Sea ice in a changing climate and impact on Inuit communities

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Sea ice in a changing climate and impact on Inuit communities

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Summary

Sea ice in Northern Canada is actively used by Inuit as a platform to travel on – for commuting and for traditional harvesting activities (hunting and fishing). This ice, which in its simplest form is not unlike ice that at the surface of freshwater bodies, such as lakes and rivers, undergoes yearly growth and melt cycles, although some can survive through one or more summer seasons. Snow falls can occur throughout the year, and is prone to redistribution by wind. Icebergs may be present in places. In general, sea ice is divided into a fast ice zone (which is tied onto the shoreline) and a more dynamic drift (or pack) ice zone. The boundary between these zones is commonly referred to as the floe edge. Overall, sea ice dynamics is very complex. Global warming and its consequences, climate change, are affecting this dynamics in many ways. This has been addressed by a large number of studies, an example of which is provided herein. As a consequence of these changes, the Inuit are no longer able to predict the behavior of that environment as well as they used to. As the Inuit food system is based on country food, these communities are particularly prone to food insecurity. Adaptation measures exist – they can be divided into behavioral (changes in the way of doing things), and technological (learning and using modern technology). The situation, however, is far from simple – a large number of socio-economic considerations need to be taken into account in order to identify solutions to this predicament. The concept of vulnerability, which has been investigated for communities in other world locations, is a function of exposure to risks and adaptive capacity. For the Inuit, these have been studied by a number of researchers with the active participation of the Northerners themselves. An adequate understanding of adaption measures is required to prepare for the future. Increasing resource access and/or reducing community needs will allow to reduce vulnerability. Moving further into the 21st century, it will be important to coordinate efforts by, and knowledge-base from, Inuit and scientific communities (‘Two Ways of Knowing’).

Table of Contents

Table of Figures

Table of tables

1. Introduction

Canada's coastline is the world's longest and the majority is in the Arctic Archipelago, an area that occupies about 40% of Canada's territory. This region is home to more than 200,000 inhabitants[1], most of whom are Inuit communities. These communities rely on sea ice for commuting, hunting, trapping, fishing and other traditional activities (NSIDC, 2020). They have always worked with and traveled on sea ice (Aporta, 2009b, Inuit Circumpolar Council, 2014). As a result, they have acquired a profound understanding of that environment and its ecosystem, and draw from them for their livelihood and well-being (Nickels et al., 2005, Inuit Circumpolar Council, 2014, Durkalec et al., 2015). They have their own extensive terminology about all aspects of that ice. For instance, *sikuaq* is ice that is thick enough to step on it; *siku* is sufficiently thick to support several people; *tuvaq* is ice that extend out from the shoreline; *sinaaq* is the edge of *tuvaq*, and has to be approached very carefully; *ivuniit* are obstructions to traveling, i.e. roughly equivalent to what is called ice ridges and rubble in the English literature (Laidler and Elee, 2008, Aporta, 2009a). Because sea ice is such an inherent part of their reality, it can be considered, from their perspective, as an 'infrastructure'. Inuit have been able to predict the behavior of that ice using traditional indicators, such as wind, currents, air temperature and cloud patterns.

Over the last few decades, the extent of sea ice, its thickness and its overall dynamics have attracted an increasing amount of attention from scientists concerned with the impact of climate change (Comiso, 2010, Jenkins and Dai, 2021, Levine et al., 2021). The Inuit have been experiencing this impact first-hand (Hinzman et al., 2005, Nickels et al. , 2005, Pearce and Smit, 2013, NSIDC, 2020). A warmer climate has been delaying ice growth and the achievement of a sufficient thickness for safe travel, with a consequent reduction in the time window used for traditional activities. Loss of equipment, injuries or death, and expensive search and rescue operations is attributed, at least in part, to a decreased familiarity with sea ice behavior (e.g. Karetak, 2017a).

Inuit are adaptable and strong, but one main concern is related to safety of travel on ice (Inuit Circumpolar Council, 2014). The following quotes encapsulate some of the context tied to these concerns:

> *To us, the ice is a place for travel. It is also a place for habitation. We are a maritime culture, and our culture, economy and identity depend upon our environment of ice and snow. (Inuit Circumpolar Council, 2014, p. 6)*

> *In the winter we travel on the ice to get to the open sea by snowmobiles; in the summer we use duralumin boats. In the spring, when the ice is slightly thinner and the first seals begin to arrive,*

[1] https://www.international.gc.ca/world-monde/international_relations-relations_internationales/arctic-arctique/index.aspx?lang=eng

> *we travel across the bay area on snowmobiles in order to get to polynyas where the seal hunt takes place. For harvesting seaweed (the bay area is rich with different kelp variety) we drill holes and catch oopa (Halocynthia or sea potatoes). (M.I. Nikolaevich, Chutotka. Inuit Circumpolar Council, 2014)*

> *When [the floe edge] is smooth all the way, that could be one of the factors in that the ice breaks easily, maybe the current is stronger in recent times. But [nowadays] it just breaks off. It's not doing what it used to anymore.(E. Kunnuk, 2004, from Laidler et al., 2009)*

These quotes were obtained from some of the sources reviewed for the present report – these sources collected information from Inuit community members by means of interviews and engagement exercises. Such observations of complex phenomena are an important set of information, a form of 'screen capture' representative of the human dimension in the Arctic. They have been overlooked in formal studies on sea ice. It is now generally agreed that, to devise adaptation measures against this changing environment, both the scientific and the Inuit perspectives ought to be considered side by side (Laidler, 2006, Laidler et al. , 2009, Inuit Circumpolar Council, 2014, Van Cooten, 2014, Segal et al., 2020).

