services weekly and regional archived sea ice charts.

3.1.1.1 Copernicus Climate Change Service (C3S) Sea Ice Concentration (SIC) Determined with Satellite Observation

The Copernicus Climate Change Services SIC dataset mentioned in Section 2.2.1.2 was accessed and climate data records from 1979 to 2015 were downloaded from the climate data store. The data were in the format of daily Network Common Data Form (NetCDF) files of sea ice concentration. An example of the raw data on February 1st, 1979, is seen in Figure 3-2.

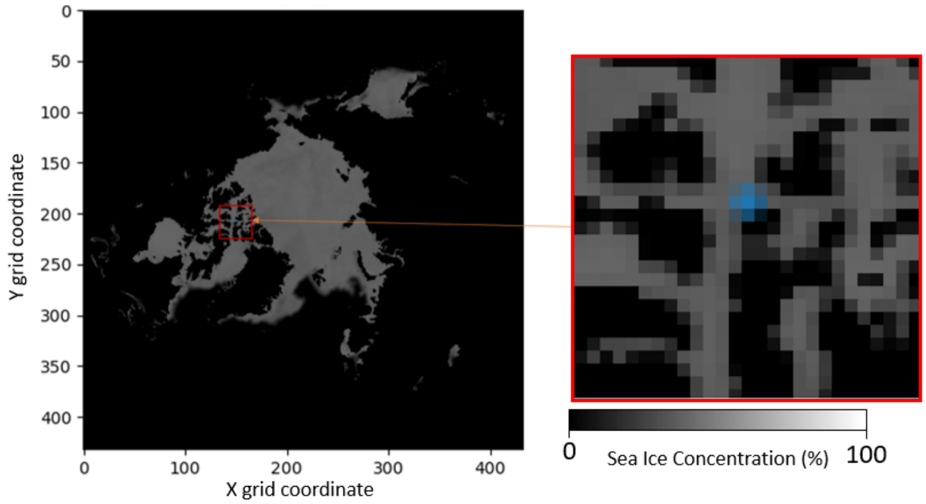


Figure 3-2: Copernicus Climate Change Services (C3S) Sea Ice Concentration on February 1st, 1979 (left) and Extraction Point for Sea Ice Concentration Near Resolute Bay (right).

Sea ice concentration at the grid cell (148, 207) was extracted to create a time series of sea ice concentration for Resolute Bay and the surrounding area. The extracted sea ice concentrations can be seen in Figure 3-3.

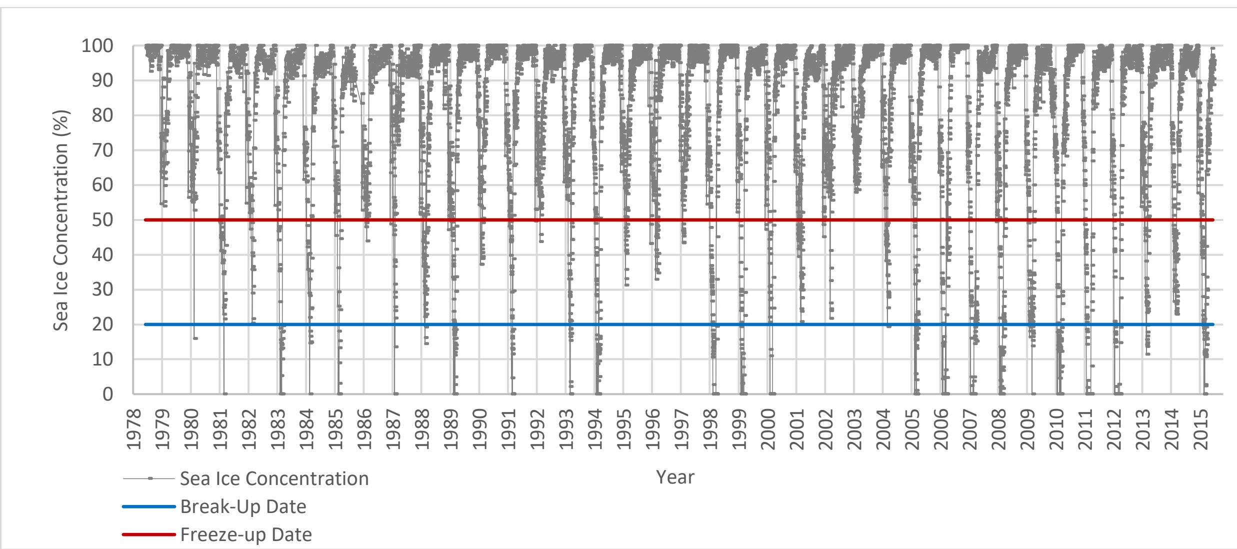


Figure 3-3: Copernicus Climate Change Services (C3S) Sea Ice Concentration Extracted from (148, 207) Resolute Bay from 1979-2015.

Sea ice concentration was used to determine break-up and freeze-up timing. An advantage to using this dataset compared to the CIS weekly and regional archived sea ice charts is its temporal precision, daily rather than weekly temporal resolution. Precision was also provided in the data itself, as the sea ice concentration was recorded as a percentage value with eight decimal places.

The sea ice charts give sea ice concentration in a range rather than an exact value of sea ice concentration. During the use of the C3S SIC data to determine break-up and freeze-up dates, break-up was considered to occur when sea ice concentration fell below 20% and did not come back above 20% again before open water. Similarly, when determining freeze-up with the C3S satellite observed sea ice concentration data freeze-up was considered to occur when sea ice concentration went and stayed above or equal to 50% for the rest of the ice-covered season. Linear regression analysis on the break-up and freeze-up dates determined with C3S satellite observed sea ice concentration is found in Section 4.1.1.1.

3.1.1.2 Canadian Ice Services (CIS) Archived Weekly Regional Sea Ice Charts

In this study historical weekly ice charts were accessed from 1982 to present time. Each ice chart was manually examined to determine the sea ice concentration in Resolute Bay. Sea ice concentration was recorded as the value directly offshore of Resolute Bay. The break-up and freeze-up dates were recorded with the assumption that break-up occurred when ice concentration was below 1-3 /10 or open water in Resolute Bay. If open water or a sea ice concentration of 1-3/10 was observed, then sea ice concentration increased above the defined threshold (1-3/10), the break-up date was recorded as the last date where sea ice concentration fell below the threshold then did not rise over it again for that ice season. Freeze-up timing was recorded as the chart date when new ice, of 4-6/10 or higher was observed in Resolute Bay. Similarly, if the sea ice concentration was 4-6/10 in a chart, then fell below four in the subsequent chart, freeze-up was not considered to have occurred. Freeze-up was defined as the last date where sea ice concentration was above 4-6/10 and stayed above or equal to 4-6/10 for that ice growth season. An example of the determining of break-up and freeze-up date in 2019 is seen in Appendix B. The results of this analysis are presented in Section 4.1.1.2.

3.1.2 Sea Ice Thickness (SIT) Methods

The following section describes the methods used to access and analyze two sea ice thickness data sources within this thesis. The two data sources of sea ice thickness data are the Copernicus Climate Change Services gridded sea ice freeboard described in Section 2.2.1.2.1 and ECCC’s weekly fast ice thickness measurements described in Section 2.2.1.2.3.

3.1.2.1 *Copernicus Climate Change Service (C3S) Sea Ice Freeboard Thickness Determined with Satellite Observation Methods*

Data were accessed from the C3S Sea Ice Thickness dataset described in Section 2.2.1.2.1. This is a 25x25 km gridded monthly dataset. Data from the four closest locations to Resolute Bay were accessed from this dataset to form four time series of sea ice freeboard thickness. The data locations and their proximity to Resolute Bay are outlined in the Figure 3-4.

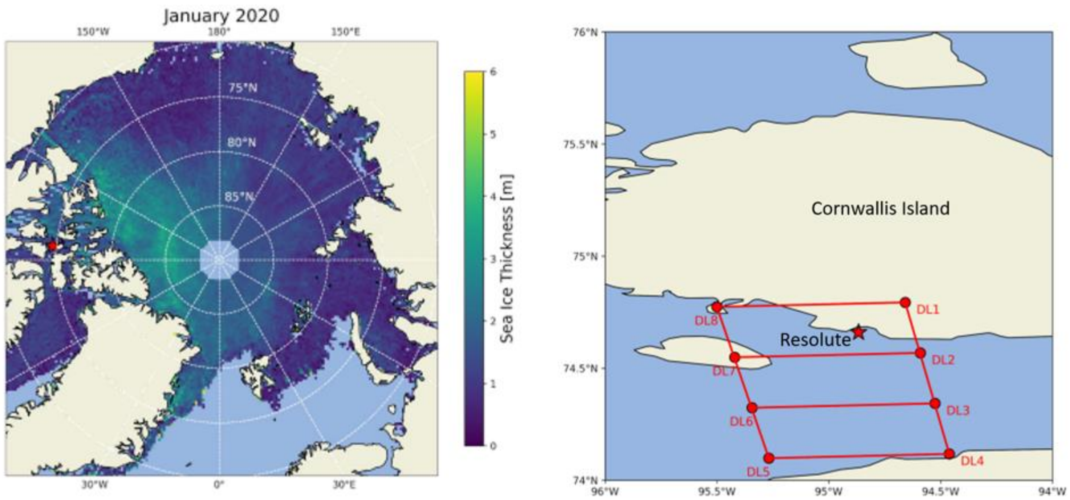


Figure 3-4: Copernicus Climate Change Services (C3S) Sea Ice Thickness Freeboard Entire Spatial Extent of Dataset in January 2020, Resolute Bay Indicated with Red Star (left) Data Access Locations (right).

Data location 8, 1, 7, and 4 coincide with on-land values and were discarded. Data location 2, 3, 5, and 6 were used in further analysis in Section 4.1.2.1.

3.1.2.2 *Environment and Climate Change Canada (ECCC) Weekly Auger Fast Ice Thickness Measurements Methods*

As described in Section 2.2.1.2.3, ECCC has two sea fast thickness datasets in Resolute Bay that collectively give weekly fast ice thickness measurements from 1947-2021. These two datasets were merged to create one consecutive dataset. The fast ice thickness was then analyzed to identify trends in annual maximum thickness, monthly fast ice thickness, monthly averaged fast ice thickness, and typical ice growth in the fast ice near Resolute Bay. Further explanation of the statistical methods used to evaluate long term trends in these data are described in Section 3.1.4. The results of this analysis are presented in Section 4.1.2.2.

3.1.3 Air Temperature Methods

In addition to available data on sea ice thickness and concentration, two stations were accessed from the Environment and Climate Change Canada historical climate records, Resolute Bay Community Aerodrome Radio Station (CARS) and Resolute Bay Airport. Both stations are near the Resolute Bay Airport, approximately 5 km from the main community. Together the stations have air temperature data from 1947-2023 with daily temporal resolution.

3.1.3.1 Freezing Degree Days (FDDs) Methods

Freezing degree days (FDDs) were calculated from the same ECCC combined air temperature dataset presented in Section 3.1.3. FDD are a commonly used metric to compare surface air temperature to sea ice development. A FDD is a measure of both how cold a winter has been and how long a winter season stayed cold (Beyene & Jain, 2018). It is calculated by the cumulative sum of the average daily degrees below freezing (-1.8 ºC for salt water) for a winter and sea ice season.

In this study, freezing degree days were calculated for each year in Resolute Bay and compared on a decadal and annual basis to assess how FDD have changed over the period of record (1948-2022) in Resolute Bay. Freezing degree days are also compared to each of the other datasets assessed in this study (C3S Break-up dates, and freeze-up dates, CIS break-up dates and freeze-up dates, C3S sea ice freeboard, ECCC annual maximum fast ice thicknesses, and monthly averaged fast ice thicknesses). These comparisons were done to determine if sea ice parameters can be correlated to freezing degree days, and if so, which parameter is most closely correlated with freezing degree days. The results of the FDD analysis can be found in Section 4.1.4.

3.1.4 Statistical Methods

The following section will introduce the statistical methods used in this thesis to evaluate time series of sea ice and air temperature in Resolute Bay.

3.1.4.1 Linear Regression and Statistical Significance

For all the datasets presented in the above sections, various methods were used to access long term historical data either on BUD, FUD, annual maximum fast ice thickness, monthly fast ice thickness, monthly averaged fast ice thickness, sea ice freeboard, or seasonal air temperature. Linear regression was the main statistical analysis preformed on each of these time series. Linear regression is done to understand whether time (the x-variable) has affected the sea ice or air temperature (the y-variable) and how the y variable has changed as a function of time. After linear regression was performed on each dataset, each trend was tested for its statistical significance. In any linear regression two values can be used to better understand how well a linear model fits the data, R^2 and the P-value.

When using numerical models to compare to observed data scientists and engineers should strive to an R^2 as close to one as possible. However, within this thesis, no model is being compared to measured data. Only measured data is being evaluated on whether linear trends are present. Therefore, a smaller R^2 is acceptable in this study. When an R^2 value of equal to or greater than 0.1 is observed a linear trend is considered. To verify that the linear trend is statistically significant and not random, the P-value is also determined. The hypothesis being tested when developing linear regression models on time series of sea ice or air temperature is over time there has been observed change in these factors. The P-value represents the probability that a statistical model, in this case linear regression, has parameters (mean and standard deviation) greater than or equal to the observed results. The P-value is also reported on a scale between 0 and 1. The greater the P-value the lower the probability of validity of the hypothesis being true. A statistically significant trend is given by a P-value of less than 5% or 0.05.

The R^2 and P-values for all parameters tested within this thesis are found in Appendix C.

3.1.4.2 Change Point Detection

Change point detection is a common method of identifying changes in the statistical parameters within a time series such as the mean and variance. It is used in financial analysis, speech pathology, and climatology. Change point detection can be done "online" in real time, or "offline" retrospectively. This study uses offline change point detection in long term time series that have data available for at least 40 years, to identify a shift in sea ice behaviour particularly air temperature and ice thickness due to climate change.

Any time series can be either stationary or non-stationary depending on the parameter it represents. A stationary time series has constant variance and does not deviate from a long-term mean. In other words, stationary time series do not have seasonality or are non-cyclical and do not have trends. Non-stationary time series either do exhibit trends, cyclical patterns, or both. Change point detection algorithms can be applied to non-stationary time series to detect when significant changes in statistical parameters (mean and variance) occur within a time series.

In this thesis, the PELT (Pruned Exact Linear Time) (Truong et al., 2020) change point detection algorithm was used with the Python package ruptures. Although many scientists document green house gasses began warming Earth's atmosphere and ocean in the 1880's, significant change is generally regarded to have begun in the 1980's. In the 1980's the Earth's atmosphere began warming consistently as a result of increased green house gasses (Reid et al., 2016). Change point detection was used on the datasets within this study that had period of records beginning before the 1980's (air temperature and ECCC fast ice thickness). The results of these analysis are presented in Section 4.1.2.2 and 4.1.3.

3.1.4.3 Anomaly Identification

An anomaly is defined as the amount a measurement differs from an observed baseline. In order to generate anomalies, a baseline average of at least a 30-year baseline period should be used (NOAA, 2020). Anomaly analysis is done in many types of data science including financial analysis, health care data and to identify global or regional climactic change. Anomaly methods are used in this thesis in Section 4.1.2.2 and 4.1.3.

3.1.4.4 Outlier Identification

In this study outliers were identified by calculating an inter quartile range (IQR), and the upper and lower limit based on the IQR. The IQR is determined by calculating the top and bottom quartile of the data (Q3 and Q1 respectively). The IQR is the difference between the top and bottom quartile (Wan et al., 2014), given by Equation 1. The upper range, or the value that determines an outlier if the data is greater than the upper limit is given by Equation 2. Finally, the lower range, or the value that determines an outlier if the data is less than the lower limit is given by Equation 3.

$$IQR = Q3 - Q1 \quad (1)$$

$$Upper = Q3 + 1.5\ IQR \quad (2)$$

$$Lower = Q1 - 1.5\ IQR \quad (3)$$

Outliers are important factors and significantly affect linear regression performance.

3.2 Traditional Inuit Knowledge Methods

The methods described in the previous section describe the process of analyzing the available quantitative scientific data on sea ice concentration, sea ice thickness, and air temperature. Quantitative data near Resolute Bay is limited in its spatial resolution and does not provide granular small-scale information about sea ice behaviour, nor can it provide information on how changes in sea ice behaviour affect the community. The Inuit live on the land and interact with the natural environment that this study seeks to characterize regularly, which gives them a wealth of knowledge about the sea ice. Where there are gaps in the scientific knowledge, traditional Inuit knowledge will be used to gain a deeper understanding of sea ice trends in Resolute Bay. In addition, the words of Inuit people who have an intimate and spiritual tie to their natural environment deserve to be heard and valued in scientific studies. The process by which a relationship was formed with the community of Resolute Bay will be described in Section 3.2.1 and the methods of collecting traditional Inuit knowledge through community interviews is found in Section 3.2.2.

3.2.1 Community Contact and Relationship Building

The candidate conducted a literature review and developed the basis of this study with the guidance of her academic advisor and the community of Resolute Bay was selected as the subject of this study due to the long history of sparse quantitative data, there had never been a study done like this in Resolute Bay, and the ease of transport from the home university in Ottawa. The process of initial contact and relationship building within the community is discussed in this section.

3.2.1.1 Initial Community Contact and Community Consultation

Contact with the community was first made by the candidate through letters, emails, and phone calls to the Hunters and Trappers Association (HTA) and the Senior Administrative Officer (SAO) in the Hamlet Office. Initial contact was made to express the intention to conduct a study on historical sea ice trends in Resolute Bay, gauge the interest of community involvement, and collect feedback on the topic and scope of the study. During this phase, it was made clear by the candidate that one of the main objectives of this study was to involve the community, share knowledge, and incorporate community feedback. Many scientific studies of Arctic environmental phenomenon are done remotely and with a lack of involvement of the community members within the area of study. Concern was expressed by the community that after the 2019 covid-19 pandemic, they were being flooded and overwhelmed with requests for research. However, the community agreed to speak to the candidate about the study.

The initial community contact described above was made in May of 2022. Two community visits were conducted by the candidate and her academic advisor in July and September of 2022. The purpose of the primary community visit in July was to introduce researchers and their study to the community, to form relationships within the community, and make connections to local establishments. Between the two trips, the candidate incorporated community feedback and used it to scope the study. The second community visit was conducted to present the research objective and methods to the community council of Resolute Bay. The research was presented at the monthly community council meeting and approval was granted from the community for the researchers to conduct their study in the community. A third trip in May of 2023 was made by the candidate and her academic supervisor to Resolute Bay to conduct community interviews, which will be described in detail in Section 3.2.2. For a more detailed summary of the first two field trips, see Appendix A.

3.2.1.2 Administrative and Regulatory Approval

To involve human participants in research at the University of Ottawa, Research and Ethics Board (REB) approval is required. The REB approval requires researchers to submit a description of the research project, rational, objectives, research question, and the methods and procedures of answering the research question. The REB application detailed, what was required of participants, how participants will be recruited, potential risks and benefits to participation in the study, how confidentiality of participants will be addressed, how the data will be stored and managed, and finally how free and informed consent will be obtained from participants. Research and Ethics Board approval was granted for this study from the REB of the University of Ottawa on May 19th, 2022.

In addition to REB approval from the home university, any research being conducted in Nunavut must also obtain approval from the Nunavut Research Institute (NRI). The NRI exists to ensure there is ethical and appropriate inclusion of Inuit residents within research. All research in Nunavut in physical/natural sciences (e.g. land and water research), is licensed by the NRI in accordance with Nunavut's Scientists Act. The NRI ensures that residents of Nunavut are consulted and engaged in research being conducted in Nunavut. As part of the NRI application, community approval of the research is required. Approval from the NRI was granted to this research on September 27th, 2022.

3.2.2 Traditional Inuit Knowledge Interview

The traditional Inuit knowledge portion of this study was community interviews conducted in May of 2023. The community traditional knowledge interviews were comprised of three parts.

- **Part 1 - Survey Form**: consisted of a printed form where participants indicate whether they have noticed positive (in agreement with expected trends) or negative (in disagreement with expected trends) or had not noticed change in certain factors.
- **Part 2 - Survey Interviews:** consisted of semi-structured interviews where participants answered questions about traditional Inuit methods of determining ice thickness, and the socio-economic impacts that the changing sea ice has had on the community.
- **Part 3 - Survey Maps:** consisted of participants indicating on three printed maps typical areas of thin ice, thick ice, areas that break-up and freeze-up first and last, and hunting and travel routes.

Each portion of the traditional Inuit knowledge interviews is explained in more detail below.

3.2.2.1 Traditional Inuit Knowledge Part 1: Survey Form

During each interview, participants were asked to fill out a printed form where they indicate perceived change in the following factors.

- Break-up and Freeze-up dates,
- Sea ice thickness,
- Seasonal temperatures within the community,
- Incidents related to sea ice,
- The presence and abundance of hunted species,
- Travel routes,
- Time people spend on ice, and
- Vessel traffic near the community.

This perceive change was recorded in the form of a “positive”, “negative” change, or “no change or unsure”. Where a “positive” change indicates a response that agrees with the expected trend, and a “negative” response is one that disagrees with the expected trend. These expected trends were developed from the literature review discussed in Section 2.1 and 2.3 and based on trends observed in other communities or Arctic-wide.

There were 17 total questions. The questions from the written form and their associated number are displayed in Table 2-1. The first (left most response) indicates a response the agrees with the expected trend.

Table 3-2: Traditional Inuit Knowledge Part 1: Survey Form Perceived Change In Sea Ice and Other Factor Interview Questions

Number	Question	Answer		
1	Has the break-up date of the sea ice changed?	☐ It is occurring **earlier**	☐No, it has not changed / Unsure	☐ It is occurring **later**
2	Has the freeze-up date of the sea ice changed?	☐ It is occurring **later**	☐No, it has not changed / Unsure	☐ It is occurring **earlier**
3	Has the open water season length changed?	☐ It is **longer**	☐No, it has not changed / Unsure	☐ It is **shorter**
4	When does sea ice become its thickest?	☐ **Later** than it used to	☐ No Change / Unsure	☐ **Earlier** than it used to
5	Has the maximum sea ice thickness changed?	☐ It has **not been as thick**	☐ No Change / Unsure	☐ It has been **thicker**
6	Have the areas of thin sea ice changed?	☐ There are **more** of them	☐ No Change / Unsure	☐ There are **fewer** of them
7	Have the areas of thin sea ice changed?	☐ They are **larger**	☐ No Change / Unsure	☐ They are **smaller**
8	Have the areas of thick sea ice changed?	☐ There are **fewer** of them	☐ No Change / Unsure	☐ There are **more** of them
9	Have the areas of thick sea ice changed?	☐ They are **smaller**	☐ No Change / Unsure	☐ They are **larger**
10	Have winter temperatures changed?	☐ Winters are **not as cold**	☐ No, they have not changed / Unsure	☐ Winter temperatures have gotten **colder**
11	Have summer temperatures changed?	☐ Summers are **warmer** than they used to be	☐ No, they have not changed / Unsure	☐ Summers are **not as warm** as they used to be
12	Have the number of sea ice incidents changed? (e.g. falls through, getting lost)	☐ There are **more incidents** now than there used to be	☐ No Change / Unsure	☐ There are **fewer incidents** now than there used to be
13	Has there been a change in presence of hunted animals on the ice?	☐ There are **fewer hunted animals**	☐ No Change / Unsure	☐ There are **more hunted animals**
14	Has there been a change in the number of new animals present in the area?	☐ There are more new animals that didn't used to be in the area	☐ No Change / Unsure	N/A
15	Have the typical travel and hunting routes on the ice changed?	☐ Travel and hunting routes have changed over time	☐ No Change / Unsure	N/A
16	Has the amount of time people spend on the ice changed?	☐ People are spending **less time** on the ice	☐ No Change / Unsure	☐ People are spending **more time** on the ice
17	Has there been a change in the amount of vessel traffic around the community?	☐ There have been **more vessels** in the bay and surrounding area	☐ No Change / Unsure	☐ There have been **fewer vessels** in the bay and surrounding area

The topic of each question is further defined in the Table 3-3.

Table 3-3: Traditional Inuit Knowledge Part 1: Survey Form Question Topics

Question Number	Question Topic
1-3	Ice Covered Time
4-9	Sea Ice Thickness
10-11	Seasonal Temperature
12	Sea Ice Incidents
13-16	Hunting Practices
17	Vessel Traffic

Questions 1-3 were focused on the break-up timing, freeze-up timing, and open water season length respectively. Questions 4-9 were on the annual maximum sea ice thickness timing, and magnitude, areas of thin ice the amount and size, and areas of thick ice the amount and size. Questions 12-17 were focused on socio-economic factors of sea ice change that have been documented in other regions outside Resolute Bay, discussed in Section 2.3.2.

Other participation information that will be collected during the interview include, age, gender, how often participants go out on the ice, time lived in Resolute Bay. This information for comment on the sample of participants whether it represents a wide or narrow distribution but will not be individually published.

3.2.2.2 Traditional Inuit Knowledge Part 2: Survey Interview

Following participants indicating perceived changes in sea ice, environmental, and socio-economic factors on Part 1's form, a 10–15-minute semi-structured interview was done to have residents expand upon the perceived changes indicated in Part 1, and the impacts of this change to the community. The outline for a script of questions asked during the interviews are below. Interviewers had these notes with them as well as audio recorders.

Introduction

- *Can you tell me your name, age, and how long you have lived in Resolute Bay?*
- *Do you go out on the ice often? To do hunting or traveling, or both?*
- *If yes – where do you go and how do you get there? (Snowmobile etc.) – reference map*
- *Do you enjoy being on the ice?*

Changes in Sea Ice

- *Can you tell me about ways Inuit determine ice thickness when it is frozen? (Cracks, colour, wind direction etc.)*
- *Can you tell me about how Inuit determine the quality of sea ice and whether it is safe for use? (Roughness, cracks etc.)*
- *Have you noticed changes in the ice thickness over time? Can you describe them?*
- *When do you consider the ice to be broken-up and frozen-up? (When it is safe to travel on? When it is cohesive rather than in floes?)*
- *What time of year does break-up and freeze-up usually occur has that changed over time?*
- *Have you noticed changes to open water season length? Can you estimate by how much it has changed?*
- *Have there been any years the standout to you as abnormal sea ice behaviour (longer or shorter coverage, thicker or thinner ice etc.) if so which years and why?*

Impacts of Changing Sea Ice to the Community

- *How have the changes in the sea ice effected the community? (Started by letting them answer but if guidance is required the following prompts were used. These prompts were based on impacts of changing sea ice to Inuit communities from previous studies presented in Section 2.3.2)*
  - *If the ice has been changing is there greater fear of incidents? Less use of the ice leading declines in mental health?*
  - *Less trust in knowledge of sea ice? Less passing down of generational oral knowledge?*
  - *Are more people having salaried jobs rather than traditional ways of life and providing food with hunting?*
  - *Is there less traditional food available in the community? Can you tell me how food sharing works?*
  - *Has there been changes to the migration patterns of typical species within the community due to the changing ice?*
  - *Have there been more vessels in the community?*

3.2.2.3 Traditional Inuit Knowledge Part 3: Survey Maps

Part 3 of the traditional knowledge interviews was a series of questions posed to interview participants about printed maps of Cornwallis Island and the surrounding areas. These questions included participants indicating with coloured markers, typical areas of thin and thick ice, areas that break-up and freeze-up first and last, and typical hunting and travel routes. The exact questions used during Part 3 of the traditional knowledge interviews are below. In both Part 2 and 3 of the interviews, the presented scripts were generally followed but, slight changes were made depending on interviews participant responses and to aid in natural flow of conversation.

Map Questions: *Map can be used at any point during interview below are some guiding questions.*

- *Which areas usually break-up and freeze-up first?*
- *Once the ice is frozen which areas typically have thinner vs thicker ice?*
- *Show areas of typical species?*
- *Show areas you hunt?*
- *Show how travel routes on ice? have they changed over time?*

Three different scales of maps were available for use during the interviews. The three different scales are presented below in Figure 3-5, Figure 3-6, and Figure 3-7.

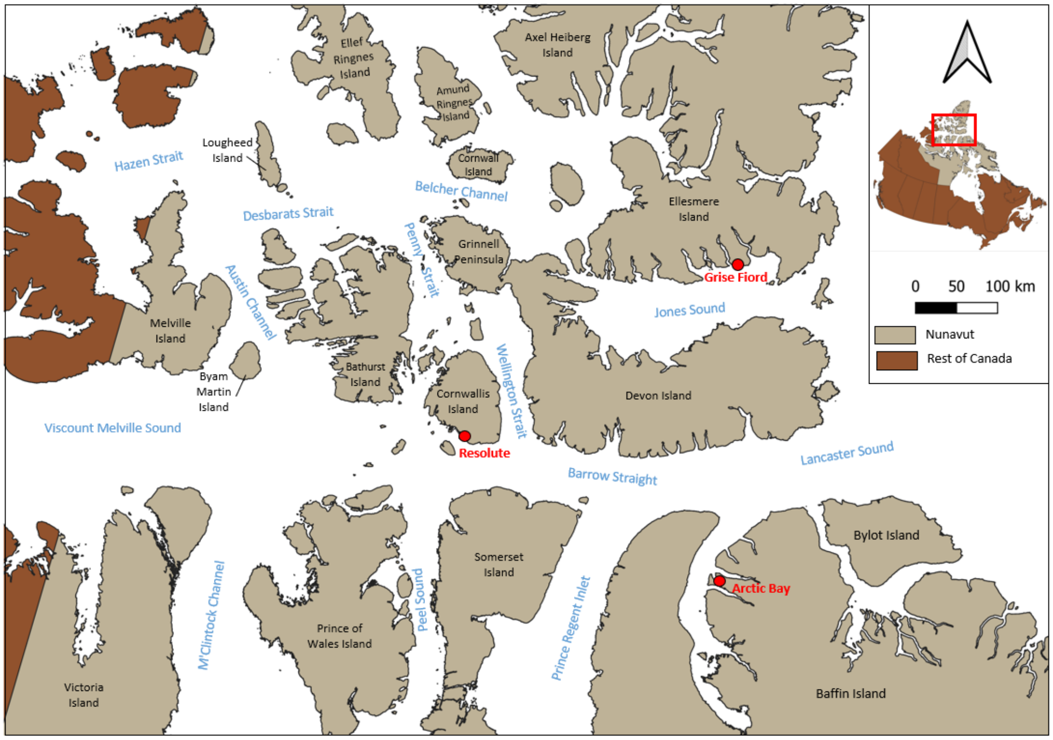


Figure 3-5: Traditional Inuit Knowledge Part 3 Map 1 of Cornwallis Island and the Surrounding Islands.

Figure 3-6: Traditional Inuit Knowledge Part 3 Map 2 of Cornwallis Island and the Surrounding Islands.

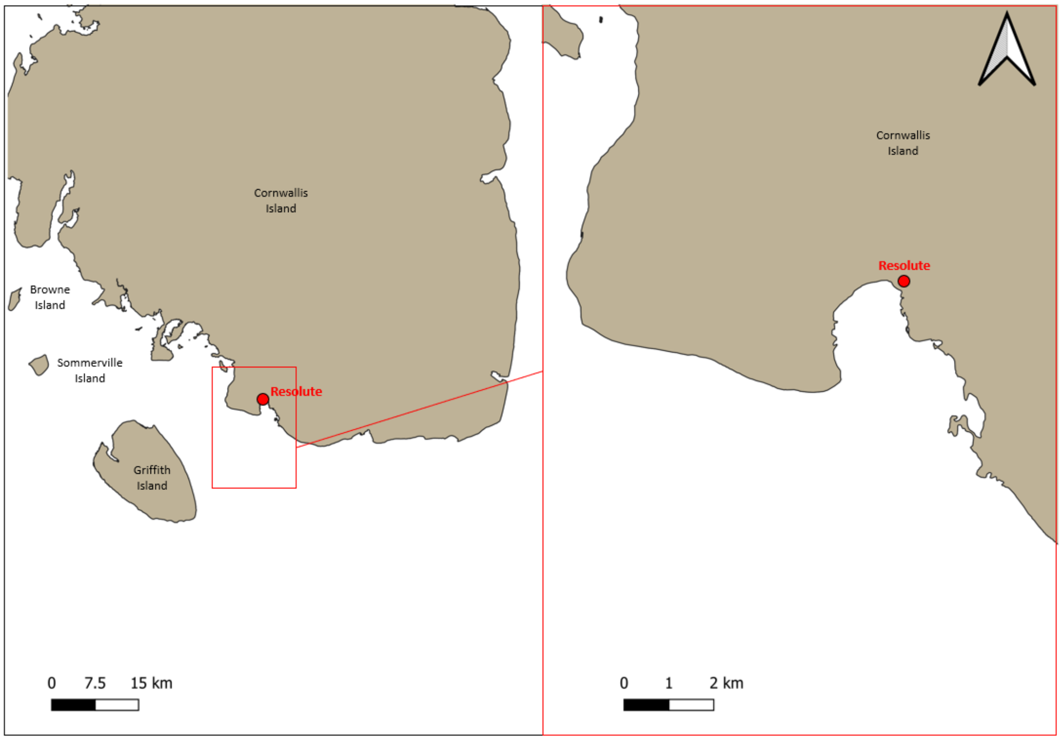


Figure 3-7: Traditional Inuit Knowledge Part 3 Map 3 of Cornwallis Island and the Bay Near the Community of Resolute Bay.

3.2.3 Advertisement of Traditional Inuit Knowledge Interview

In order to recruit community members to participate in the traditional Inuit knowledge interviews, the survey was advertised in several ways. One month, and one week before survey, a flyer was posted on the community Facebook page. The flyer instructed residents to contact the candidate for sign-up. Prior to the survey the candidate emailed flyers to the SAO. These flyers were posted in the Co-op, post office, and Hamlet Office. In addition to flyers posted in the community and virtually on the community Facebook page, the candidate also went on the CBC local Resolute Bay radio station to advertise the survey one week and one month prior to the interviews. Once the candidate and her academic advisor arrived in the community, they also engaged in knocking on doors to advertise the survey. The advertisement form used in the survey has been included in Appendix D.

4 Results

The following section will present the results of both the desktop data study as well as the traditional Inuit knowledge survey.

4.1 Scientific Results

Section 2 introduced the datasets used in the scientific portion of this study. Section 3 described the methods of accessing and analyzing these data. This section will present the results and findings of the analysis on sea ice concentration, fast ice thickness, sea ice freeboard thickness, and air temperature data in Resolute Bay.

4.1.1 Break-up Date (BUD) and Freeze-up Date (FUD) Results Based on Sea Ice Concentration (SIC)

The first parameter analyzed was the break-up and freeze-up dates in Resolute Bay based on both C3S and CIS data. The results of these analysis are below in Section 4.1.1.1. (C3S), 4.1.1.2 (CIS), and 4.1.1.3 (an average of the two).

4.1.1.1 Copernicus Climate Change Services (C3S) Sea Ice Concentration (SIC) Results

A time series of sea ice concentration was developed from extracting one spatial point near Resolute Bay from the C3S satellite observed sea ice concentration dataset. The break-up and freeze-up date thresholds were defined as when the sea ice concentration fell and stayed below 20% and returned and stayed above 50% respectively. The break-up was considered as the first day the sea ice concentration stayed below 20%. Similarly, freeze-up was defined as the first day the sea ice concentration went and stayed above 50%. There were some missing data within this dataset, two years (1979 and 2003) where the sea ice concentration did not reach above 50%, and 11 years (1979, 1982, 1986, 1990, 1992, 1995, 1996, 2001, 2002, 2003, and 2014) where the sea ice concentration did not fall below 20%. The only year that had significant data missing (88 consecutive missing days) was 1986. This year of data was removed from further analysis.

An example of how the break-up date and freeze-up date were determined through sea ice concentration measurements using the year 2011 is presented in Figure 4-1.

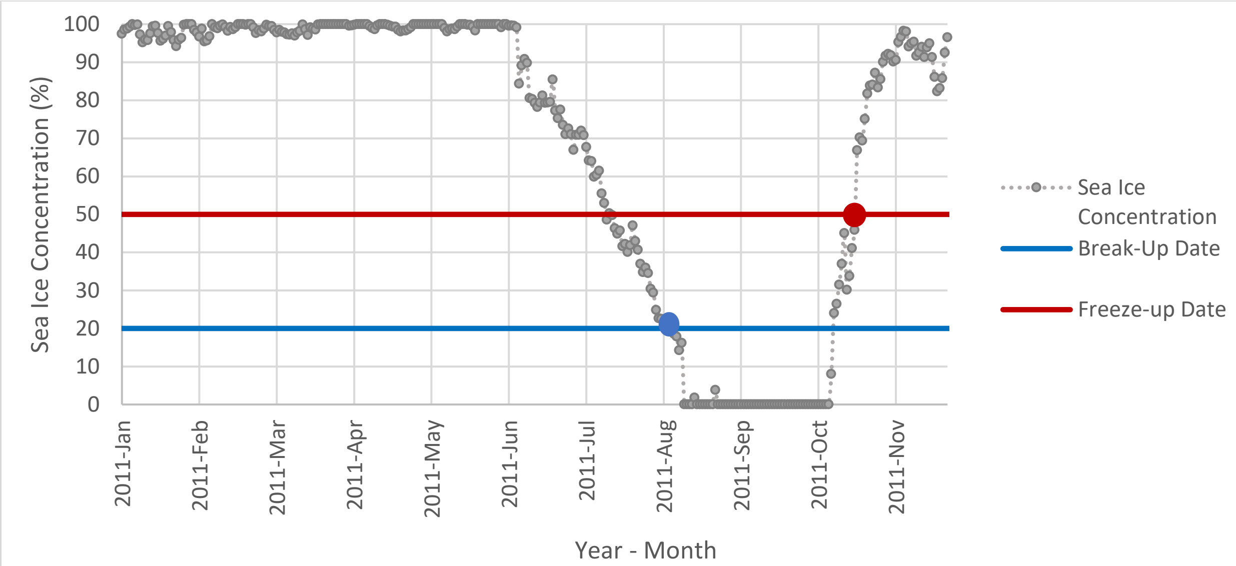


Figure 4-1: Break-up and Freeze-up Date Determined in 2011 as Determined by Copernicus Climate Change Services (C3S) Sea Ice Concentration (SIC) Measurements.

The procedure described above was used to determine the break-up and freeze-up date each year, and linear trends were developed on how the break-up and freeze-up date have changed over the period of measurement of 1979-2015. To note, if the sea ice concentration did not fall below 20% within any given year, there was no break-up or freeze-up date recorded. Figure 4-2 presents the recorded break-up and freeze-up dates from 1979-2015 and a linear trendline.

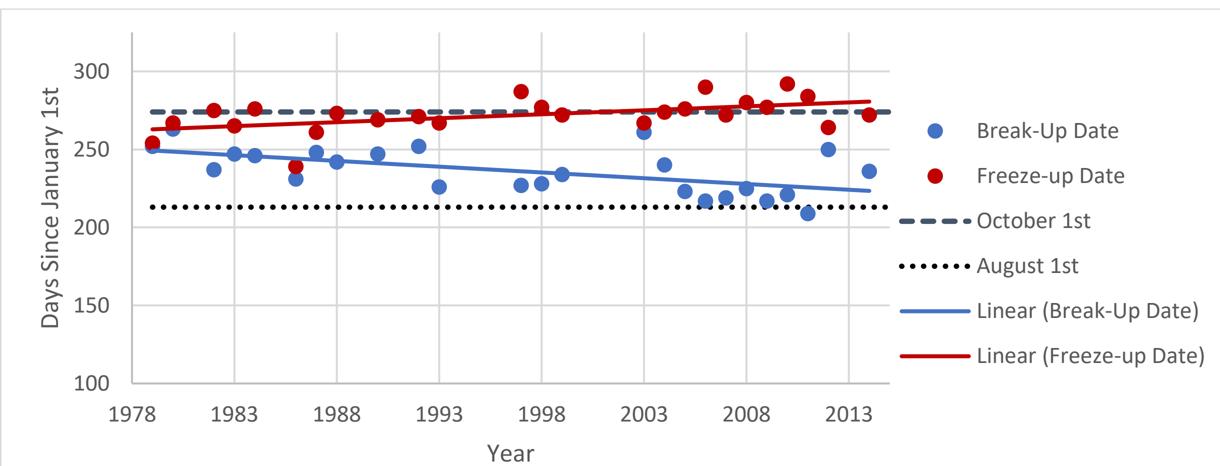


Figure 4-2: Linear Regression of Number of Days Since January 1st and the Annual Sea Ice Break-up and Freeze-up Date in Resolute Bay between 1979 and 2015 as Determined by Satellite Derived Copernicus Climate Chang Service (C3S) Sea Ice Concentration (SIC) Measurements.

The C3S data showed that the break-up date occurred on average 0.74 days earlier per year, for a total of 27.3 days earlier in 2015 than in 1979. The freeze-up date occurred on average 0.51 days later per year, and 18.8 days later in 2015 than in 1979. In addition to determining the break-up date (the first date when sea ice concentration fell and stayed below 20%), the date SIC was at 0% was also examined. For the first 25 years of SIC measurements, the SIC reached 0% every two to three years. However, from 2004 onward, SIC reaching 0% was a regular occurrence. Figure 4-3 shows the number of days SIC at 0% over the period of record.

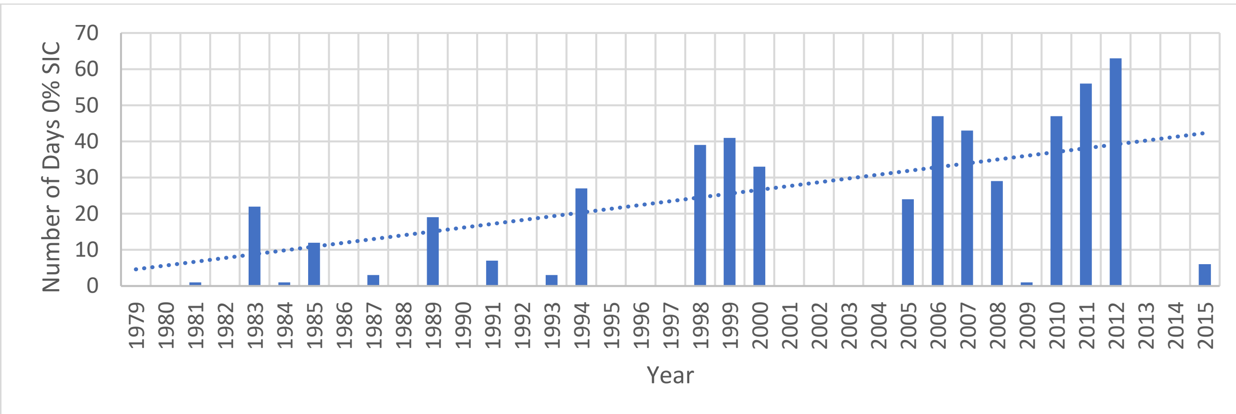


Figure 4-3: Linear Regression of Number of Days per Year between 1979 and 2015 where Sea Ice Concentration (SIC) was equal to 0% as determined by Satelite Derived Copernicus Climate Change Services (C3S) Sea Ice Concentration (SIC) Measurements.

The number of days at 0% sea ice concentration increased by one day a year on average from 1979 to 2015.

4.1.1.2 Canadian Ice Services (CIS) Archived Weekly Regional Sea Ice Charts Results

The eastern Arctic sea ice chart archives were accessed from 1982-2022 to determine if break-up dates were occurring earlier and if freeze-up dates were occurring later in Resolute Bay. The methods of determining the break-up date, and freeze-up dates are discussed in Section 3.1.1.2 as well as Appendix B. The break-up date was defined as the date where sea ice concentration reached and stayed below 1-3/10 within a calendar year. The freeze-up date was defined as the first date where sea ice concentration reached and stayed above 4-6/10 within a calendar year. These methods were defined before the manual interpretation of sea ice charts were conducted to ensure there was no error resulting from human interpretation of the charts. The Figure 4-4 presents the break-up and freeze-up dates each year in calendar days (days since January 1st) as determined by manual interpretation of the CIS charts.

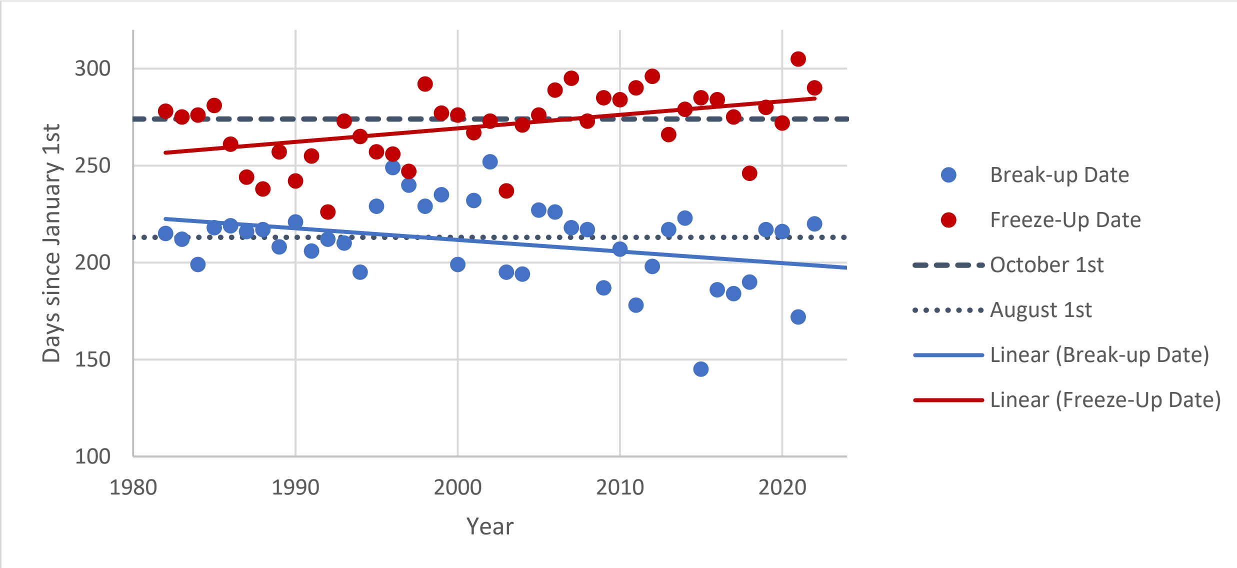


Figure 4-4: Linear Regression of Number of Days Since January 1st and the Annual Sea Ice Break-up and Freeze-up Date in Resolute Bay between 1982 and 2022 as Determined by Canadian Ice Services (CIS) Archived Weekly and Regional Archived Sea Ice Charts.

A linear regression was performed on both the freeze-up and break-up date. Both regression trends were statistically significant. Based on Figure 4-, the freeze-up date occurred on average 0.60 days later per year, the break-up date occurred on average 0.70 days earlier per year. Break-up timing occurred 28.0 days earlier, the freeze-up date occurred 24.0 days later in 2022 than in 1982.

4.1.1.3 Combined Copernicus Climate Service (C3S) and Canadian Ice Service (CIS) Results

Both the C3S and CIS datasets report sea ice concentration and were used above to define the break-up date and freeze-up date in Resolute Bay. These datasets were also used together to determine the break-up date and freeze-up date. If only one data source had available data in a given year, it was used alone to determine the break-up date and freeze-up date. If both data sources had available data an average of the two dates were used. Figure 4-5 shows the break-up and freeze-up date as determined by both datasets.

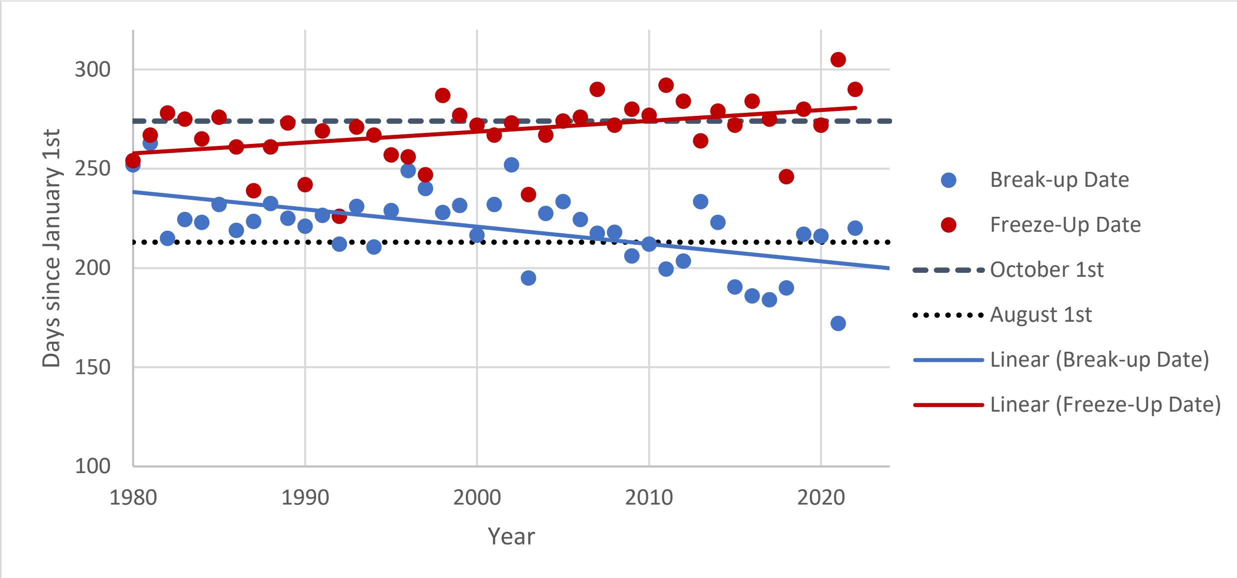


Figure 4-5-: Linear Regression of Number of Days Since January 1st and the Annual Sea Ice Break-up and Freeze-up Date in Resolute Bay between 1979 and 2022 as Determined by the Average of Canadian Ice Services (CIS) Archived Weekly and Regional Archived Sea Ice Charts and Copernicus Climate Change Services (C3S) Sea Ice Concentration (SIC) Measurements.

Using both datasets together, the break-up date was determined to occur 0.87 days earlier, and the freeze-up date 0.55 days later per year. The break-up date occurred 37.5 days earlier and the freeze-up date occurred 23.4 days later in 2022 than in 1979.

4.1.2 Sea Ice Thickness Results

Two datasets were used to assess sea ice thickness, C3S sea ice freeboard from 2002-2020 and ECCC fast ice thickness from 1947-2021. The results of these analysis are presented in Section 4.1.2.1 and 4.1.2.2.

4.1.2.1 Copernicus Climate Change Service (C3S) Sea Ice Freeboard Thickness Results

For this portion of the scientific analysis the dataset described in Section 2.2.1.2.1 was used and four points were accessed near Resolute Bay using the methods described in Section 3.1.2.1. The time series of sea ice thickness freeboard was plotted in Figure 4-6 at four locations and linear regression performed on each dataset.

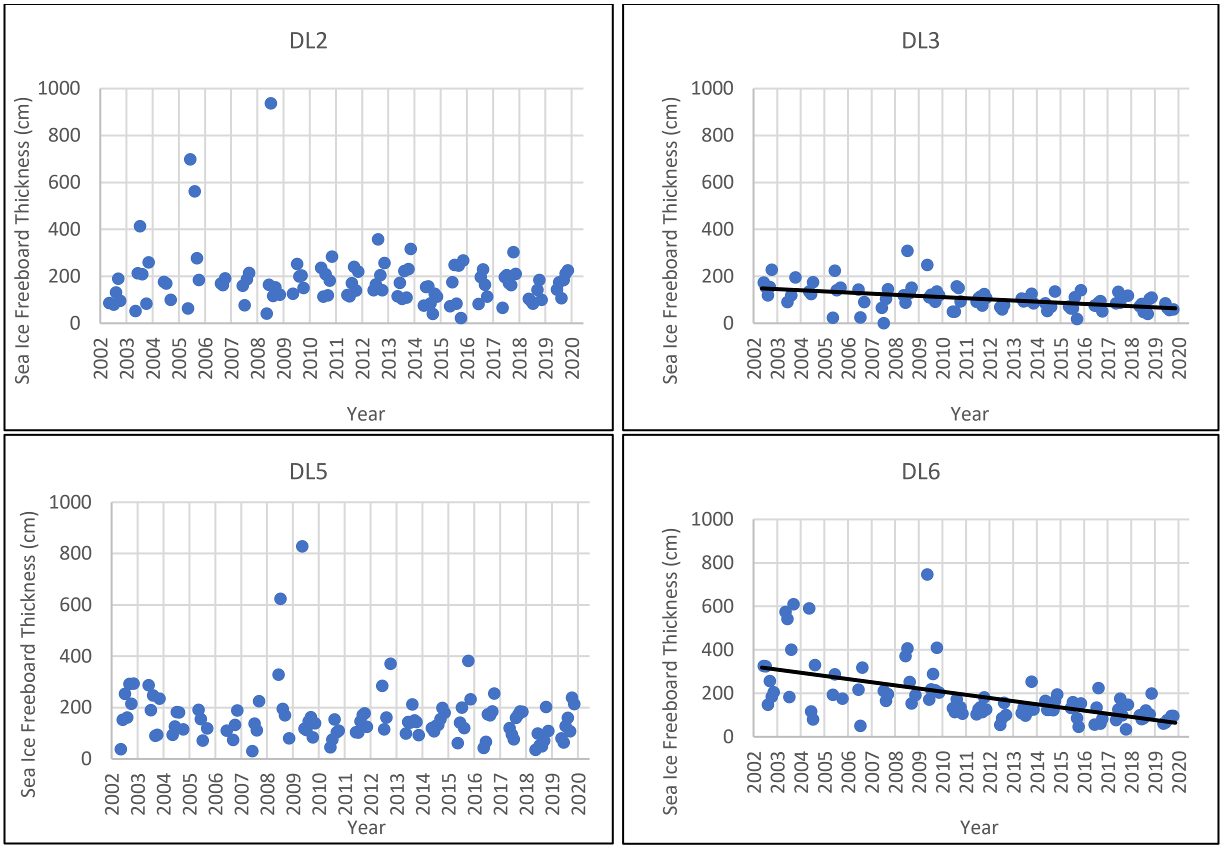
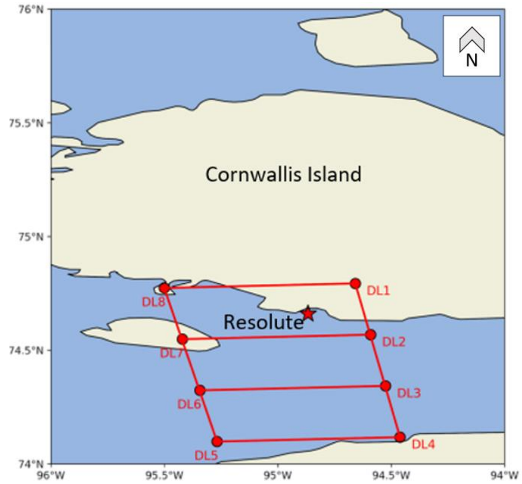


Figure 4-6: Linear Regression of Copernicus Climate Change Services (C3S) Sea Ice Freeboard Thickness at Four Locations Near Resolute Bay between 2002 and 2020.

All the data locations are offshore of Resolute Bay in the Barrow Strait. DL2 being the nearest to shore of Cornwallis Island, DL3 is approximatly mid-channel between Cornwallis Island and Somerset Isalnd to the southeast of Resolute Bay. DL6 is mid-channel between Cornwallis Island and Somerset Island to the southwest of Resolute Bay and DL5 is just offshore of Somerset Island. Linear regression were performed on each dataset, the sea ice freeboard is decreasing at DL3 and 6. The trends identified at DL2 and DL5 were considered statistically insignficiant. The rate of change in sea ice freeboard and the average change in sea ice freebaord at each location is presented in Table 4-1.

Table 4-1: Rate of Change and Average Sea Ice Freeboard Thickness Change Between 2002 and 2020 at Four Locations Near Resolute Bay from Copernicus Climate Change Services (C3S).

Data Locations	Data Location ID	Rate of Change of Sea Ice Freeboard (cm/year)	Average Change in Sea Ice Freeboard from 2002-2020 (cm)
	DL2	-3.94	71.0
	DL3	-4.85	87.4
	DL5	-3.03	54.5
	DL6	-14.49	260.8

*Red Text indicates a statistically insignificant trend

DL6 sea ice freeboard was thicker than DL3 even though they are longitudinally in line with each other. Sea ice in the Barrow Strait breaks-up from east to west and freezes-up from west to east. DL6 being further west than DL3 and having thicker sea ice freeboard measurements aligns with expectations of thickness based on known break-up and freeze-up patterns. Sea ice at DL6 would have more time to grow in thickness over the ice-covered season than at DL3. Of note within these results, DL6 sea ice freeboard thickness was decreasing at more than three times the rate of DL3, for a total decrease of 2.6 m between 2002 and 2020.

4.1.2.2 Environment and Climate Change Canada (ECCC) Weekly Fast Ice Thickness Results

A dataset maintained by Environment and Climate Change Canada described in further detail in Section 2.2.1.2.3 was used to determine how annual maximum ice thickness has changed over time, as well as monthly fast ice thickness, and monthly averaged fast ice thickness. Additionally, the dataset was used to characterize typical fast ice thickness growth in Resolute Bay. The results of this analysis are outlined in the following Sections 4.1.2.2.1 and 4.1.2.2.2 below.

4.1.2.2.1 Annual Maximum and Minimum Fast Ice Thickness Results

The weekly measurements of fast ice thickness in Resolute Bay over the entire period of record along with the annual maximum and annual minimum ice thickness are plotted in Figure 4-7.

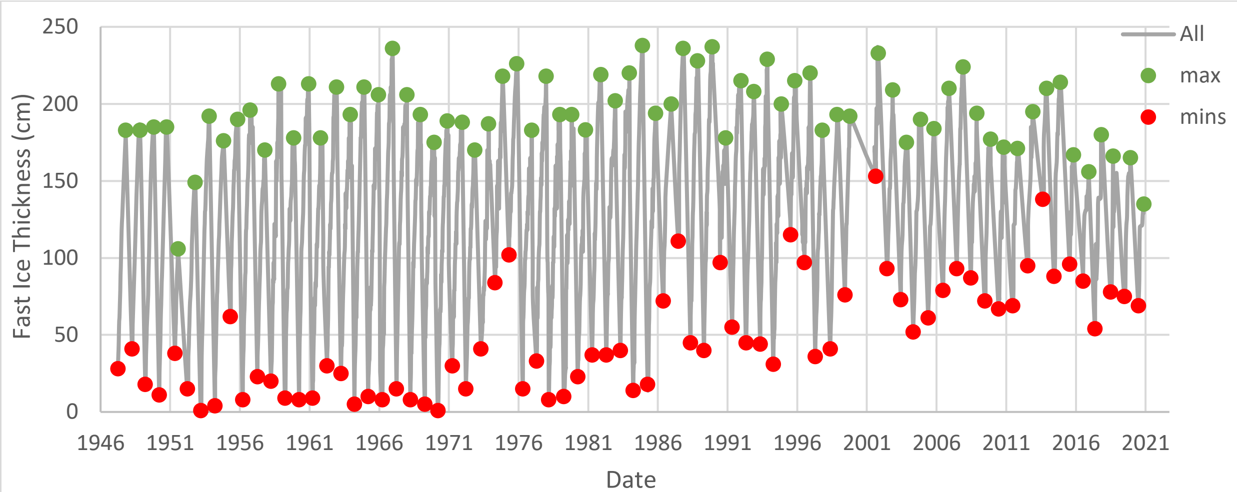


Figure 4-7: Environment and Climate Change Canada (ECCC) Fast Ice Thickness Measurements, Annual Maximum, and Annual Minimum Fast Ice Thickness from 1947-2021 in Resolute Bay.

Typical fast ice growth in Resolute Bay begins in the end of August and beginning of September, the ice grows in thickness linearly and then plateaus and reaches a maximum in April, May, or June before breaking up in June, July or August. Fast ice growth patterns can be seen in Figure 4-8 below. All the ice thickness measurements taken between 1947 and 2021 are plotted on an annual ice growth season starting from September 1st.

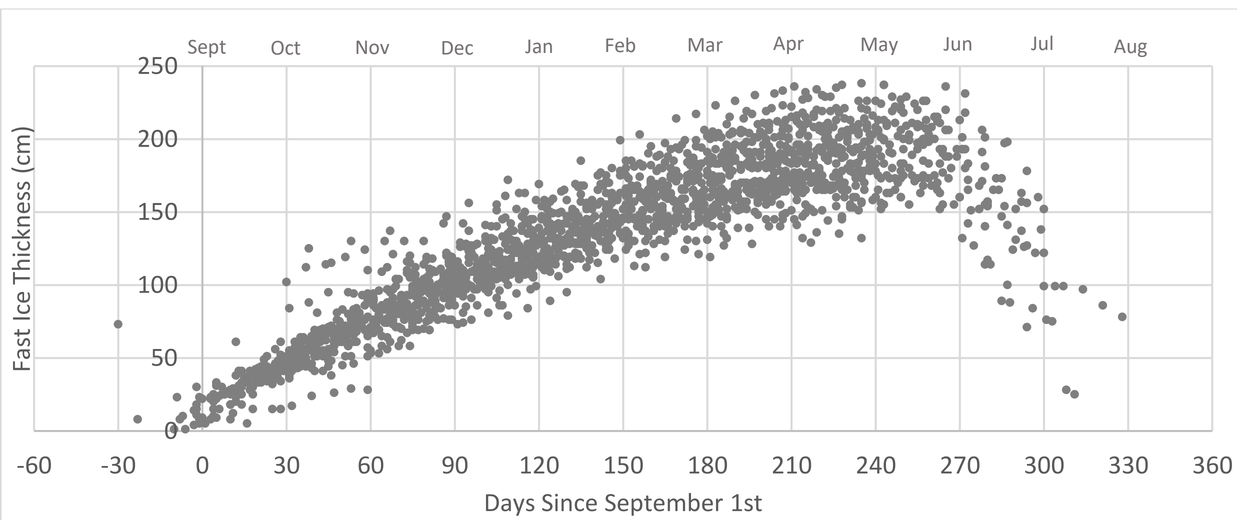


Figure 4-8: Environment and Climate Change Canada (ECCC) Typical Fast Ice Thickness Growth Based on all Measured Data from 1947-2021 Plotted Days Since September 1st.

This study seeks to identify trends in changing ice conditions in Resolute Bay. Trends were not developed for the annual minimum thickness, Figure 4-7 shows that between 1947 and 1971 ice thickness measurements were being taken at or below one cm indicating that the measurements were capturing the annual minimum thickness. After 1986 however, measurements of ice thickness went to a minimum of 40 cm and after 2000 there were no measurements of ice thickness below 50 cm. These missing measurements of ice that is less than 50 cm thick were due to policy changes by ECCC for safety reasons no ice could be measured below 50 cm. Therefore, trends cannot be developed on how the annual minimum ice thickness has changed over time if the measurements were not capturing measurements of ice below 50 cm.

Trends were developed and are discussed below for the annual maximum ice thickness. Figure 4-8 shows that the ice reaches a maximum thickness in April, May, or June. With fewer measurements being taken per year in the later part of this dataset, it is possible that the maximum fast ice thickness may also not be included in the data. In order to limit the risk that the maximum ice thickness was being missed, the date at which the maximum ice thickness occurred in each year was determined. Figure 4-9 shows which month the annual maximum measurement occurred in and the percentage of annual maximum measurements that occurred within each month.

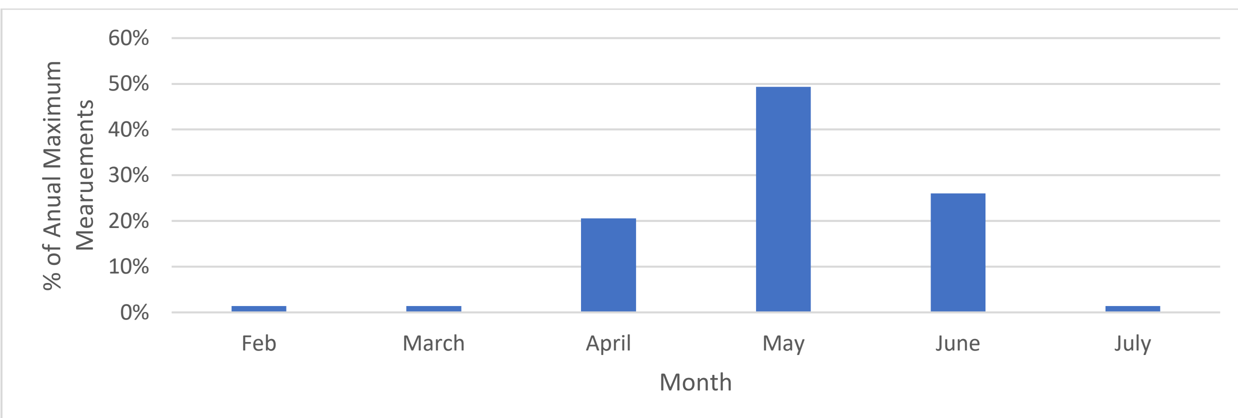


Figure 4-9: Environment and Climate Change Canada (ECCC) Fast Ice Thickness Annual Maximum Measurements Percent Occurrence per Month.

Figure 4-9 determined that 98% of annual maximum thicknesses were recorded in April, May, or June. It can therefore be concluded that when developing trends in the annual maximum ice thickness, the data did record the occurrence of the annual maximum unlike the annual minimum based on typical ice growth patterns presented in Figure 4-8.

The PELT change point detection algorithm described in Section 3.1.4.2 was applied to the time series of annual maximum fast ice thickness in order to detect the change point in the time series. The results of this analysis are presented in Figure 4-10.

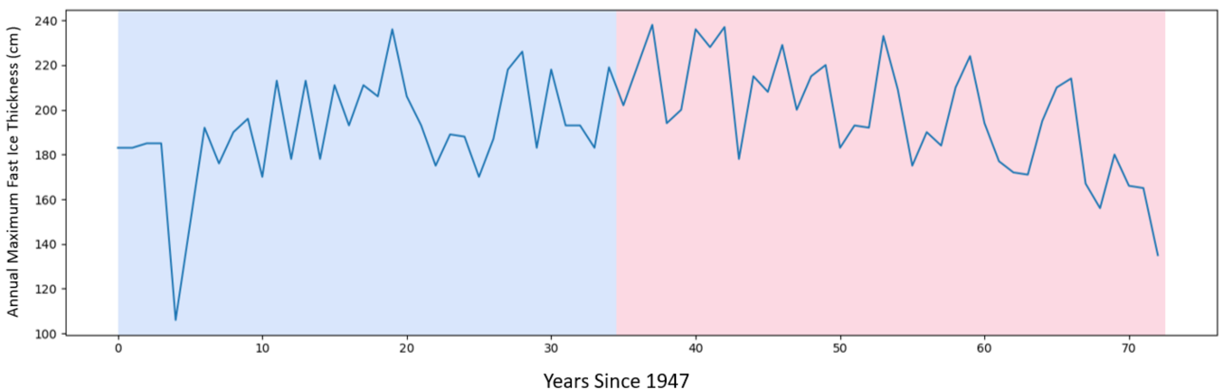


Figure 4-10: Environment and Climate Change Canada (ECCC) Annual Maximum Fast Ice Thickness Change Point Detection PELT Search Method.

The PELT algorithm found a shift in the dataset in 1981. As such, linear regression was preformed on annual maximum fast ice thickness pre-1981 and post-1981. The results of this analysis are presented in Figure 4-11.

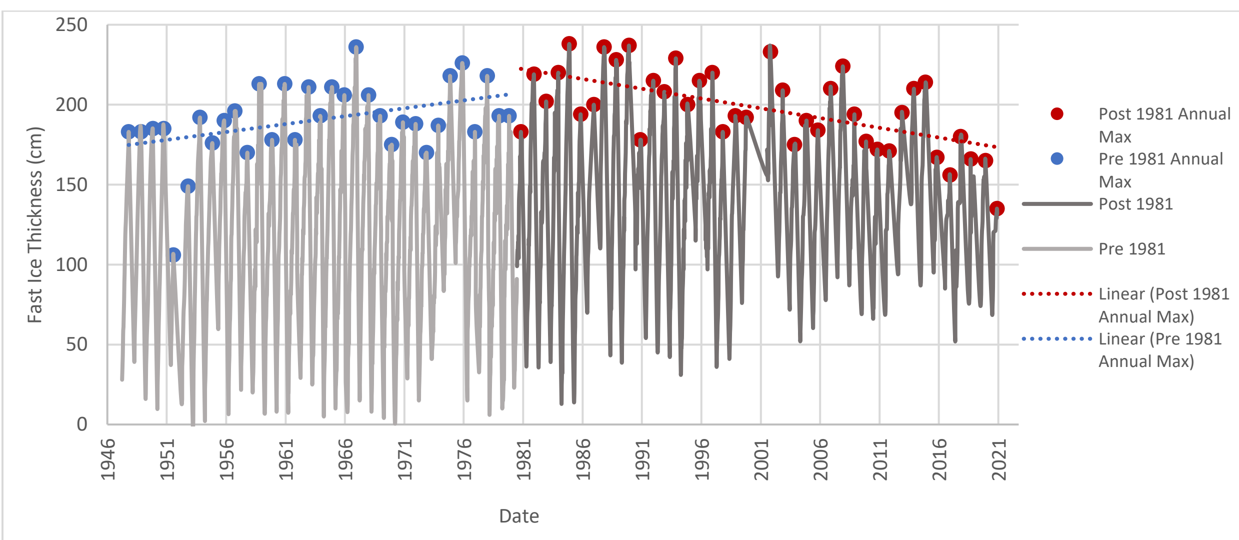


Figure 4-11: Linear Regression of Environment and Climate Change Canada (ECCC) Fast Ice Thickness Before and After 1981.

Prior to 1981, the annual maximum ice thickness was increasing at a linear trend of 0.99 cm per year based on the linear regression. After 1981, the annual maximum ice thickness began decreasing at a rate of 1.2 cm per year. From 1981 to 2021 the annual maximum ice thickness has decreased by 33.2 cm on average after increasing on average from 1948-1981 by 32.5 cm. The fast ice thickness results presented in this section are from a location directly offshore of the community of Resolute Bay. The fast ice thickness differences were in the order of 30 cm over 40 years. Comparatively, the sea ice freeboard thickness results presented in Section 4.1.2.1 were in the order of 2.6 m on average over 18 years.

4.1.2.2.2 Monthly Fast Ice Thickness Results

In addition to analyzing the annual maximum ice thickness measurements, the ECCC fast ice dataset was broken down by measurements that occurred in October through June of each ice season. July, August, and September were excluded due to the limited number of sea ice measurements occurring in the summer months. The number of measurements from 1947-2021 in the months evaluated are presented in Figure 4-12.

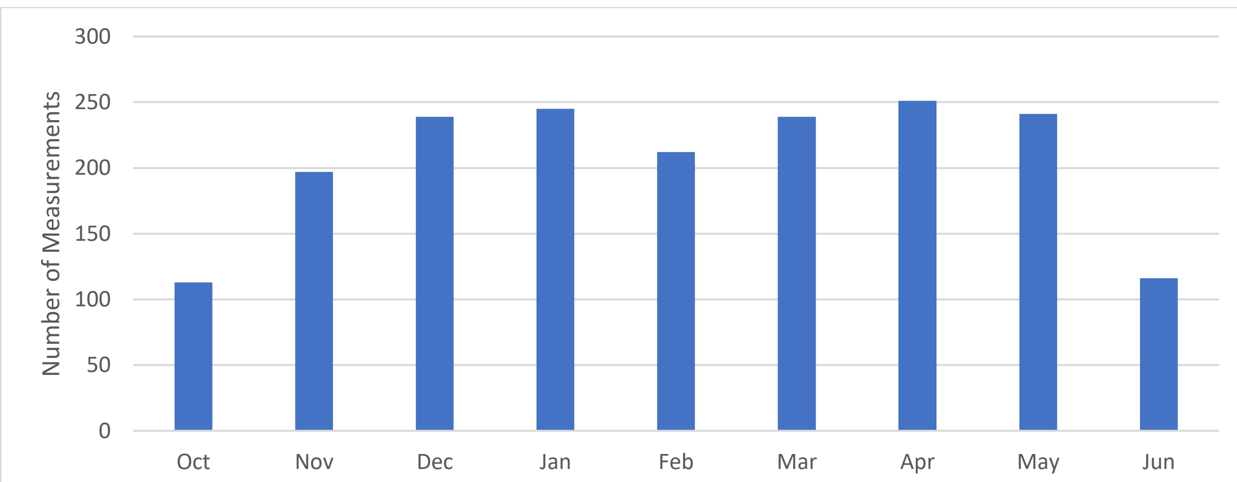


Figure 4-12: Environment and Climate Change Canada (ECCC) Fast Ice Thickness between 1947 and 2021 Number of Measurements per Month.

One time series per month for all the measurements occurring in the months October-June were input into the PELT change detection point algorithm. Figures associated with the monthly fast ice change point detection can be found in Appendix E. The change points (CPs) in each monthly time series are presented in Table 4-2.

Table 4-2: Environment and Climate Change Canada (ECCC) PELT Change Point Detection of Monthly Fast Ice Thickness.

Month	CP1	CP2	CP3	CP4
Oct	1960-10-11	1972-10-13	-	-
Nov	1960-11-11	1972-11-17	1985-11-22	-
Dec	1960-12-16	1974-12-06	1986-12-08	1998-12-19
Jan	1964-01-03	1976-01-30	1989-01-20	2002-01-18
Feb	1967-02-18	1984-02-12	1999-02-19	-
Mar	1967-03-03	1984-03-05	2002-03-01	-
Apr	1969-04-18	1986-04-11	2002-04-26	-
May	1970-05-01	1986-05-02	2003-05-16	-
June	1969-06-27	1983-06-17	-	-

The segment within each time series between the change points were analyzed to determine the if there were statistically significant linear trends in the data. If the R^2 value was above 0.1 and the P-value below 0.05, the segment between change points was considered to have a linear trend. Table 4-3 summarized whether statistically significant linear trends were found between change points for each month.

Table 4-3: Presence of Statistically Significant Linea Trends in Environment and Climate Change Canada (ECCC) Monthly Fast Ice Thickness.

Month	Statistically Significant Trend Found
October	No
November	No
December	No
January	Yes
February	Yes
March	Yes
April	Yes
May	Yes
June	No

The months with statistically significant trends are presented below. February will be used as the example from Figure 4-12 and Table 4-3. Figure 4-13 shows the segments between change points for all of the fast ice measurements taken in February between 1947 and 2021.

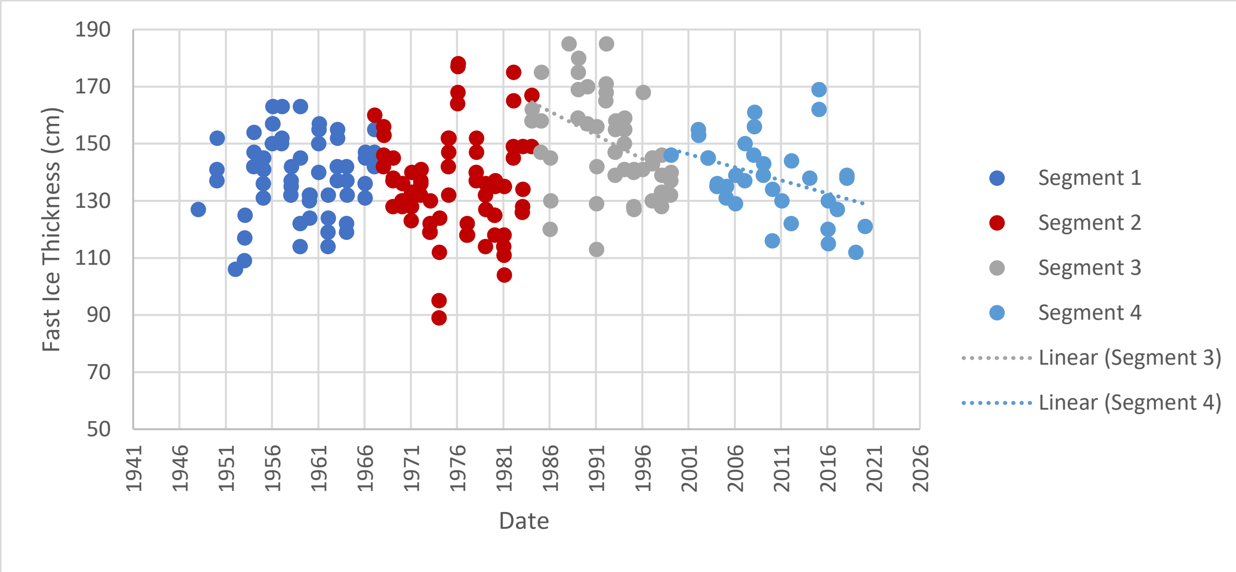


Figure 4-13: Linear Regression of Segments Between Change Points for Environment and Climate Change Canada (ECCC) Fast Ice Thickness Measurements in February Between 1947 and 2021.

The rate of change for the linear trend line through each February segment in Figure 4-13 are presented below in Table 4-4. Statistical information on the R^2 and P-value are presented in Appendix C.

Table 4-4: Linear Regression of the Segments Between Change Points in Environment and Climate Change Canada (ECCC) Fast Ice Thickness in February.

Segment	Start Date	End Date	Slope (cm / year)	Total Change over Time Period (cm / year)
1	1947	1967	-0.18	-3.66
2	1967	1984	-0.003	-0.051
3	1984	1999	-1.70	-25.5
4	1999	2021	-0.91	-20.0

*Red text indicates non statistically significant trends.

Where the slope in a segment was near zero, there was no or nonsignificant change in February fast ice thickness over time within that segment. February fast ice thickness began to decrease in

1984 at a rate of 1.7 cm per year until 1999, the rate slowed to a decrease of 0.91 cm per year between 1999 and 2021. A plot and table similar to Figure 4-13 and Table 4-4 are presented for each month in Appendix E. Table 4-5 shows the change in monthly fast ice thickness per segment.

Table 4-5: Linear Regression of Environment and Climate Change Canada (ECCC) Fast Ice Thickness from January to May 1947-2021.

Month	Segment	Start Date	End Date	Slope (cm/year)	Total Change over Time Period (cm)
January	1	1947	1964	0.657	11.7
	2	1964	1976	1.20	14.4
	3	1976	1989	2.66	34.6
	4	1989	2002	-1.20	-15.6
	5	2002	2021	-0.986	-18.7
February	1	1947	1967	-0.183	-3.66
	2	1967	1984	-0.002	-0.034
	3	1984	1999	-1.68	-25.2
	4	1999	2021	-0.913	-20.1
March	1	1947	1967	0.110	2.20
	2	1967	1984	0.146	2.48
	3	1984	2002	-1.79	-32.2
	4	2002	2021	-1.57	-29.8
April	1	1947	1969	0.474	10.4
	2	1969	1986	1.64	27.9
	3	1986	2002	-2.23	-35.7
	4	2002	2021	-2.23	-42.4
May	1	1947	1970	0.620	14.3
	2	1970	1986	2.19	35.0
	3	1986	2003	-1.64	-27.9
	4	2003	2021	-2.34	-42.1

*Red text indicates statistically insignificant trends

Based on the non-significant change in fast ice thickness in either the first or first and second segments, a decrease in January fast ice thickness began in 2002. The February and March fast ice thickness began to degrease in 1984, and the April and May fast ice began to decrease in 1986. In the months, January, April, and May there was a statistically significant increase in fast ice thickness between the years 1976-1989, 1969-1986, and 1970-1986 respectively. The three highest rates of fast ice thickness decline were observed in April from 1986-2002, April in 2002-2021, and May from 2003-2021. These rates of change resulted in a total average decrease in April fast ice thickness of 78 cm from 1986 to 2021 and a decrease in May fast ice thickness by 42 cm from 2003-2021.

4.1.2.2.3 Monthly Averaged Fast Ice Thickness Results

Similar to the analysis that was done in Section 4.1.2.2.2, change point detection was done on time series of monthly averaged fast ice thickness for the months of October-June. Instead of determining the change point on every measurement taken within a month, a time series was developed with one point per year from 1947-2021, that point being the average of all the measurements taken within a given month. This was done to be able to correlate fast ice thicknesses to freezing degree days. The full results of the change point detection of monthly averaged fast ice thickness can be found in Appendix F. Table 4-6 summarizing the change points that were determined in each monthly averaged fast ice thickness time series.

Table 4-6: Change Point Detection in Environment and Climate Change Canada (ECCC) Monthly Averaged Fast Ice Thickness Between 1947-2021.

Month	CP
October	None
November	None
December	1980
January	1983
February	1984
March	1982
April	1983
May	1979
June	None

No change points were detected in the months of October, November, and June. For the remaining months (December-May), linear trends were developed. There were no statistically significant trends prior to the change points. However, all the linear trends after the change point were statistically significant. Figure 4-14 and Table 4-7 show the monthly averaged fast ice thickness per year before and after the change points.

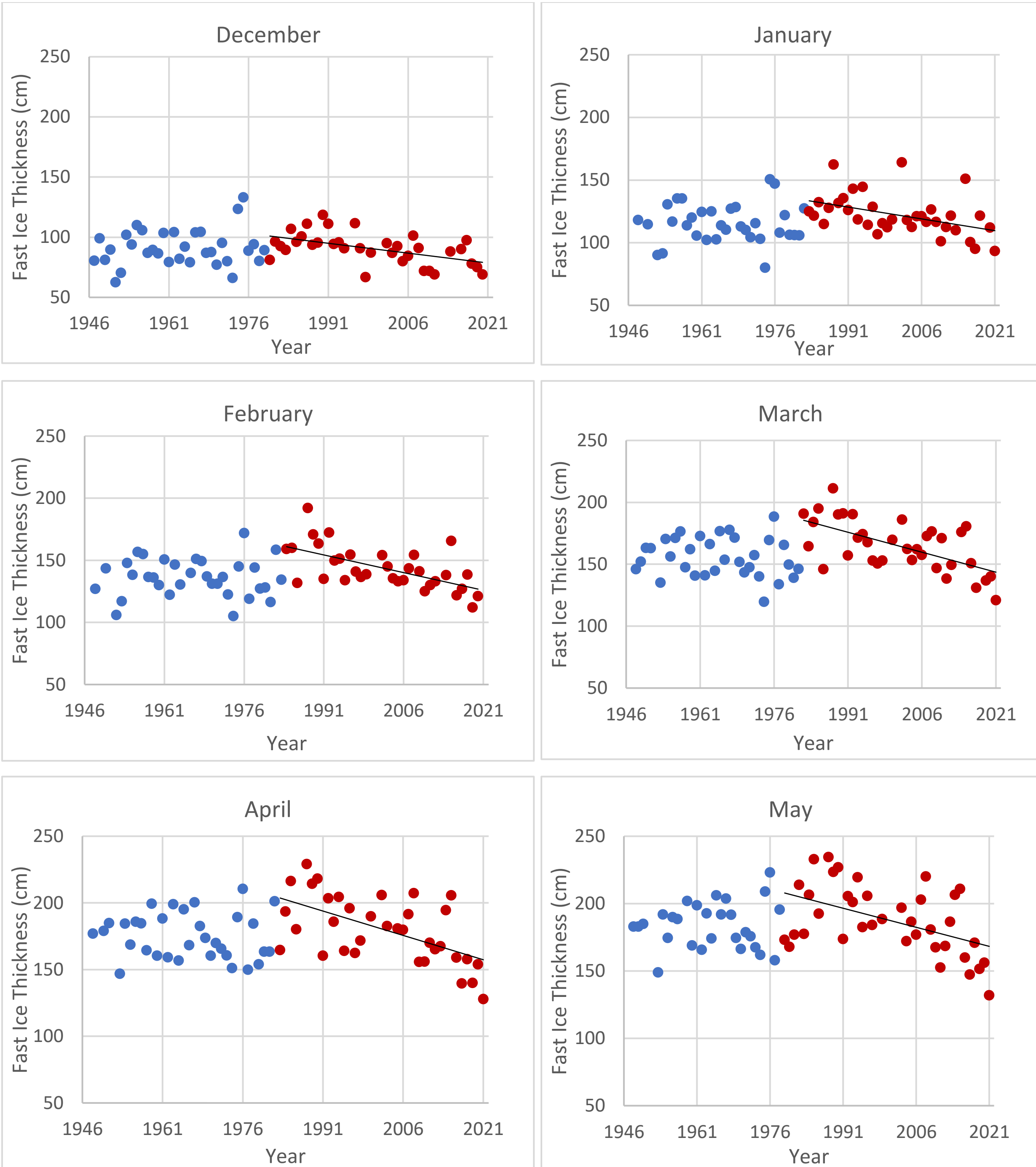


Figure 4-14: Linear Regression of Environment and Climate Change Canada (ECCC) Monthly Averaged Fast Ice Thickness Between 1947-2021 Before and After the PELT Change Point Detection.

Table 4-7: Linear Regression of Environment and Climate Change Canada (ECCC) Monthly Averaged Fast Ice Thickness Between 1947-2021 Before and After the PELT Change Point Detection.

Month	Time Period	Slope (cm/year)	Total Change over Time Period (cm)
December	1980-2021	-0.546	-22.4
January	1983-2021	-0.627	-23.8
February	1984-2021	-0.948	-35.1
March	1982-2021	-1.07	-41.7
April	1983-2021	-1.22	-46.4
May	1979-2021	-0.943	-39.6

In every month from December – May, after the change point in the time series (between 1979 and 1984), there was a decrease in the monthly average fast ice thickness. The months of March and April had the most severe change of 1.07 and 1.22 cm/year respectively.

4.1.3 Air Temperature Anomaly Results

To analyze trends in how land air surface temperatures have increased over time, annual temperature anomalies were calculated from both a 1947-1977 baseline and 1947-2023 baseline temperatures. It is common practice by climatologist when developing anomalies to use a baseline or long-term average of at least 30 years.

In this portion of the scientific analysis, temperature data were used to calculate air temperature anomalies both annually and monthly. These air temperatures were then compared to global temperature anomalies.

4.1.3.1 Annual Air Temperature Anomalies in Resolute Bay and Globally

Air temperature anomaly analysis is a common way to display the effects green house gas emission and climate change have on a warming climate. National Oceanographic Atmospheric Association (NOAA) produces temperature anomalies with respect to the 1900-2000 average. Figure 4-15 shows the annual anomaly in global land surface temperature from 1940-2023 relative to a 1900-2000 average.