2. Background and rationale

If we rely on historical writings, we note that the first source of credible information for sea ice dates back to 2300 years ago in the Greek literature, then by Irish monks 1200 years ago and others later on (Dieckmann and Hellmer, 2010, Weeks, 2010). The major impetus in the study of sea ice was eminently utilitarian: the search of a North West and a North East passage (to reduce the travel distance between Europe and Asia). The initial thrust for the studies began with the explorers of the 18th and 19th centuries. Since then, and still today, much of the knowledge-base generated was about how to avoid ice or how to effectively navigate through it. Formal scientific writings only appeared late in the 1800's. Several meetings took place as part of the First International Polar Year (IPY), held in Europe between 1879 and 1891, established priorities for Arctic research, laid out several objectives in guiding exploration endeavors (Steltner, 1984). The first metal ice-breaking ship to conduct scientific research was built by the Russians and used at the beginning of the 20th century.

The bulk of the effort in the actual understanding of sea ice – its nature, properties and dynamics – really started after World War II, when the Arctic acquired a strategic status during the Cold War and served as a basis for a variety of operations. Oil and gas offshore activities and maritime traffic were also an incentive, and a source of observations, to better comprehend sea ice. The interest in this geophysical system, in its own right, also stimulated a large number of studies by intrigued and enthusiastic scientists. After the end of the Cold War, focus was drawn toward environmental, ecological and human aspects. In more recent years, many studies have focused on the effects of climate change on seasonal ice coverage. Because of its thermal, optical and chemical properties, sea ice is known to play a critical role in the Earth's climate system and ocean processes – it is an inherent part of a complex ecosystem (Shokr and Sinha, 2015).

For thousands of years before the events described above (Riewe, 1991), Inuit people had been living alongside sea ice, as they adapted their migrations to nature's seasonal behavior. Their profound knowledge of their environment was transmitted orally from one generation to the next. Their understanding of sea ice was so as to best use it, a perspective quite different from that of scientists and engineers, who did not live in that environment. Inuit knowledge is referred to as *Inuit Qaujimajatuqangit* (IQ), which means *'That which has long been known by Inuit'*[2] *(Karetak et al., 2017)*. While IQ's enabling ability to respond to a relatively stable environment has developed over the course of many generations, in contrast, the impacts of a changing climate have been observed only in the last several decades. Such a short time frame does not allow adaptation via experience.

How do we collectively handle this predicament as we move further into this century? This question may be tackled with the concept of 'Two Ways of Knowing', i.e. "bringing together science and Traditional Knowledge of indigenous peoples to study the Arctic environment" (Inuit Circumpolar Council, 2014). It is with this perspective in mind that an increasing number of studies have been engaging northern communities. This report is meant as a bird's eye view of various elements that this concept entails.

3. Objectives

The objectives of this report are as follows:

- To present general notions on, and examples of, various aspects of sea ice – micro- and macro-features, distribution, seasonal dynamics as well as an example of a study done on sea ice.
- To provide a succinct overview of climate change impact on sea ice.
- To briefly summarize sea ice usage by Inuit communities, and challenges related with climate impact, based on a number of documents written by members of the Inuit communities, and by scientists who were responsive to the concerns of these communities with regards to their environment.

The target audience for this report are mainly scientists, government officials and members of the wider public who are interested in sea ice and its relevance to Northern communities. Inuit may also find this report a helpful reference to bring up a discussion tables.

4. A brief introduction to sea ice

This section provides some basic information on sea ice. We begin with ice formed from non-saline water, i.e. from lakes and rivers – the equivalent of water from a standard household tap.

[2] http://pikialasorsuaq.org/en/Inuit-knowledge

This is referred to as 'freshwater ice', which is compared with ice produced from saline water bodies (oceans and seas), known as 'sea ice', or 'saline ice'. Snow, which is also frozen water, and therefore a form of ice, is brought up. We will also include iceberg ice, which is part of the sea ice environment in many locations – although it is also non-saline, its origin is quite different from that of river and lake ice. In order to best appreciate the differences between these ice types, we will resort to a well-known observation technique – the production of 'thin sections' and their observation in cross-polarized light[3]. This will be followed by a simplified overview of sea ice dynamics and its evolution. One case example is then described: a study of sea ice thickness over time. For the reader's convenience, Table 1 contains definitions associated with common sea ice terms in English. Inuit terminology is extensive – see Segal et al. (2020) for corresponding terms and context.

4.1. Ice formation

Natural ice can grow from water bodies made either from freshwater, as is the case of lakes and rivers, or from seas and oceans. Brackish water, a mixture of both, also exist, for instance where a river mouth opens up to body of sea water.

4.1.1. Freshwater ice

For the bulk of the world's population, which lives at lower latitudes, there is no such thing as natural ice, because the air temperatures are too high. For these inhabitants, the ice cube shown in Figure 1 may be the only form of ice they may ever see (at least, those people that can afford a freezer). Nonetheless, that cube can still convey basic information on the nature of that material. It is cold – its temperature may be at, or anywhere below, 0^{o}C. Unlike other materials[4], it is less dense than water, so it floats. Ice is brittle – it will break into pieces if dropped on a hard floor[5], such that it can be easily crushed in a kitchen blender.

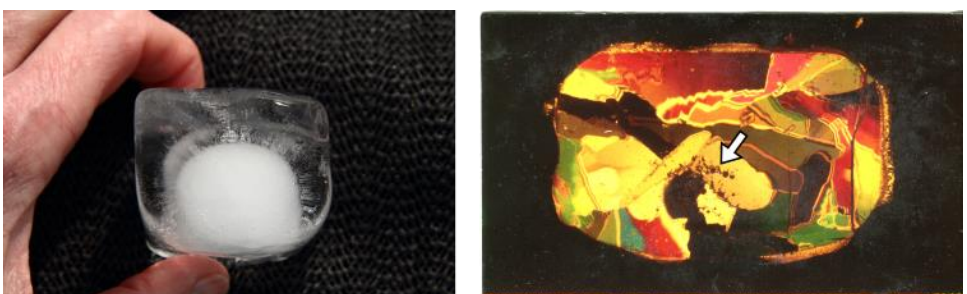

Figure 1: Left) A standard ice cube – the white zone in the center is where tiny air entrapments have developed during freeze-up. Right) Thin section of an ice cube – the various colors are the crystals (the white arrow points to the largest air entrapments – the smaller ones are not visible under these light conditions). The scale at bottom right is in millimeters.

[3] A thin section is made by shaving a slice of ice down to about 1 mm in thickness. It is then observed between two polarizing filters (similar to those used for sunglasses) – the optical properties of ice causes crystals of different orientations to be displayed in different colors.

[4] Two other exceptions are germanium and silicon, both important components in electronics, e.g. semi-conductors.

[5] In comparison, a piece of metal, or other material, close to its melting temperature (e.g. a red hot iron ingot) will dent upon impact.

Table 1: Sea ice terminology – the definitions were drawn from various sources.

Term	Definition
Canopy	Topography along the ice cover's underside.
Drift ice	Ice not attached to the shoreline and free to move mainly due to the winds and tide cycles. Also called pack ice.
First-year ice	Sea ice that formed during the winter of the current year.
Floe	An individual slab of drift ice 20 m or more across – some may enclose ice ridges or iceberg fragments.
Floe edge	Limit between the fast ice and the drift ice, where open water commonly occurs.
Fracture	Break or rupture through an ice cover, which may evolve into a lead.
Frazil ice	Fine ice crystals that develop below the water surface and in large quantities, contributing to the formation of extensive expanses of ice cover.
Iceberg	Drifting fragment of glacial ice, which can be all sizes and shapes, and originate from a glacier or shelf ice.
Ice edge	Synonym of 'Floe edge'
Ice foot	A ring of frozen ice formed as a result of the rise and fall of tides or other motions.
Keel	The underside of an ice feature, namely an iceberg or a pressure ridge.
Landfast ice	Sea ice that is attached to the shoreline.
Lead	Linear open water expanses, varying in width from a few meters to kilometers.
Level ice	Sea ice that has not been deformed.
Multi-year ice	Sea ice that has survived at least two summers.
Old ice	Sea ice that has survived at least one summer.
Pack ice	Synonym of 'Drift ice'.
Pancake ice	Roughly circular features made from ice slush, centimeter- to meter-scale size, with a raised rim as a result of these features bumping into each other.
Polynya	Areas of open water (or recent, thinner ice), generally non-linear in shape and less than a few kilometers in dimension, often found along the coastlines or next to landfast ice.
Pressure (or ice) ridge	Linear expanse of ice rubble produced as a result of interacting ice floes.
Rubble	Fragments of an ice cover broken up as a result of deformation, e.g. from waves or from the interaction between ice floes.
Sail	The part of a pressure ridge that projects upward, above the surrounding water surface or ice cover.
Second-year ice	Sea ice that has survived one summer.
Shelf ice	Expansion of a glacier from the land onto the sea, where it spreads out into a floating ice sheet.

4.1.2. Saline ice

Sea ice, the outcome of seawater freeze-up, occupies about 10% of the world ocean's overall surficial extent (more in the winter, less in the summer), and is found primarily in the Arctic basin and in a belt surrounding Antarctica. A good number of monographs, treatises and scientific articles have been produced about that material. Recent examples from the English literature include those of Wadhams (2000), Dieckmann and Hellmer (2010), Thomas and Dieckmann (2010), Timco (2010), Weeks (2010), Leppäranta (2011), Weiss (2013), and Shokr and Sinha (2015). Standard sea water can be replicated quite closely by dissolving one teaspoon of table salt in about 250 ml (one cup) of tap water.

What is the difference between ice grown from freshwater and that grown from saline water? Figure 2 addresses that question – growth of the same ice crystal 'template' was done in freshwater and in saline water. Note the irregular grain boundaries and the linear entrapments at these boundaries and inside the crystals. The saline ice is made from 'platelets', i.e. elongated zones inside each crystal, which are separated by linear entrapments, known as 'brine pockets'. The reason is that, in addition to air, they contain various chemicals, e.g. mainly sodium and chlorine, with minor amounts of sulphates, potassium, calcium, magnesium and carbon dioxide.

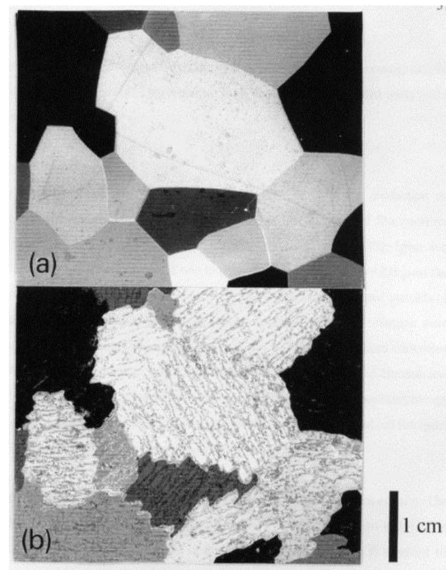

Figure 2: a) Growth of crystals in freshwater. b).Growth of the same crystals in saline water (from Barrette et al., 1993). Scale at bottom right.

4.1.3. Growth process and ice formation

Figure 3 is an example of an idealized ice growth scenario, which is mostly observed in calm waters. The water surface is initially seeded with ice nucleus, here represented by snowflakes, which then proceeded to grow downward. Note that the seeds could also be other ice particles above the water surface; alternatively, they could come from the water itself (known as 'frazil ice'). This scenario typically leads to what is called columnar-grained ice, also called 'congelation ice' (referring to gradual downward growth). It is instructive here again to compare this scenario for ice grown from freshwater with that grown from saline water, as shown in Figure 4. As in Figure 2, the most notable differences are the shape of the crystals and the nature of the entrapments. A more turbulent state of the water will involve more intricate processes, but the columnar-grained congelation ice remains an important component of the overall ice mass. Where the conditions are such that the ice cover is broken up into pieces, overlaps with adjacent expanses, or other interaction processes are involved, this leads to a complex ice structure.