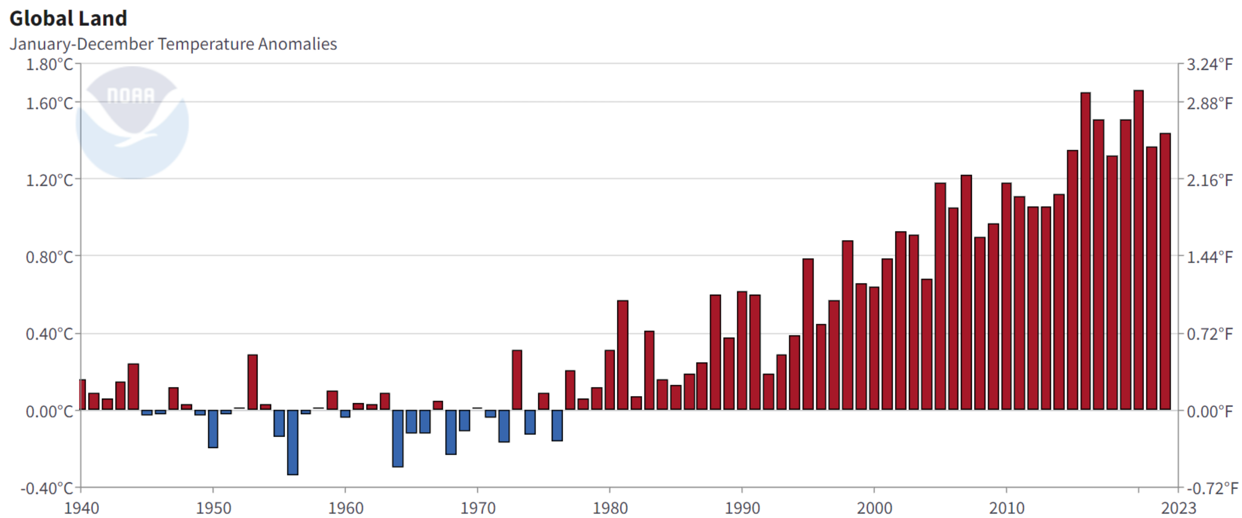


Figure 4-15: National Oceanic and Atmospheric Administration (NOAA) Global Land Surface Air Temperature Anomalies from 1940-2023 based on a 1900-2000 Baseline Average Temperature (Climate Change: Global Temperature | NOAA Climate.Gov*, 2023.)*.

The maximum positive anomaly being 1.66 °C in 2020. Exclusively positive anomalies began to occur after 1976. A similar analysis was done based on two weather data stations near Resolute Bay. Figure 4-16 and Figure 4-17 below show the calculated annual temperature anomalies compared to both a 1947-1977 baseline and a 1947-2022 baseline.

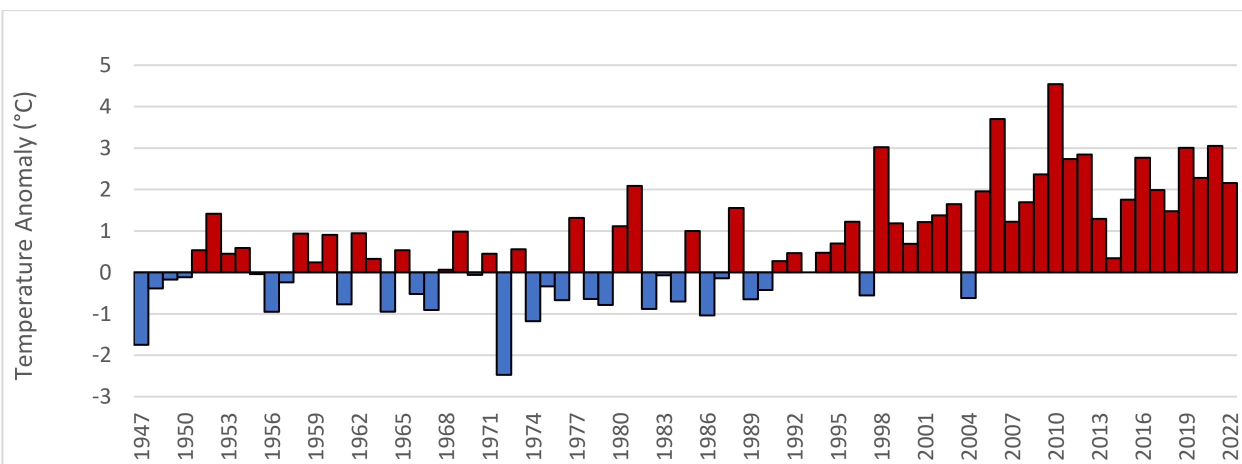


Figure 4-16: Environment and Climate Change Canada (ECCC) Annual Air Temperature Anomaly in Resolute Bay From 1947-2022 Based on a 1947-1977 Baseline.

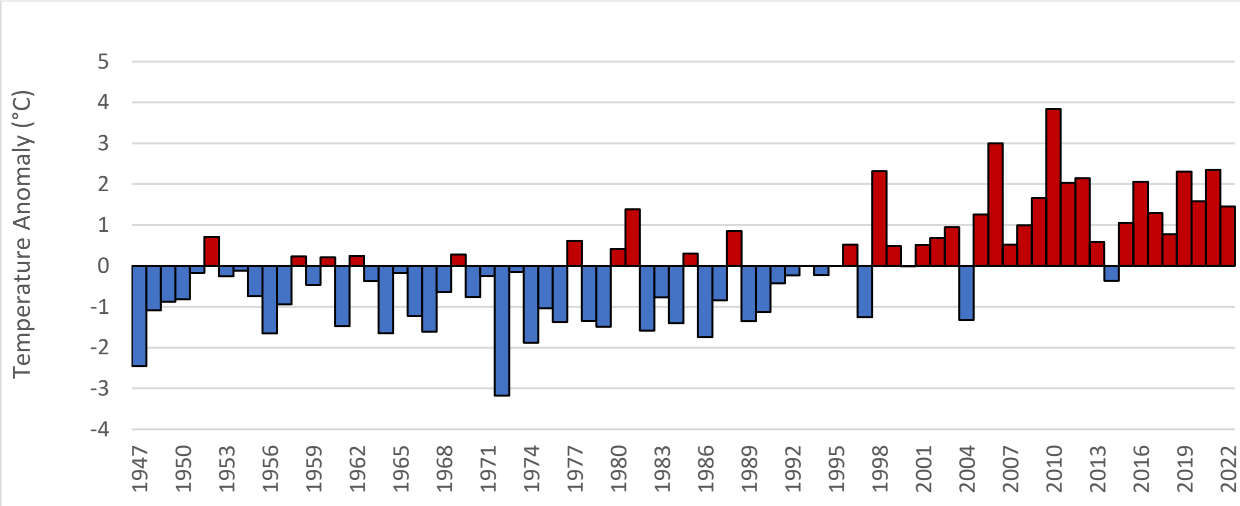


Figure 4-17: Environment and Climate Change Canada (ECCC) Annual Air Temperature Anomaly in Resolute Bay From 1947-2022 Based on a 1947-2022 Baseline.

An outlier temperature anomaly was identified in 1993. The 1993 data were removed from the annual anomaly calculations. After further analysis of the data, it appears that most years have a measurement every day. However, 1993 is missing several measurements approximately 2-3 per month. January and December (two of the colder winter months) are missing 15 and 14 days of data respectively in 1993.

Air temperature anomalies compared to a 1947-1977 baseline begin to shift to exclusively positive anomalies in 1990, where this shift occurs in the 1947-2022 baseline later in 1995. The positive anomalies are greater in the last three decades in the 1947-1997 baseline than 1947-2022 baseline. Similarly, the negative anomalies are more exaggerated Both Figure 4-16 and Figure 4-17 show that temperatures before the 1990's in Resolute Bay were colder than after the 1990's.

Temperature anomalies experienced in Resolute Bay are also larger, both positively and negatively, than the global anomalies. The maximum air temperature anomaly experienced in Resolute Bay is 3.8 °C above average compared to the maximum of 1.66 °C globally.

The change point detection PELT algorithm was used to identify the change point in the NOAA global air temperature and Resolute Bay annual temperature anomalies (1947-2022 baseline). A summary of the change points identified in each dataset are summarized in Table 4-8.

Table 4-8: National Oceanic and Atmospheric Administration (NOAA) Global and Environment and Climate Change Canada Resolute Bay Air Temperature Anomaly Change Point Detection.

Dataset	CP1 - Year	CP2 - Year
NOAA Global	1969	1994
Resolute Bay	1980	-

The change point algorithm detected two change points in the global air temperature anomalies. The first in 1969 and the second in 1994. The results of the change point detection algorithm on NOAA's global air temperature anomalies are presented in Figure 4-18. The change point detection results confirmed that before 1969, there was no statistically significant change in air temperature anomaly globally. After 1969, air temperature anomalies were increasing globally. After 1994, air temperature anomalies started to increase more rapidly.

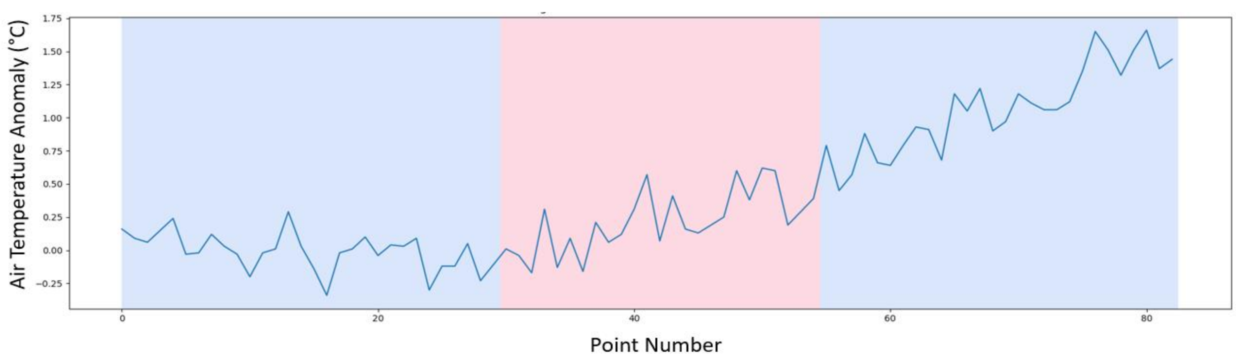


Figure 4-18: National Oceanic and Atmospheric Administration (NOAA) Global Air Temperature Anomaly Change Point Detection

Only one change point was detected in Resolute Bay air temperature anomalies in 1980. The results of the PELT algorithm used on air temperature anomalies in Resolute Bay are presented in Figure 4-19. The change point timing of air temperature anomalies in Resolute Bay, aligned with the change points identified in both annual maximum and monthly averaged fast ice thickness data which.

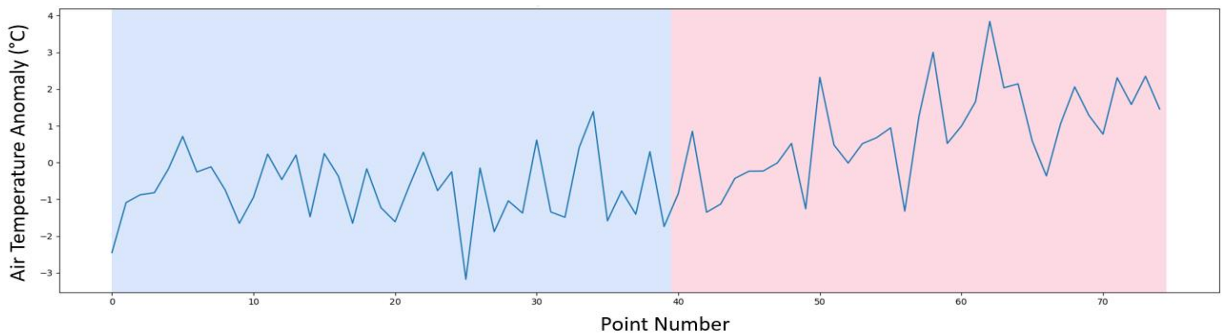


Figure 4-19: Environment and Climate Change Canada (ECCC) Resolute Bay Air Temperature Anomaly Change Point Detection.

In order to compare the rates of temperature change globally and in Resolute Bay, statistically significant linear trends were developed from the first change point onward in each time series. Figure 4-20 shows the temperature anomalies before and after the identified change points, and a linear regression after the first identified change point.

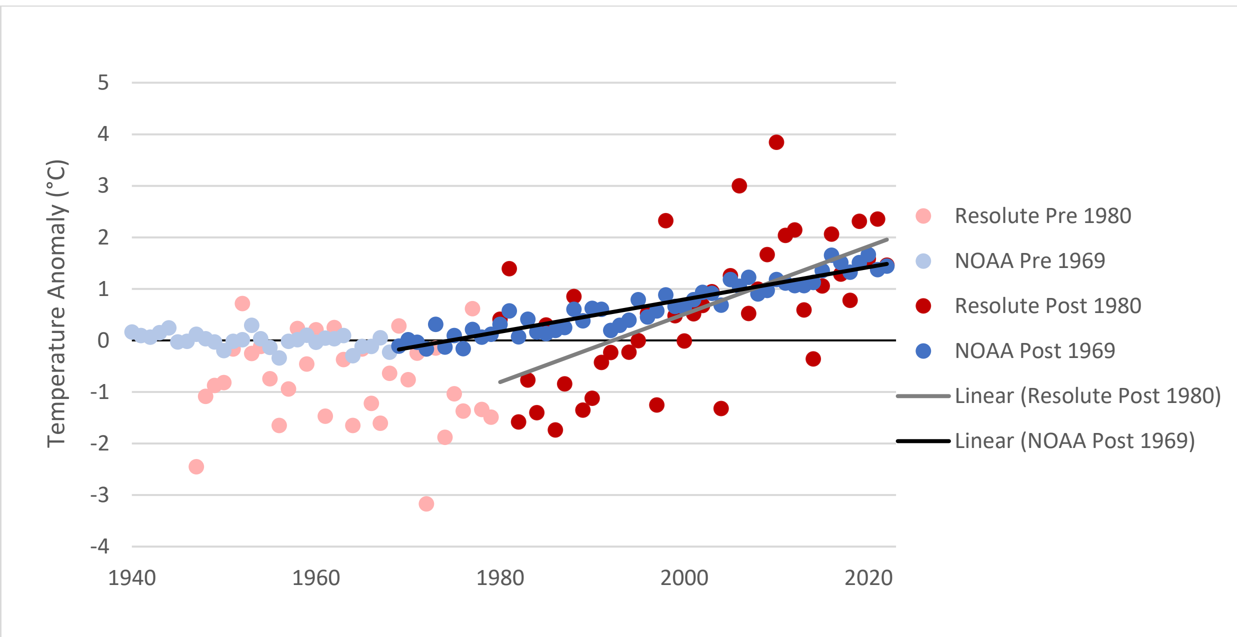


Figure 4-20: Linear Regression of National Oceanic and Atmospheric Administration (NOAA) Global and Environment and Climate Change Canada (ECCC) Resolute Bay Air Temperature Anomalies After Identified Change Points from 1940-2021.

The air temperatures in Resolute Bay are rising at the twice the rate of the global average after the first change point identified in each dataset.

4.1.3.2 Monthly Air Temperature Anomalies

In addition to annual air temperature anomalies, monthly air temperature anomalies were calculated based on 1947-2022 baselines. This analysis was done to determine in which season the most severe change in temperature are occurring. The monthly air temperature anomalies are presented in Figure 4-21.

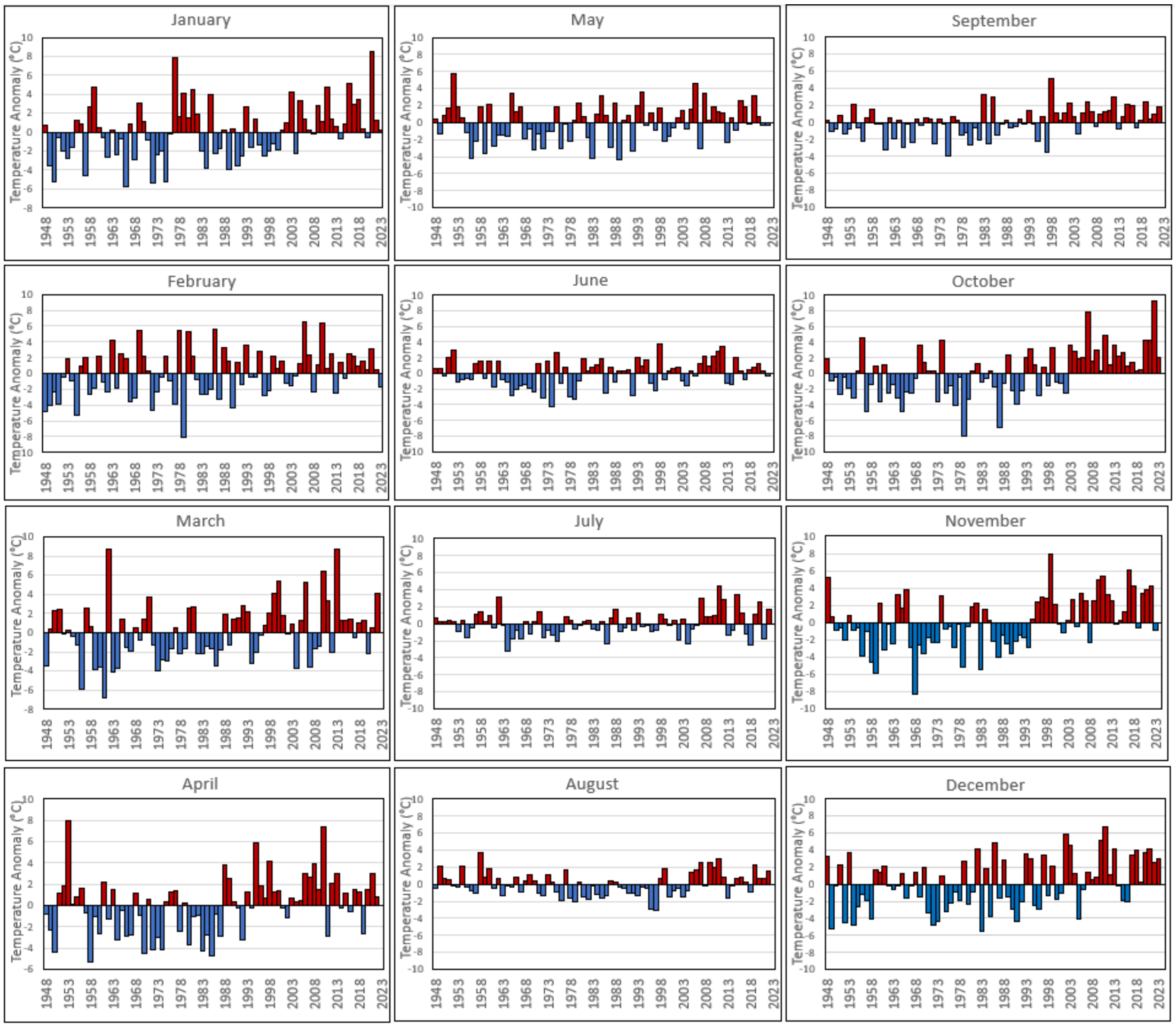


Figure 4-21: Environment and Climate Change Canada (ECCC) Monthly Air Temperature Anomalies from 1947-2023 Based on a 1947-2023 Baseline.

Summer months in Resolute Bay (June-August) are not experiencing as severe of temperature change than the winter months (December-February). The most distinct change from negative anomaly to positive anomalies occur in October and November with no negative anomalies since 2003 in October.

The PELT change point detection algorithm was used on each monthly air temperature anomaly time series to identify on a monthly basis, when temperatures began to rise in Resolute Bay. Table 4-9 summarizes in each month what year was identified by the algorithm to be a change point.

Table 4-9: Environment and Climate Change Canada (ECCC) Resolute Bay Monthly Air Temperature Anomaly Change Point Detection from 1947-2021.

Month	CP Year
January	1981
February	N/A
March	1986
April	1986
May	1986
June	1981
July	1981
August	1981
September	1981
October	1986
November	1986
December	1981

For a full summary of the change point detection for monthly air temperature anomalies the reader is directed to see Appendix G. The timing of the change point detection in air temperature compared to the fast ice thickness is compared in Section 5.1.5

4.1.4 Freezing Degree Days (FDDs) Results

The methods described in Section 3.1.3.1 were used to calculate freezing degree days in Resolute Bay based on ECCC air temperature data between 1947 and 2022. Years with fewer than 365 days of measurements (1992, 1993, 1947, and 2023) were removed from the analysis to capture an accurate estimate of FDD. The first analysis done was to look at FDD in Resolute was to group values by decade. A plot of FDD in Resolute Bay per decade can be seen in Figure 4-22.

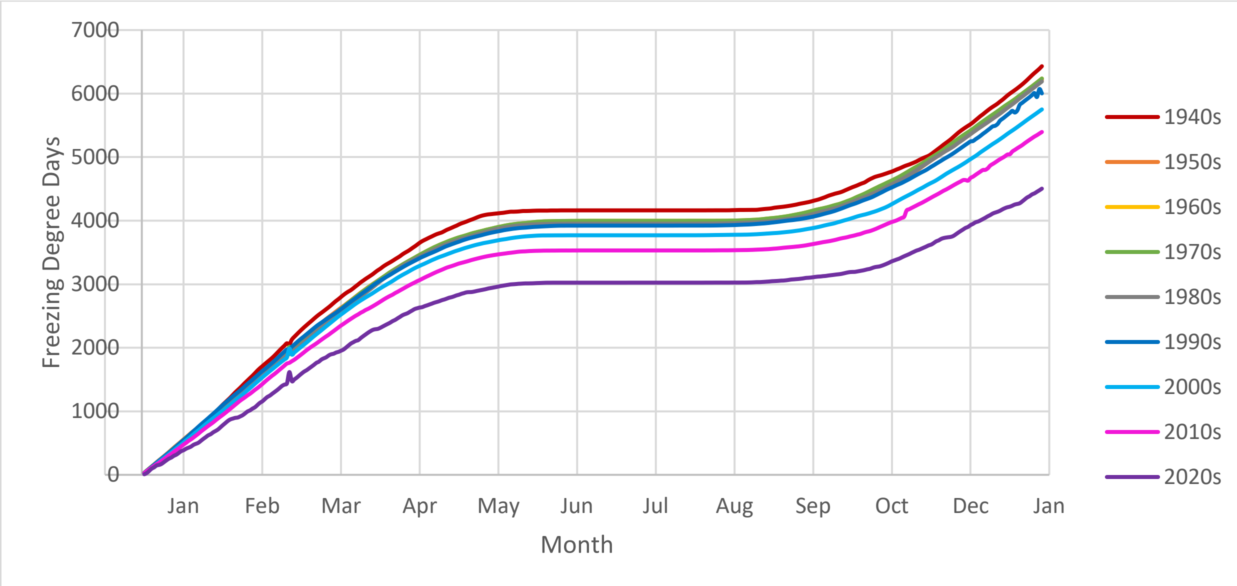


Figure 4-22: Freezing Degree Days (FDDs) in Resolute Bay Per Decade Based on Environment and Climate Change (ECCC) Air Temperature Data from 1948-2022.

These decadal curves were calculated by averaging the FDD values per calendar day over a 10-year period. However, the 1940's only includes 1948 and 49, and the 2020's only includes the years 2020-2022. The 1940's FDD curve is the highest curve. The 1950-90's curves are all within a 200 FDD range of each other as of December 31st. In the 2000's by December 31st, the average FDD over the decade falls by approximately 320 FDD from the 1990's curve at the same point. The 2010's curve decreases again in the by another 356 FDD. The 2020's curve only includes two years of data but is already 892 FDD lower than the 2010's by December 31st.

To analyze FDD on an annual basis, the total cumulative sum of FDD in each year were plotted against time. Or in other words the FDD on December 31st of each year is plotted in the Figure 4-23.

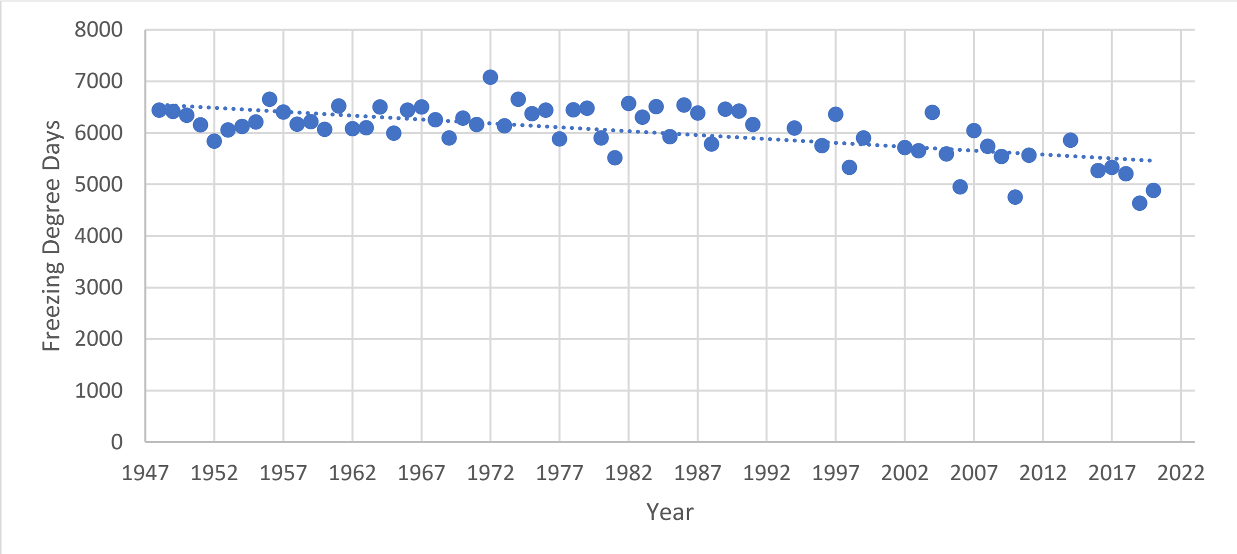


Figure 4-23: Linear Regression of Annual Freezing Degree Days (FDDs) as of December 31st from 1948-2022.

In order to determine if and how sea ice parameters were correlated to FDD in Resolute Bay, the December 31st cumulative total FDD were plotted against annual sea ice parameters and linear regression and statistical significance tests were conducted.

The following list of sea ice parameters examined in this study were correlated to FDD in Resolute Bay.

- C3S Break-up and Freeze-up Dates
- CIS Break-up and Freeze-up Dates
- C3S and CIS Averaged Break-up and Freeze-up Dates
- C3S Annual Average Sea Ice Freeboard Thickness – Averaged at Four Locations (DL2, DL3, Dl5, and DL6)
- C3S Annual Average Sea Ice Freeboard Thickness DL2
- C3S Annual Average Sea Ice Freeboard Thickness DL3
- C3S Annual Average Sea Ice Freeboard Thickness DL5
- C3S Annual Average Sea Ice Freeboard Thickness DL6
- ECCC Annual Maximum Fast Ice Thickness Pre-1981
- ECCC Annual Maximum Fast Ice Thickness Post-1981
- ECCC Monthly Average Fast Ice Thickness (November – June)

4.1.4.1 Freezing Degree Days (FDDs) Correlated with Break-up and Freeze-up Date in Resolute Bay

Freezing degree days were plotted on the x-axis against break-up and freeze-up date (in the number of days in the year) for both BUD and FUD, CIS and C3S. Secondly, the average BUD and FUD calculated from both datasets was also correlated to FDDs. Figure 4-24 shows the correlation between FDD and BUD and FUD given by C3S, Figure 4-25 shows FDD vs BUD and FUD given by CIS, and Figure 4-26 shows the correlation between FDD and an average BUD and FUD from both datasets.

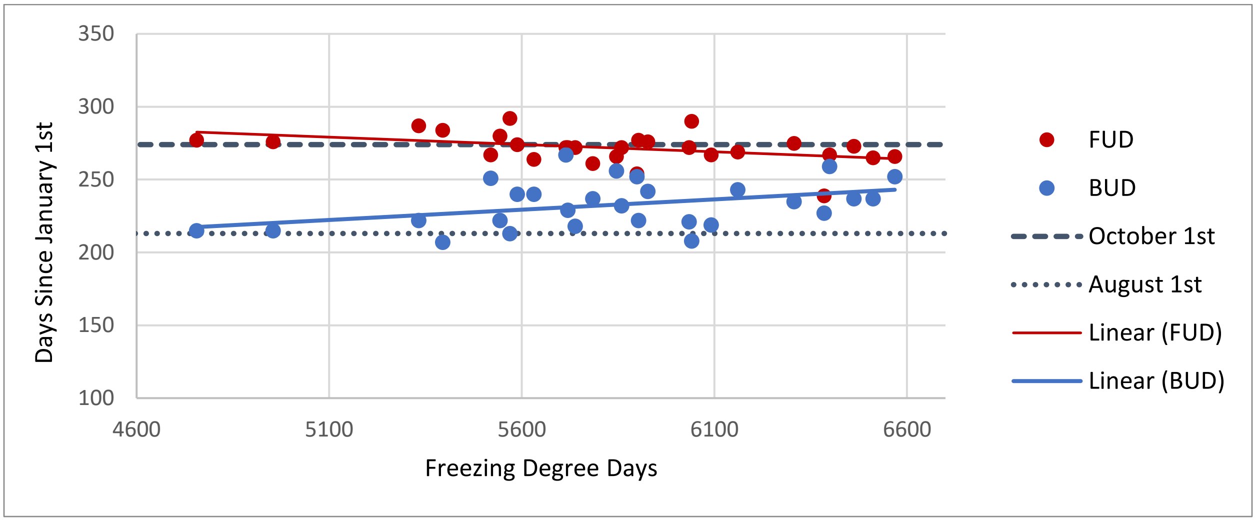


Figure 4-24: Freezing Degree Day Correlation Between Break-up Date (BUD) and Freeze-up Date (FUD) given by Copernicus Climate Change Service (C3S) Sea Ice Concentration.

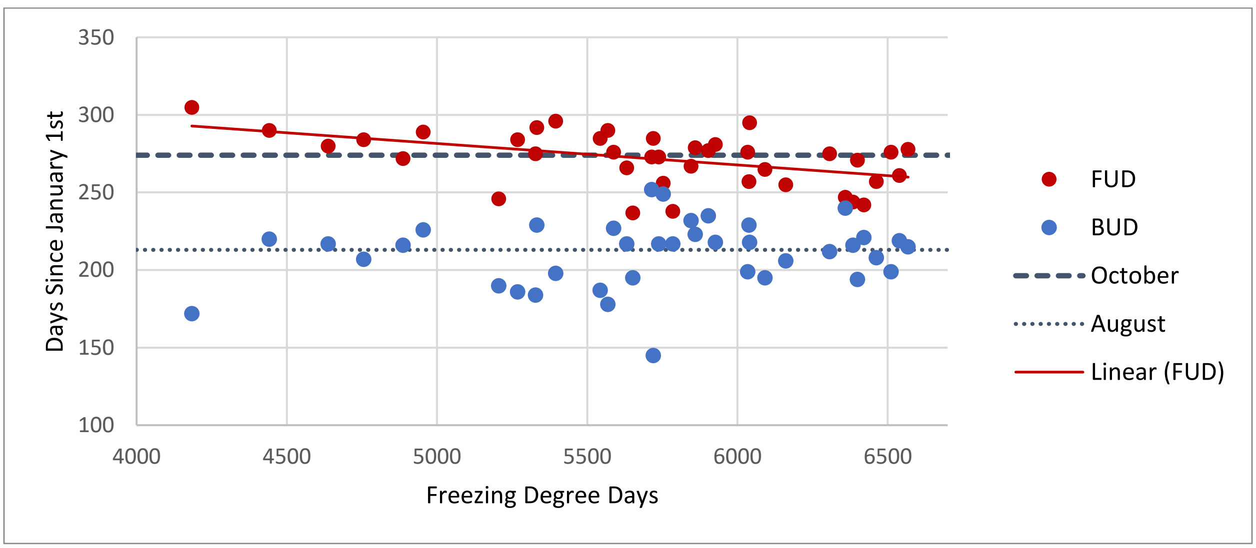


Figure 4-25: Freezing Degree Day Correlation Between Break-up Date (BUD) and Freeze-up Date (FUD) given by Canadian Ice Services (CIS) Archived Weekly Regional Sea Ice Charts.

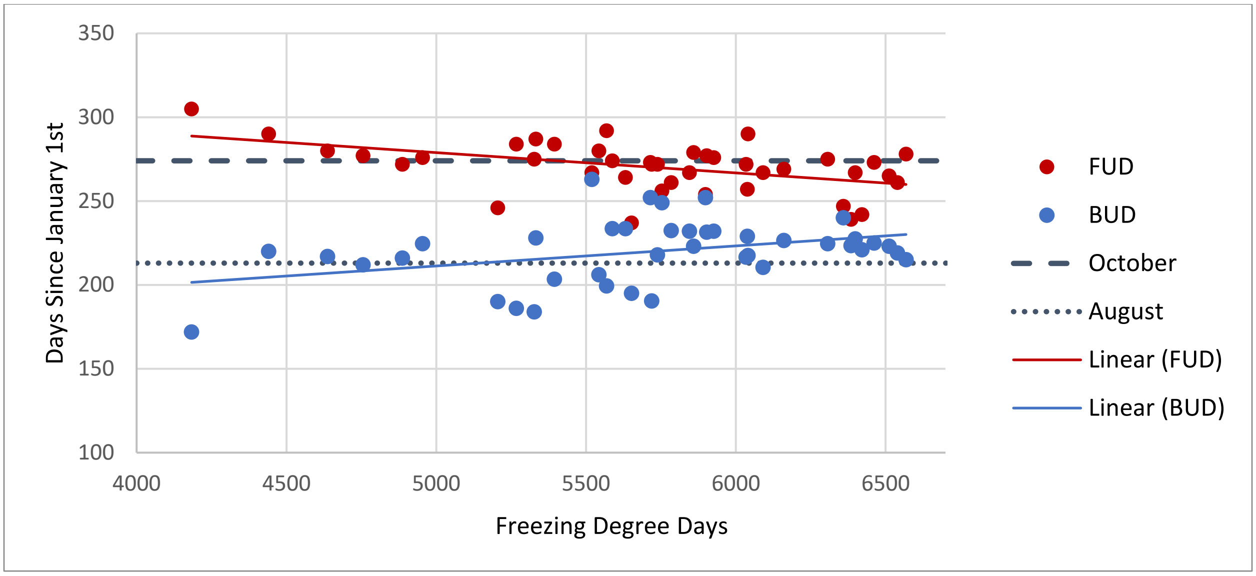


Figure 4-26: Freezing Degree Day Correlation Between Break-up Date (BUD) and Freeze-up Date (FUD) given by both Copernicus Climate Change Service (C3S) Sea Ice Concentration and Canadian Ice Services (CIS) Archived Weekly Regional Sea Ice Charts.

All of the linear trends identified between FDD an BUD and FDD and FUD are considered statistically significant except the correlation between FDD and BUD given by CIS data. Generally, FDD are positively correlated with break-up dates occurring later in the year, and negatively correlated with freeze-up dates occurring earlier in the year. A summary of the correlation results is shown in Table 4-10.

Table 4-10:Linear Regression of Freezing Degree Days (FDDs) and Break-up and Freeze-up Dates.

Sea Ice Parameter	Time Period	Slope (Days/FDD)	Total Change over Time Period (days)
BUD C3S	1979-2015	5.14	185.0
BUD CIS	1982-2022	2.41	96.4
BUD C3S CIS Average	1979-2022	4.41	189.6
FUD C3S	1979-2015	-4.42	-159.1
FUD CIS	1982-2022	-5.04	-201.6
FUD C3S CIS Average	1979-2022	-3.69	158.7

*Red text indicates statistically insignificant trends

Based on the R^2 values, correlations were stronger between FDD and FUD in all three of the datasets presented above.

4.1.4.2 *Freezing Degree Days (FDDs) Correlated with Sea Ice Freeboard in Resolute Bay*

No statistically significant trend was identified in the correlation between the average of sea ice freeboard thickness at all four locations. Figure 4-27 shows FDD vs averaged sea ice freeboard at all four data locations.

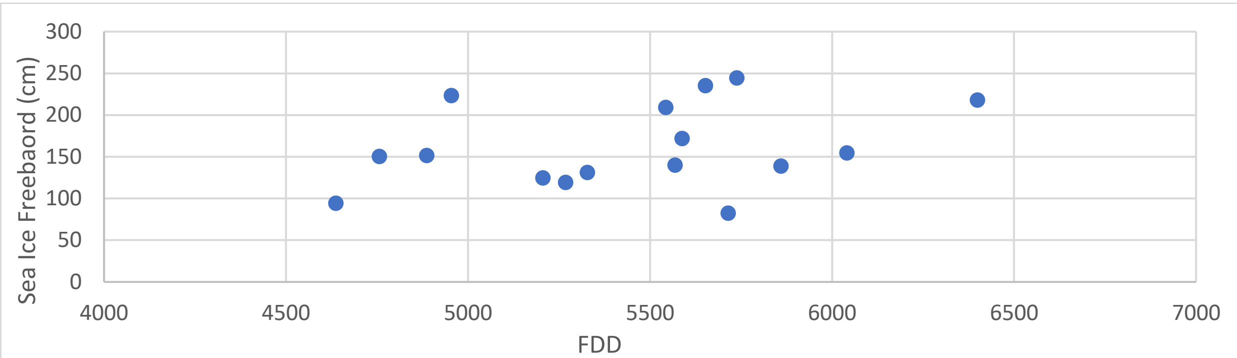


Figure 4-27: Freezing Degree Day (FDD) Correlation to Copernicus Climate Change Services (C3S) Annual Average Sea Ice Freeboard Thickness at Four Locations in the Barrow Strait.

Each location was assessed separately for correlation to FDD in Resolute Bay. Figure 4-28 represents each data location described in Section 4.1.2.1.

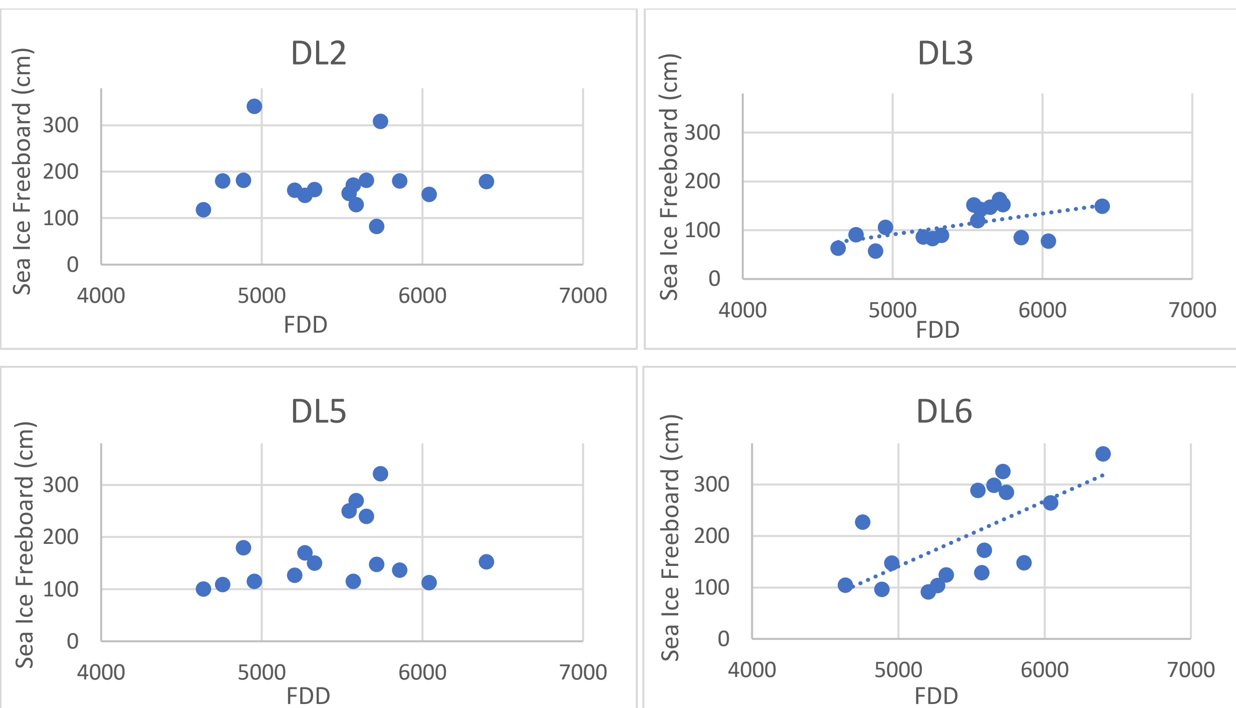


Figure 4-28: Freezing Degree Day Correlation to C3S Sea Ice Freeboard Thickness at location DL2 (top left), DL3 (top right), DL5 (bottom left), and DL6 (bottom right).

Statistically significant trends were present in the correlation of FDD to sea ice freeboard at DL3 and DL6. All the linear trends are presented in this section are presented below in Table 4-11.

Table 4-11:Linear Regression of Freezing Degree Day and Copernicus Climate Change Services (C3S) Sea Ice Freeboard Thickness between 1947-2021.

Sea Ice Parameter	Time Period	Slope (cm/FDD)	Total Change over Time Period (cm)
C3S Four Location Annual Average Sea Ice Freeboard Thickness	2002-2020	11.64	209.5
C3S DL2 Annual Average Sea Ice Freeboard Thickness	2002-2020	-4.75	-85.5
C3S DL3 Annual Average Sea Ice Freeboard Thickness	2002-2020	14.23	256.1
C3S DL5 Annual Average Sea Ice Freeboard Thickness	2002-2020	13.80	248.4
C3S DL6 Annual Average Sea Ice Freeboard Thickness	2002-2020	43.07	775.3

*Red text indicates statistically insignificant trends

4.1.4.3 Freezing Degree Days (FDDs) Correlated with Environment and Climate Change Canada (ECCC) Annual Maximum Fast Ice Thickness

Two separate linear trends were developed for the annual maximum fast ice thickness before 1981 and after 1981 based on the PELT change point detection described in Section 4.1.2.2.1. Fast ice thickness from both time periods was plotted against the FDD over the same period to assess the correlation between the two parameters. Figure 4-29 and Figure 4-30 show FDD plotted against annual maximum ice thickness based on ECCC fast ice thickness measurements between 1948 and 1981 and 1982 and 2021 respectively. Table 4-12 summarizes the statistical parameters associated with the linear regressions presented below.

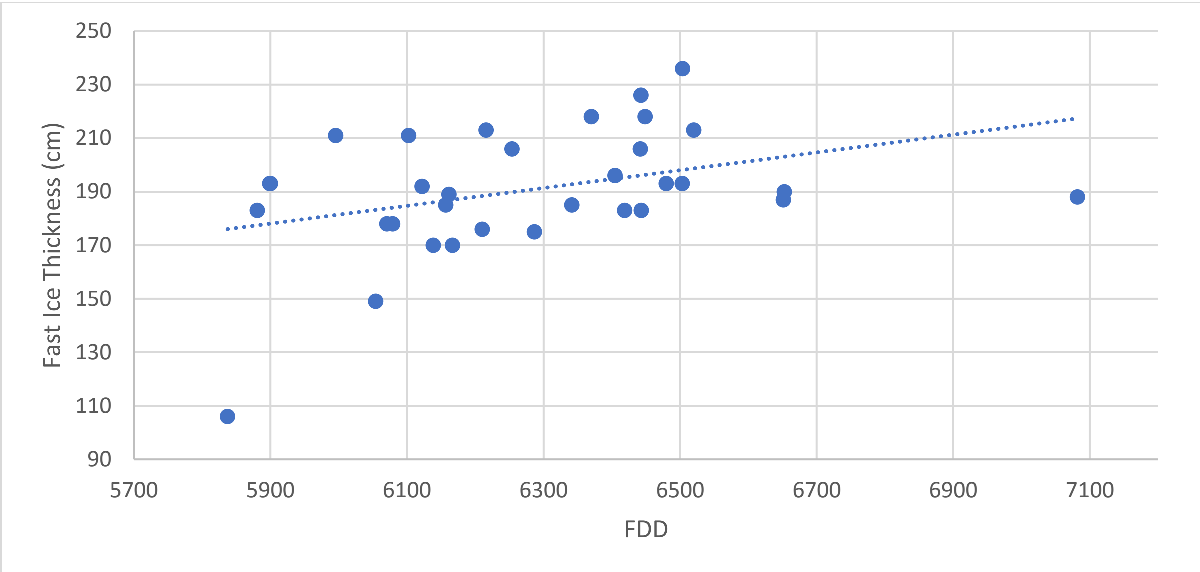


Figure 4-29: Freezing Degree Day (FDD) Correlation to Environment and Climate Change Canada (ECCC) Annual Maximum Fast Ice Thickness from 1948-1981.

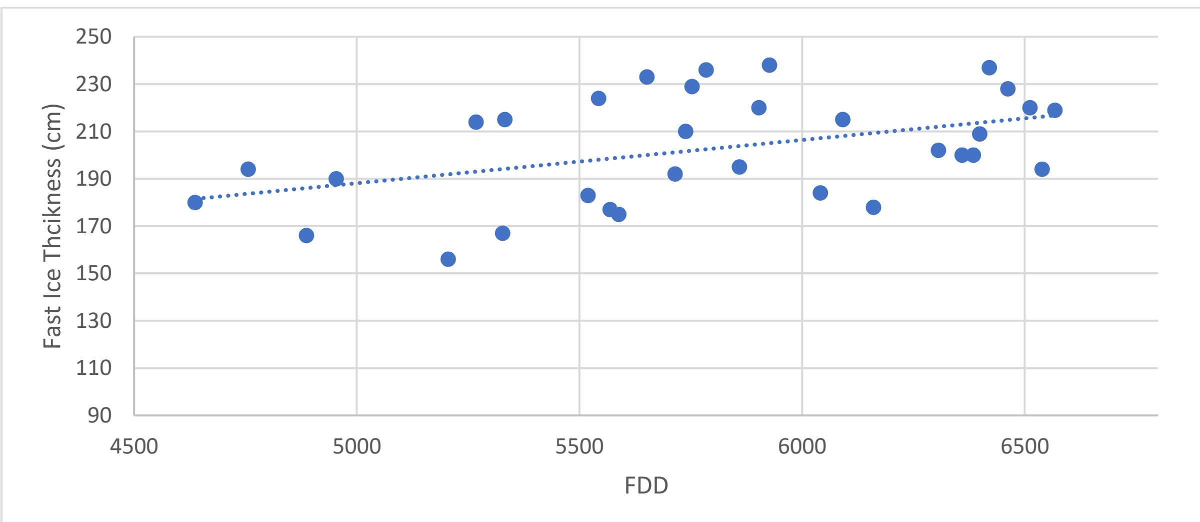


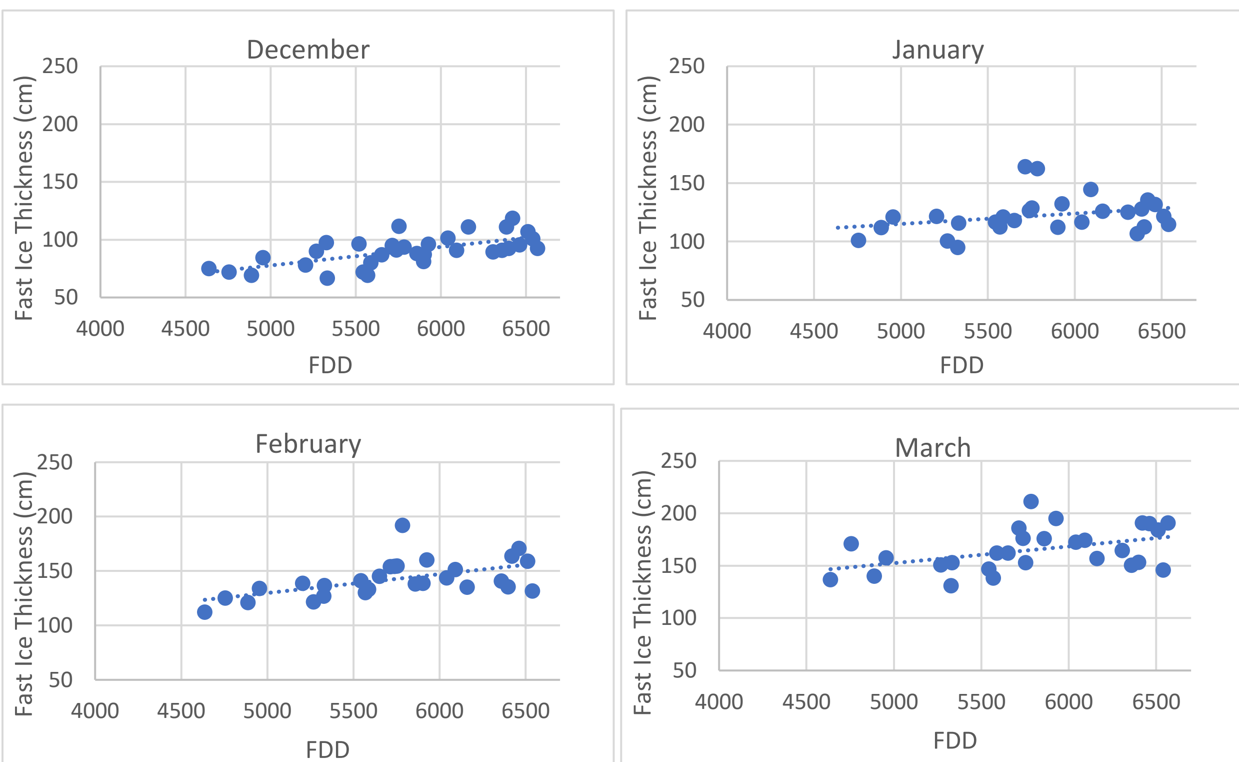
Figure 4-30: Freezing Degree Day (FDD) Correlation to Environment and Climate Change Canada (ECCC) Annual Maximum Fast Ice Thickness from 1982-2021.

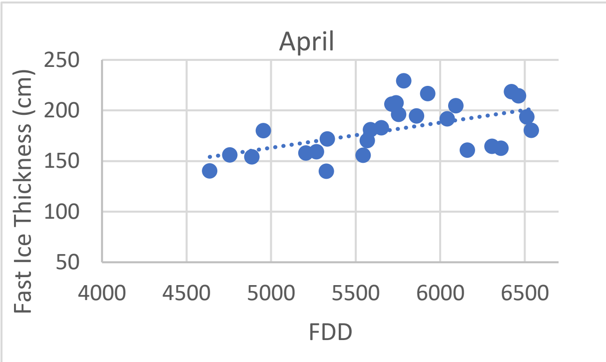
Table 4-12: Linear Regression of Freezing Degree Day and Environment and Climate Change (ECCC) Fast Ice Thickness between 1947-2021.

Sea Ice Parameter	Time Period	Slope (cm/FDD)	Total Change over Time Period (cm)
ECCC Annual Maximum Fast Ice Thickness	1948-1981	12.12	400.0
ECCC Annual Maximum Fast Ice Thickness	1982-2021	8.47	330.3

4.1.4.4 *Freezing Degree Days (FDDs) Correlated with Environment and Climate Change Canada (ECCC) Monthly Averaged Fast Ice Thickness*

The monthly averaged fast ice thickness time series described in Section 4.1.2.2.3 were correlated to annual freezing degree days in Resolute Bay. A plot of the annual FDD and average Fast Ice thickness after the change point each month from December-May can be seen in Figure 4-31 and the rates of change and statistical parameters are presented in Table 4-13.





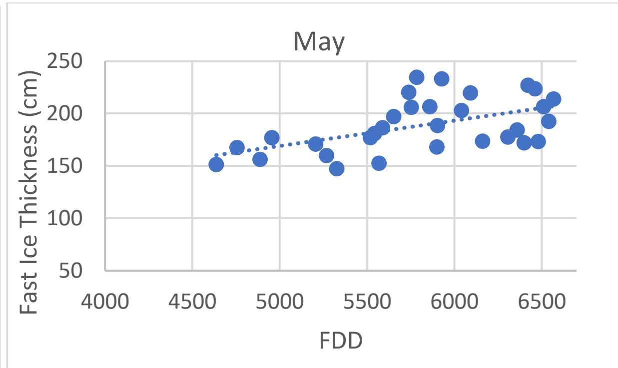


Figure 4-31: Linear Regression of Environment and Climate Change Canada (ECCC) Monthly Fast Ice Thickness and Freezing Degree Days (FDDs).

Table 4-13: Linear Regression of Environment and Climate Change Canada (ECCC) Monthly Fast Ice Thickness and Freezing Degree Days (FDDs).

Month	Time Period	Slope (cm/FDD)	Total Change over Time Period (cm)
December	1980-2021	0.0160	0.66
January	1983-2021	0.0106	0.40
February	1984-2021	0.0169	0.63
March	1982-2021	0.0187	0.73
April	1983-2021	0.0265	1.00
May	1979-2021	0.0264	1.10

*Red text indicates statistically insignificant trends

4.1.5 Scientific Study Results Summary

The following section summarizes the findings of Section 4.1 Scientific Results. Only the statistically significant trends are presented in the summary.

Table 4-14: Break-up and Freeze-up Date Results Summary.

Data Source	Parameter	Slope (days / year)	Time Period	Total Change over Time Period (days)
C3S - SIC	BUD	-0.74	1979-2015	27.3
	FUD	0.51	1979-2015	18.8
CIS - SIC	BUD	-0.70	1982-2022	28.0
	FUD	0.60	1982-2022	24.0
Averaged (C3S & CIS) SIC	BUD	-0.87	1979-2022	37.5
	FUD	0.55	1979-2022	23.4

*Negative values indicate days earlier per year, positive values indicate days later per year

The scientific results of each dataset showed that break-up dates are changing more rapidly than freeze-up dates.

Table 4-15:Annual Sea Ice Thickness Results Summary.

Data Source	Parameter	Slope (cm / year)	Time Period	Total Change over Time Period (cm)
C3S	Sea Ice Freeboard DL3	-4.85	2002-2020	-87.4
	Sea Ice Freeboard DL6	-14.49	2002-2020	-261
ECCC	Annual Maximum Fast Ice Thickness	0.99	1948-1981	32.5
	Annual Maximum Fast Ice Thickness	-1.2	1981-2021	-33.2

Both the C3S and ECCC datasets indicate that fast ice and sea ice thickness in the Barrow Strait are decreasing. DL6 is further west than DL3 had more severe decline in ice thickness. Ice freeboard had more substantial decreases in thickness than fast ice thickness.

Table 4-16: Increases in Monthly Fast Ice Thickness Based on Environment and Climate Change Canada (ECCC) Fast Ice Thickness Measurements.

Month	Slope (cm / year)	Time Period	Total Change over Time Period (cm)
Jan	2.66	1976-1989	34.6
Apr	1.64	1969-1986	27.9
May	2.19	1970-1986	35.0

Periods of increasing fast ice thickness were noted in the months of January, April, and May in the 1970’s and 1980’s.

Table 4-17: Decreases in Monthly Fast Ice Thickness based on ECCC Fast Ice Thickness Measurements.

Month	Slope (cm / year)	Time Period	Total Change over Time Period (cm)
Jan	-0.96	2002-2021	-18.76
Feb	-1.68	1984-1999	-25.20
	-0.913	1999-2021	-20.09
Mar	-1.79	1984-2002	-32.22
	-1.57	2002-2021	-29.83
Apr	-2.23	1986-2002	-35.68
	-2.23	2002-2021	-42.37
May	-1.64	1986-2003	-22.88
	-2.23	2003-2021	-40.14

Decreasing ice thickness was observed in the months of January, February, March, April, and May after the mid 1980's. The most severe rate of change occurred in April and May between 2002-2021.

Table 4-18: Decreases in Monthly Averaged Fast Ice Thickness based on ECCC Fast Ice Thickness Measurements.

Month	Slope (cm / year)	Time Period	Total Change over Time Period (cm)
Dec	-0.545	1980-2021	-22.35
Jan	-0.627	1983-2021	-23.83
Feb	-0.948	1984-2021	-35.08
Mar	-1.07	1982-2021	-40.66
Apr	-1.22	1983-2021	-46.36
May	-0.943	1979-2021	-39.61

Similar to the monthly results, the monthly averaged results of fast ice thickness decline were the most substantial in April and May.

4.2 Traditional Inuit Knowledge Results

The methods of collecting traditional Inuit knowledge via community interviews were described in Section 3.2 of this thesis. This section will document the results of the community interviews and is organized as follows.

- Demographics of Survey Respondents
- Results from the Traditional Inuit Knowledge Part 1: Survey Form
- Results from the Traditional Inuit Knowledge Part 2: Survey Interview
- Results from the Traditional Inuit Knowledge Part 3: Survey Maps

4.2.1 Demographics of Survey Respondent Results

During the interview process, demographic information was collected such as, gender, age, ethnicity, as well as sea ice use frequency. A total of 17 interviews were conducted during the period of May 18th to May 20th of 2023. No children under 18 were interviewed as per the Research and Ethics Board approval discussed in Section 3.2.1.2. The total population of Resolute Bay as of 2021 was 183 people. Of the total population, approximately 110 are over the age of 18. As such, of the adult population of Resolute Bay, 15.4% participated in a sea ice interview for this study. Figure 4-32 represents the age range of participants in the community interviews.

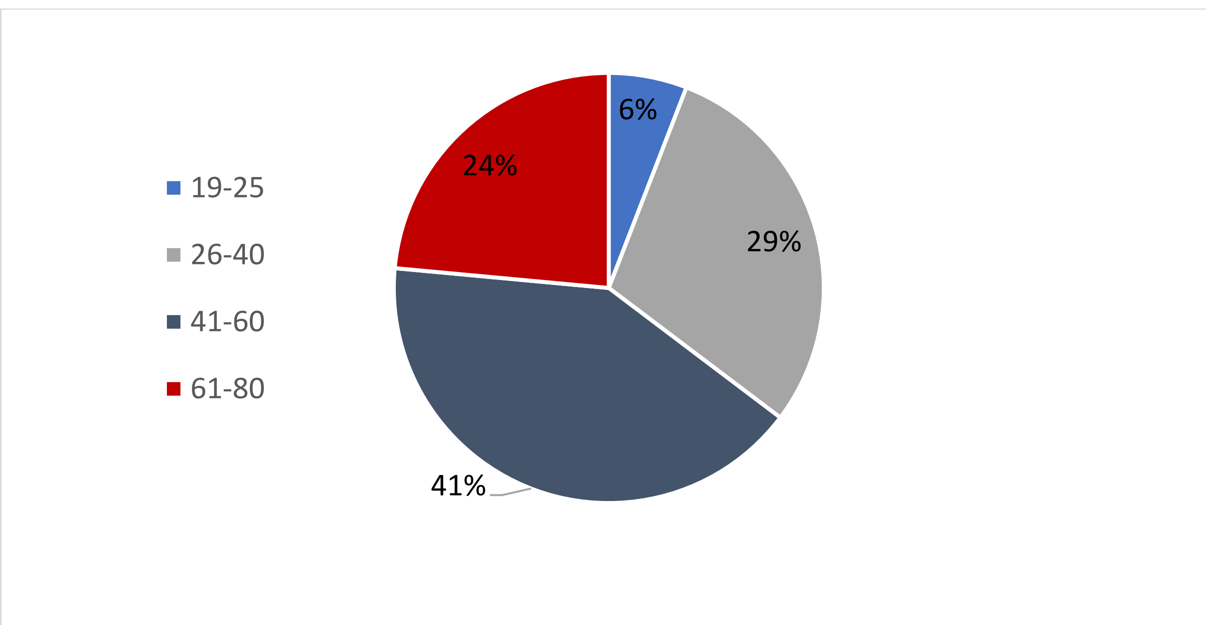


Figure 4-32: Age Range Distribution of Traditional Inuit Knowledge Interview Participants.

The majority of the participants were in the 41-60 range, followed by the 26-40 range, then 61-80, the least number of participants were in the 19-25 range. The ethnicity and gender of participants are presented below in Figure 4-33.

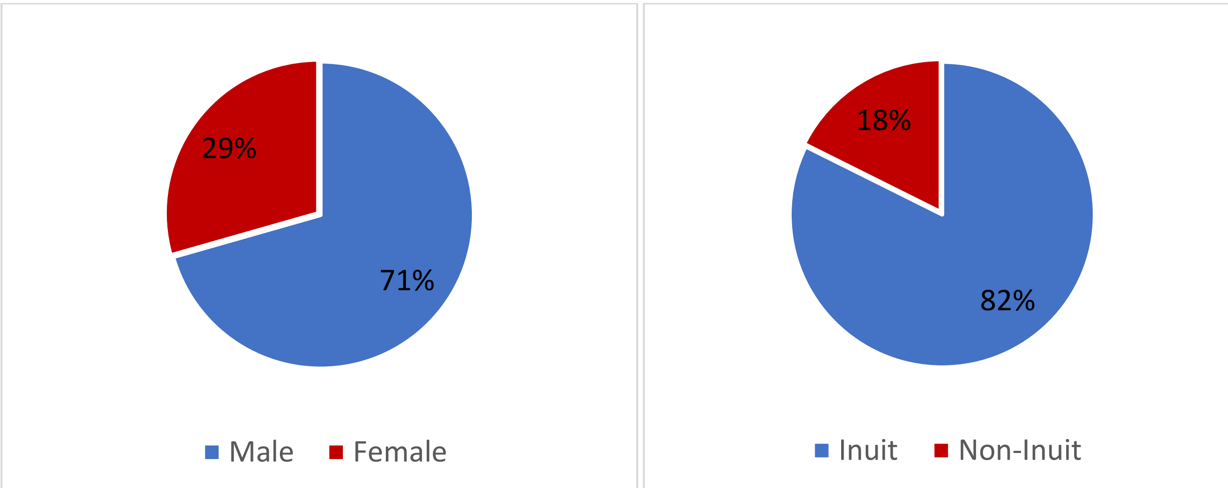


Figure 4-33: Gender (left) and Ethnicity (right) of Traditional Inuit Knowledge Interview Participants.

The interview participants were primarily male with a 71% male, 29% female split. Many females were interested in the interview display and asked questions about the contents of the interivew. But, declined with many saying "I don't go out on the ice." Although there are female hunters in the community, the majority of the hunters and frequent ice users are male. The interview was designed such that even non-hunters could particpant and share knoweldge. Yet, more men participated in the survey than women. The majority of the participants in the survey were Inuit. Which is reflective of Statistics Canada's most recent estimate of 83% of the population of Resolute Bay are Inuit.

The survey also requested participants indicate whether they considered themselves frequent users of the sea ice or knoweldge holders within the community, moderate users of the sea ice, or inrequent users of the sea ice. Figure 4-34 demonstrates the distribution of sea ice use rates of the interview respondants.

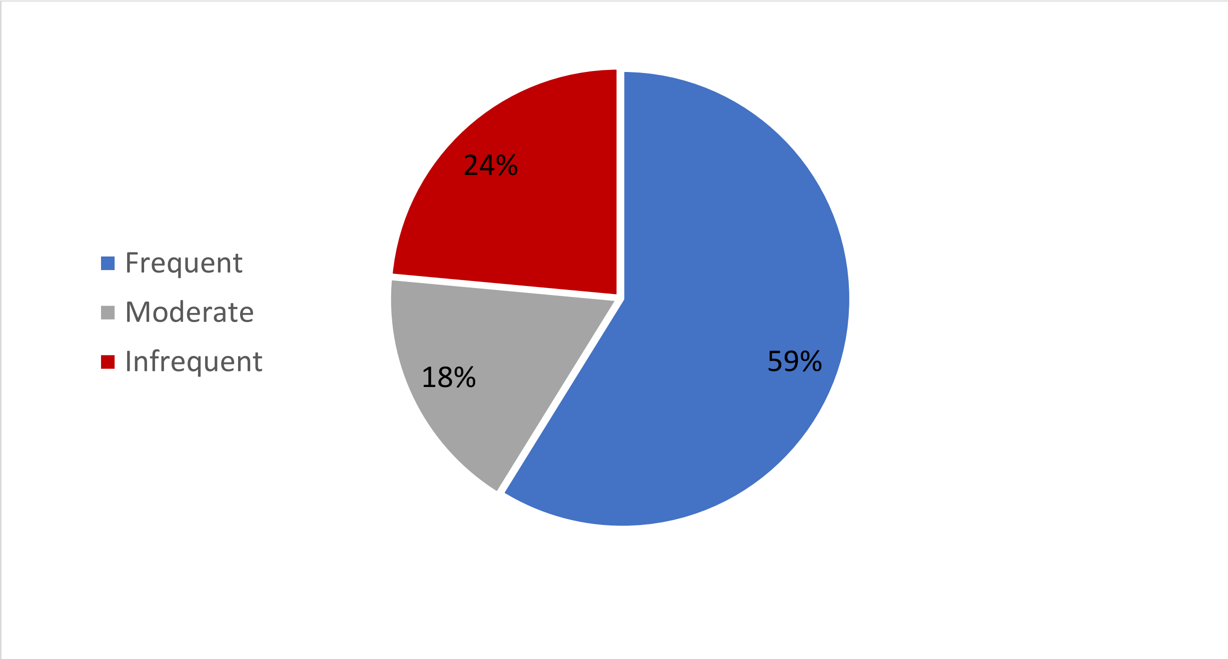


Figure 4-34: Traditional Inuit Knowledge Interview Participant Frequency of use of the Sea Ice.

Most of the respondents to the survey were either frequent or moderate users of the sea ice. However, even if a respondent was an infrequent user of the ice their responses could still provide insight about the sea ice from their experience living in Resolute Bay. There were always options to respond with unsure or did not notice change.

4.2.2 Traditional Inuit Knowledge Part 1: Survey Form Results

The results of interview participants that filled out the form outlined in Section 3.2.2.1 are presented in Figure 4-35.

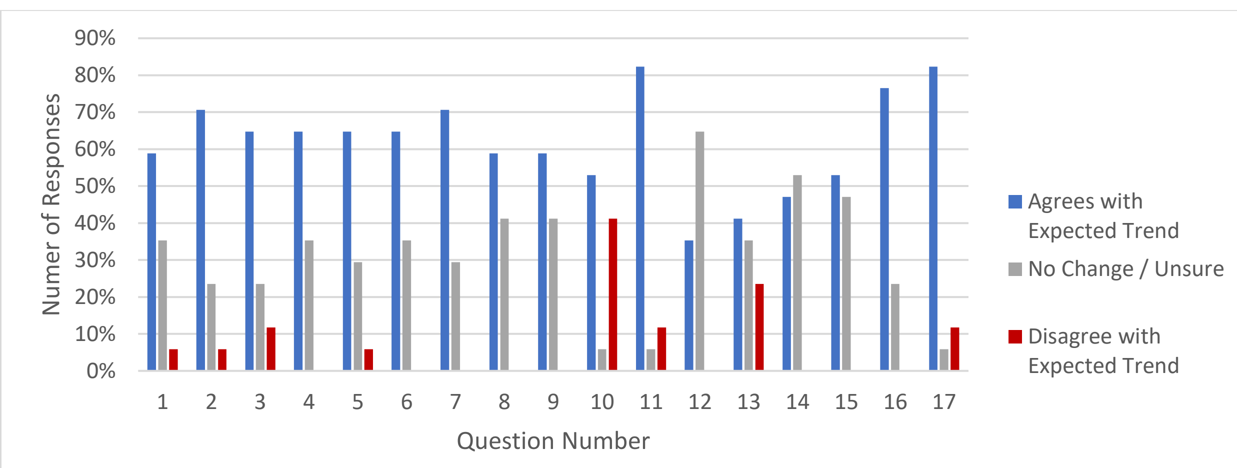


Figure 4-35: Responses from Traditional Inuit Knowledge Interview Part 1: Survey Form (n=17).

The largest consensus from survey respondents was on question 17, 16, and 11 at 82%, 76%, and 82% respectively. Participants agreed that there has been an increase in vessel traffic in the community, people spending less time on the sea ice, and that there have been warmer summer temperatures. The largest instances of people indicating they were not sure or had observed no change was during question 12, 14, and 15. The topics of these questions were the frequency of incidents related to the sea ice, whether hunting and travel routes have changed, and whether there has been a change in the number of new species in the area. The largest variability in a question response was question 10 where participants were asked whether winter temperatures had gotten colder or less cold. However, climate change does not only cause temperatures to rise, it can also mean that weather is getting more extreme. Including extreme cold or an increased incidence in the severity and frequency of winter storms.

Filtering the results of Part 1 to only include participants who indicated they were moderate or frequent users of the sea ice increased consensus on all of the questions, as seen in Figure 4-36.

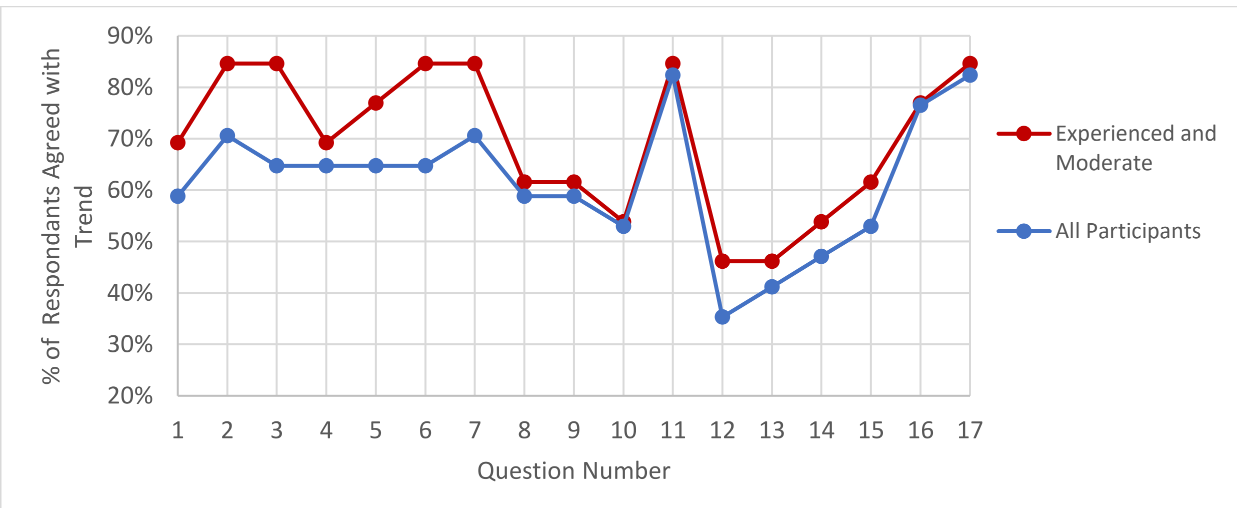


Figure 4-36: Frequent and Moderate Ice Use Responses from Traditional Inuit Knowledge interview Part 1 Survey Form.

The percent of respondents that agreed with the expected trend increased most on questions 2, 3, 5, 6, and 7 when considering only participants with frequent or moderate sea ice use. These were all questions relating to sea ice behaviour.

4.2.3 Traditional Inuit Knowledge Part 2: Survey Interviews Results

Part 2 of the interview after respondents had filled in their written forms, was a 10-minute semi-structured interview. The script followed during this interview can be seen in Section 3.2.2.2. The results within this section, where possible, are presented as direct quotes from individual participants to preserve the Inuit meaning behind the response and significant value on oral history.

"I look at the ice, I feel the ice, I look where I am, make sure my step is solid."

– Paul, Elder.

4.2.3.1 Thickness of the Sea Ice Survey Responses

The following excerpts from semi-structured interviews are focused on responses to questions about sea ice thickness.

"About 20-30 years ago ice used to be 8 ft thick, ocean sea ocean. Now it's only 3 ft thick, or even 2 ft."

– Roger, experienced hunter.

"*When I started out it seemed to be a lot thicker and now it has started getting thinner. Over the years, there has been more fresh and mushier ice.*"

– Peter, experienced hunter.

"We started coming up here in the mid 90's and in 2010 you really notice a difference in the thickness."

- Michael, retired ship captain.

"It is not as thick as it used to be."

– Paul, Elder.

"*In the 1990's the ice was up to 7ft thick now we are lucky to get 2 ft of ice.*"

– Joadamee, experienced hunter.

"*There are more areas of thin ice because we used to be able to go to Somerset, but it is getting harder now a days because there is all this open water. Now they* (hunters) *have to go in-between Griffith or behind because of the open water."*

– Sarah, hunter.

4.2.3.2 Inuit Methods of Determining Sea Ice Thickness Survey Responses

The following excerpts from semi-structured interviews are focused on responses to questions about Inuit methods of determining sea ice thickness and if the ice is safe for use.

Visual Observation of Colour

"You can tell by looking at it, it is darker when it is thinner, and not as dark when it is thicker."
- Susan, Elder.

"If you are close, you are able to see the snow. If it is lighter, there is no ice just snow. If it is darker, it is likely safe, it is just water on top of the ice."
– Matthew, hunter.

"You can tell how thick the ice is by it's colour, we watch the ice each season."
– Peter, experienced hunter.

"In some areas you see the ice darker, it means it is thinner, and lighter is thicker."
– Patrick, experienced hunter.

"It gets more pale when it is thick because the water freezes, when it is thin usually not much snow and darker colour and grey because of the moisture. When it is pale white it is safe to use, when it is grey, it is a good three inches."
– Paul, Elder.

Use of the Harpoon

"I use a harpoon if it is thin ice"
- Tabitha, experienced hunter.

"*Well, we have a harpoon or an axe we use it all the time to check the ice conditions and how thick it is. One inch is good to walk on but not to drive on."*
– Peter, experienced hunter.

"*When it is really thin, I use a harpoon and I stab it. The number of times I stab it, if I do it consistently, will tell me how thick it is. So, if you have a reference from a long time ago, and then you consistently do it, you'll have a reference point, and you can gauge it from that. Four hits are good enough for me and the dogs, but I can do two hits with the dogs, but it is* *dangerous, but you can do it. Four hits is good for a snowmobile."*

– Devon, experienced hunter.

Use of Ice Features (Seal Holes, Cracks)

"Look through the seal holes or we look at ice leads like cracks in the ice."

- Paul, Elder.

"We go up to seal holes, or the cracks that have formed in the ice and we check the thickness."

- Roger, experienced hunter.

"Through cracks we can see and measure the thickness of the ice."

– Tabitha, experience hunter.

"By the seal hole, we look down at the thickness."

– Patrick, experienced hunter.

Other Environmental Factors

"*I can only tell if it is dangerously thin, it depends on the snow, or on the sky. If there is open water in the distance, there will be cloud cover because of the moisture from the water going up into the sky*."

-Matthew, hunter.

4.2.3.3 Break-up and Freeze-up Timing and the Open Water Season Length Survey Responses

The following excerpts from semi-structured interviews are focused on responses to questions about the break-up timing, freeze-up timing, the length of the open water season, and whether those dates have changed over time.

Break-Up Timing

"The break-up is about a month early than it used to be most of that is to the east. There is open water between here and Arctic Bay."

– Michael, retired ship captain.

"Sometimes the break-up timing comes early."

– Peter, experienced hunter.

"The very first time we lost ice in July… oh it was quite a while ago maybe 10 years ago."

– Tabitha, experienced hunter.

<u>Freeze-Up Timing</u>

"The ice takes longer to form."

– Matthew, hunter.

"Freeze-up is about a month later than it was when we first started to come up here."

– Michael, retired ship captain.

"It (open water season) *has gotten longer by months it used to freeze up in December now it's February."*

- Roger, experienced hunter.

"It (the ice) *is becoming thinner because it is freezing up later."*

– Tabitha, experienced hunter.

"It has been taking longer to freeze-up, it usually freezes-up September 29th or 30th like the bays but the last two years it was freezing October 9th and October 8th this year."

– Devon, experienced hunter.

"*I notice the freeze-up has been a little later over the years, growing up it used be in August, late August or early August not too often September maybe 2nd or 3rd week would be safer to go on with snow mobiles.*"

– Mark, experienced hunter.

"Freeze-ups are a lot later now, but some people will take chances, but there are some people who will make sure it is safe before you go on it."

– Susan, Elder.

"Yes, there have been changes over time by about three to five weeks later."

– Patrick, experienced hunter.

Open Water Season Length

"I would say it (the open water season) *is becoming longer, more like 11 days or so maybe two weeks. It gets way dangerous way earlier like 3 months earlier and it opens 11 days earlier."*
– Matthew, hunter.

"The open water season is weeks longer it could be as long as a month."
– Tabitha, experienced hunter.

"The open water season is three months now. Break-up to open water usually takes about 2 weeks July 12 -20 to the first week of August. I have to stock up on seals for that time because I can't hunt on the ice, but I also can't boat."
– Devon, experienced hunter.

"When I lived here as a little girl oh you know the ice was so thick, that there had been a time where they had to blow up some ice so ships could go through. We used to be able to go hunting until all the ice got blown away, but today it melts now, and it never used to melt."
– Susan, Elder.

4.2.3.4 Impacts of Sea Ice Change on the Community Survey Responses

The following quotes from the semi-structured interviews were participants responses when asked how the changes they described were affecting the community.

Availability of Seals and Changes to Species Migration Patterns

"From 2000 onwards, our seals they changed their pattern fast. There was open water just close by, they wouldn't make seal breathing holes, they would just stay out in the open water and sit in the cracks we've been relying for 40+ years always having seal holes. They change fast they didn't take 2-3 years to do it."
- Joadamee, experienced hunter.

"The seal hunting seems to be shorter for spring, less seal in the community."
- Sarah, hunter.

"There have been fewer seals, it's been harder to get seals, the last time I got a seal was I think either January or December."
– Devon, experienced hunter.

"There was a researcher, he was finding whales, narwals, belugas and bowheads are staying longer in the Lancaster Sound area, they usually disappear into Baffin Bay but now they are staying longer in open water."

– Joadamee, experience hunter.

"There are more animals coming up here whales even birds are different."

- Roger experienced hunter.

Availability of Traditional Food in the Community

"There is less traditional food, they are brining in reindeer it is not from here."

- Michael, retired ship captain.

"The bear tags last longer, no one is eating it as much as they used to."

– Sarah, occasional hunter.

"We had more traditional food maybe 6 years ago, but now not so much."

– Absalem, hunter.

"They don't go as much hunting now a days because it is not eaten as often, you can just go to the store and buy their meat."

– Sarah, hunter.

Ease and Frequency of Hunting and Travel on the Ice

"The way it happens now, it is getting pretty hard to travel because with the ice forming later, it is rougher creating more ice packs. Before most of it was smooth ice because when rough ice forms its winds and currents, and the ice builds up on itself. That wouldn't happen because the ice was thick and dense enough that it wouldn't pack. Since the ice is thinner and less dense there is more pack ice than ever before."

- Matthew, hunter.

"We used to be able to go hunting until all the ice got blown away, but today it melts now, and it never used to melt. There has also been less hunting in the late spring."

– Susan, Elder.

"The changes impact us a lot for hunting as we like to go hunting as soon as it freezes-up before it gets too cold, you can still hunt in the cold but it the freeze-up was later than normal."

– Patrick, hunter.

"We don't go camping as much the ice is too thin to travel on, people are more cautious."

- Roger, experienced hunter.

"There has been less hunting time on the ice."

– Joadamee, experienced hunter.

"There was a year there when there was no ice in the passage during the summertime all the way from the west to the east. What started happening is we started getting rolling waves because it is so shallow here, in the passage and the wind was coming from the Arctic Ocean, we couldn't even get out in the water there were waves they were 3-5 ft tall and 2-3 ft apart. That was just one year, once the ice starts disappearing in the summertime that might become a real problem because we can't go out there and it probably would affect the migrating mammals and the seals who live here."

– Joadamee, experienced hunter.

"People have been boating more, growing up I never had a boat because it didn't make sense but now that open water is longer, I got myself a boat."

– Devon, experienced hunter.

Trust in Traditional Knowledge

"People do not have the same trust in the ice they know the changes that have taken place they can't rely on what their traditional knowledge ways."

– Michael, retired ship captain.

"The hunters are more cautious, and I don't trust in my ability to know the ice all the time."

- Paul, Elder.

4.2.4.5 Environmental Factors

The following passages from the semi-structured interviews were what participants shared about their natural environment that was not directly about the sea ice including the weather, and ocean currents.

Weather

"Weather is more humid now, the cold when you go out hunting. The clothes used to wear when it was dry is no longer enough, we have to change the clothes we wear when we go hunting."

– Joadamee, experienced hunter.

"Winter temperature, they are colder we never used to get -50 we used to have a lot of blizzard days, after a blizzard it warms up. But here it seems like more frequent of that -50."

-Sarah, hunter.

"We have warmer summers too we never used to have rain."

-Sarah, hunter.

Relationship between Currents and the Sea Ice

"I think less ice is caused by more current, its temperature driven. The water is warmer and moving faster it is melting the bottom of the ice."

- Michael, retired ship captain.

"The ice takes longer to form what seemed like happened the hot salt water from the south it would come in low and now it is coming into the high Arctic higher and higher going to the surface more. Before it was 150 to 250 ft deep, and it would stay down there now for some reason the hot sea water from the south has started to rise to the surface."

– Matthew, hunter.

"We have a lot of current in front of our island here in-between Griffith Island, there are a lot of areas where it thins out really fast."

– Tabitha, experienced hunter.

"Cold currents come south from Bathurst Island and warm currents come through Lancaster Sound."

– Joadamee, experienced hunter.

4.2.4 Traditional Inuit Knowledge Part 3: Survey Map Results

The final portion of the traditional knowledge interviews was asking participants specific questions about printed maps with coloured pens. These results are presented in this section.

4.2.4.1 Areas of Thin and Thick Ice and Areas that Break-up First

The responses relating to thin ice, thick ice, and areas that break-up first were manually digitized with QGIS 3.8 and combined on one map, presented below in Figure 4-37.

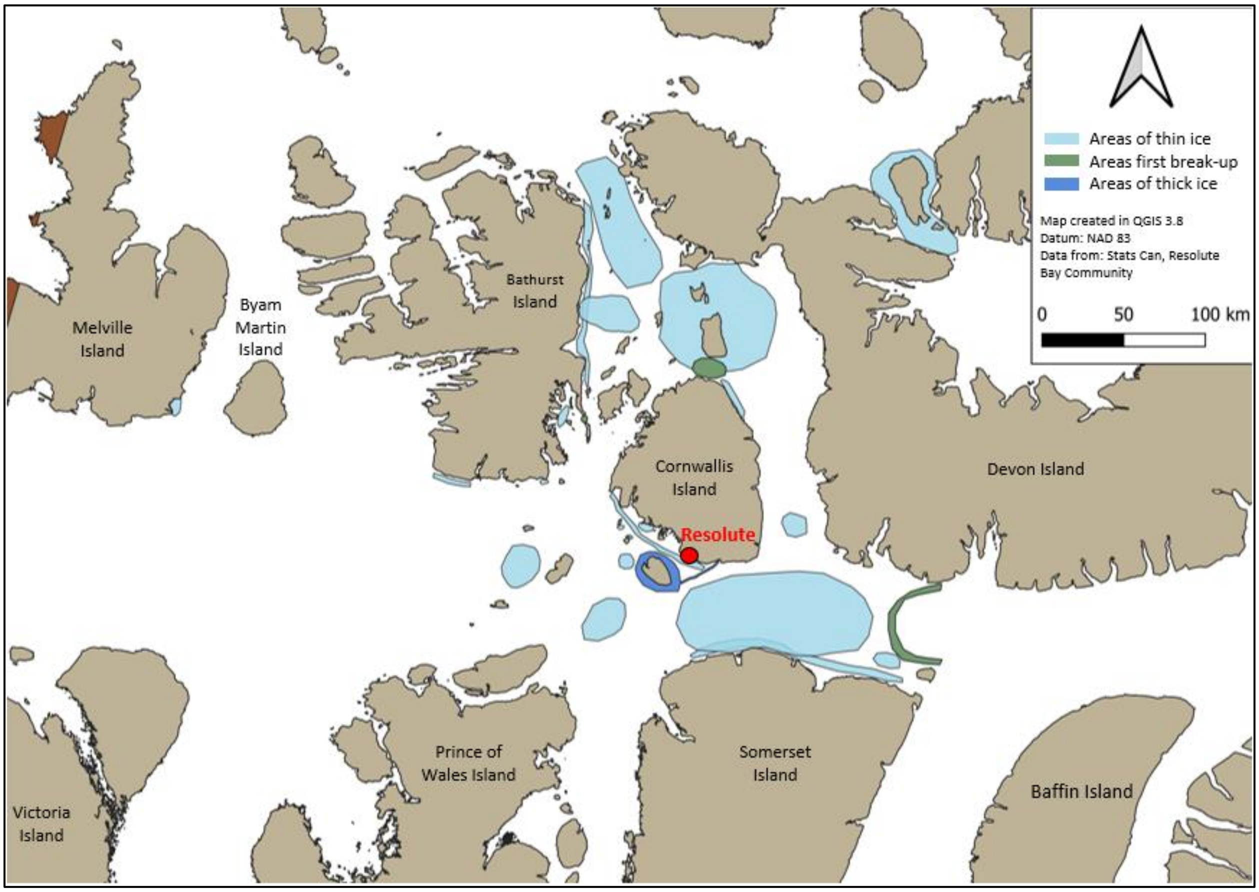


Figure 4-37: Traditional Inuit Knowledge Survey Part 3 Map Results of Typical Areas of Thin and Thick Ice and areas that Break-up First.

Many respondents indicated the same areas of thin ice. These being mainly between the islands northwest of Cornwallis Island (Bathurst, Crozier, Barring Island in Penny Strait), near the northern shore of Somerset Island, between the islands to the southwest of Cornwallis Island (Browne Island, Lowther Island, Young Island), and in Wellington Strait. More participants identified areas of thin ice rather than typically thicker ice. An interpretation of this result is that thin ice causes more risk to community members, and as such is more memorable. In addition to the areas that are identified in Figure 4-37, respondents also indicated:

- Areas of thin ice are also areas that tend to develop polynyas.
- The area between Griffith Island and Cornwallis Island gets thin because of strong currents.