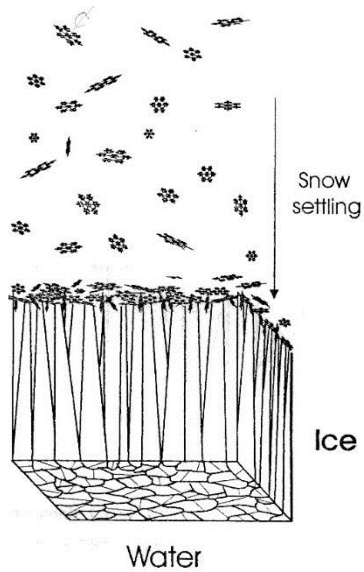

Figure 3: A typical example of one ice growth scenario (there are many others), where the ice surface is initially 'seeded' with snow – that layer then grew downward.

4.1.4. Ice cover melting

As the average air temperature, and the sun's radiation, increase progressively in the spring, melting of ice surface begins and continues throughout the summer (Figure 5). This is known as surface ablation, which leads to the formation of surface melt ponds. These may eventually drain down through the ice into the ocean water below. Melting can also proceed from its bottom surface and edges (where there is open water), because of the warmer ocean water. The relative importance of surface or basal melt of an ice sheet will depend on ocean temperature and air temperature. In some areas, the air temperature remains cold while the water is fairly warm.

4.1.5. Sea ice that survives a melting season

If an ice expanse happens to survive the summer, it will begin to grow and thicken again the next autumn and winter. This is called second-year ice, or multi-year ice if the ice has survived two or more summers. Old ice alludes to sea ice that has survived at least one summer, i.e. it includes second-year ice and multi-year ice. Old ice is typically thicker than first-year ice – it is also mechanically stronger because of the brine drainage from the ice structure that occurs over the summer, leading to lower ice salinity.

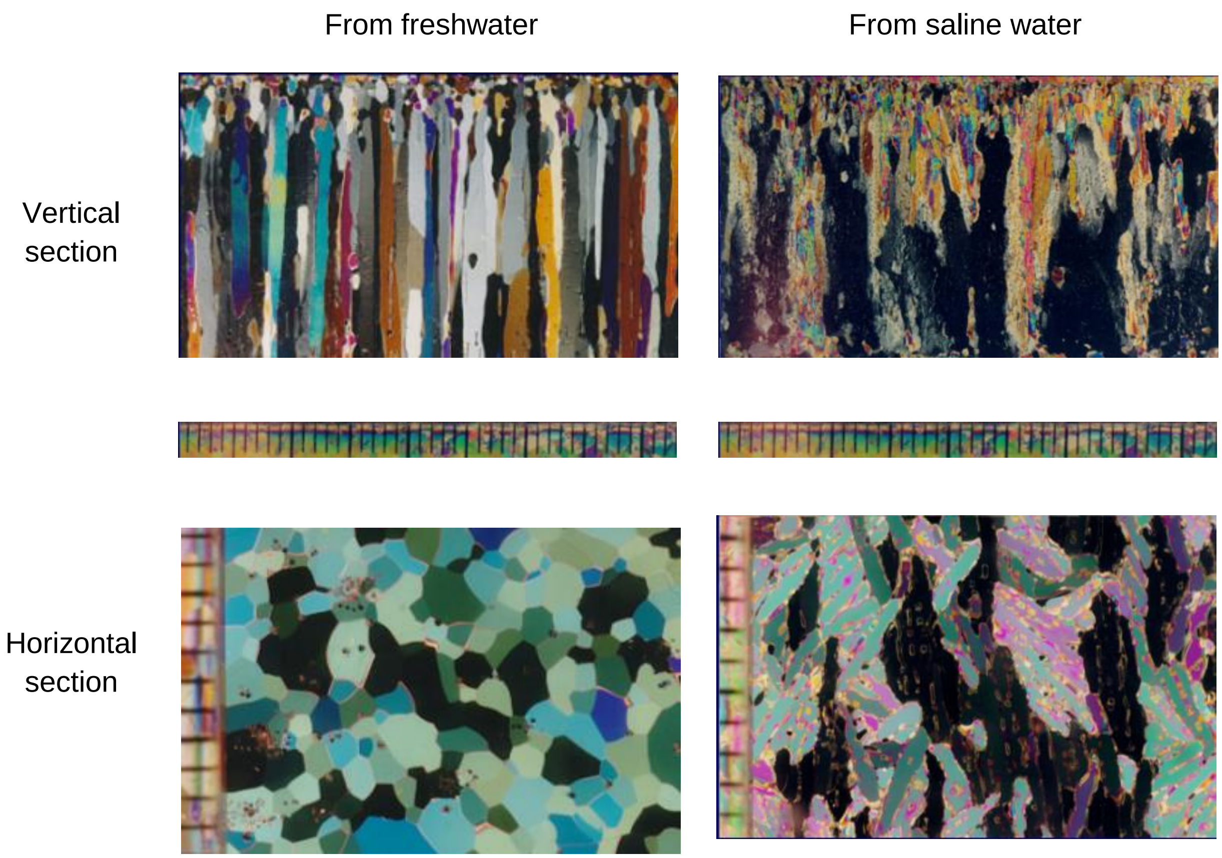

Figure 4: Another comparison of ice grown from freshwater (left) with that grown from saline water (right), in vertical (top) and horizontal (bottom) sections. The scales are in millimeters.