- Shoreline points are often dangerously thin earlier than other areas.
- Thicker ice on the west side of Cornwallis towards Russel Island.
- There is usually thin ice in the inlets of Cornwallis Island in the Fall.

When asked about which areas break-up first, many respondents indicated that areas within Barrow Strait break up first, the break-up moves west to east, and break-up happens in a semi-circular shape. Other areas identified as breaking up first were in between the islands north of Cornwallis Island and around Ohio Island. Participants also indicated the areas that break-up first, freeze-up last, and are the same as areas of typically thin ice.

4.2.4.2 Areas and Timing of Freeze-up

The following section presents information that participants indicated about the areas surrounding Resolute Bay that freeze-up first and the general timing of that freeze-up. The areas were indicated on printed maps and manually digitize using QGIS 3.8 to produce the map in Figure 4-38.

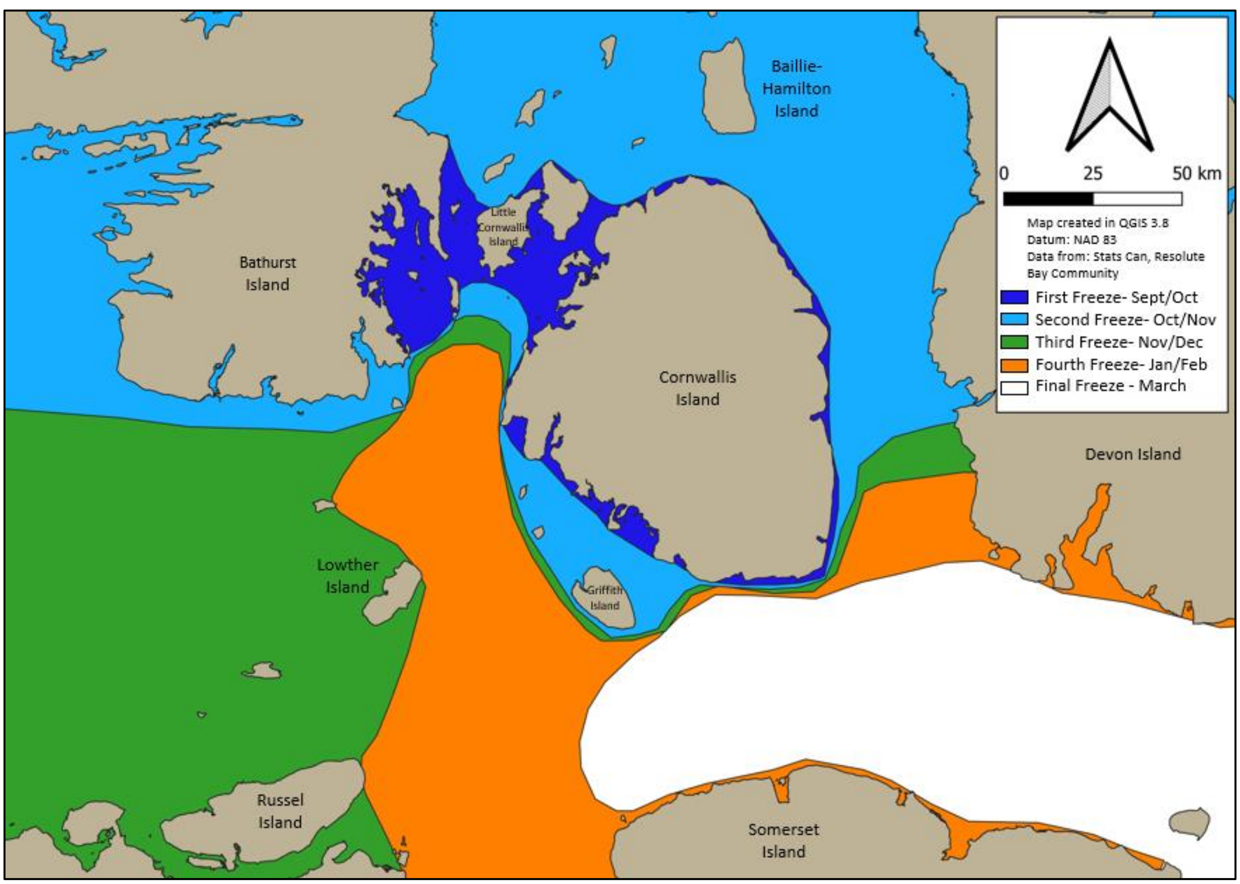


Figure 4-38: Traditional Inuit Knowledge Survey Part 3 Map Results of Freeze-up Timing and Areas.

Many respondents indicated that the bays around Cornwallis Island froze-up first. Then, after the bays were frozen, Barrow Strait freezes-up from west to east. Outside of what is indicated on the maps above, one participant shared the sewage outfall into the bay near Resolute Bay changes the timing of the freezing where there is warm water being discharged in bay.

4.2.4.3 Typical Hunting and Travel Routes

In addition to documenting sea ice behaviour on the printed maps, participants were also asked to indicate their typical hunting and travel routes as well as hunting locations. Figure 4-39 is the digitized version of the routes and hunting locations participants indicated.

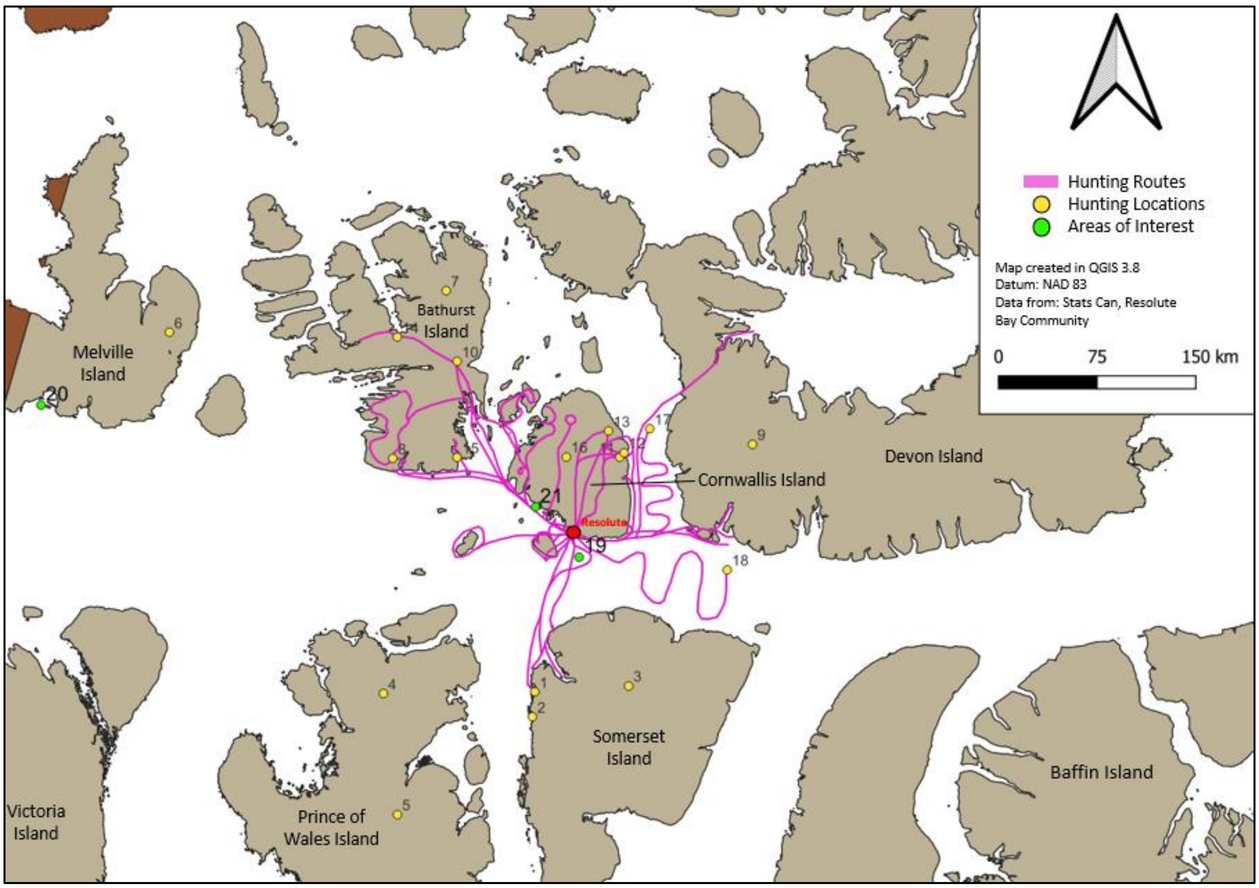


Figure 4-39: Traditional Inuit Knowledge Survey Part 3 Map Results of Typical Hunting and travel Routes and Destinations.

The magenta lines in Figure 4-39 represent the hunting routes that interview participants indicated. Many hunters travel hundreds of kilometers on single or multi-day hunting trips to remote cabins or carrying Qamutiik, that offer overnight shelter, behind snowmobiles or dog teams. Typically hunted species include caribou, muskox, bearded seals, ringed seal, walrus, beluga, polar bear, and ptarmigan. Hunters also indicated locations where they went fishing. The yellow and numbered points in Figure 4-39 represent hunting locations indicated by interview participants, and the green points indicate other areas of interest and knowledge to document. Each point's description and ID number is defined in the Table 4-19.

Table 4-19: Hunting Location and Area of Interest Point Legend.

Point ID	Point Description
1	Fishing Location
2	Fishing Location
3	Hunting Location
4	Hunting Location
5	Fishing Location
6	Hunting Location
7	Hunting Location
8	Caribou Hunting Location
9	Muskox Hunting Location
10	Hunting Cabin / Caribou Hunting Location
11	Lake Fishing
12	Lake Fishing
13	Lake Fishing / Geese and Ptarmigan Hunting Location
14	Lake
15	House
16	Muskox Hunting
17	Polar Bear Hunt
18	Polar Bear Hunt
19	Rough ice causing detour in hunting route, because it stayed open for so long this year, and it piled up on the ice
20	Franklin Shipwreck
21	Last year this area stayed thin for a very long time, even though it is very close to the land

4.2.4.4 Other Knowledge to Document

Other than what has been documented in the previous sections, in interviews with participants shared the following knowledge. An area on the southeast shore of Bathurst Island was identified as an area where the ice moves in and out and when boaters go out during early break-up have historically got stuck. There was an area of early open water identified between Somerset Island and Baffin Island. Ice flows were also identified as coming down through Penny Strait toward Cornwallis Island.

4.2.5 Traditional Inuit Knowledge Results Summary

The following section will provide a summary of the information presented in Section 4.2.

4.2.5.1 Traditional Inuit Knowledge Part 1: Survey Forms Results Summary

Table 4-20 summarizes the responses from Part 1 of the traditional knowledge survey from only participants who indicated they were either moderate or frequent users of the sea ice.

Table 4-20: Traditional Inuit Knowledge Part 1: Survey Form Moderate and Frequent Ice User Results Summary.

Question Topic	Agrees with Expected Trend	Neutral	Disagrees with Expected Trend
BUD	is occurring later	No change or Unsure	is occurring earlier
	69%	31%	0%
FUD	is occurring earlier	No change or Unsure	is occurring later
	85%	15%	0%
Timing of Thickest Sea Ice	Thickest Earlier	No change or Unsure	Thickest Later
	85%	15%	0%
Magnitude of Thickest Ice	Thinner	No change or Unsure	Thicker
	69%	31%	0%
Areas if thin ice (#)	More	No change or Unsure	Fewer
	85%	15%	0%
Areas if thin ice (size)	Larger	No change or Unsure	Smaller
	85%	15%	0%
Areas if thick ice (#)	Fewer	No change or Unsure	More
	62%	38%	0%
Areas if thick ice (size)	Smaller	No change or Unsure	Larger
	62%	38%	0%
Winter Temperatures	Warmer	No change or Unsure	Colder
	54%	8%	38%
Summer Temperatures	Warmer	No change or Unsure	Colder
	85%	8%	8%
Ice Incidents	More	No change or Unsure	Fewer
	46%	54%	0%
# Of Hunted Species	Fewer	No change or Unsure	More
	46%	31%	23%
New Species	More new species	No change or Unsure	N/A
	54%	46%	
Hunting Routes	Routes changed	No change or Unsure	N/A
	62%	38%	
Time Spent on Sea Ice	Less	No change or Unsure	More
	77%	23%	0%
Vessels Near Community	More	No change or Unsure	Fewer
	85%	0%	15%

4.2.5.2 Traditional Inuit Knowledge Part 2: Survey Interviews and Part 3: Printed Maps Results Summary

The following conclusions can be drawn from the traditional knowledge interviews:

- Sea ice is getting thinner over time,
- Break-up is occurring earlier,
- Freeze-up is occurring later,
- There are fewer seals, seal migration patterns are changing,
- There is less traditional food available in the community,
- The sea ice is more difficult to travel on,
- There is less trust in traditional knowledge of the sea ice,
- There are warmer temperatures occurring in the summer and the winter,
- There has been a change to current patterns, where there are faster currents there is also thinner ice,
- Thin ice occurs in the Barrow Strait, north of Cornwallis Island, and between Bathurst and Devon Island,
- The sea ice freezes from north to south then west to east,
- The bays break-up last and freeze-up first,
- And the sea ice in the Barrow Strait freezes-up and breaks-up in a semi-circular pattern due to warm currents from Baffin Bay coming east to west into the Strait.

5 Discussion

This section will provide discussion regarding the results presented in Section 4.

The Discussion section is organized as follows:

- Scientific Discussion,
- Traditional Knowledge Discussion,
- Comparison of Scientific Results to Traditional Knowledge Results,
- Limitations of this study, and
- Impacts and application of study findings.

5.1 Scientific Discussion

The following section includes discussion of each of the scientific results including, break-up and freeze-up timing, sea ice freeboard, air temperature anomalies, and the correlation of air temperature to sea ice behaviour.

5.1.1 Break-up and Freeze-up Timing Discussion

Both the C3S SIC, and the CIS archived sea ice charts find that break-up is occurring earlier and freeze-up is occurring later now than in previous decades. The C3S and CIS rate of change of break-up date was 0.74 earlier per year and 0.70 days earlier per year respectively. Similarly, the freeze-up dates were becoming later by 0.51 days per year and 0.60 days per year respectively. However, generally, the C3S SIC reports break-up dates later in the year than CIS does. Freeze-up dates agree better between datasets. The difference in the break-up date between datasets is attributed to the disagreement in sea ice concentration reported in the C3S and CIS datasets. For example, as stated in Section 4.1.1.1, within the C3S SIC dataset there were two years (1979 and 2003) where the sea ice concentration did not reach above 50%, and 11 years (1979, 1982, 1986, 1990, 1992, 1995, 1996, 2001, 2002, 2003, 2014) where the sea ice concentration did not fall below 20%. In the CIS dataset, from 1982-2022 each year the timing varied, but SIC always fell below 1-3/10 and returned above 4-6/10. This disagreement could be attributed to two possible causes. The first being the SIC in the CIS dataset being reported in a range of values causing inaccuracy. The second is the spatial coarseness of the C3S data, the SIC reported is an averaged representation of a large spatial area, not the exact SIC near Resolute Bay.

Both datasets were designed to give information on sea ice behaviour on a large Arctic (C3S) or regional (CIS) scale in the case of the C3S and CIS data respectively. Both datasets were used to only access one spatial point within the larger spatial scale. There are limitations associated with taking one point out of a larger spatial dataset including over smoothing and spatial coarseness. These limitations further illustrate the importance of involving local Inuit knowledge for their granular small scale understanding of sea ice behaviour.

5.1.2 Sea Ice Freeboard Discussion

In the C3S sea ice freeboard results discussed in Section 4.1.2.1, where significant trends were identified, sea ice freeboard thickness was decreasing. At two locations (DL2 and DL5) in the Strait, the data did not lead to significant trends in freeboard decline and the analysis was inconclusive, due to the presence of outliers. However, at DL3 and DL6 there was a clear trend in sea ice freeboard decline. DL3 sea ice freeboard was decreasing at a rate of 4.85 cm / year and DL6 at 14.49 cm / year.

When the sea ice freeboard thicknesses were plotted against time in Figure 4-6, many outliers were observed in the datasets. Specifically, at DL2 the top four sea ice freeboard thicknesses recorded were 412.8 cm, 562.1 cm, 697.4 cm, 936.5 cm. These four points were identified as outliers above the upper limit based on the IQR, 95% of the data at DL2 were below 353.7 cm. Similarly, at DL5 there were five points identified above the upper limit based on the IQR. Both DL2 and DL5 did not have statistically significant linear trends, as standard linear regression, used in this thesis, is sensitive to outliers.

The data at DL6 had more variance in sea ice freeboard than any of the other locations. The differences between the data at these locations illustrates just how varied and complex sea ice can be in terms of thickness. Sea ice thickness varies considerably at different spatial points and is dependant on many mechanisms such as sea ice ridging, wave overtopping, and calving. It is important to note that for the investigation into the C3S data, only sea ice freeboard data were available. Freeboard is only an estimate of the height of sea ice above the ocean surface at other locations in the dataset and not the draft depth of the ice below the ocean surface or snow depth on top of the ice. Although the satellite data accessed in this study can provide information about sea ice freeboard, without an increase in surveillance of sea ice with other techniques it is impossible to get a clear picture of sea ice thickness through the current state of observation data available.

5.1.3 Air Temperature Anomaly and Freezing Degree Days (FDDs) Discussion

By comparing linear trends in Resolute Bay and globally after 1970, Resolute Bay air temperature anomalies are increasing at twice the rate of global temperature anomalies. Arctic amplification is a well-known phenomenon of Arctic regions warming faster than the global average. The findings in this study were consistent and support the Arctic amplification phenomenon. In many circumstances, Canadian Inuit populations are the first and most severely impacted by climate induced changes to environments. This study showed specifically in Resolute Bay how the air temperature is increasing more severely than the global average. As the earth continues to warm, this finding implies that Resolute Bay’s environment will be impacted at an even greater rate than it is currently.

5.1.4 Correlation of Freezing Degree Days (FDDs) and Air Temperature Anomalies to Sea Ice Behaviour

This study found that freezing degree days in Resolute Bay have been significantly decreasing from 1947-2023 at a rate of -15.11 FDD / year. In addition to the rate of decrease, FDDs in Resolute Bay started decreasing more substantially in the 2000s, 2010s and 2020s. When the sea ice behaviour examined in this study (BUD, FUD, sea ice freeboard, and fast ice thickness) were correlated to FDDs in Resolute Bay this study found as FDDs decrease, the BUD occurs earlier, FUD occurs later, and both sea ice freeboard and fast ice thickness decrease.

The monthly air temperature anomalies in Resolute Bay began to change in either 1981 or 1986 depending on the month. Fast ice thickness began to change between 1979-1984. Table 5-1 presents a comparison between the change points identified in these two factors. Change points in both fast ice thickness and monthly air temperature anomaly occurred within 1-7 years of each other, which is evidence supporting the finding that air temperature anomalies increasing cause fast ice thickness decline.

Table 5-1: Change Factor Identification Comparison between Fast Ice Thickness and Air Temperature.

Month	Fast Ice Thickness Change Point	Monthly Air Temperature Anomaly Change Point
December	1980	1981
January	1983	1981
February	1984	N/A
March	1982	1986
April	1983	1986
May	1979	1986

When comparing the statistical parameter R^2, of the FDD correlation to sea ice parameters assessed in this study, the top correlations were between FDDs and December, May, and April fast ice thickness. April and May in Resolute Bay are the months that experience the thickest fast ice over the measurement period. The largest statistically significant rates of change in sea ice factors corresponding to a decrease in FDDs in Resolute Bay were the C3S freeboard thickness at DL3, and DL6. Both these results indicate that sea ice thickness (fast ice or freeboard) is more sensitive to changes in FDDs than the break-up and freeze-up timing. This finding is important for the eventual predictive sea ice tools for communities, FDDs can more accurately be used to predict sea ice thickness than break-up and freeze-up timing. In Section 4.1.3.1, the change point identified in the Resolute Bay air temperature (1980) supports the general conclusion of green house gasses and consistent effect on air temperature in the 1980's. The alignment between the change point identified in Resolute Bay air temperature anomalies, annual maximum, and monthly averaged fast ice thickness further supports that FDDs can be used to predict sea ice thickness. Freezing degree days are used in other applications like lake or canal ice thickness calculations, this studies finding supports that FDDs is an accurate predictor of sea ice thickness in an Arctic coastal environment.

5.2 Traditional Inuit Knowledge Discussion

This section will describe both successes and lessons learned when conducting traditional Inuit knowledge interviews in Resolute Bay.

5.2.1 Successes and Lessons Learned

One of the main motivations of this study was the lack of involvement of Inuit people in scientific research. Researchers are prone to conducting studies on the impacts of climate change on Arctic environments without consulting the people who are being most impacted by those changes. This study sought to form equal partnership with the community of Resolute Bay. Although this study succeeded in a meaningful partnership, the researcher approached the community to request a partnership rather than one being requested by the community. When Inuit are given the power and right to self governance in research, research topics emerge that reflect Inuit and community values. Inuit communities are often inundated with requests for consultation, partnership, and knowledge. These requests can easily become overwhelming for small communities who lack the resources or availability to partner with academic and industry institutions on all the various requests they receive. In the future, where possible, an academic partnership with an Inuit community should be fostered by the community accessing funding and requesting partnerships from academic institutions to ensure that the community priorities are reflected in the motivation of the study.

A major contributor to the high number of interviews conducted was the practice of meeting the community at locations that are part of their daily routine, rather than forcing them to a separate uncommon location. Or in other words meet them where they are instead of having them come to you. The advertisement material presented in Appendix D clearly states the community interviews would take place in the Hamlet Office of Resolute Bay. After the first full day of interviews in May of 2023, no one had come to conduct an interview despite the monetary reward, free food, advertising on the community Facebook page, and public radio. Quickly and spontaneously, the location of the interviews was altered to the Tudjaat Co-op grocery store. Because Resolute Bay is a small community of 183 people, the Co-op serves as a social hub where many community members visit multiple times a day. The change in interview location resulted in an increase in the number of interviews to 2-3 interviews per hour.

It is important when scientific researchers go into communities that they recognize the privilege and bias they may previously hold, as well as have a meaningful understanding of the issues that communities face. Before going to the community of Resolute Bay for this research, the historical governance of Nunavut and community history of Resolute Bay was researched and presented to all attending the research trips. It was critical, especially when conducting interviews, that researchers understood the, at times painful, history of the people they are interviewing.

The final lesson learned is the need for researchers to give back to the community, particularly when they are requesting knowledge sharing from community members. Researchers should strive to give time and energy to the community outside of just monetary supplements. This was done in this project in the form of providing meals to participants in the interviews, as well as allowing for anyone in the community to take food home to share with others who did not participate in the interview. In addition, when interviews were not being conducted in the evenings, the research team spent time at the local community center playing games with the children in the community. Finally, after this thesis is completed, the candidate and her academic advisor plan to return to Resolute Bay to communicate the findings of this study back to the community. They will also preform a presentation at the local school about the partnership between Inuit knowledge and science through two-eyed seeing to encourage youth involvement in scientific studies and promote careers in science and engineering as potential career paths for Inuit youth.

5.2.2 Traditional Inuit Knowledge Interview Discussion

The findings of the traditional Inuit knowledge interviews about the sea ice and air temperatures were mainly as expected, break-up is occurring earlier, freeze-up later, ice is getting thinner, and summer temperatures are becoming warmer. An interesting finding from the traditional Inuit knowledge interviews was that participants were more able or willing to identify areas of thin ice rather than thick ice. Figure 4-37 indicated 10+ distinct areas where participants ladled areas of thin ice, but only 1 area of thick ice. This result was mirrored in Part 1 survey form, levels of consensus were higher in question 5 and 6 (about thin ice) than 7 and 8 (about thick ice). This was likely due to the increased occurrence of thinner ice posing a greater risk to traditional Inuit culture and hunting practices in Resolute Bay, so it is more memorable to residents when asked.

Traditionally, in Inuit as well as Canadian Indigenous culture there is value in the interconnectedness of life, and the natural environment. This value was evident in the interview responses as well. Scientific studies at a graduate level often seek to study one specific topic. This study strictly sought to characterize sea ice behaviour. However, sea ice behaviour is very dependant on many factors. A surprising finding in this study was the relationship between ocean currents and sea ice. Many participants vocalized the changes and effects of ocean currents on sea ice behaviour.

5.3 Comparison of the Scientific and Traditional Inuit Knowledge Results

This section will compare the results of the scientific and traditional Inuit knowledge from this study. Although comparisons are made, each knowledge source will not be invalidated by the other in the case of disagreement, rather taken together to form a more holistic understanding of historical sea ice behaviour in Resolute Bay.

5.3.1 Agreement Between Scientific Knowledge and Traditional Inuit Knowledge

In many cases in this study traditional knowledge and scientific analysis agreed and came to similar findings. Where the most value was added however was the ability of traditional knowledge to fill data gaps in the scientific data. Both traditional Inuit knowledge interviews as well as the CIS sea ice charts documented the same break-up and freeze-up patterns. Participants described the sea ice breaking up in Baffin Bay first, then the break-up moving from east to west throughout the Barrow Strait. The same is documented in the archived CIS sea ice charts. A semi-circular pattern of break-up is evident in multiple years of the sea ice archived charts, participants explained to researchers that this pattern is observed due to warmer currents coming into the Strait from Baffin Bay and then turning around to flow back out of the Strait, a factor that the scientific data was unable to identify on its own. In addition, traditional knowledge was able to provide a more spatially refined understanding of break-up and freeze-up that the sea ice charts, or satellite observed SIC could not. During the interviews, participants indicated that the bays freeze-up first and break-up last. They also identified that which bays have stayed open for longer historically, scientific data did not have the spatial resolution to identify ice characteristics of the individual bays surrounding Cornwallis Island.

When asked how much the open water season (the time between break-up and freeze-up) has changed by the majority participants responded with it has gotten longer by weeks or months which is consistent with the findings in the scientific portion of this study.

The sea ice freeboard thicknesses observed at DL6 were generally thicker than those observed at DL3. This observation aligns with the scientific and traditional knowledge understanding of break-up and freeze-up patterns. DL6 is further west than DL3, meaning it would freeze earlier and break-up later, allowing the sea ice to grow to a larger thickness throughout the ice-covered season.

Both traditional knowledge and scientific knowledge indicated that the sea ice has been becoming thinner over time.

5.3.2 Disagreement Between Scientific Knowledge and Traditional Inuit Knowledge

The scientific portion of this study found that both break-up dates are occurring earlier, and freeze-up dates are occurring later. The average of both the C3S SIC and CIS ice charts showed that break-up dates are changing more rapidly than freeze-up dates. Break-up dates are changing at a rate of 0.87 days earlier per year compared to freeze-up dates occurring 0.55 days later per year. However, during Part 1 of the traditional knowledge study of the moderate and frequent ice users, 69% of participants indicated that break-up dates were occurring earlier and 85% of participants agreed that freeze-up dates were occurring later. In both cases the majority of respondents agreed that break-up dates were occurring earlier and freeze-up later but there was higher consensus in respondents about the change in freeze-up than break-up. The reader is directed to look at the responses of questions regarding break-up dates, and freeze-up dates from Part 1 of the traditional knowledge interview in Table 5-2.

Table 5-2: Traditional Inuit Knowledge Part 1: Survey Form Moderate and Frequent Ice User Break-up and Freeze-up Date Results Summary.

Question Topic	Agrees with Expected Trend	Neutral	Disagrees with Expected Trend
BUD	is occurring later	No change or Unsure	is occurring earlier
	69%	31%	0%
FUD	is occurring earlier	No change or Unsure	is occurring later
	85%	15%	0%

The air temperature anomaly analysis in Section 4.1.3 found that winter months are experiencing greater temperature change than summer months. However, during the traditional knowledge interviews, 85% of respondents indicated that summer temperatures were getting warmer compared to only 54% of respondents agreeing that winter temperatures were becoming warmer. A summary table of the traditional knowledge responses to temperature change question is provided in Table 5-3.

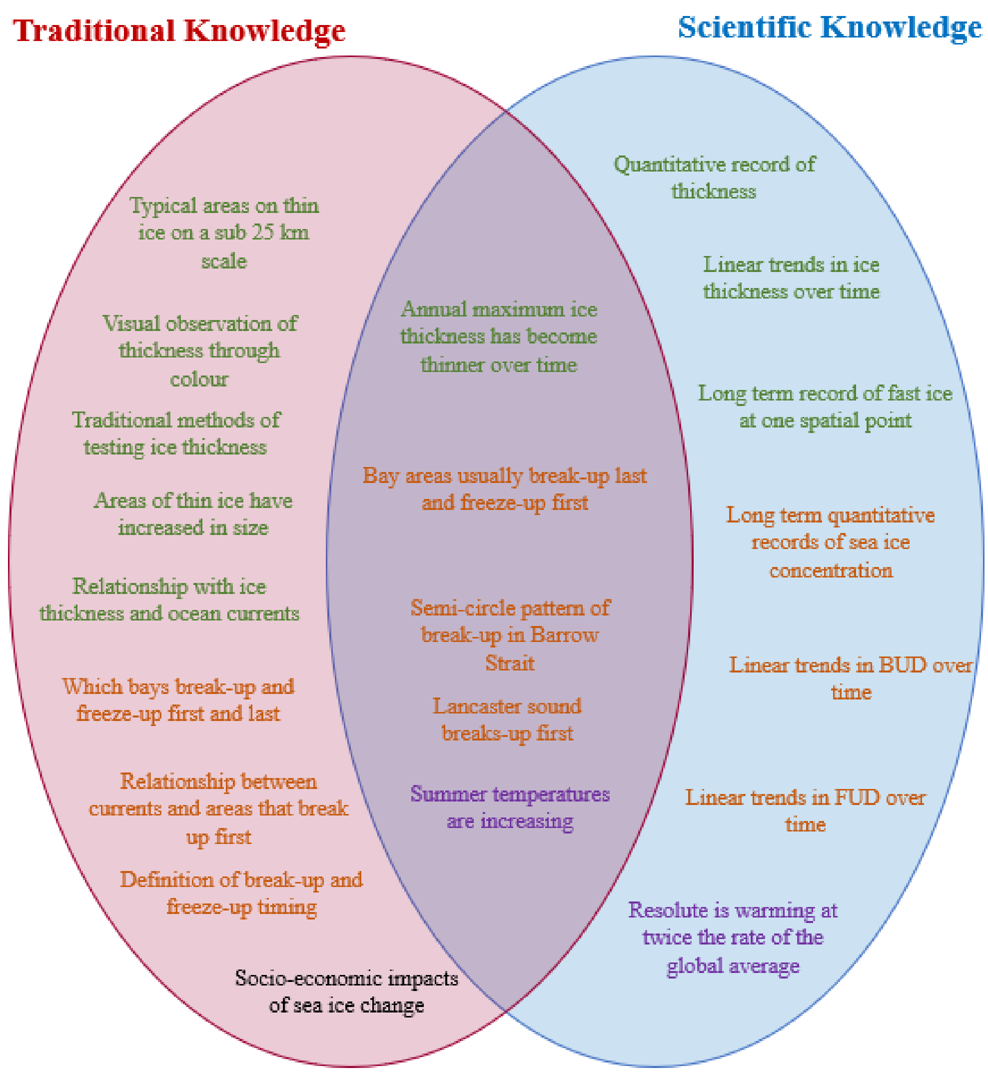
Table 5-3: Traditional Inuit Knowledge Part 1: Survey Form Moderate and Frequent Ice User Seasonal Temperature Results Summary.

Question Topic	Agrees with Expected Trend	Neutral	Disagrees with Expected Trend
Winter Temperatures	Warmer	No change or Unsure	Colder
	54%	8%	38%
Summer Temperatures	Warmer	No change or Unsure	Colder
	85%	8%	8%

Climate change does not solely increase air temperature, it also causes an increase in the frequency and intensity of storms as well as an increase in occurrence of extreme cold temperatures. As such, part of the reason for low consensus and recognition of warming in winter temperatures could be due to the perception of an increase in storminess or severe weather events in Resolute Bay. In hindsight, questions about the temperatures in the spring and fall should also have been included in the survey form as well as a question that distinguishes between winter storminess and temperatures.

5.3.3 Visual Venn diagram Comparison of Scientific and Traditional Inuit Knowledge

To summarize the findings of the traditional and scientific portions of this study, the following Venn diagram is presented in Figure 5-1.



Conclusions related to sea ice thickness
Conclusion related to break-up timing and freeze-up timing
Conclusions related to air temperature
General conclusions

Figure 5-1: Venn Diagram Comparison of Conclusions given by Traditional Inuit Knowledge and Scientific Knowledge about Climate Induced Sea Ice Decline in Resolute Bay.

The traditional knowledge portion of this study was also able to provide many insights that scientific knowledge alone could not. There were several benefits of including traditional knowledge within this study. The **first** being the involvement of the community, community priorities and goals were prioritized during the development of this study. The **second** benefit was the sharing of knowledge both by researchers to the community and vice versa. All of the findings from this study are to be shared with the people of Resolute Bay. Community members hold a plethora of small-scale knowledge about the sea ice, their environment and how it has changed over time. The findings of the sea ice on this small scale provided the detail that in its current state scientific observation was unable to do. Including traditional knowledge such as areas of thin ice, identified areas that freeze-up first and break-up last, the relationship between ocean currents and sea ice behaviour, and traditional hunting routes and locations, allowed for this thesis to present a holistic view of sea ice change and how that change is affecting the community of Resolute Bay. Effects including fewer seals and less traditional food available in the community, people spending less time on the sea ice, more difficulty using the ice for travel and hunting, and a lack of trust in traditional knowledge.

5.4 Limitations of this Study

One of the motivations for this study was the current lack of recorded sea ice data in remote Arctic communities. However, this lack of data also poses a challenge to developing statistically significant trends. A total of four sea ice datasets were accessed during this study and each of these data sources came with challenges including periods of missing data. To mitigate this limitation, the statistical significance of all trends was tested.

This study strictly sought to identify historical trends and does not use complex methods of predictions such as numerical models or machine learning. This study does not assess wave ice interaction, the response of sea ice to ocean currents, or ice dynamics. Additionally, sea ice does not stay stationary, it moves with ocean and wind driven currents as well. This study does not address sea ice and iceberg motion.

In the two SIC datasets, break-up was assumed to occur when SIC fell and stayed below 20% and freeze-up was when it returned above and stayed above 50%. During Part 3 the semi-structured interviews, participants were asked to define break-up and freeze-up. Community members consider the break-up date to be when they can no longer walk on or use snowmobiles on the ice and freeze-up when it is safe again to do so again. The break-up date as defined by the scientific portion of this study is not the same as the break-up date considered by Inuit in Resolute Bay. A scenario when there are icebergs present in the bay near Resolute Bay but not a solid ice sheet would cause a high SIC in scientific data, but those conditions would not be safe to walk or drive a snowmobile on.

In total, the candidate and her academic advisor visited Resolute Bay on three separate occasions. Observing the ice conditions near Resolute Bay during these periods allows for valuable comparison and visualization of examples of sea ice concentration measurements. The date of the first visit to Resolute Bay was July 25th, 2022. The CIS ice chart was pulled from this day. The chart reported a SIC of 70%. The area near Resolute Bay within the sea ice chart and a photo taken of ice conditions on July 25th, 2022, is shown in Figure 5-2.

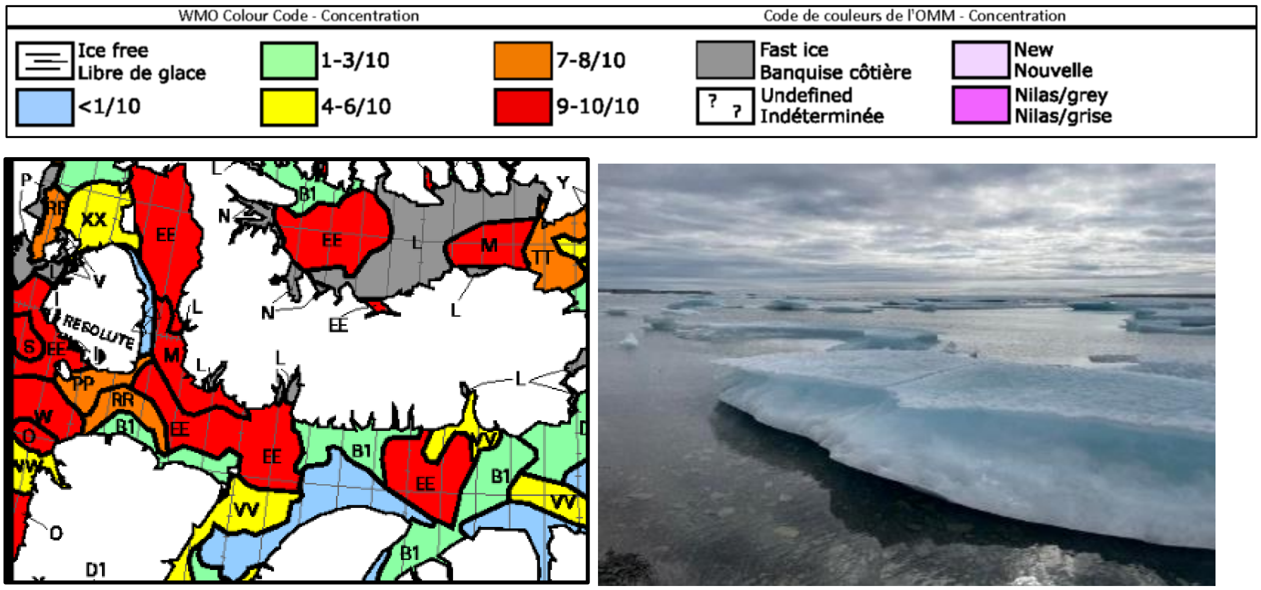


Figure 5-2: July 25th, 2022, ice conditions CIS ice chart (left) and visual observation (right).

The second visit occurred September 26th, 2022. The CIS chart showed a <10% SIC. The SIC and a photo of the ice conditions that day are seen in the Figure 5-3.

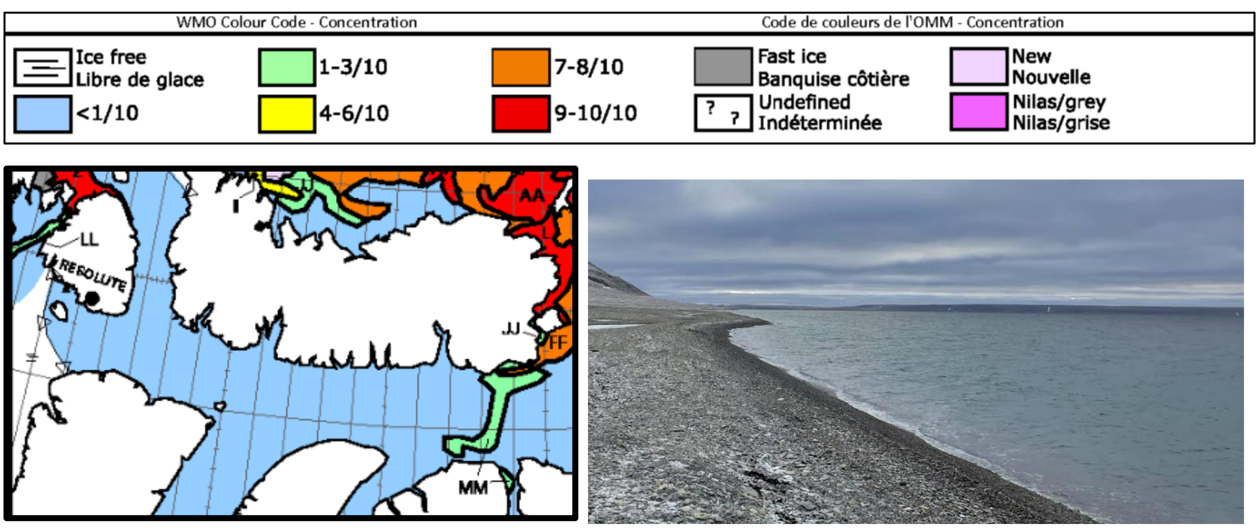


Figure 5-3: September 26th, 2022, ice conditions CIS ice chart (left) and visual observation (right).

Finally, the ice conditions for the final visit on May 19th, 2023, as presented in the sea ice charts in visual observation is seen in Figure 5-4. The visual observation photo was taken on a snowy day with low visibility. The right side of Figure 5-4 is a photo taken during a trip out on the sea ice with a dog team and local guide. The sea ice on this day was frozen solid.

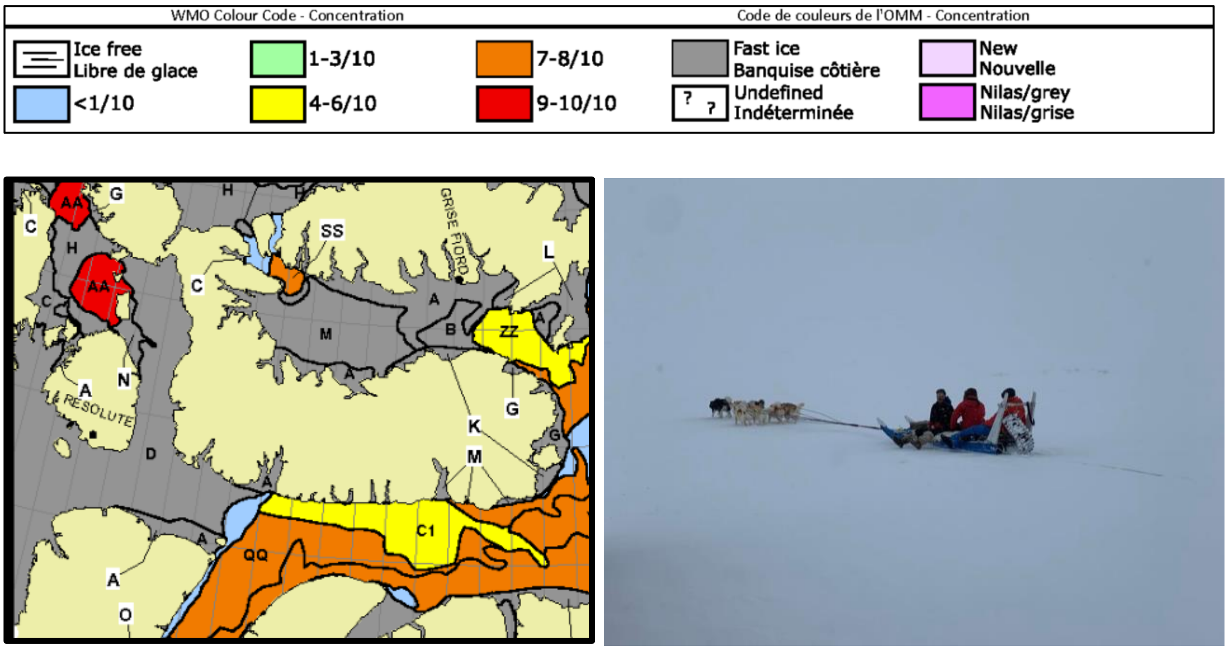


Figure 5-4: May 19th, 2023, ice conditions CIS ice chart (left) and visual observation (right).