4.2. Snow

Snow crystallizes in air before settling on the ground. Although snowflakes are of all shapes, they all have six branches (because ice belongs to the hexagonal crystal system). These branches are able to grow freely in the open space around them. This is in contrast to ice forming in freshwater or saline water which is, of course, surrounded with water (no branches). Snow is a complex material – it is at a crossing between water's liquid, solid and gaseous phases. As such, it can change in texture very quickly from the instant it settles on the ground. Were it to melt or be rained over, it can refreeze into a strikingly different material. It also compacts under its own weight and recrystallizes. In the Arctic, snow falls can occur throughout the year, even during the summer. Snow thickness is not always excessive; it may be less than half a meter. However, it is prone to redistribution by wind, oftentimes accumulating in areas where the sea ice surface is rough, e.g. at pressure ridges. The snowdrift themselves can have many shapes and consolidation states. Because of its low density, snow acts as an insulation layer (similar to styrofoam): it reduces the ice's growth rate.

4.3. Icebergs

Iceberg ice is a form of freshwater ice. It is the ultimate outcome of snow accumulation on top of glaciers or ice shelves, which turns into ice under pressure and slowly flows downward or spread outward under its own weight. Once a glacier or an ice shelf reaches the sea, it may extend further outward. It then breaks into pieces, a process called 'calving', yielding icebergs or ice island fragments – these are sometimes incorporated in sea ice expanses (an example is shown in Figure 6).

Figure 5. Sea ice fracture and surface melt. Photo: D. Sudom, NRC

Figure 6. Iceberg surrounded by sea ice, Labrador Sea. Source: D. Sudom, NRC

The Greenland ice sheet is the major source of icebergs in the Arctic – they can also originate from elsewhere in the Archipelago, namely from Baffin Island. Many thousands are generated every year. Some may then drift their way west through Lancaster Sound, into the Canadian Archipelago, while others drift southward to Labrador and Newfoundland. Icebergs can tip over without warning, which presents risks to boaters that come too close to large ones. Because of the draft of their keel, these ice features can become grounded as they drift toward shallower waters – that is when they can stabilize. They can then become incorporated into landfast ice.

4.4. Sea ice expanses and dynamics

Sea ice dynamics is very complex – many factors come into play in determining what particular scenario will take place at any location and given time of the year. These factors also determine, at a regional scale, sea ice type, extent and distribution. For the purpose and intent of this report, some generalizations will be made. Figure 7 displays a generic (and condensed) scenario capturing as many sea ice features as possible, for illustrative purposes. Figure 8 and Figure 9 show the contrast between a flat ice surface and an irregular surface, the latter consisting of ice rubble.

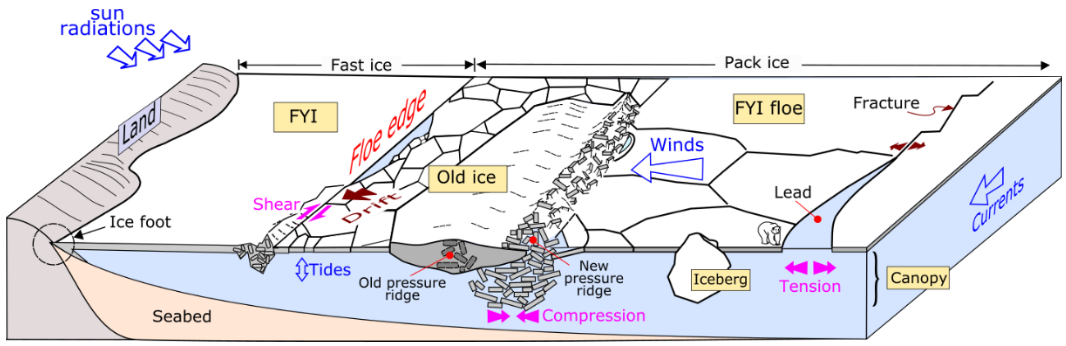

Figure 7: Simplified example of one amongst an infinite number of sea ice scenarios in the Arctic seas (see Table 1 for definitions). The bear provides a sense of scale.

Figure 8. Ice-strengthened ship transiting through a flat ice cover. Source: D. Sudom, NRC

Figure 9. Heavily ridged and rubbled ice, Labrador Sea. Source: D. Sudom, NRC

When ice grows outward from the shoreline (in a similar fashion as it does from river and lake shorelines), it is referred to as ‘landfast ice’. In the sea, landfast ice can eventually, in the course of the winter, extend out several kilometers and achieve a considerable thickness. Beyond the landfast ice edge, which is also called the ‘floe edge’ – *Inuinnaqtun* (Segal et al. , 2020), the sea ice is dynamic. That zone is known as the ‘drift ice’ (or ‘pack ice’) zone, with individual slabs of ice (‘floes’) interacting with each other in various ways. For instance, when two floes are pushed against each other, a ‘pressure ridge’ may result. A shear ridge may developed as two floes pass by each other. The drift ice zone is also where ‘frazil ice’ is generated – these are small crystals that form below the water surface (as mentioned earlier), and may accumulate into ‘pancake ice’, then form floes or even a continuous ice cover. Open water areas typically occur in the drift ice zone, for instance, between individual floes, or where a fracture occurs, which evolves into a ‘lead’, or into a ‘polynya’. Old ice features and icebergs are sometimes incorporated into the drift ice.

Several sources of forcing, i.e. phenomena that exert changes in the environment, affect sea ice. The main ones are as follows:

- *Winds*: Wind drag is an important contributing mechanism to ice drift – a rough ice surface, such as when there are ice ridges, are more exposed to wind action then level ice. At any location, there could be dominant wind directions during the year.
- *Water currents*: Water currents are either regional or local – in the latter case, they can can be driven by the tidal cycles, with a corresponding change in current direction.
- *Sun’s radiations*: These play a role in warming up and softening the ice surface, thereby contributing to melting and the formation of melt ponds.