The ice in the first comparison on July 25th, 2022, would not have been considered as broken up by the scientific analysis as it is above 20% SIC. However, when the ice is in floes as it is in Figure 5-2 Inuit hunters would not be able to safely travel on this ice. The second and third comparison during the open water (September) and ice-covered season (May) align well with sea ice chart measurements. The requirement of a quantitative limits to define break-up and freeze-up during a scientific study of linear trends, does not capture the complexities of sea ice break-up. Many interview participants shared that particularly in Resolute Bay, the sea ice may break-up, exit the bay, then subsequently return into the bay via surface and wind transport many times in a break-up period. There is a period between sea ice break-up and open water that the scientific portion of this study does not consider.

5.5 Impacts, Application of Study Findings, and Areas for Future Research

5.5.1 Impacts of Study Findings

This study found that the break-up date in Resolute Bay is occurring earlier and the freeze-up later. There are several environmental impacts of the open water season being longer including, increased interaction between the air and the sea causing higher sea surface temperatures. As the open water season lengthens there will be an increase in the number of severe storms occurring during open water, causing wave action on permafrost coasts, which is likely to lead to coastal erosion.

Each year the sea ice in the northern most part of the Arctic stays frozen. A blue ocean event is a term used to describe the possibility of all the ice in the Arctic melting. Arctic sea ice serves as a powerful tool to absorb heat from Earth's atmosphere and a blue ocean event would have severe consequences on weather patterns in the northern hemisphere, lead to extreme weather events in other parts of the world, disrupt ocean current circulation, affect marine ecosystems and lead to further warming of Earth's climate (NSIDC, 2020). A decline in sea ice also poses a threat to the traditional Inuit way of life, that many people in Resolute Bay have been fighting to preserve. Inuit people have had to be incredibly resilient throughout history during many attempts at assimilation to not lose their cultural practices, and that resilience is being required again to maintain hunting practices in the face of climate change.

5.5.2 Application of Study Findings

Global predictions of temperatures based on greenhouse gas concentration trajectories have been defined as three different RCP scenarios. Using the air temperature findings from this study, RCP scenarios could be used to develop temperature predictions in Resolute Bay. This could be combined with this study's findings on the correlation between sea ice behaviour and freezing degree days to perform projections of sea ice behaviour (thickness, break-up dates and freeze-up dates) in Resolute Bay.

6 Conclusions

This study is an application of two-eyed seeing methods to fully characterize historical sea ice and air temperature in Resolute Bay using both scientific and traditional knowledge. This study sought to identify trends in historical sea ice behaviour including break-up timing, freeze-up timing, annual maximum ice thickness, and monthly ice thickness. Air temperatures were analyzed to correlate freezing degree days with the aforementioned sea ice behaviour. Both the scientific knowledge and traditional knowledge indicated that freeze-up is occurring later, break-up is occurring earlier, and ice thickness is decreasing. Fast ice thicknesses in April and May are declining the most rapidly. This study found that sea ice thickness is more sensitive to air temperature than the timing of break-up and freeze-up. With air temperatures in Resolute Bay warming at twice the rate of the global average, the sea ice has started to evolve in the 1970's and 80's. This study successfully used traditional Inuit knowledge to supplement data gaps in scientific data. This study also documented the socio-economic impacts changing ice conditions are causing in the community. These impacts include fewer seals in the community, less traditional food available, people spending less time on the ice, less trust in traditional knowledge, and more difficulty traveling on the ice.

Declining sea ice affects Inuit communities of Canada's Arctic but also to global climate systems including impacts on air circulation and ocean currents. Without sea ice reflecting heat back into the atmosphere through the albedo effect, the Earth's temperature will continue to rise more rapidly. The findings from this study can be further applied to aid in Inuit community adaptation to climate induced change by using correlations identified to develop predictive models and tools for community use. By including traditional Inuit knowledge and working with communities to have self governance over the research conducted in and on their lands, a more holistic understanding of the physical and natural environment can be accomplished in equal partnership with Inuit communities and Western, colonial, scientific research.

6.1 Recommendations for Future Research

The following topics have been identified as potential areas for future research.

- Use SmartICE data when available to continue to develop a data base of sea ice thickness in Resolute Bay.

- Similar type of analysis on quantitative historical sea ice data and traditional Inuit knowledge in other communities to create a larger multiple community data base of climate impacts to sea ice.
- Incorporate sea ice motion, and address the research question: where do sea ice floes near Resolute Bay come from and go to?
- Develop a predictive tool for sea ice on a community scale in Resolute Bay by accessing RCP projections of air temperature in Resolute Bay, and using the correlations identified in this study to predict future break-up dates, freeze-up dates, fast ice thickness, and sea ice freeboard in Resolute Bay.
- Develop a predictive tool for sea ice in Resolute Bay using methods such as numerical modelling or neural networks.
- Continue using two-eyed seeing methodology to document other climate impacts to Resolute Bay.

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Appendix A – Field Reports from Community Trips

A. July 2022 Field Visit Report, Resolute Bay, Nunavut

A.1. Introduction

This report summarizes and documents the activities and lessons learned during a field visit to Resolute Bay conducted by Alexandra Forsythe (lead researcher) and Dr. Ioan Nistor (academic supervisor) between July 26th to July 29th, 2022.

Figure A - 1: Panoramic View of Resolute Bay.

A.1.1. Project Background

Climate change is causing sea ice to decline in thickness, extent, and age, globally and Arctic-wide. These changes are having severe impacts to Inuit communities who use the ice for traditional hunting for most of the year. Hunting practices are becoming more dangerous, and Inuit hunters can no longer rely on generations of traditional knowledge due to extreme and rapid changes rendering weather patterns and ice conditions far more difficult to predict. Hunting is extremely culturally significant to Canadian Inuit. The loss of ability to hunt causes food insecurity and reliance on store bought rather than nutrient dense traditional foods. Canadian Inuit have been severely historically mistreated through residential schools attempting cultural assimilation, the eradication of cultural practices, and the forced relocations of families by the Canadian Federal Government. They have been incredibly resilient and fought to keep their traditional practices alive. Canadian Inuit hunters now face new adaptation measures with global climate change causing changes to the ice.

Numerical models and predictive neural networks are capable of forecasting sea ice change based on climate change scenarios globally and Arctic-wide. Expected changes to sea ice on a small local and community scale are far less understood by the scientific community. This is in part due to the remoteness of Canadian Arctic communities and a lack of quantitative recorded data. The atmosphere, ocean, and sea ice are all complex environments that are interconnected. The purpose of this study is to identify correlations between air temperature to the development of dangerous and declining ice conditions. A mixed method study is being conducted on Resolute Bay, Nunavut. Both technical analysis of existing data as well as community interviews will be used to identify trends. Although there is a lack of recorded data, Inuit hunters have a wealth of knowledge on their local coastal and ice environments. Interviews with community members will encompass questions about how ice and environmental factors have changed spatially and over time.

A.1.2. Purpose of Trip and Project Timeline

The purpose of this preliminary trip was for researchers to introduce themselves and their study to the community, and form connections with locals and knowledge holders. There will be another trip Scheduled in the end of September for a presentation to the community council of Resolute Bay for their approval of the survey occurring in the spring of 2023.

Table A - 1: Thesis Study Timeline.

January - May 2022	May- July 2022	July 2022	September 2022	October 2022 - April 2023	May - June 2023	October 2023
Conduct literature review of previous studies in this field.	Community contact made remotely via phone and email.	First field visit to community to introduce the study.	Presentation of study to community council for approval and second community visit.	Scientific study on existing historical quantitative data.	Community survey.	Provide findings of both data study and survey to community in report.

A.1.3. Preparation for Community Consultation

The following section depicts a summary of the research done by researcher Alexandra Forsythe on meaningful community consultation. These notes were provided to Dr. Ioan Nistor before the trip as well as Dr. Tomoya Shibayama in subsequent September 2022 trip.

The following behaviour and phrases should be avoided during meaningful consultation with Inuit. (*23 Tips on What Not to Say or Do When Working with Indigenous Peoples.*, n.d.)

- Avoid words such as:
    - "Stakeholders" very corporate project-based talk
    - Colloquialisms
        - Indian giver, Indian summer, pow wow, rain dance, totem pole, circle the wagon, too many chiefs not enough Indians, Indian time.
    - Acronyms or too much technical talk
    - "equal" Indigenous people are not equal to other Canadians, they have more rights, such as right to hunt and fish on traditional lands, and right to self governance. Sometimes the use of "equal" is seen as asking them to give up these rights.
- Call the community what they call themselves:
    - Inuit – refers to many people is the plural,
    - Inuk – refers to one person,
    - Quasuitturmiut – what the people of Resolute Bay call themselves.
- Avoid behaviour such as
    - Forcing timelines / insisting on dates and times to meet
        - ask a good time for them.
        - recognize they are in high demand; you may be encroaching on their hunting time.

- Coming with a completed draft and plan of what you are doing remain open to feedback.

A brief history of Resolute Bay and Community Challenges to be aware of and sensitive toward (*Community Histories 1950 - 1975 | The Qikiqtani Truth Commission*, 2013)

- No Inuit people lives in Resolute Bay in the 19th century. It was uninhabited until 1947 a US-Canadian weather station was set up and in 1949 the Royal Canadian Air Force station was created in 1949.
- Government of Canada relocated Inuit families from Pond Inlet, Northwest Territories, and Inukjak, Quebec to Resolute Bay from 1953-1955.
- When relocated, often forcefully they were promised the ability to hunt plentiful game even though no wildlife studies had been conducted and no Inuit had lived in the area for centuries.
- RCMP promised families could return to their homeland after one year if they weren't happy with the arrangement, but these promises were never honoured.
- Families were relocated in September of 1953 after walrus migration season and before the winter of full darkness that most weren't accustomed to, without proper housing available heading into the winter.
- The relocated struggled for years with the loss of ties to their original land, differences in languages between the people of Pond Inlet and Inukjak, insufficient housing, inability to hunt and reliance on more store-bought food.
- Existing foreign bureaucratic structure of the military base and large white presence in the community caused tensions.
    - Inuit in Resolute Bay faced game laws and had to hunt illegally to feed their families.
    - Large presence of white people also introduced alcohol and substance abuse.
- The community of Resolute Bay was shaped by the high Arctic relocation program and has a short but important history. Many residents still have dark memories and resentment toward the program.
- In the 1960's and 70's the community started to become more of a permanent settlement rather than an artificial government relocation location. Hunting, trapping, and fishing practices evolved and continue to be a very important part of Inuit life.

Effects the High Arctic Relocation Process had on Inuit Life (*Moving Toward Saimaqatigiingniq | The Qikiqtani Truth Commission*, 2015)

- The Qikiqtani Truth Commission found the following key themes to the impact the period between 1950-1975 on Inuit Communities
    - **Transition from nomadic life to life in settlements** – pre-1950, most Inuit lived on land, sea, and ice, nomadically and moved to follow game to provide shelter, food and, clothes. Some transitioned willingly to settlements to be closer to services (health care, schools, and housing) but some were not given a choice. Adapting to foreign ways of living in settlements to access services lead to poverty, illness, hopelessness, and substance abuse. When Inuit moved into the settlements sometimes there was no housing available. Daily life and social culture changed in settlements.
    - **Sled dogs (Qimmiit) –** were killed in settlements and Inuit lost the ability to hunt. Dogs posed challenges in the settlement because RCMP officers were afraid of them. Authorities shot and killed many of the sled dogs.

- **Substance abuse –** hopelessness, resentment boredom, and disillusionment, lead to abuse of alcohol and illegal drugs in settlements. Both of these substances were foreign to Inuit life and culture and there was no social infrastructure to deal with addictions.
- **Residential Schooling –** Inuit children, required to be in school, were no longer able to learn valuable hunting and traditional skills. Children separated from their families and sent to residential schools which was traumatic for parents and children. Children experienced mental and physical abuse for speaking their traditional Inuktitut language.
- **Health care and separation of families –** government officials evacuated sick Inuit sometimes against their will and were not able to return home for a year or more. Family members were not allowed to communicate to their loved ones, they were often not taken back to their community, returned to wrong locations, and family members were not informed of deaths.

- Elders are often saddened and haunted by this period.

A.2. Trip Schedule and Detailed Notes on Meetings

Day 1: July 26th Travel and Arrival Day

- **5:45 PM** – Landed in Resolute Bay and met Colleen who works for South Camp Inn accommodation and took researchers to South Camp Inn.
- **7:00 PM** – Had dinner at the South Camp Inn with two construction workers working for ATCO at the water treatment plant.
- **7:00-8:00 PM** – Chatted with ATCO head mechanic for Resolute Bay, Guy.
- **8:00-9:00 PM** – Walked along shoreline near community to observe the ice. Saw the current raw sewage outfall. Devon Manik approached researchers on the beach and took Alexandra on an ATV tour of the community and surrounding area. Showed Alexandra his sled dog team.

Day 2: July 27th First Day in Community

- **7:30 AM** – Breakfast at South Camp Inn with Keelan, an environmental consultant working for Outcome a small consultancy updating weather station infrastructure in northern communities within Nunavut. He has history working with TetraTech and Golder, he put researchers in contact with Joadamee Iqaluk – a local resident Keelan has worked with for wildlife guiding in remote areas surrounding the community.
- **9:00 AM** – Meeting with Ian Dudla, Senior Administrative Officer of Resolute Bay at the Hamlet Office. He advised researchers about the next council meeting occurring on August 15th, 2022, that researchers may present the study at. He showed researchers the conceptual designs for a new dock within Resolute Bay prepared by Advision.
- **10:00 AM** – Many community businesses operate on limited hours because there is not demanded to keep businesses open for 8 hours a day. Post office and local grocery store were both not open, so researchers walked around the community admiring the local houses.

Figure A - 2: Local Houses of Resolute Bay.

- **10:30-11:30 AM** – Visited the local health center and spoke to Will the manager of the health clinic. He informed researchers of the health status of the community.
- **12:00-2:00 PM** – Lunch at hotel and down time to answer emails and take notes.
- **2:00-4:00 PM** – Hike to top of hill for a better view of community from above.

Figure A - 3: Views from Above in Resolute Bay.

- **4:00-6:00 PM** – Down time.
- **6:00 PM** – Dinner at South Camp Inn.
- **7:30-9:30 PM** – Driven tour of community with Guy, locations included airport and surrounding area, historic Thule site and forced relocation monument, the research going on surrounding the incoherent scatter radar, and Tupirvik territorial park.

Day 3: July 28th Second Full Day in Community

- **8:30-10:00 AM** – Breakfast at hotel, spoke to the ATCO hotel manager about his business in Resolute Bay for the last 25 years.
- **10:00 AM-12:00 PM** – Hike to glacial river to investigate Resolute Bay and surrounding area.
- **12:00 PM** – Lunch at hotel.
- **1:00 PM** – Visit and introduction at post office with Ralph manager at post office has lived in Resolute Bay for 47 years.
- **1:15 PM** – Introduction at Hunters and Trappers Office, spoke with Nancy the administrative manager. Unfortunately, Philip Manik (chairmen of HTO) was busy meeting with the Nunavut Planning Commission.
- **3:00-4:30 PM** – Spoke with Devon.

- **4:30-6:00 PM** – Spoke with Joadamee much of the meeting discussion with both Joadamee and Devon is described in the sections below.
- **6:00 – 8:00 PM** – Dinner at hotel, packing for departure the following day.

Day 4: July 29th Travel Day back to Ottawa

- **8:00 AM** – Breakfast at Hotel.
- **8:30 AM-10:30 AM** – pack and prepare for departure.
- **10:30 AM** – Pay accommodation and ride to airport.

A.3. Discussion of Lessons from the Field Visit

A.3.1. Community History

Resolute Bay is located on Cornwallis Island, it is the second furthest North community within Nunavut that has year long inhabitants. There are whalebone structures near the hamlet which archologist have linked to the Thule nomadic Inuit people who are thought to have lived on the island then left about one thousand years ago. The US-Canadian weather station and Royal Canadian Air Force station were set up in 1949. After the Thule people there was no one living in Resolute Bay until 1953, when the Federal Government relocated families living in Pond Inlet, now Nunavut then Northwest Territories and Inukjauk in Northern Quebec. These relocated families were promised plentiful game to hunt even though no wildlife studies were conducted. Families were also promised that if they did not enjoy their relocation they could move back to their original communities after one year, however these promises were never upheld. The first families that moved there were relocated in September the biggening of the cold and dark harsh winter in Resolute Bay. There was no infrastructure or housing set up for relocated families. The relocated struggled for years lost ties to their original land. Eventually community infrastructure was developed but Inuit people were forced to live in settlements rather than their usual nomadic lifestyles. The transition to life in settlements was difficult for many and lead to struggles with addiction and poverty as this type of life was new to Inuit people. RCMP officers and government officials believed that transitioning Inuit into living in settlements so they could access facilities and services was beneficial. This transition however was also a way to extinguish traditional Inuit ways of life. RCMP officers shot and killed qimmiq (Inuktitut word for sled dog), stating they were causing problems in the community. The killing of the sled dogs lead to extreme sadness and the loss of Inuit ability to hunt traditionally. Further assimilation and cultural genocide happened through Inuit children from Resolute Bay being removed from their homes and brought to the residential school in Pond inlet between 1960 and 1996. Many lost their ability to speak their traditional language and suffered physical, mental, and sexual abuse. Despite these tragedies, eventually in the 1960's and 70's the community started to become more of a permanent settlement rather than an artificial government relocation location. Hunting trapping and fishing practices evolved and continue to be an important part of Inuit life. The government and people of Canada continue the long process of truth and reconciliation with Inuit people.

A.3.2. Pre-History

Many Indigenous people believe in creationism. Some tell creation stories of their people being descendants of the great wolf or crow. Their cultural tie to the land is significant and many Indigenous cultures believe that all life is born from the land. Many Indigenous people have pushed back against the land bridge theory. The land bridge theory describes a time thousands of years ago where lower sea levels allowed people to migrate across the Bering Strait from Asia and Siberia into Northern Canada. Many extremist right wing groups use this theory to dispute Indigenous land claim agreements in Canada stating that Indigenous people are immigrants and the land does not truly belong to them. The land bridge is a popular theory on pre-history and early life in Canada however other theories exist. It is important when speaking to Indigenous people about their beliefs not to center, Eurocentric, Western prioritizing scientific beliefs. Indigenous people of Canada believe they became nations here rather than migrating from elsewhere. In speaking to a local (Joadamee) he shared his belief on how Inuit culture and life in the Canadian Arctic came to be. Inuit culture is based on following animals in search of food. he believes life began in the Arctic and people spread out across the world and settled in warmer more tropical regions with an abundance of greenery and wildlife. He questions the scientific belief that people migrated to the Arctic and he said with a smile "who would come to the cold hard and dark Arctic in search of food when they had an abundance in a warmer location". He believes life began in the Arctic and people migrated and spread from there.

A.3.3. Inuktitut Language

The traditional Inuit language spoken in Inuit Nunangat is Inuktitut. There are many dialects depending on the community and region the speaker is in. Inuit culture and language is orally focused. Written language and alphabets were non-existent in the Inuit traditional language. It wasn't until settlers and missionaries came to Arctic Canada that they fabricated the alphabet that today is used as Inuktitut. The alphabet is a segmented writing system. Where each symbol represents a syllable or sound. The Inuktitut syllabics were developed from Cree script. The Cree script has the same symbols, but each symbol is used to represent a different sound. There was animosity in the community that the same script was used for southern Indigenous communities and northern Inuit communities. It extinguishes the rich cultural differences between the nations. Due to the emphasis on oral language and sound, the pronunciation of each syllable is felt deep in the throat.

Resolute Bay specifically is one of the more English-speaking communities within Nunavut. When the original relocated families arrived in Resolute Bay, they were from different parts of Inuit Nunangat and did not speak the same dialect of language. Because of this, they were unable to communicate in traditional language and reverted to English. Many other factors play into why the use of Inuktitut is diminishing in Northern communities for example use of Inuktitut in the workplace is limited because it being an older language there is on Inuktitut word for "screwdriver" or "forklift". When Inuktitut becomes difficult, people naturally transition to English. Inuktitut is more common in Elders and older generations, but when Elders are speaking with their grandchildren and youth in the community they transition to English. In order to revive their traditional language Resolute Bay community members often spend time in Pond Inlet, where the language use is much stronger. A language that is not being practiced is difficult to maintain.

A.3.4. Economic Status

Resolute Bay is one of the economically better off communities within Nunavut. This is in part due to the research and military presence in the community. The Department of National Defence (DND) has a large base in Resolute Bay. DND provided an Automatic Landings System (ALS) at the Resolute Bay airport. Nunavut only has two airports with this system Iqaluit, the capitol, and Resolute Bay. This system allows for plane to land much more easily with less effort from the pilot. Airports without this system rely solely on the pilot's vision and control of the aircraft. Due to this system, larger and more planes are able to land on the airstrip. This causes greater presence of research and other institutions in Resolute Bay. There is an international search and rescue program ran out of Resolute Bay, where search and rescue staff are trained for Arctic expeditions. There is also a NASA astronaut training program in Resolute Bay, due to the regional environment and weather being similar to that on Mars. The Polar Continental Shelf Program is a research program present in Resolute Bay funded by Natural Resources Canada. Many high Arctic research programs receive funding through the Polar Continental Shelf Program. Resolute Bay is also a jumping off point due to the airport facilities to all other locations in the Canadian high Arctic. Flights must land in Resolute Bay going to Eureka, Gris Fiord, and Alert. ATCO has a very large presence in Resolute Bay providing infrastructure such as the community wastewater and drinking water treatment facilities. As such, ATCO has built a staff camp that provides extremely high-quality accommodation and food to researchers, staff, and tourists.

The prices of produce within grocery stores have come down in recent times due to Amazon providing free shipment of dry goods to northern Canadian Inuit communities. Due to the increased supply of product, prices in grocery stores have naturally come down. The produce found in Nunavut is extremely fresh. Locals described to researchers the distribution process of fresh produce. In southern Canadian grocery stores produce often sits in warehouses, or in shipment containers for large periods of time. By the time consumers purchase goods they have much shorter shelf life than products in the Arctic. Fresh produce comes every two weeks via airplane. The produce comes directly from suppliers and spends less time in transit and storage and will often last the full two weeks or even longer in grocery stores or in consumers homes.

Currently Resolute Bay receives a fresh produce shipment every two weeks, and a dry food and fuel supply once per year in the summer via sea lift. Sea lifts are large boats that come into the coastal communities of Nunavut to supply dry produce and fuel. Many communities in Nunavut do not have the appropriate marine infrastructure to support ships of this size so barges go out to receive the crates rather than the ships docking. Either the Federal or Territorial Government is funding various projects to go through development of new docks and piers in all of the coastal communities in Nunavut.

A.3.5. Community Infrastructure

There are 66 houses within Resolute Bay. Few of these houses are purchased and owned by residents. The great majority of houses are government assets that are rented to Inuit people living in Resolute Bay. Inuit are given government subsidies for housing. Their rent is on a sliding income scale and fuel for heat is provided by the Federal Government. There is currently a project being conducted by ATCO for the development and construction of a drinking water treatment facility and wastewater treatment facility. The current wastewater management is raw sewage outfall into the bay near the community of Resolute Bay. The treatment plant will allow for treated rather than raw sewage to be released. The Government of Nunavut is funding the design and construction of a new community dock. It is currently in the concept design stage the concepts are posted in the Hamlet Office to have residents vote on their preference. Resolute Bay is a remote location that is very expensive to mobilize and demobilize construction and infrastructure projects. There are many abandoned projects still in Resolute Bay including abandoned Coast Guard ships, fuel storage facilities, Government of Canada power lines and more. Some companies go bankrupt and never retrieve their assets from Resolute Bay leaving them sitting in the community.

A.3.6. Alcohol Use withing the Community

There are two types of communities in Nunavut, dry communities and restricted access communities. Resolute Bay is a restricted access community. Alcohol is not sold locally but it is possible to order alcohol to the community. However, all orders are subject to approval by the local RCMP officers and orders only come once every two weeks. From discussion with locals, there are some use and abuse of substances mainly alcohol in the community. The Qikiqtani Inuit Association truth and Reconciliation Commission speaks about Inuit use of alcohol as an issue that faces many communities in Nunavut. Inuit people were never exposed to alcohol until it was introduced with the presence of outsiders to the community. There was no history of use, limited instruction and awareness on safe use, and no social infrastructure to support addictions issues. The lasting effects of mistreatment and generational trauma often cause feelings of hopelessness and destitution leading to substance abuse.

A.3.7. Health and Medical Practices within the Community

After speaking with the manager at the local health clinic, researchers got a well-rounded picture of community health. Due to the evolved economic status within the community, many people also have better social determinants of health. It is more regular for locals to request regular health check ups, or advanced dental care. In many communities in Nunavut the only dental care offered is tooth pulling. There has been demand for and the local health center has started offering regular dental cleanings and cavity fillings. The health center also offers mental health services and has an on-site registered psychologist.

A.3.8. Hunting Practices and Local Wildlife

Resolute Bay has the healthiest population of polar bears in Nunavut and as such they receive the most polar bear tags for hunting than any other community. The species typically hunted in the area are ringed seals, polar bear, narwal, muskox, beluga, and caribou. Many (about 40-50) people hunt within the community as much as they can given work schedules. Some even hunt as their full-time employment. Researchers spoke with Devon Manik a 21-year-old hunter within the community who is employed by the QIA to hunt full time. He is passionate about wildlife, the local environment, and the resurrection of traditional methods of Inuit hunting. Devon uses a team of sled dogs to hunt on the ice in the winter. However, he often hunts alone using only his team so is limited on how far he can travel to hunt as it is more unsafe to hunt alone. He also uses snowmobiles as do other hunters within the communities. Some of these hunting expeditions last days at a time, Devon sleeps and warms up in shelters pulled by the snow mobiles. Devon uses an Indigenous owned and created app on his smart phone to track his hunting activities. The app is called SIKU the Inuktitut word for ice. It tracks hunters' activities, shows water depths, and shows other hunters messages tagged with a location where they have observed cracks in the ice, wildlife location. He says without the app he can still always find his way home using the local landmarks as guidance. Devon plans to start a business doing guided Arctic wildlife tours.

A.4. Photos Taken During the Field Visit with Descriptions

Figure A - 4: Devon Manik's Canadian Inuit Dog Sled Team (left), four-month-old sled dog puppy named Woody (right).

These dogs live outside year-round. They are all Canadian Inuit Dog's which have similar genetic make up to huskies but are different based on breading and evolution in the Canadian Arctic. They have developed thick coats and large paws to keep warm even in -50-degree Celsius temperature. In the winter they are used to pull the sled and track animals on hunting expeditions on the ice. In the summer to keep up with their strength and cardio. The dogs train by running along side snowmobiles. They are fed two seals every two days and live beside a fresh water source. These dogs are skilled hunters but have been socialized and are very friendly with humans. When a dog retires from its career as a sled dog it becomes a local domestic dog. Many remote Indigenous communities struggle with domestic dog population. There are no vets within communities, so dogs are not spayed or neutered. There ends up being more dogs than people want or can take care of, and they are sent to southern Canada for adoption. Every few years however, veterinarians travel up to communities and offer spay and neutering clinics to help keep the number of domestic dogs manageable for the community. Almost every household in Resolute Bay has at least one domestic dog.

Figure A - 5: Abandoned Muskox Scull on the Beach in Resolute Bay (left), Ice Floes in the Bay at Resolute Bay (center), Abandoned Coast Guard Ship on the Beach in Resolute Bay (right).

There were many bones on the beach in Resolute Bay. As mentioned in the body of this report, many people within Resolute Bay hunt, they eat all the meat of the animal they kill and use the furs to make clothing or other items. Very little of the animal goes to waste. Intact sculls are kept and displayed in homes or around the community. Other bones are discarded on the beach. The scull in Figure A - 5 is a muskox scull and was not kept as the horns were broken off. Ice floes are present in the bay for some time after the sea ice breaks up for the summer. The timing when the ice floes leave the bay and travel with currents further offshore varies every year. This year the ice floes stayed in the bay longer than usual. The ice floe position varies within the bay throughout the day based on the winds and the tide. Hunters are eager for ice floes to leave the bay so they can take their boats out safely for fishing. As mentioned above, it is very expensive to remove any equipment from Resolute Bay. The ship in the right photo is an abandoned coast guard ship that sits on the beach in Resolute Bay.

Figure A - 6: Original Remains of the Thule People Who Lived in the Area as a Nomadic Society (left and center). Monument to Relocated Families (right).

The structure on the left was built into the ground by rocks and whale bones. The entrance is seen in the center of the photo. The structure in the photo was the base, snow blocks would be used to create an igloo structure on top of this base. The structure in the center is made entirely of whale bones. The photo on the right is a photo of the monument to honour the first families forced to relocate to Resolute Bay in 1953.

Figure A - 7: Lead Researcher and Academic Supervisor on Shoreline of Resolute Bay with an Iceberg (left), Ice on the Shore of Tupirvik Territorial Park Northwest of Resolute Bay (center), Glacial River Flowing into Resolute Bay.

The photo on the right of Figure A - 7 was taken of the river at a relatively low flow condition. Banks indicated higher flow is present during the spring melt. Locals shared that locals swim in this pool on a hot day of 15 °C. It shows a natural pool that forms, and the water slows down (right).

B.September 2022 Field Visit Report, Resolute Bay, Nunavut

B.1. Introduction

This report summarizes and documents the activities and lessons learned during a field visit to Resolute Bay conducted by Alexandra Forsythe (lead researcher), Dr. Tomoya Shibayama (research collaborator / observer) and Dr. Ioan Nistor (academic supervisor) between September 24th to 27th, 2022.

Figure A - 8: View of Resolute Bay from Looking North.

B.2. Trip Schedule and Detailed Notes on Meetings

Day 1: September 24th Travel and Arrival Day

- **8:00-11:00 AM –** First leg of trip from Ottawa Airport to Iqaluit airport. The Canadian North flight was experiencing mechanical issues with the plane. Researchers boarded on time but had to de-board the plane, spend about an hour and a half in the Ottawa airport, re-boarded the flight and were able to take off after about 2 or 3 hours of delays. Lead researcher Alexandra sat next to Emily Illnik on the Ottawa to Iqaluit flight. Emily works as a translator in Iqaluit. Her company was involved in the translation work done for the QIA community histories and truth and reconciliation committee. She is a very kind and warm person that was open to conversing with Alexandra for the entirety of the flight. They spoke about many things including.
    - Emily sees herself as not only an interpreter as her day job but and educator in her community and culture to keep the proper pronunciation and use of traditional language alive. She will comment on Facebook posts or have conversations in person if she notices improper use. She feels it is important to politely correct, so the traditional pronunciation does not die out with youth speaking less Inuktitut.
    - Emily grew up in Arviat Nunavut. She lives in Iqaluit now, most of her family is still an Arviat or in Rankin Inlet.
    - Emily attended residential school in Churchill Manitoba when she was 14 up until 18. She did not have as negative of an experience than others, but she was still devastated when forced to leave her family and attend school.
    - Her diet consists of mainly country food provided to her by her family; her favourite is caribou meat.
    - She and her family have many name sakes which are very popular in Inuit culture. A name sake cannot be passed down until the person you are being named after has died.

    - Inuit culture values family and family extends past just he nuclear direct family grandchildren are the children of your nieces and nephews as well.
    - Inuit people are strong and resilient, Inuit women do not scream at childbirth they are taught to weather their bodies storm, push through the pain and not bring their child into a screaming world - doctors remark on this admirable strength when they give birth.
    - She spoke a lot about the generational traumas of Inuit people and the substance abuse, presence of Canada, sadness it brings her.
    - The reason for her travel was a medical check up on the two mechanical valves in her heart. She spoke about being at peace with death when it comes.
- **12:00 PM – 3:00 PM –** Layover in Iqaluit. There was a delay in the flight on to the communities to wait for people on the Ottawa to Iqaluit flight. There was a special weather statement due to fog and clouds in the two community stops before Resolute Bay on the way from Iqaluit. Pilots and Canadian North staff warned the flight may not be able to land in either Pond Inlet or Arctic Bay but will land in Resolute Bay. Customers on the flight had to choose whether to chance the landing or be booked on the next flight the following day. There were groups that chose both to come on the flight and some to stay. The flight landed in Pond Inlet but was deemed unsafe to land in Arctic Bay.
- **9:00 PM –** Landed in Resolute Bay. The ATCO staff accommodated 16 people who were supposed to go to Arctic Bay in Resolute Bay. Alexandra spoke to a QIA representative for Arctic Bay that had been traveling to Iqaluit for the trade show. They spoke about the differences between Arctic Bay and Resolute Bay. Arctic Bay is a larger community. His opinions were that Arctic Bay had a bit more of a community feel, it is busier more people out and about. He speculated that this may be due to increased his word was, "colonization" in Resolute Bay due to the presence of research, the military, and Polar Continental Shelf Program.

Day 2 – September 25th – First Day in Community

- **9:00 AM – 12:00 PM -** Walked to the shoreline, saw intact vertebrae of a ringed seal, as well as top and bottom of a Caribou jaw. Researchers also saw a treated ringed seal skin drying on the beach. Walked to the swimming pond researchers had seen in the summertime, it was interesting to see the seasonal comparison.
- **12:00 PM –** Lunch with Derrick. Derrick toured the researchers around the surrounding areas of Resolute Bay including dynamite beach and Allan Bay. There had been polar bear sightings around this area, but none were seen during the outing. Two bearded seals were spotted swimming in the ocean at dynamite beach. Researchers also observed naturally formed breakwater structures.

Day 3: September 26th – Second Day in Community

- **8:30-10:30 AM –** Breakfast in hotel.
- **10:30 AM –** Researchers went to health center to introduce themselves; the nurses were busy with patients, so researchers moved on as to not take up time and resources which local residents required.
- **10:40 AM** – Went to Hamlet Office to speak to Ian Dudla SAO, Ralph post office employee and financial aid for hamlet was also there. Ian had just come off a month in Edmonton. Ralph had been covering for him while he was away.
- **11:00 AM** – Met with Joadamee Amagoolik outside the HTO office. He is on the board of directors for the HTO. He recommended the best way to get people involved in our study was to

post posters in the community – at CO-OP, in post office, and post on Resolute Bay "Buy and Sell Page" on Facebook.

- **12:00 PM** – Hotel for Lunch.
- **1:30 PM** – Virtual meeting with Trevor Bell SmartICE. He gave information about the SmartICE program. There is an existing Inuit Guardian program that has a representative in each community in the Lancaster sound area. SmartICE doesn't want to compete with the same individuals so are exploring partnership agreements. Dr. Nistor brough up grant money available from the NRC that needs to go to the community. This grant money could be used to deploy the SmartICE sensors in Resolute Bay. Information SmartICE needs form the community is how many sensors are they interested in, where would they like them deployed.
- **2:00 PM** – Coffee with Joadamee Iqaluk. We spoke to Joadamee about many things but most of note were his opinions on equipment for measuring ice. He spoke about the SmartICE sensors. His opinion was that Inuit don't want to rely on the sensors, because they need to rely on traditional knowledge. Relying on the sensors could cause a false sense of security and lead to more incidents. He also spoke about when Inuit people are getting old and want to die. Many go out to the ice and die on the land. He echoed Emily's perspective of Inuit being very comfortable with the idea of death when it comes. Joadamee has read articles written about historical nomadic Inuit people leaving their "weak Elders" out on the land so they could keep moving. He finds this historically inaccurate due to the respect Inuit culture shows to their Elders and this practice of dying on the land by choice.
- **4:00 – 6:00 PM** – Derrick, Arctic photographer and Navigation Canada employee took us out in his truck to explore the surrounding area of Resolute Bay. We went to the memorial for a historical plane crash that happened in Resolute Bay, as well as to the solar radar sensors.
- **6:00 PM – 6:45 PM** – Dinner in Hotel
- **7:00 PM** – Community Council Meeting, Hamlet Office of Resolute Bay. Researchers presented a proposal of the research methods and objectives at the meeting and received verbal and written approval of the study.

Day 4: September 27th – Travel Day Home

- **5:30 AM – 12:00 PM:** travel back to Iqaluit from Resolute Bay
- **12:00 PM** – Met Emily who toured us around Iqaluit, saw large tidal range, the tide was down during plane landing. Went the Nunatta Sunakkutaangit museum, tried to go to the country food store it was closed, went to Malikkat Inuit arts and crafts store. Got a good view of Iqaluit from above.
- **3:00 PM – 8:00 PM** – in airport and traveled back to Ottawa.

B.3. Lessons Learned and Successes During Field Visit

B.3.1. Local Wildlife

There were several (3-4) polar bear sightings surrounding the community in the two days the researchers were in Resolute Bay. Polar bears are classified as marine animals and spend most of their time on the ocean either on the sea ice or swimming between ice floes. During ice break-up they swim to thick multi-year ice and swim between landforms and islands. Polar bears also travel north in the summer in search of more ice. In the late fall they will be near the community again awaiting freeze up of the ice. Within the 2-3 days before researchers arrived in Resolute Bay, there was a large beluga whale migration surrounding Resolute Bay. Many locals describe "they had never seen so many belugas in the bay before." Some describe the habit of the belugas that roll around on the gravel bed of the shallow water to clean their skin. Inuit hunter Devon Manik killed and prepared four belugas during this time. Researchers were able to see the carcases left on the beach. These carcasses however attracted polar bears for feeding. One of the polar bear sightings that occurred was in early morning a bear was feeding on the carcases. The researchers observed these carcasses on two subsequent days. When the researchers went back to observer the carcasses' a second time they had been moved and polar bear bite marks and footprints could be seen. Researchers observed two bearded seals during their exploration.

Figure A - 9: Beluga Carcases on the Shoreline After Hunting and Preparing.

B.3.2. Surrounding Landscape

During this visit the temperatures ranged between base temperatures of -4 to -10 Celsius. There was a mix of sun and cloud in the sky both days, as well as 30 km/hour winds one day. The windchill brought the "feels like" temperature down to about -14 °C. There was light snow on the ground however it did not snow while the researchers were there. During the last field visit in July, there were large ice floes in the bay that came in and out with the wind. This time there was no ice floes in the bay, and the sea ice had not yet begun to freeze. Due to the salinity and movement of the water locals estimated the water temperature to be about -2 °C at the time the researchers were there. During the field visit, the researchers walked to the glacial river that flows into the bay. The researchers had observed this bay on their last visit in July. Photos were taken at the same place looking the same direction for comparative purposes. The freshwater river had just started to freeze. However, the thickness was not very thick >5 cm. Researchers were easily able to break the ice with the weight of a rock. See the images of the glacial river in September and July compared in Figure A -10.

Figure A - 10: Beginnings of Frozen Pond September 27th (left), Same Glacial River Flow in July 28th 2022 (right).

During their trip the researchers also explored driving north and west of the community with Derrick Brown, Navigation Canada employee. Derrick is in Resolute Bay in months long shifts providing constant maintenance and surveillance of the airport automated landing system. Derrick took the researchers to Allan Bay, Dynamite Beach, Becher Bay, and Sheringham Point. During this exploration the researchers were able to get a feel for the surrounding landscape. The above areas can be seen better on a map of Cornwallis Island in the Figure A - 11 and Figure A - 12.

Figure A - 11: View looking Southwest from Becher Bay.

Figure A - 12: View looking Southeast from Dynamite Beach.

Figure A - 13: Map of Bays Surrounding Cornwallis Island.

B.3.3. Community Council Meeting

Researchers Forsythe and Nistor were scheduled to present their research project at the August 15th, 2022, community council meeting. This presentation would have been conducted remotely via Microsoft Teams. However, the community has a quorum in order for decisions to be made. The August 15th meeting was canceled due to quorum not being met. The community council meeting was re-scheduled for the Monday September 26th while the researchers were in Resolute Bay. Researchers Forsythe, Nistor, and Shibayama attended the meeting. Nistor introduced himself, Forsythe (his MASc student) and Shibayama (his collaborator). Forsythe then went on to introduce the project to the community council. The six-slide presentation went through the studies description and goals, a proposed timeline, presented the current scientific understanding of sea ice modelling, presented this study's mixed science and traditional knowledge approach, and finally presented this study's approaches and values. Emphasis on valuing Inuit and scientific ontologies as equals and including the community throughout all phases of the project was presented. Researchers also stressed the interest in involving community needs within the research and asked the council members for feedback on topics of inclusion within the study.

Following the presentation, the floor was opened to discussion with the council members. One council member stated she was very appreciative of the study being conducted as well as the involvement with the community she approves of the study going forward. A different member of the council stated she would like researchers to look at ice movement, to determine where the large ice floes entering the bay originate from.

Figure A - 14: Researcher Shibayama (left) and researcher Nistor (right) outside the Hamlet Office before the community council meeting.

B.3.4. Steps Moving Forward

- Submit a Polar Continental Shelf Program application.
- Continue data desktop study.
- Incorporate community feedback into study.
- Preparation for community study.
  - Rates for catering were discussed with ATCO South Camp Inn.
  - Discuss hosting the survey in the Hamlet Office building recreation center.
  - Prepare material for the survey.

Appendix B – Canadian Ice Services Archived Weekly and Regional Archived Sea Ice Charts Used to Determine Break-up and Freeze-up Date

The following appendix shows an example of how the break-up date and freeze-up date were determined from the archived eastern Arctic from Canadian Ice Services weekly regional ice charts. This example shows to progression of sea ice charts in 2019 over the break-up and freeze-up period. Only a subset of each chart near Resolute Bay is shown.

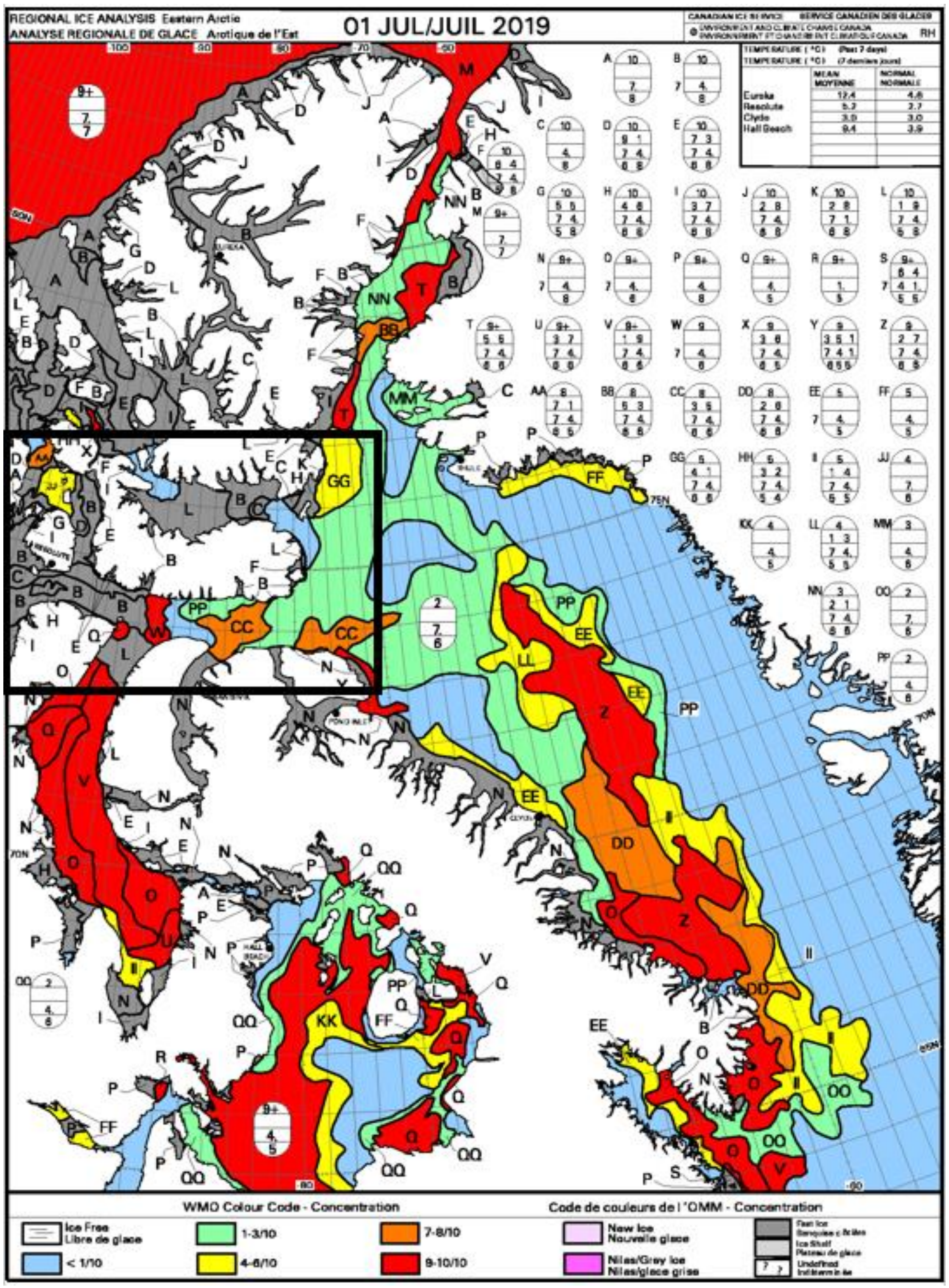


Figure B - 1: July 1st, 2019, Entire Spatial Extents of Sea Ice Chart and Resolute Bay and surrounding Area Subset.

The evolution of sea ice concentration in the previously identified sub area surrounding Resolute Bay from July 1st, 2019, to August 26th, 2019, is shown below.

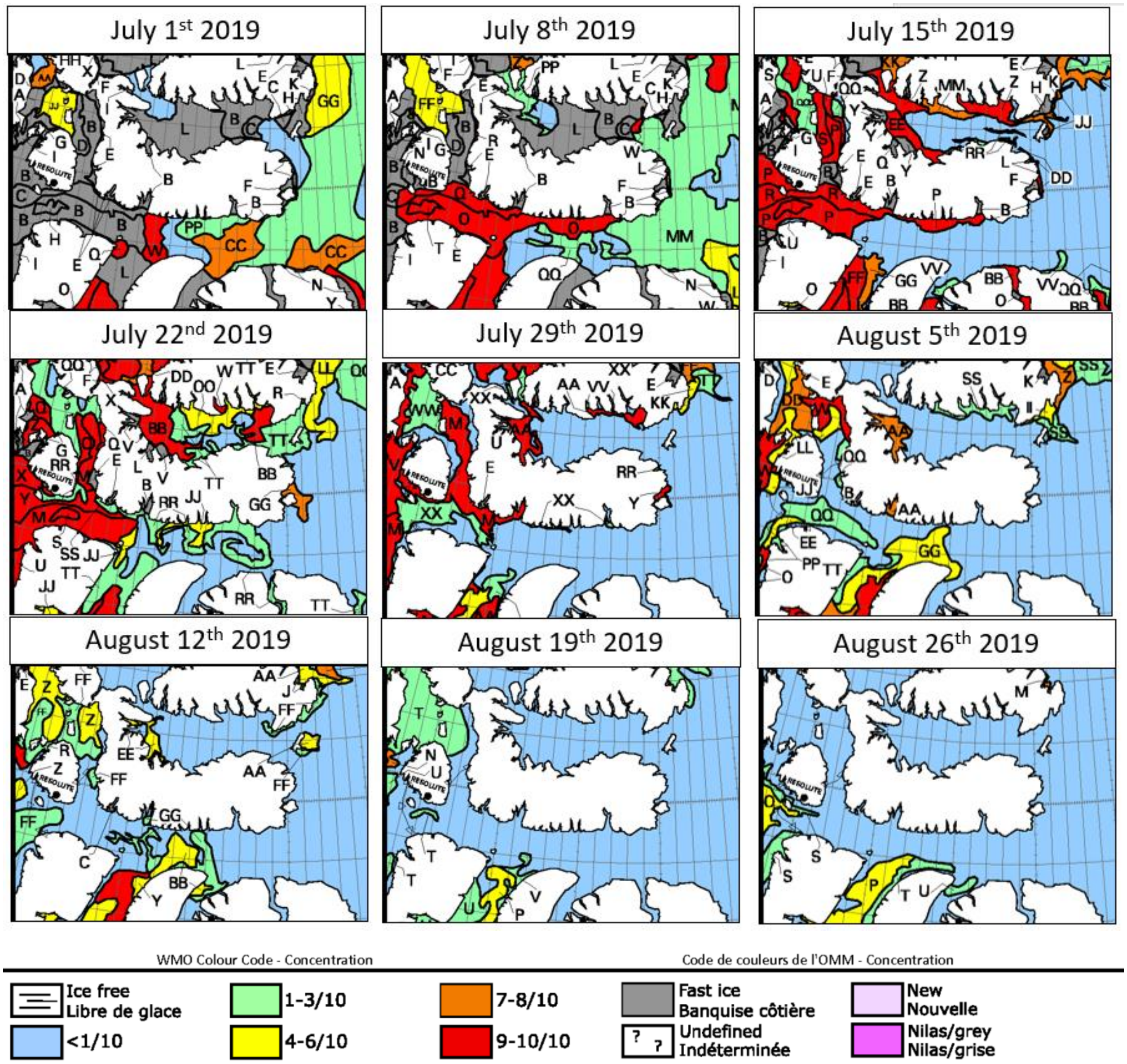


Figure B - 2: Canadian Ice Services (CIS) Archived Weekly Regional Ice Chart Progression from Fast Ice to Open Water in 2019 (July 1st – August 26th).

As described in Section 3.1.1 the break-up date is defined as the last date when sea ice concentration is reported offshore directly south of Resolute Bay below 1-3/10 and stays below 1-3/10. For example, in the above progression. A sea ice concentration of 1-3/10 is reported in Resolute Bay on July 22nd. However, the sea ice goes up to 9-10/10 again in the July 29th cart. Therefor, the recorded break-up date was August 5th for this year. Figure B - 3 presents the ice conditions surrounding Resolute Bay from during the freeze-up period from August 26th to October 21st, 2019.

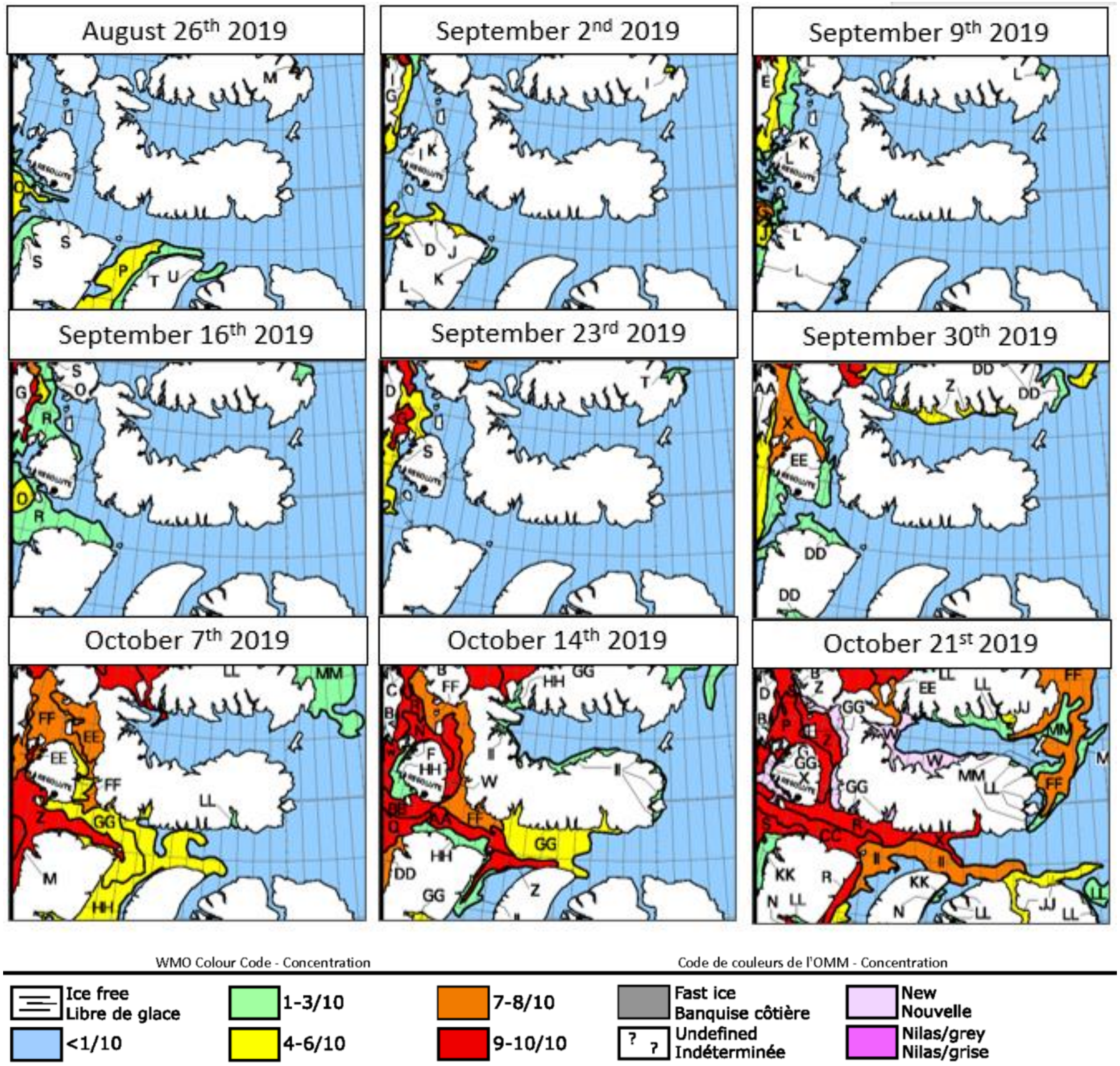


Figure B - 3: Weekly Regional Ice Chart Progression from Open Water to 9-10/10 Sea Ice Concentration in 2019 (August 26th- October 21st).

Figure B - 3 depicts how the sea ice concentration increased surrounding Resolute Bay in 2019. Open water was observed surrounding Resolute Bay until the week of October 7th. October 7th was recorded as the freeze-up date in 2019.

Appendix C – Statistical Parameters

Table C - 1: Statistical Parameters R^2 and P-Value for Linear Regression in Sea Ice Parameters and Air Temperature in Resolute Bay over Time.

Data Source	X	Y	Slope	Units	R^2	P-Value
CIS Break-up Date	Year	Break-Up Date	-0.70	days / year	0.118	0.028
CIS Freeze-up Date	Year	Freeze-up Date	0.60	days / year	0.213	0.002
C3S Break-up Date	Year	Break-Up Date	-0.74	days / year	0.328	0.006
C3S Freeze-up Date	Year	Freeze-up Date	0.51	days / year	0.265	0.026
C3S 0% SIC	Year	Days at 0% SIC	1.05	days / year	0.334	0.006
CIS C3S Average Break-up Date	Year	Break-Up Date	-0.87	days / year	0.340	1.534E-04
CIS C3S Average Freeze-up Date	Year	Freeze-up Date	0.55	days / year	0.187	0.007
C3S Sea Ice Freeboard DL2	Year	Sea Ice Freeboard	-3.94	cm / year	0.027	0.102
C3S Sea Ice Freeboard DL3	Year	Sea Ice Freeboard	-4.85	cm / year	0.263	4.38E-07
C3S Sea Ice Freeboard DL5	Year	Sea Ice Freeboard	-3.03	cm / year	0.023	0.125
C3S Sea Ice Freeboard DL6	Year	Sea Ice Freeboard	-14.49	cm / year	0.321	2.63E-09
C3S All Location Average	Year	Sea Ice Freeboard	-4.27	cm / year	0.264	1.29E-05
ECCC Annual Max Thickness Pre 1981	Year	Annual Maximum Fast Ice Thickness	0.99	cm / year	0.164	0.019
ECCC Annual Max Thickness Post 1981	Year	Annual Maximum Fast Ice Thickness	-1.20	cm / year	0.359	4.46E-05
FDD Air Temperatures Resolute Bay	Year	FDD	-17.16	FDD / year	0.470	2.19E-11

*Red Text indicates statistically insignificant trends

Table C - 2: Statistical Parameters R^2 and P-Value for Linear Regression in Freezing Degree Day Correlation to Sea Ice Parameters in Resolute Bay.

Data Source	X	Y	Slope	Units	R^2	P-Value
CIS Break-up Date	FDD	Break-Up Date	0.009	days / FDD	0.051	0.255
CIS Freeze-up Date	FDD	Freeze-up Date	-0.014	days / FDD	0.238	0.002
C3S Break-up Date	FDD	Break-Up Date	0.014	days / FDD	0.150	0.042
C3S Freeze-up Date	FDD	Freeze-up Date	-0.010	days / FDD	0.175	0.027
CIS C3S Average Break-up Date	FDD	Break-Up Date	0.014	days / FDD	0.150	0.018
CIS C3S Average Freeze-up Date	FDD	Freeze-up Date	-0.012	days / FDD	0.266	0.001
C3S Sea Ice Freeboard DL2	FDD	Sea Ice Freeboard	-0.013	cm / FDD	0.009	0.694
C3S Sea Ice Freeboard DL3	FDD	Sea Ice Freeboard	0.039	cm / FDD	0.265	0.024
C3S Sea Ice Freeboard DL5	FDD	Sea Ice Freeboard	0.038	cm / FDD	0.076	0.253
C3S Sea Ice Freeboard DL6	FDD	Sea Ice Freeboard	0.118	cm / FDD	0.351	0.008
C3S All Location Average	FDD	Sea Ice Freeboard	0.032	cm / FDD	0.092	0.206
ECCC Annual Max Thickness Pre 1981	FDD	Annual Maximum Fast Ice Thickness	0.023	cm / FDD	0.312	0.033
ECCC Annual Max Thickness Post 1981	FDD	Annual Maximum Fast Ice Thickness	0.033	cm / FDD	0.139	1.79E-04
ECCC December Average Fast Ice Thickness	FDD	December Average Fast Ice Thickness	0.016	cm / FDD	0.432	0.005
ECCC January Average Fast Ice Thickness	FDD	January Average Fast Ice Thickness	0.011	cm / FDD	0.132	0.381
ECCC February Average Fast Ice Thickness	FDD	February Average Fast Ice Thickness	0.017	cm / FDD	0.275	0.069
ECCC March Average Fast Ice Thickness	FDD	March Average Fast Ice Thickness	0.019	cm / FDD	0.292	0.027
ECCC April Average Fast Ice Thickness	FDD	April Average Fast Ice Thickness	0.027	cm / FDD	0.361	0.003
ECCC May Average Fast Ice Thickness	FDD	May Average Fast Ice Thickness	0.026	cm / FDD	0.361	0.008

*Red Text indicates statistically insignificant trends

Appendix D – Traditional Inuit Knowledge Survey Advertisement Flyer

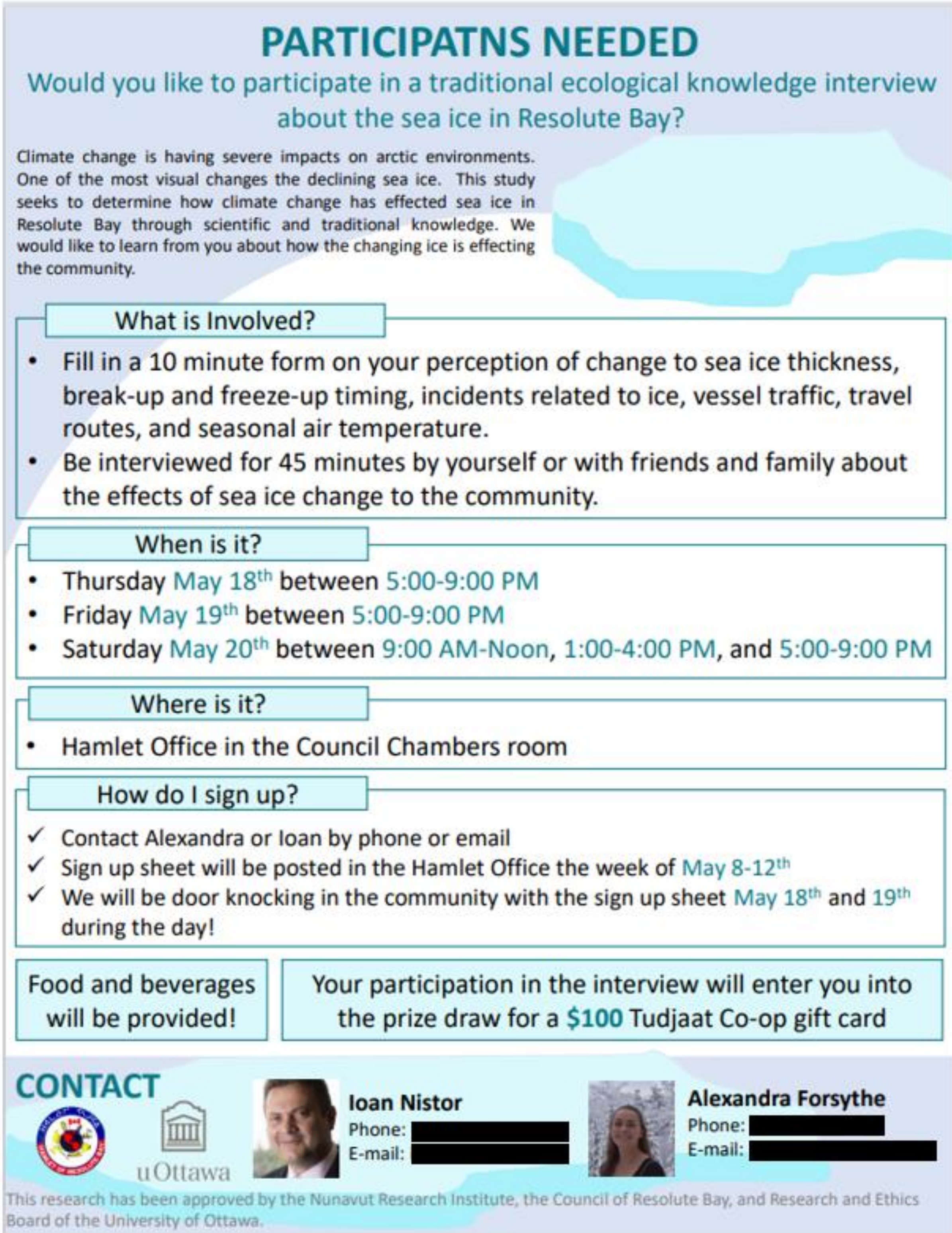


Figure D - 1: Traditional Inuit Knowledge Interview Advertisement.

Appendix E – Environment and Climate Change Canada (ECCC) Monthly Fast Ice Thickness Change Detection

October

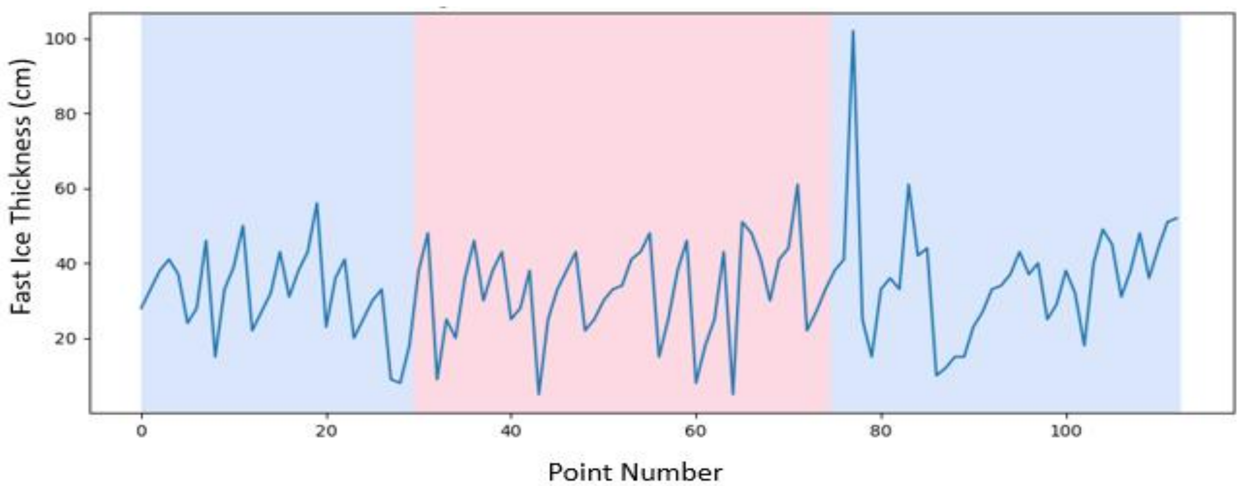


Figure E - 1: PELT Change Point Detection Algorithm October Fast Ice Thickness from 1947-2021.

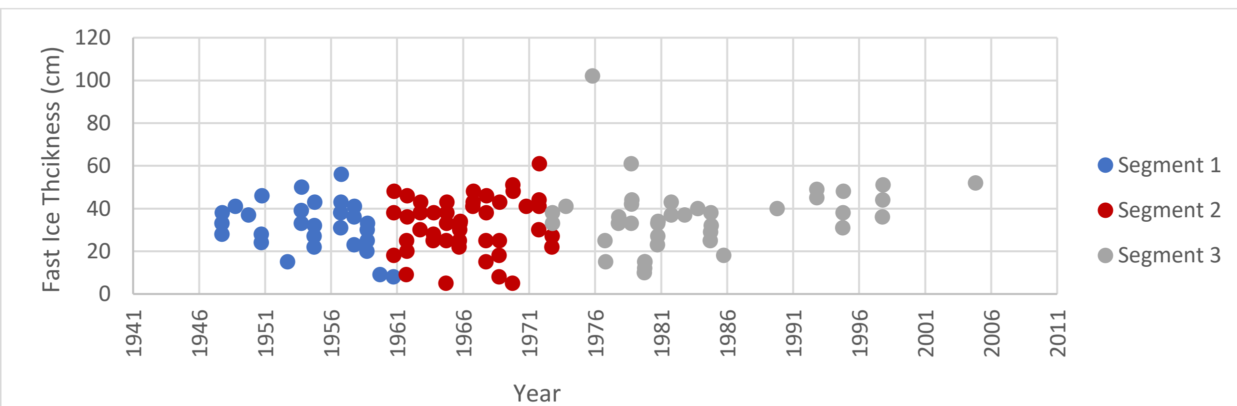


Figure E - 2: Segments between PELT Change Points of October Fast Ice Thickness from 1947-2021.

Table E - 1: Linear Regression Between PELT Change Points of October Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1960	-0.803	0.076
2	1960	1972	0.402	0.013
3	1972	2021	0.365	0.032

*Red text indicates non statistically significant trend

No statistically significant trends were identified in October fast ice thickness between 1947-2021

November

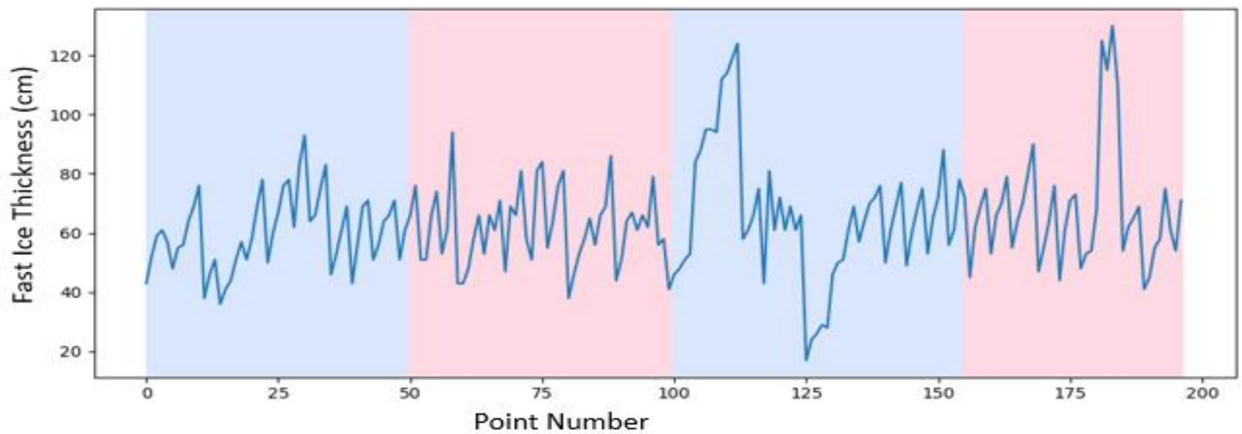


Figure E - 3: PELT Change Point Detection Algorithm November Fast Ice Thickness from 1947-2021.

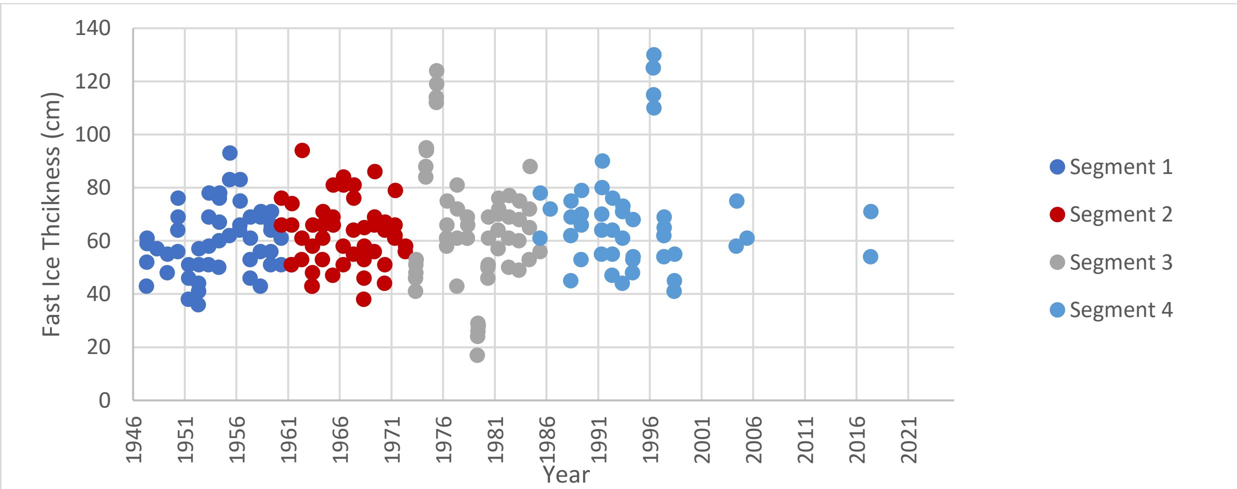


Figure E - 4: Segments between PELT Change Points of November Fast Ice Thickness from 1947-2021.

Table E - 2: Linear Regression Between PELT Change Points of November Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1960	0.767	0.056
2	1960	1972	-0.110	0.001
3	1972	1985	-1.46	0.051
4	1985	2021	-0.073	0.001

*Red text indicates non statistically significant trend

No statistically significant trends were identified in November fast ice thickness between 1947-2021

December

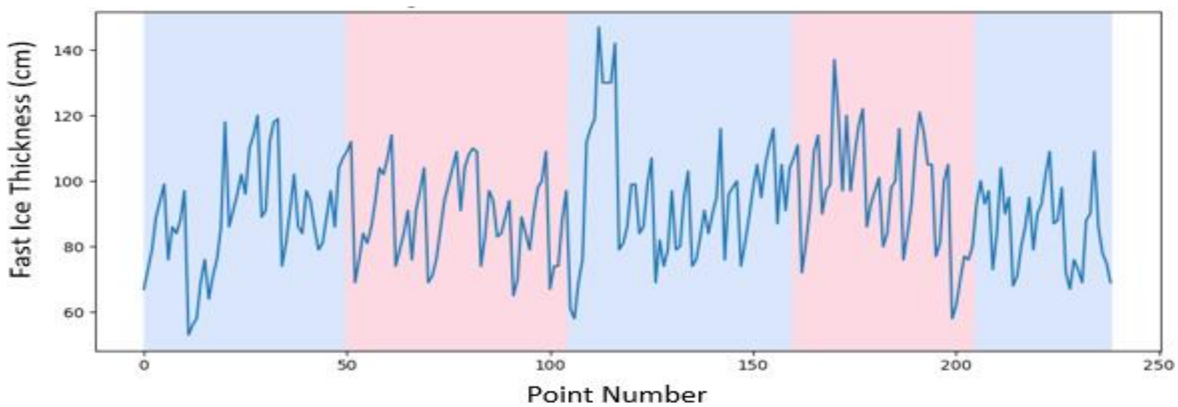


Figure E - 5: PELT Change Point Detection Algorithm December Fast Ice Thickness from 1947-2021.

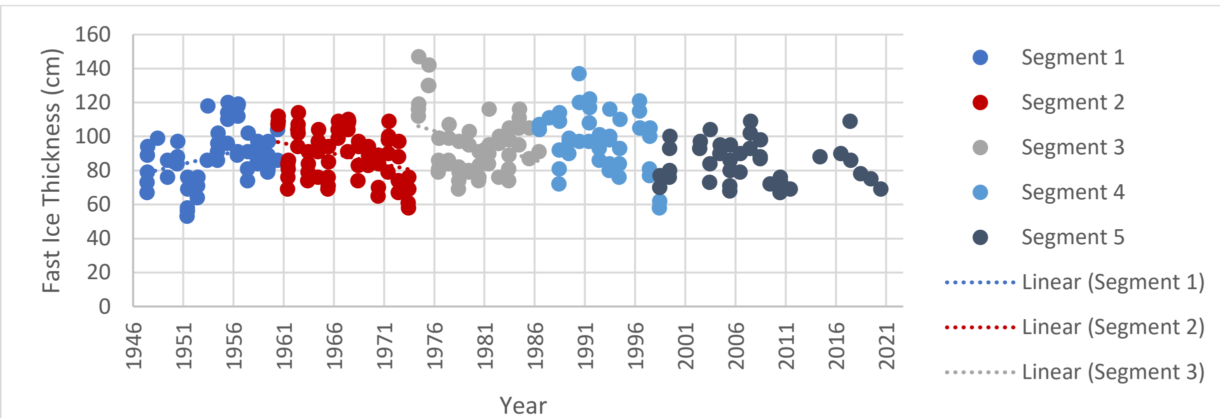


Figure E - 6: Segments between PELT Change Points of December Fast Ice Thickness from 1947-2021.

Table E - 3: Linear Regression Between PELT Change Points of December Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1960	1.42	0.118
2	1960	1974	-1.24	0.117
3	1974	1986	-1.72	0.104
4	1986	1998	-1.46	0.089
5	1998	2021	-0.183	0.009

*Red text indicates non statistically significant trend

The trends identified in December fast ice thickness are an increase in thickness from 1947-1960 by 1.42 cm/year. Fast ice started decreasing in 1960-1974 by 1.24 cm/year, the rate of decrease increased to 1.72 cm/year from 1974 to 1986. There were no statistically significant trends identified after 1986.

January

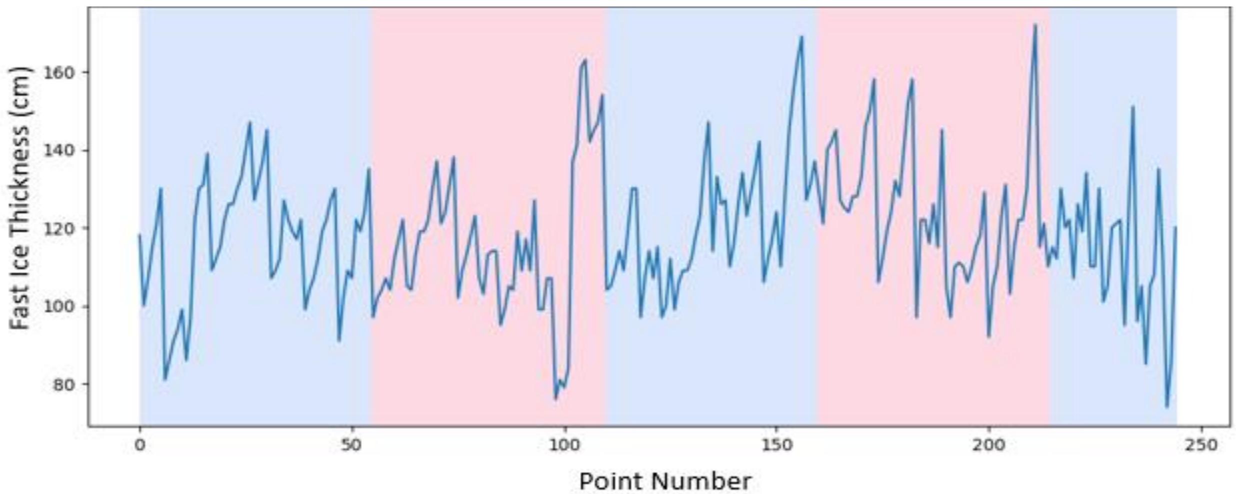


Figure E - 7: PELT Change Point Detection Algorithm January Fast Ice Thickness from 1947-2021.

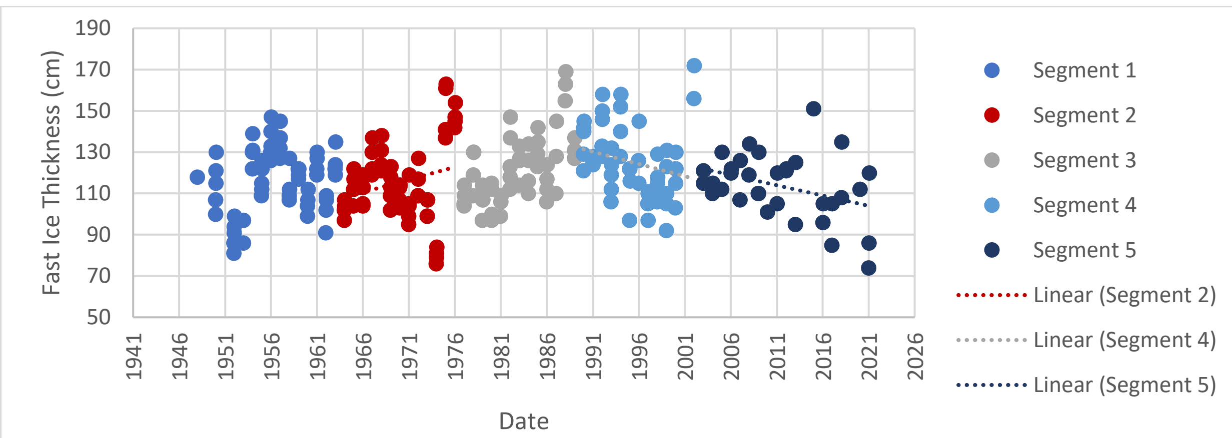


Figure E - 8: Segments between PELT Change Points of January Fast Ice Thickness from 1947-2021.

Table E - 4: Linear Regression Between PELT Change Points of January Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1964	0.657	0.030
2	1964	1976	1.20	0.055
3	1976	1989	2.66	0.347
4	1989	2002	-1.20	0.057
5	2002	2021	-0.986	0.132

*Red text indicates non statistically significant trend

The trends identified in January fast ice thickness are an increase in thickness from 1964-1976 by 1.20 cm/year. Further increase in fast ice thickness was observed from 1976-1989 at a rate of 2.66 cm/year. A decrease in fast ice thickness was observed in 2002 to 2021 at a rate of 0.99 cm/year.

February

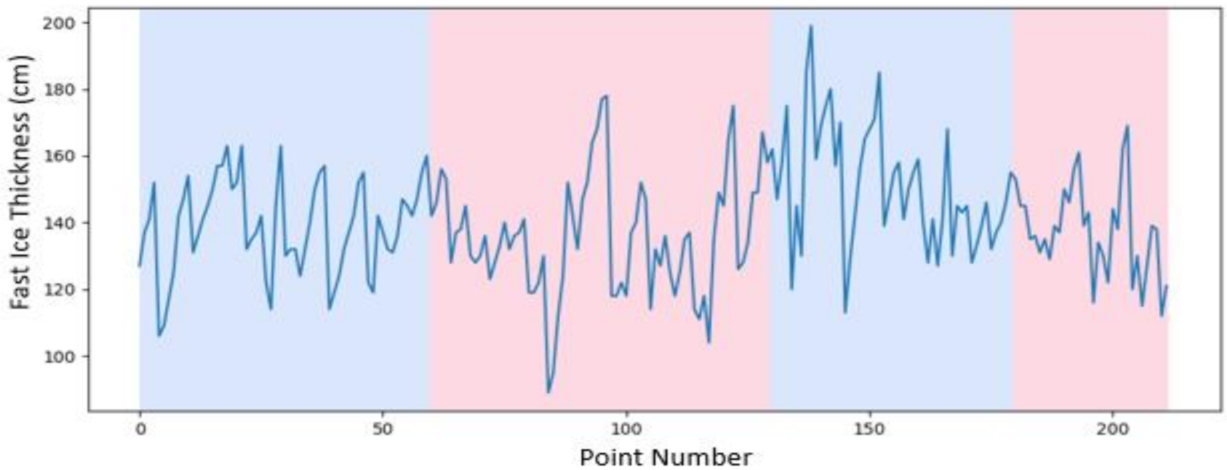


Figure E - 9: PELT Change Point Detection Algorithm February Fast Ice Thickness from 1947-2021.

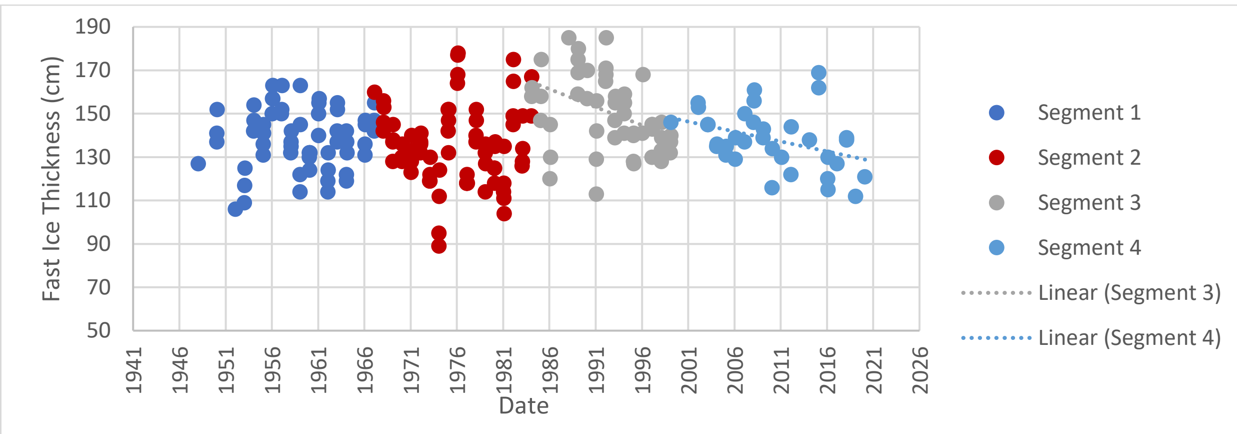


Figure E - 10: Segments between PELT Change Points of February Fast Ice Thickness from 1947-2021.

Table E - 5: Linear Regression Between PELT Change Points of February Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1967	-0.183	0.003
2	1967	1984	-0.003	4.00 E -07
3	1984	1999	-1.68	0.159
4	1999	2021	-0.913	0.143

*Red text indicates non statistically significant trend

The trends identified in February fast ice thickness are a decrease in thickness from 1984-1999 by 1.68 cm/year. Further increase in fast ice thickness was observed from 1999-2021 at a rate of 0.913 cm/year.

March

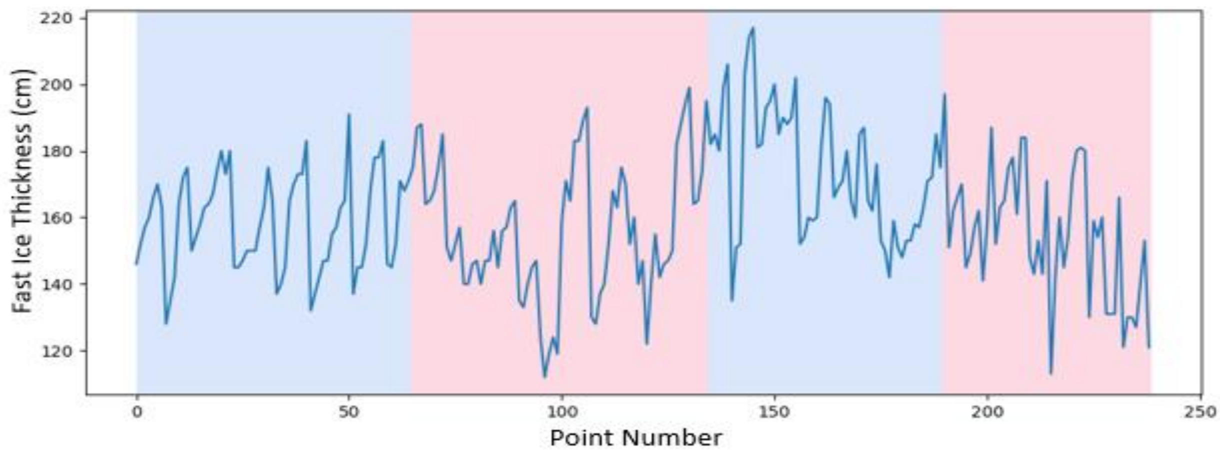


Figure E - 11: PELT Change Point Detection Algorithm March Fast Ice Thickness from 1947-2021.

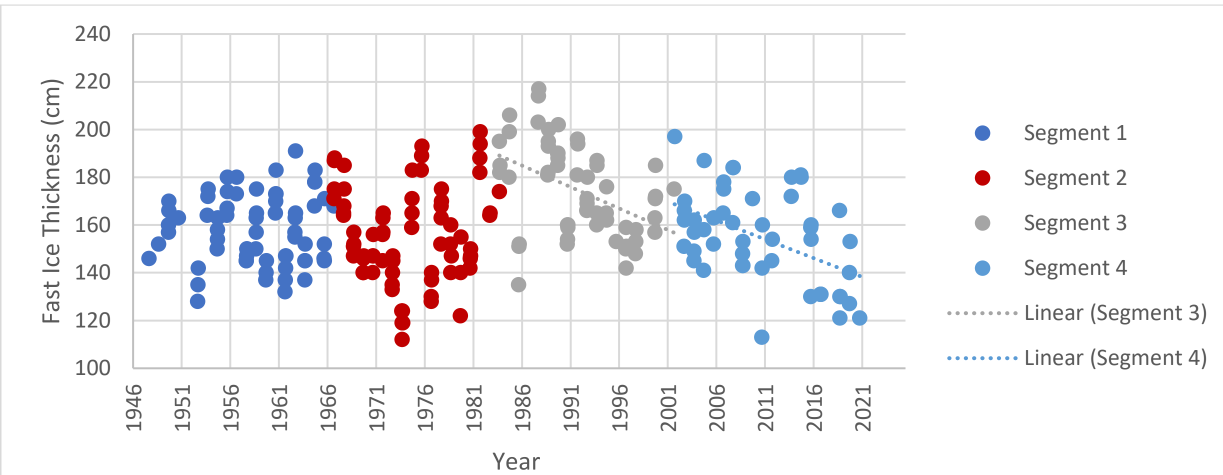


Figure E - 12: Segments between PELT Change Points of March Fast Ice Thickness from 1947-2021.