Overall, sea ice is a complex geophysical material. Such a brief description can only offer a glimpse of that complexity. It does so by capturing, to a small extent, the essence of natural ice in its various forms, and how sea ice can evolve over time, annually or across decades. As mentioned later in this report (and summarized in the appendix), there is a clear difference in the standpoints of scientists and of Inuit. For the former, sea ice is a topic of study, based mostly on observations acquired remotely (namely via satellite), ultimately aimed at a comprehensive understanding of processes. For the Inuit, sea ice is a traveling platform used in day-to-day living, at a local scale, it is deeply ingrained in their culture, and safety is paramount. As climate change impact, in its various manifestations, gets progressively more disturbing, the need for integrating everyone’s standpoint is becoming more pressing.

5. Climate impact on sea ice

A lot of material has been written on the impact of a changing climate on sea ice, and it remains a vibrant research field (e.g. Tivy et al., 2011, Strong and Rigor, 2013, Comiso et al., 2017, Loewen, 2020, Squire, 2020). Until now, our knowledge-base has been obtained in several ways, namely by scientists spending a given amount of time (days to weeks) on the ice or on-board a ship, so as to collect data of various nature. In more recent times, much of the information on sea ice has been gathered via satellite sensors that capture imagery or remotely sense ice presence and attributes. Various sources (e.g. governmental bodies, and international collaborative research centers) disseminate vast quantities of information about environmental parameters, such as temperature, humidity, wind patterns, tidal cycles, ocean circulation and sun radiations. Computer modelling has become a tool of choice in bringing together a lot of that information. This represents a means of testing out the theoretical basis that has been developing over the last number of decades on the interaction at different scales between ocean, ice and atmosphere.

So as to briefly summarize the relevant information, we will draw on a recent report entitled *Canada in a Changing Climate: Advancing our Knowledge for Action*, by Bush and Lemmen (2019).

5.1. Global warming and climate change

‘Global warming’ and ‘climate change’ are two different, albeit related, concepts. Global warming is a term used to designate the temperature increase of the Earth’s system since the pre-industrial age, in the mid-18th century. At that time, societies began to extract fossil fuels (coal, hydrocarbons, natural gas) from the ground and use it to feed combustion engines and other such technological developments. The reason for warming is as follows. The atmosphere is mostly composed of nitrogen (78%) and oxygen (21%), with minor amounts of other components, namely CO_2, water vapor (H_2O), methane (NH_4), ozone (O_3) and nitrous oxide (N_2O). These minor components are collectively referred to as ‘greenhouse gases’ because of their ability to absorb infrared radiations emitted by the Earth’s surface, thereby trapping heat in the atmosphere. *This is a natural process* – the temperature that is thus achieved is high enough to support life on the planet, i.e. it raises the Earth’s mean surface temperature from about −16°C to about +15°C.

However, the burning of fossil fuels generates additional greenhouse gases – CO_2 being the most abundant – which causes additional heating, currently estimated at about 1ºC above pre-industrial level. This appears rather small but it has key consequences on the temperature distribution over the Earth’s surface, air circulation, precipitation, and a number of other phenomena. *This ultimate outcome is called ‘climate change’*. Note that such warming events occurred several times across the geological ages. What is happening today, however, affects a large human population; it is also ‘self-inflicted’.

Climate change is defined by Bush and Lemmen (2019) as *“[a] persistent, long-term change in the state of the climate, measured by changes in the mean state and/or its variability*”. This encompasses an increase in the frequency, intensity and duration of climate and weather extremes. The impact of climate change manifests itself in a number of ways, namely temperature, precipitation (rain, snow), sea ice extent, freshwater availability and sea level. Although flooding is an important concern, it is due to a combination of factors, which “makes projecting future changes in these events very challenging” (Bush and Lemmen, 2019, FAQ 6.1). In the following, only changes in temperature and sea ice are brought up.

5.2. Temperature changes

Warming has not been uniform across the Earth’s surface. In general, it is strongest at high northern latitudes and over land (as opposed to over oceans). Canada is a northern country and has a large landmass. Also, the progressive loss of snow and sea ice reduced the surface reflectivity and, as a consequence, the surface absorbs more energy. As a result, warming across our country has been about twice the global average. Figure 10 illustrates the change in distribution of annual air temperature between 1948 and 2016. This figure displays an increase from 0.5ºC in the east to about 3.5ºC westward, with the maximum in the north-west. The greatest warming is thought to have occurred in the winter. Further warming is expected overall, but its extent will depend on our ability to control the emission of greenhouse gases, known as 'climate change mitigation'[6]. This is shown in Figure 11, where the annual temperature change over Canada, for each year from 1900 to 2100, is indicated. That change is relative to the 1986-2005 period, which is used as a baseline. Note the difference in temperature increase predicted by a low and a high emission scenario, i.e. whether or not we can reduce emissions.

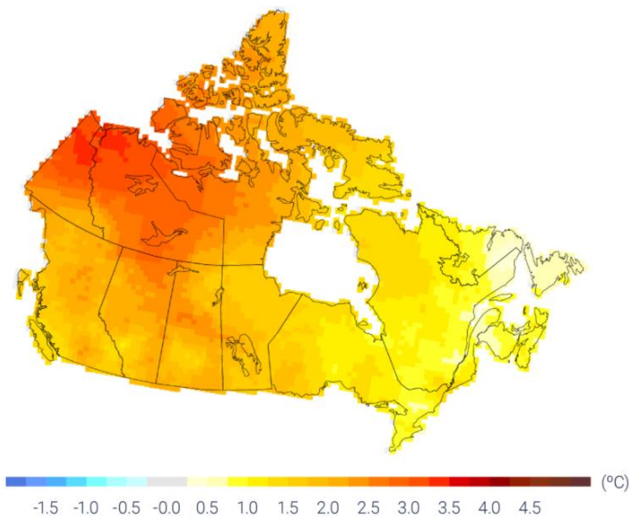

Figure 10: Changes in annual air temperature in Canada (deg. C) observed between 1948 and 2016 (Bush and Lemmen, 2019, Fig. 4.3).

5.3. Sea ice

As a result of climate change, summer sea ice in area across Northern Canada has been steadily decreasing, at a rate 5% to 20% per decade since 1968 (
Figure 12, Figure 13). That decline in extent also applies to multiyear ice. Currently, "[t]he consensus from climate models is that a summertime sea ice–free Arctic could be a reality under a high emissions scenario by mid-century" (Bush and Lemmen, 2019, FAQ 5.1). In addition, perennial sea ice, i.e. that which never melts, has been progressively replaced with thinner seasonal sea ice. This is shown in Figure 14, which illustrates the probability of achieving open water conditions by 2050. Note that, for Coral Harbour in Hudson Bay, our earlier analysis already indicated ice-free conditions in August and September. This means that no fast ice is present along the coast in those months, although drift ice may still occur.

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[6] There is an important distinction between 'climate change *mitigation*', which is about reducing emissions at the source, and 'climate change *adaptation*'. Adaptations are means of reducing the negative effects of climate change, or realize positive effects, so as to minimize risks.

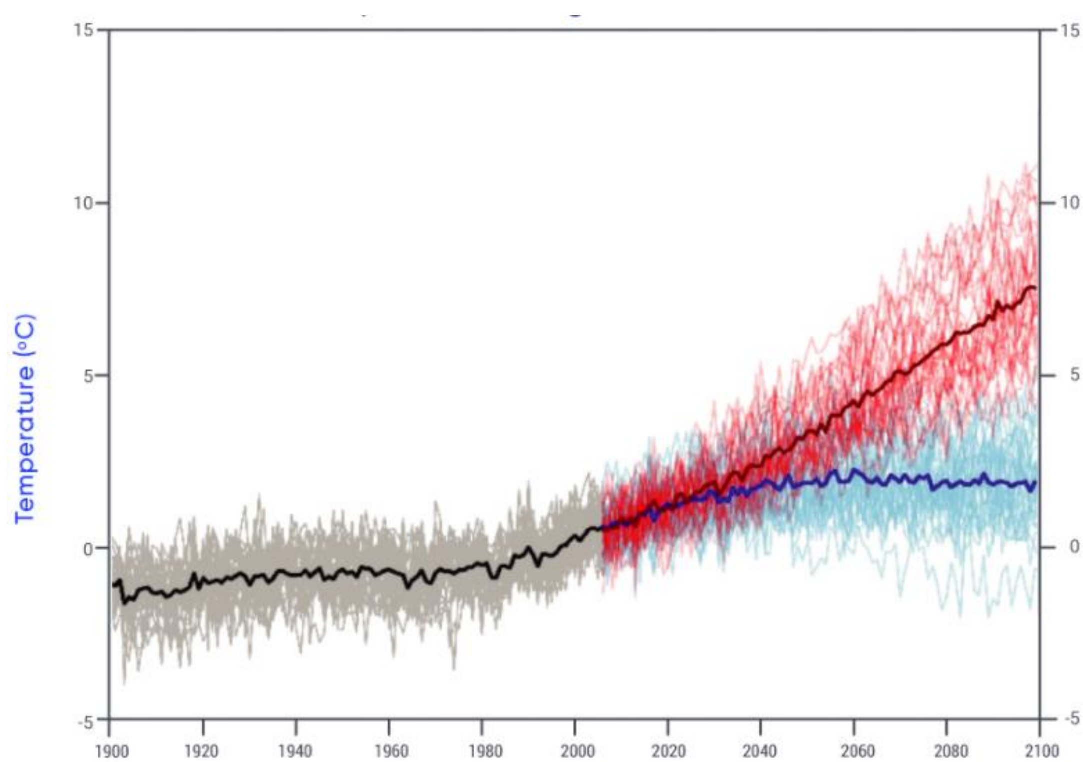


Figure 11: The temperature changes from 1900 to 2100 in Canada (Bush and Lemmen, 2019, Fig. 4.8). The grey trace is the observed temperature, the blue and red lines are predictions for a low and a high emission scenario, respectively.