Table E - 6: Linear Regression Between PELT Change Points of March Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1967	0.110	0.002
2	1967	1984	0.146	0.001
3	1984	2002	-1.79	0.200
4	2002	2021	-1.57	0.223

*Red text indicates non statistically significant trend

The trends identified in March fast ice thickness are a decrease in thickness from 1984-2002 by 1.79 cm/year. Further increase in fast ice thickness was observed from 2002-2021 at a rate of 1.57 cm/year.

April

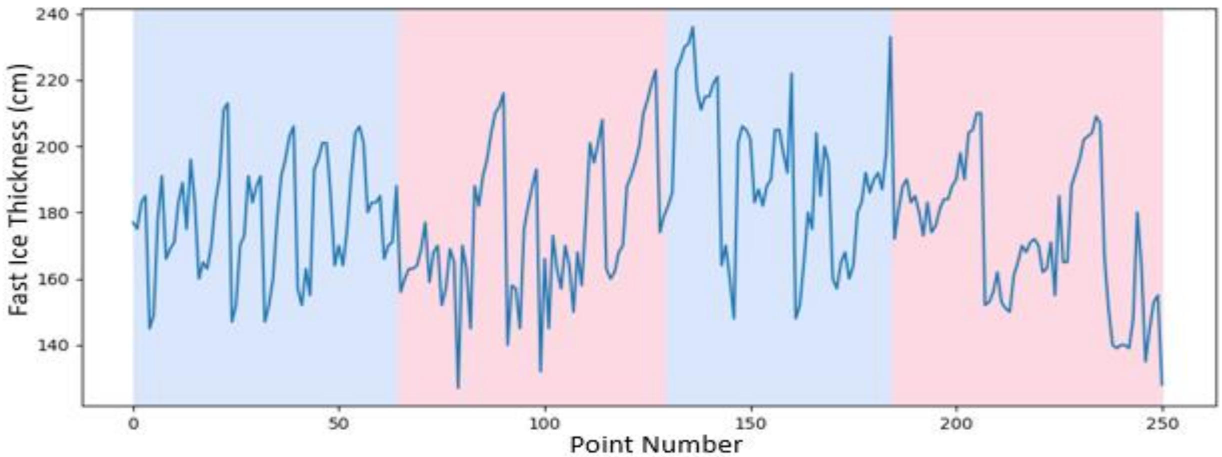


Figure E - 13: PELT Change Point Detection Algorithm April Fast Ice Thickness from 1947-2021.

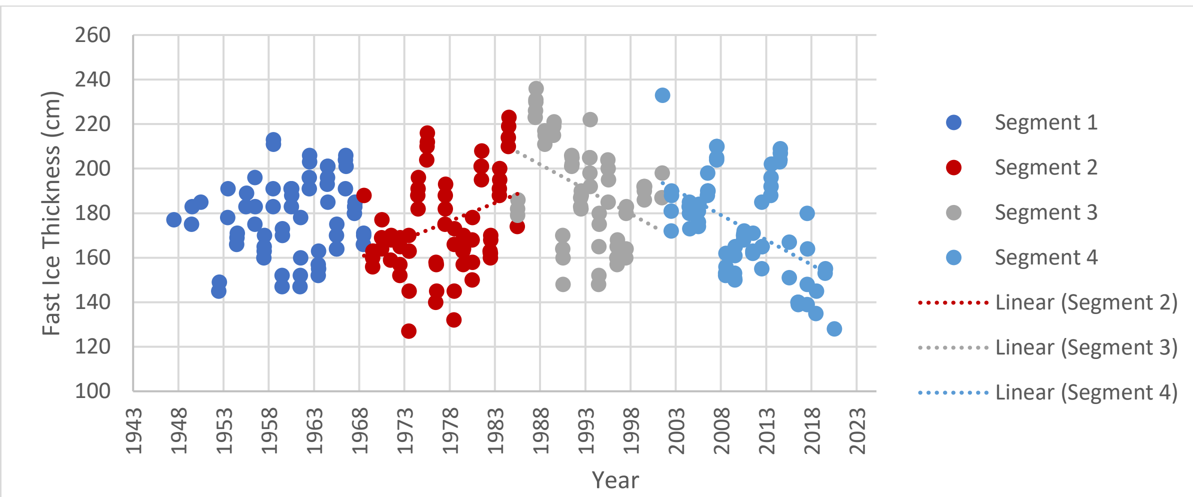


Figure E - 14: Segments between PELT Change Points of April Fast Ice Thickness from 1947-2021.

Table E - 7: Linear Regression Between PELT Change Points of April Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1969	0.475	0.021
2	1969	1986	1.64	0.124
3	1986	2002	-2.23	0.166
4	2002	2021	-2.23	0.215

*Red text indicates non statistically significant trend

The trends identified in April fast ice thickness are an increase in thickness from 1969-1986 by 1.64 cm/year. A decrease in April fast ice thickness from 1986-2021 by 2.23 cm/year.

May

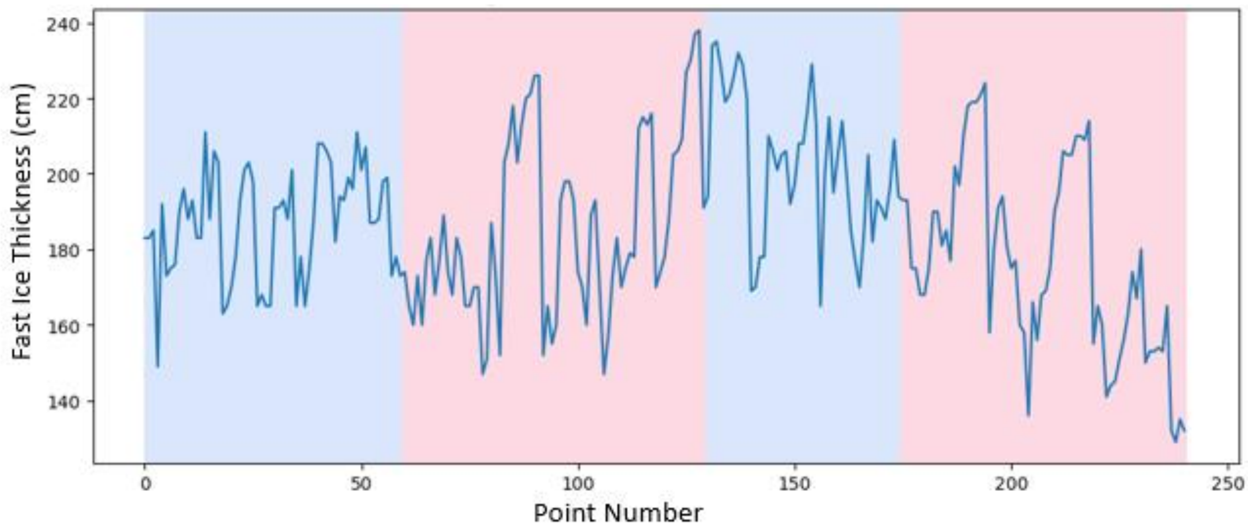


Figure E - 15: PELT Change Point Detection Algorithm May Fast Ice Thickness from 1947-2021.

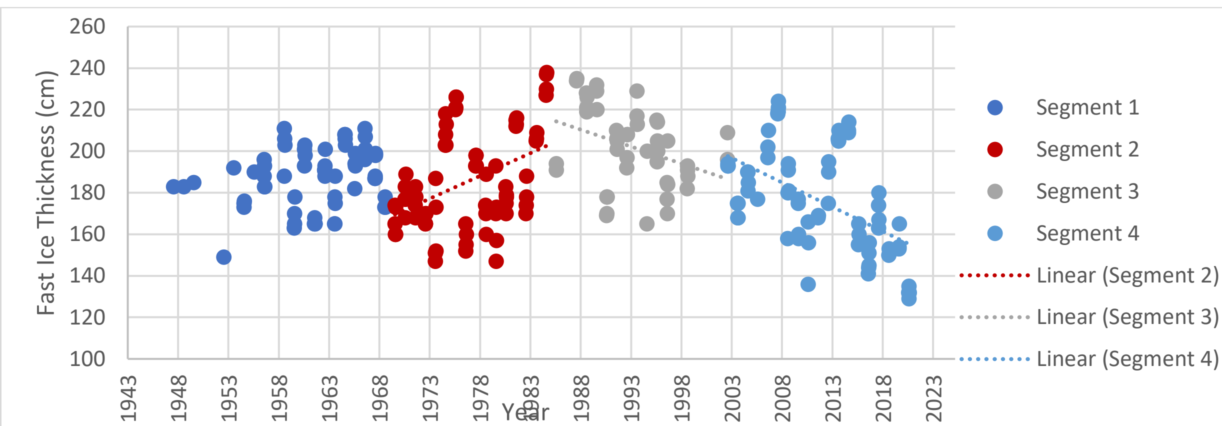


Figure E - 16: Segments between PELT Change Points of May Fast Ice Thickness from 1947-2021.

Table E - 8: Linear Regression Between PELT Change Points of May Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1970	0.621	0.051
2	1970	1986	2.19	0.179
3	1986	2002	-1.64	0.124
4	2002	2021	-2.34	0.276

*Red text indicates non statistically significant trend

The trends identified in May fast ice thickness are an increase in thickness from 1970-1986 by 2.19 cm/year. There was a 1.64 cm/year decrease in May fast ice thickness from 1986-2002 and a 2.34 cm/year decrease from 2002-2021.

June

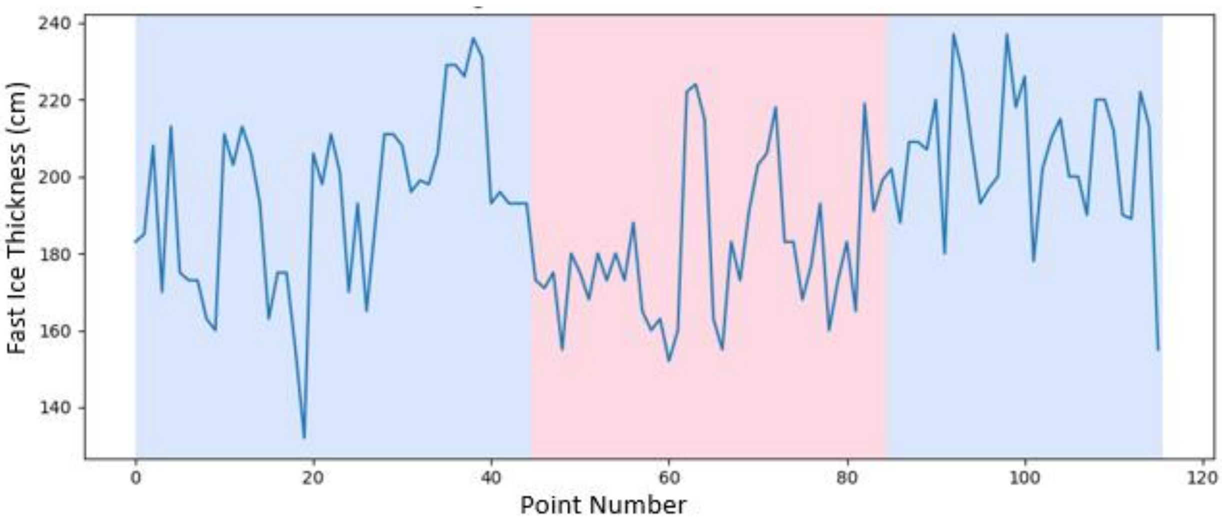


Figure E - 17: PELT Change Point Detection Algorithm June Fast Ice Thickness from 1947-2021.

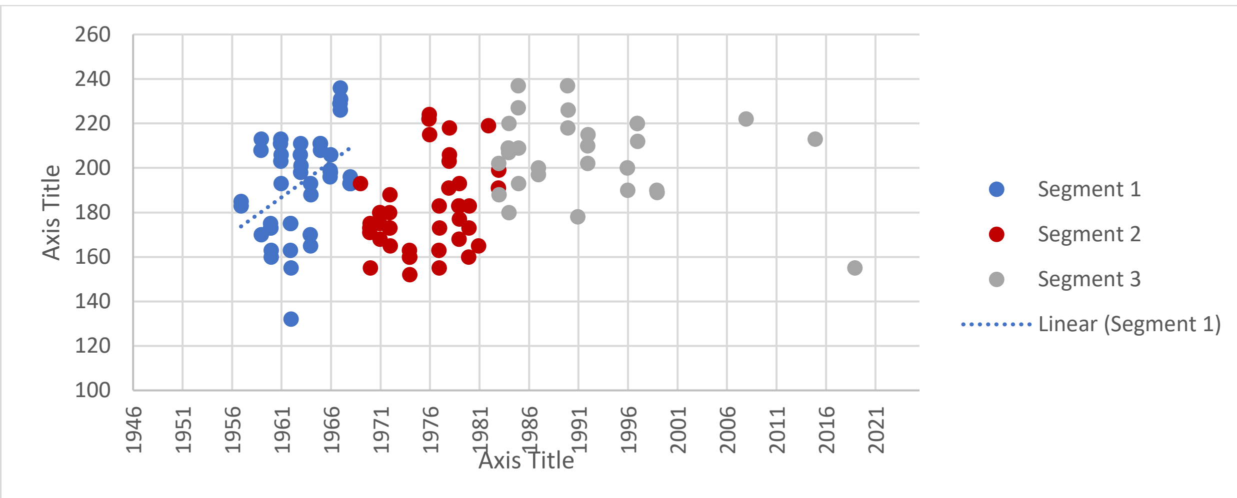


Figure E - 18: Segments between PELT Change Points of June Fast Ice Thickness from 1947-2021.

Table E - 9: Linear Regression Between PELT Change Points of June Fast Ice Thickness from 1947-2021.

Segment	Start Date	End Date	Slope (cm/year)	R^2
1	1947	1969	3.21	0.195
2	1969	1983	1.50	0.097
3	1983	2021	-0.475	0.063

*Red text indicates non statistically significant trend

The only statistically significant trend identified in June fast ice thickness is the increase in fast ice thickness by 3.21 cm/year from 1947 to 1969.

Appendix F – Environment and Climate Change Canada (ECCC) Monthly Averaged Fast Ice Thickness Change Detection

December

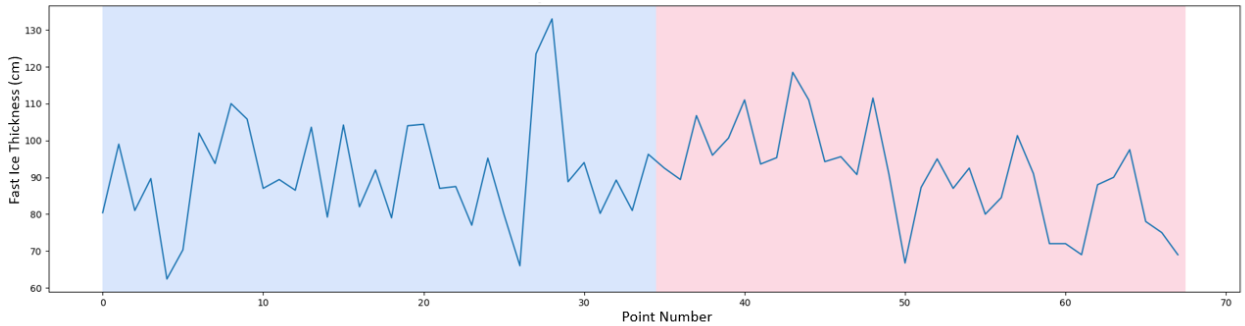


Figure F - 1: PELT Change Point Detection Algorithm December Averaged Fast Ice Thickness.

January

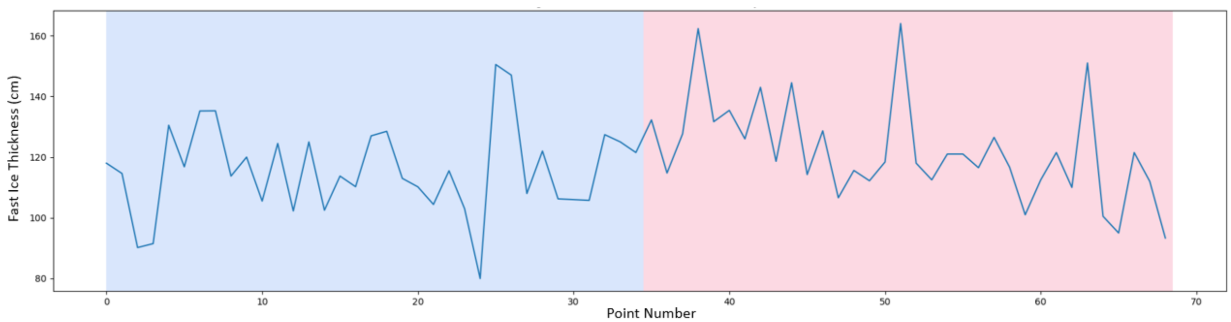


Figure F - 2: PELT Change Point Detection Algorithm January Averaged Fast Ice Thickness.

February

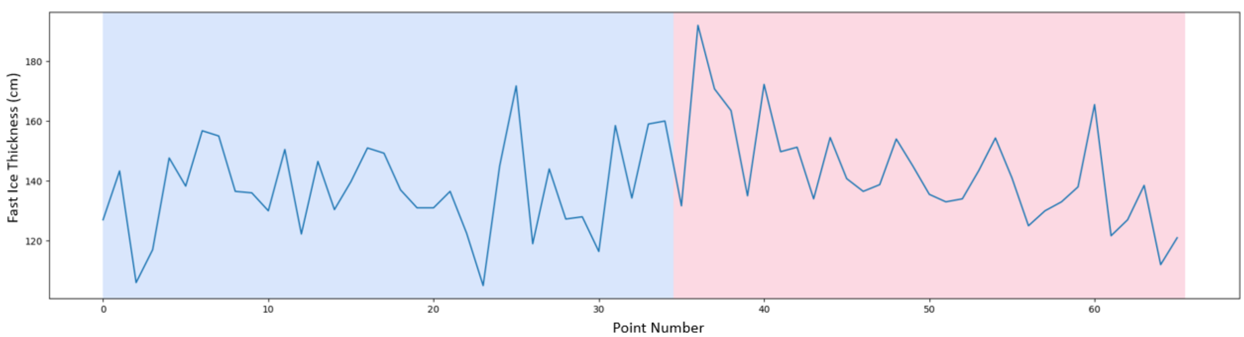


Figure F - 3: PELT Change Point Detection Algorithm February Averaged Fast Ice Thickness.

March

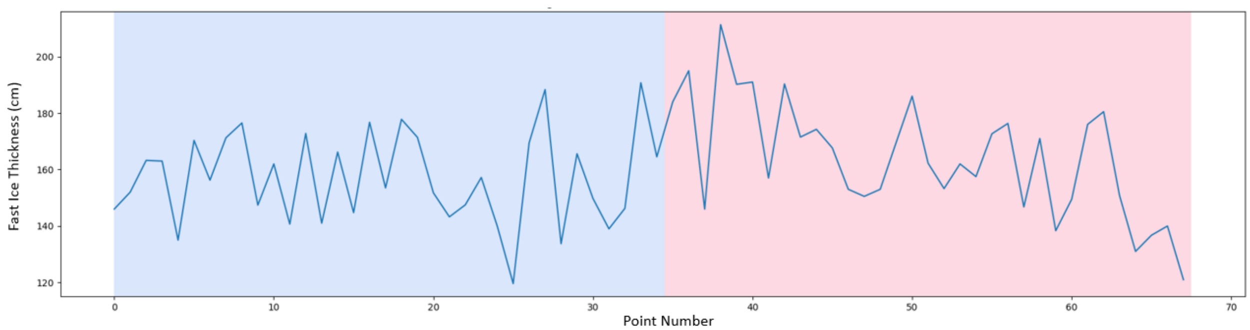


Figure F - 4: PELT Change Point Detection Algorithm March Averaged Fast Ice Thickness.

April

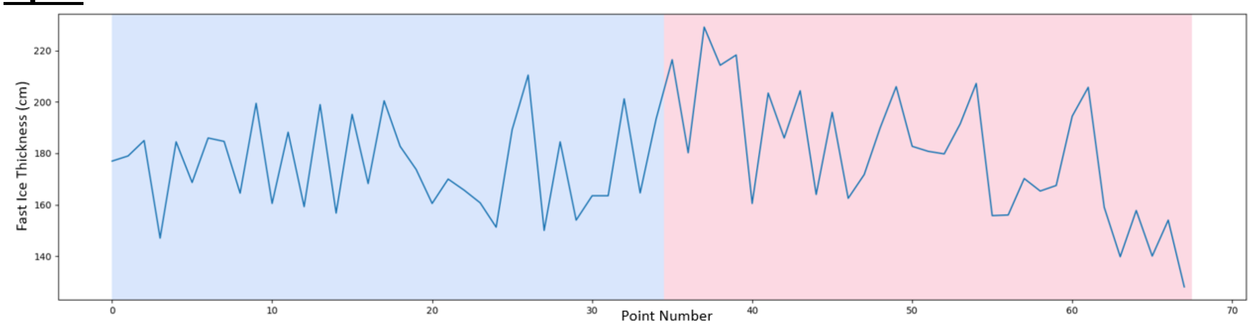


Figure F - 5: PELT Change Point Detection Algorithm April Averaged Fast Ice Thickness.

May

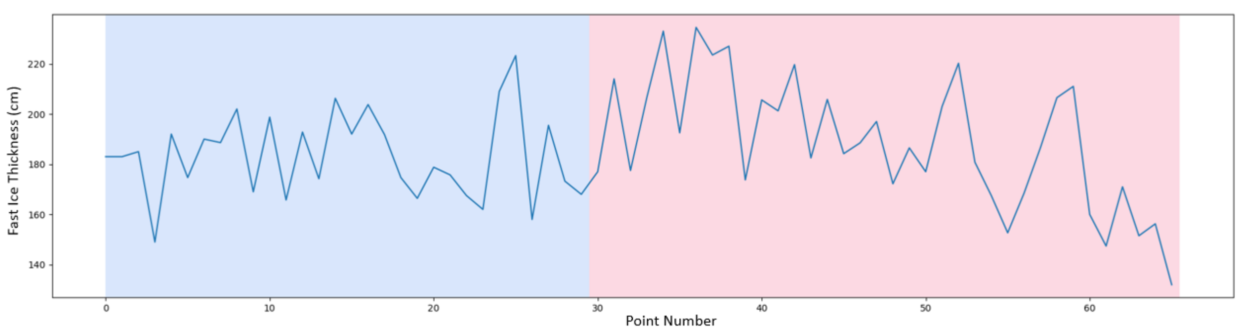


Figure F - 6: PELT Change Point Detection Algorithm May Averaged Fast Ice Thickness.

Appendix G – Environment and Climate Change Canada (ECCC) Monthly Averaged Air Temperature Anomaly Change Point Detection

January

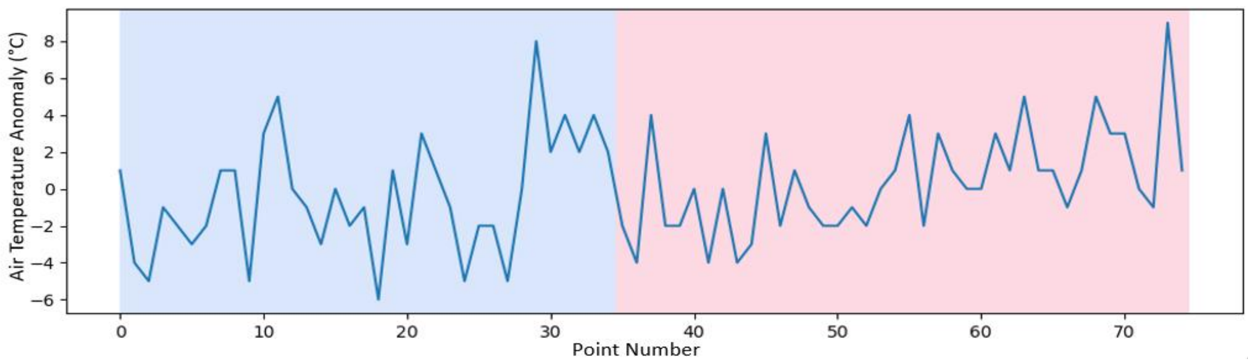
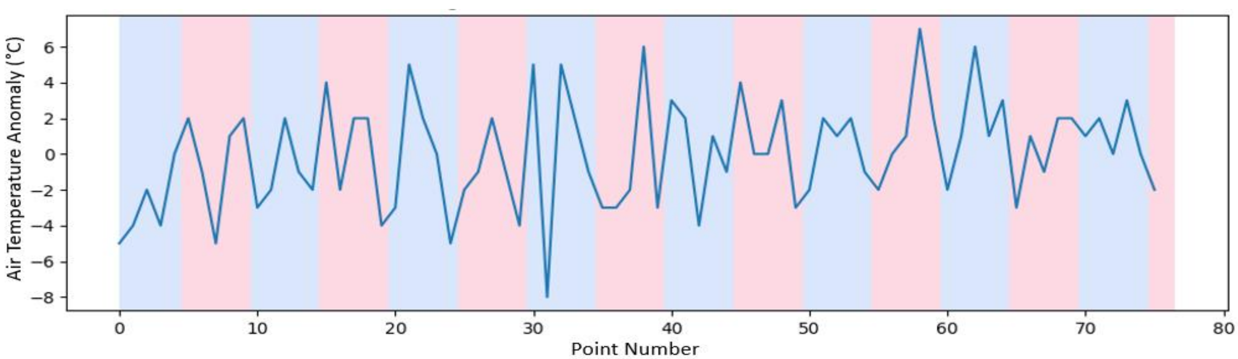


Figure G - 1: PELT Change Point Detection Algorithm January Air Temperature Anomaly.

February



Note: no distinct change point was identified in February air temperature anomalies.

Figure G - 2: PELT Change Point Detection Algorithm February Air Temperature Anomaly.

March

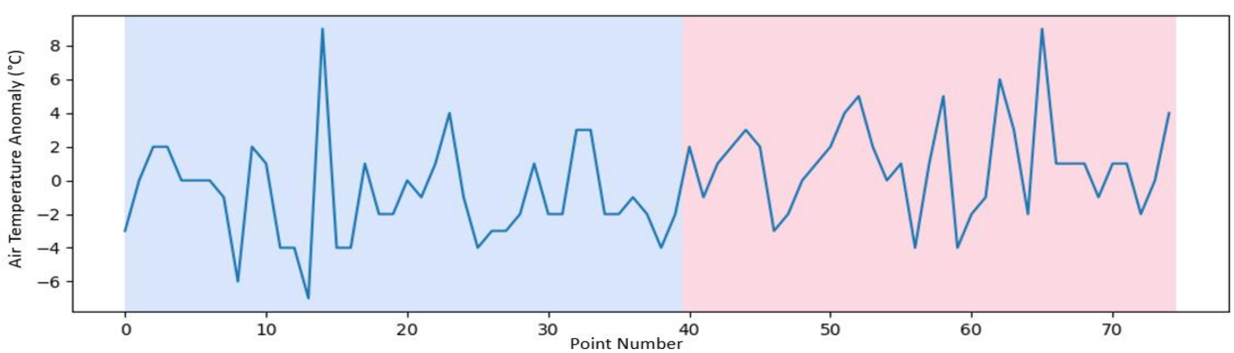


Figure G - 3: PELT Change Point Detection Algorithm March Air Temperature Anomaly.

April

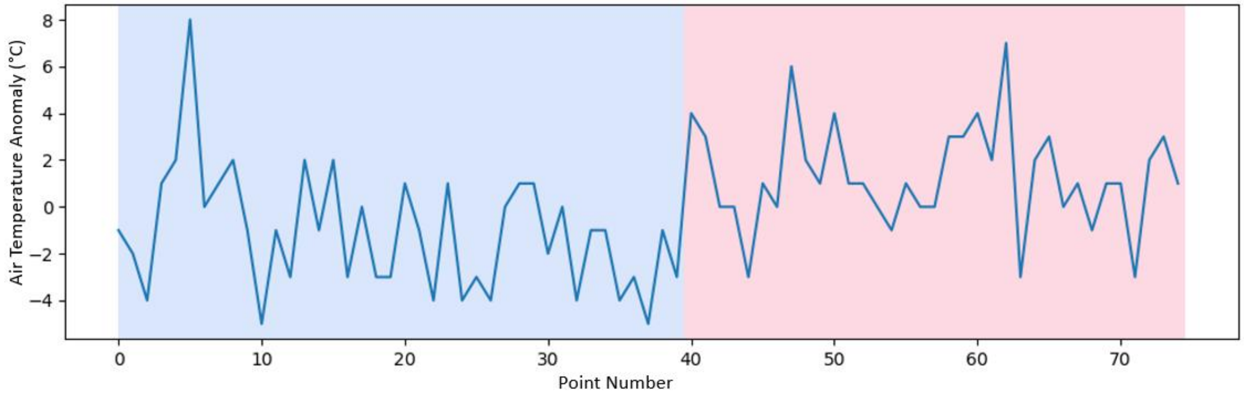


Figure G - 4: PELT Change Point Detection Algorithm April Air Temperature Anomaly.

May

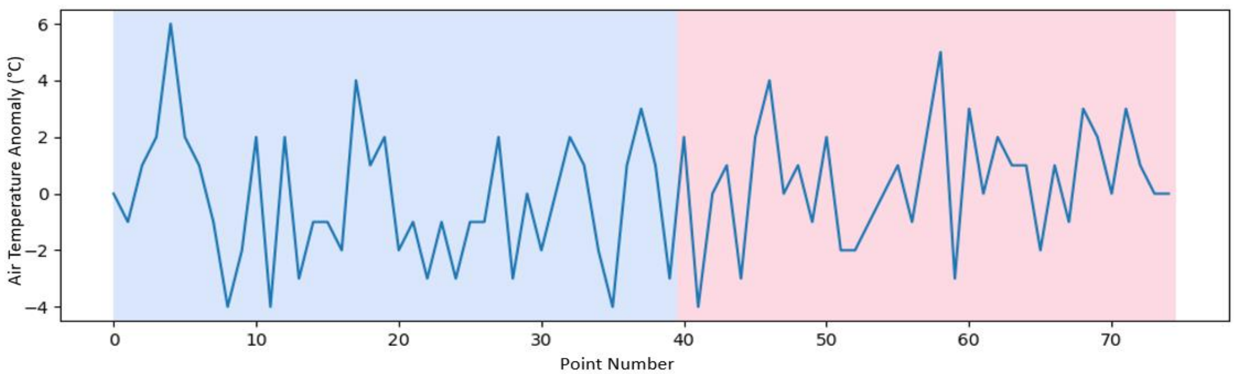


Figure G - 5: PELT Change Point Detection Algorithm May Air Temperature Anomaly.

June

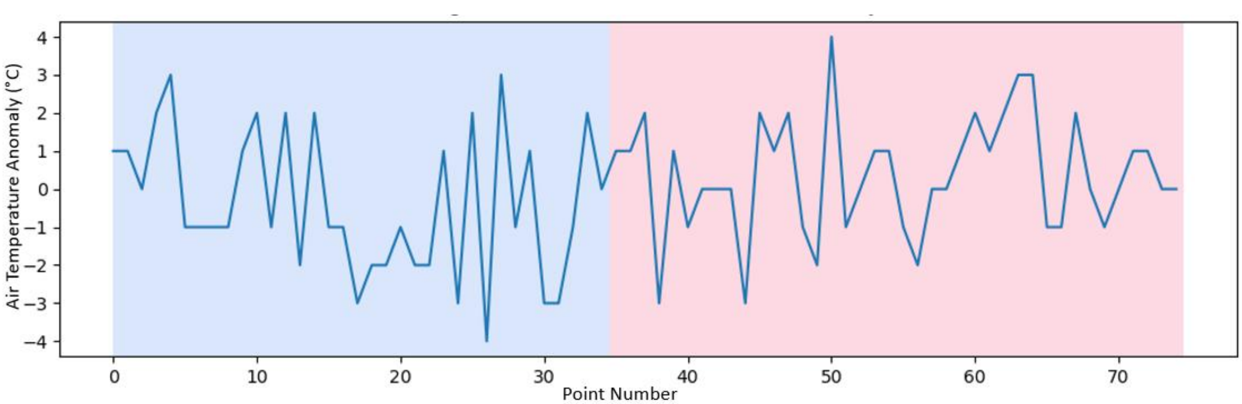


Figure G - 6: PELT Change Point Detection Algorithm June Air Temperature Anomaly.

July

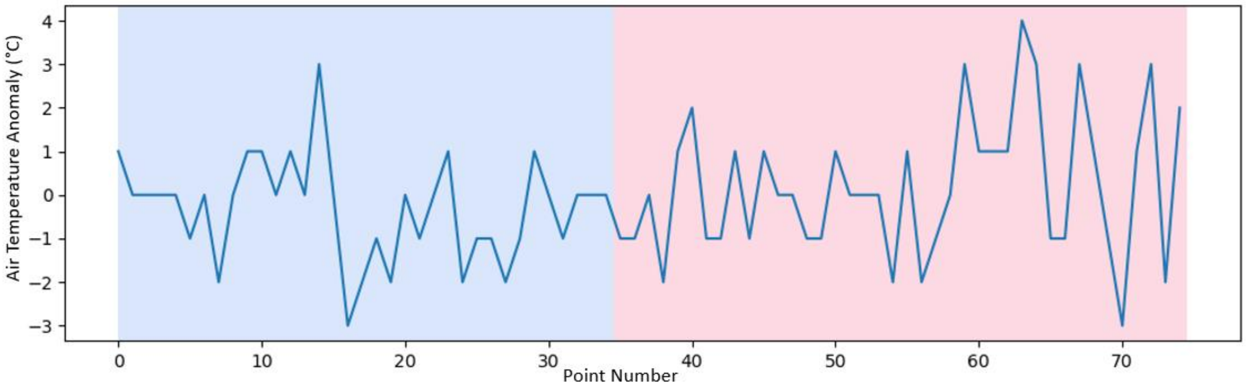


Figure G - 7: PELT Change Point Detection Algorithm July Air Temperature Anomaly.

August

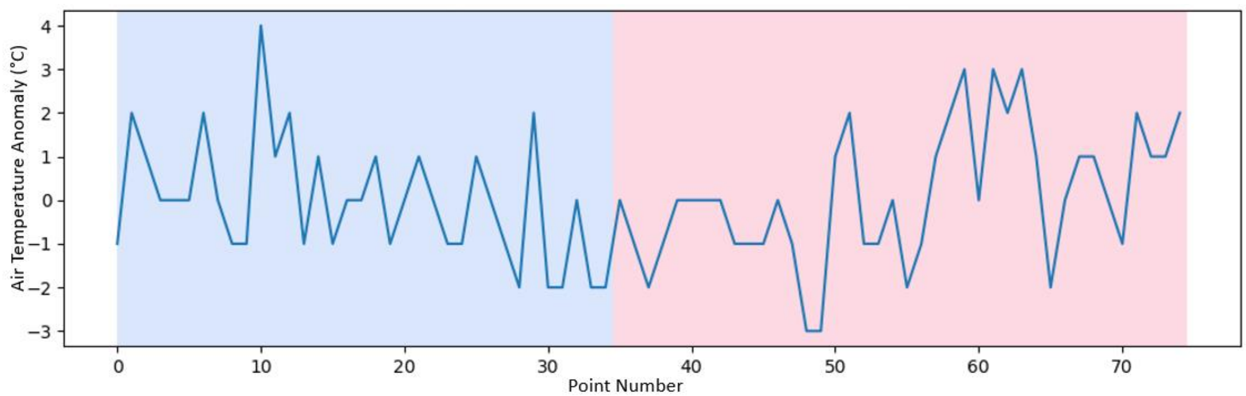


Figure G - 8: PELT Change Point Detection Algorithm August Air Temperature Anomaly.

September

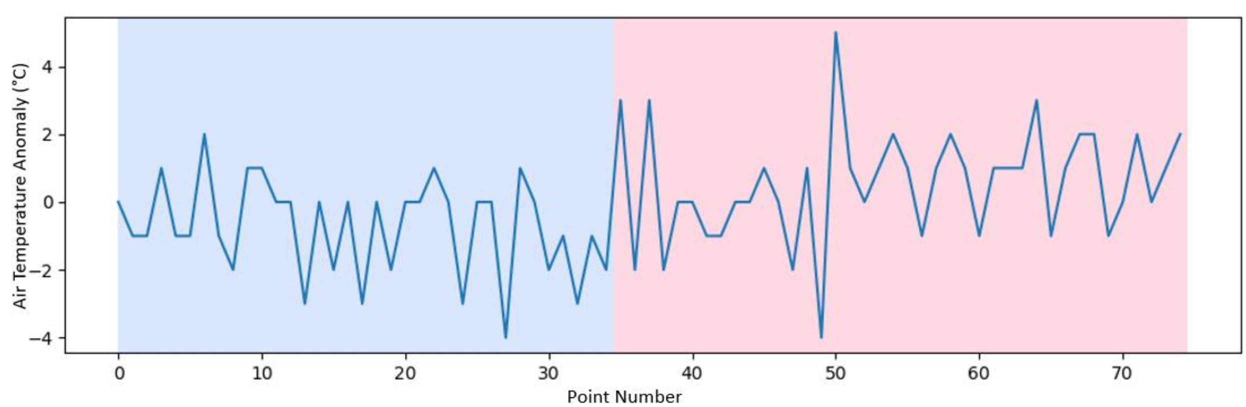


Figure G - 9: PELT Change Point Detection Algorithm September Air Temperature Anomaly.

October

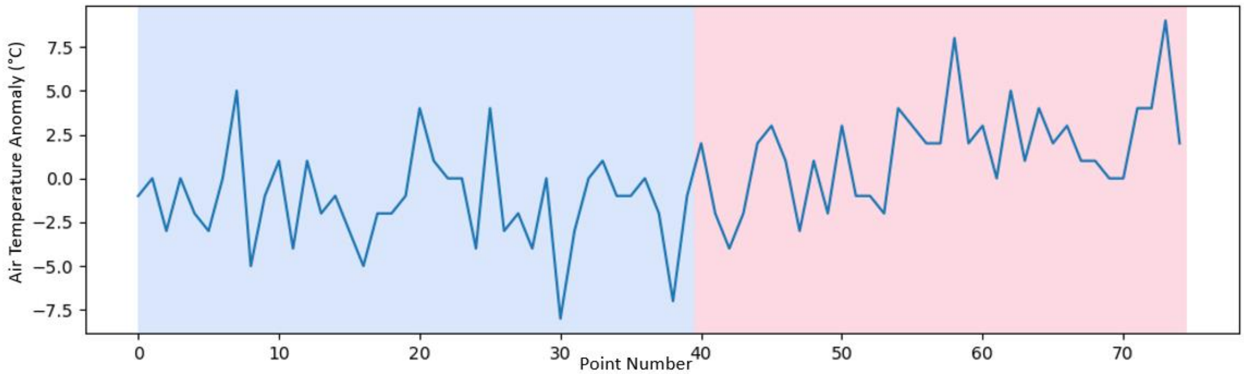


Figure G - 10: PELT Change Point Detection Algorithm October Air Temperature Anomaly.

November

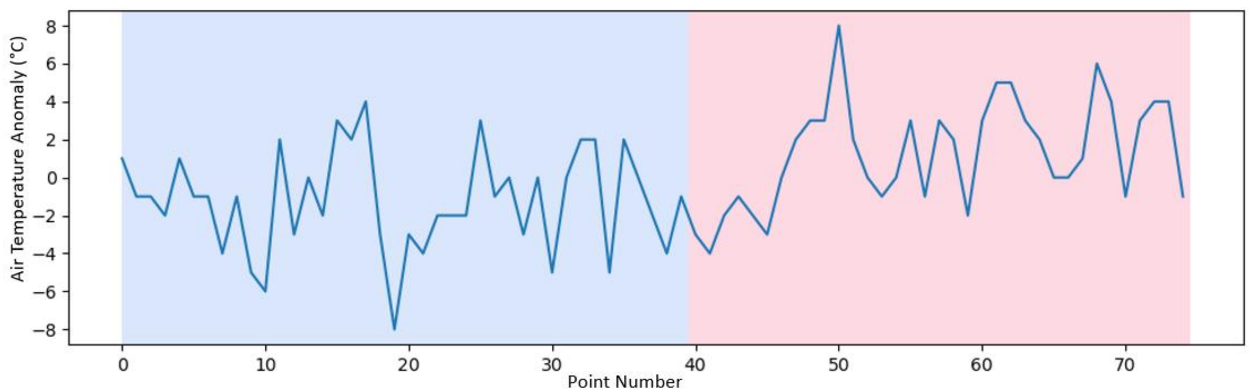


Figure G - 11: PELT Change Point Detection Algorithm November Air Temperature Anomaly.

December

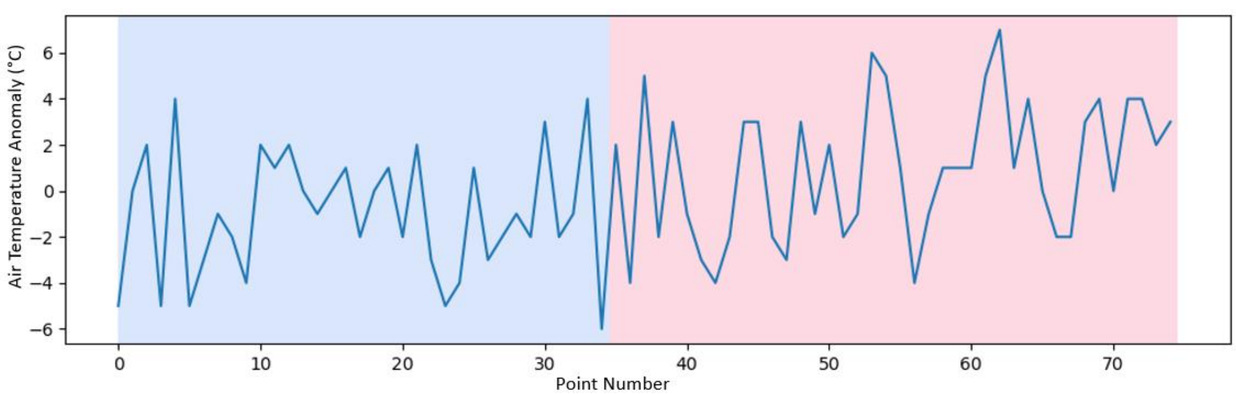


Figure G - 12: PELT Change Point Detection Algorithm December Air Temperature Anomaly.