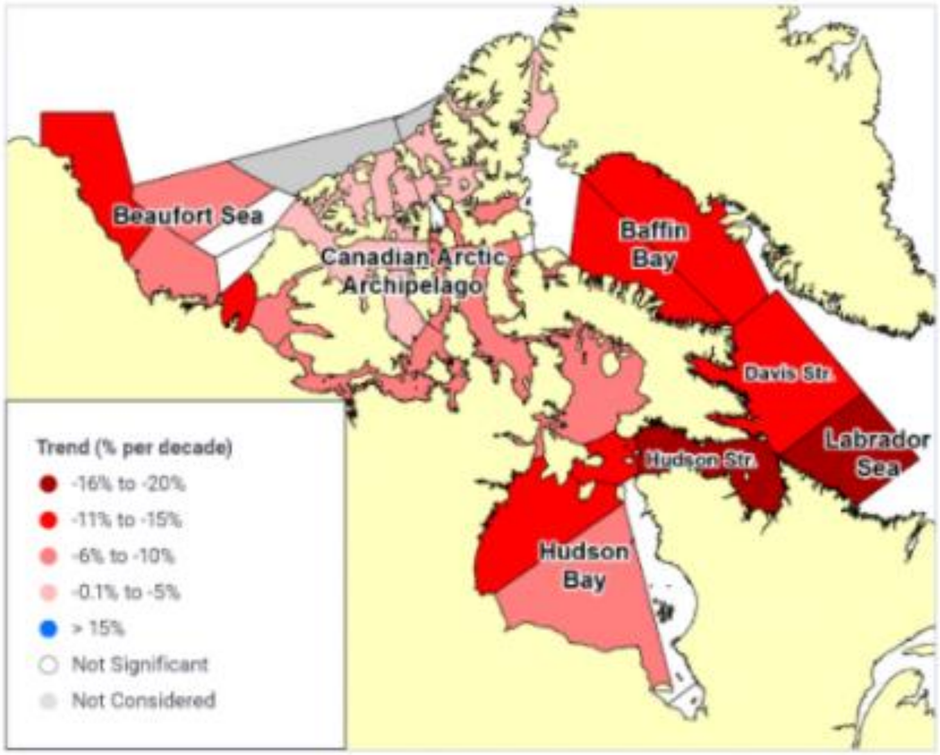


Figure 12: Variation ('Trend') in sea ice summer extent from 1968 to 2016 (Bush and Lemmen, 2019, Fig. 5.7).

A reduction in sea ice extent also means waterways become navigable to ocean freighters. To a large extent because of this (though also because of technological advances), the historical navigation barrier is becoming progressively more surmountable. Both the North West and the North East passages are open in some years (Dieckmann and Hellmer, 2010). This has implications for climate and ecosystems, and for the inhabitants of the North, as it constitutes a threat to the Inuit way of life, to Arctic mammals and birds. Efforts are underway to make Inuit people more aware of vessel traffic. The Enhanced Maritime Situational Awareness (EMSA)[7] system is an example. The system, accessible via an easy-to-use web-based platform, is meant to increase marine safety, to promote environmental protection and to facilitate accessibility to space-based data.

[7] https://tc.canada.ca/en/marine-transportation/navigation-marine-conditions/enhanced-maritime-situational-awareness-initiative-pilot-projects

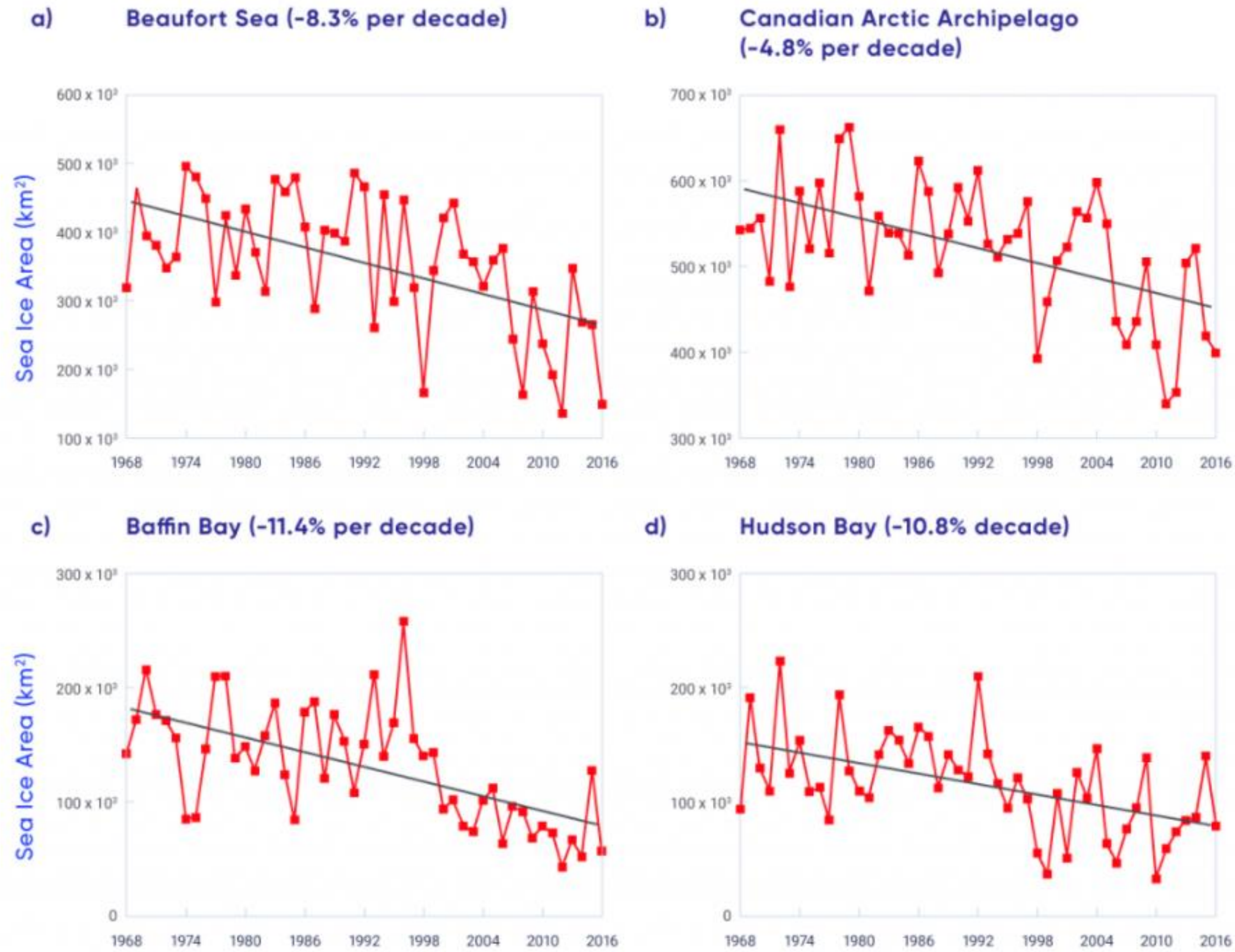


Figure 13: Sea ice area during the summer from 1968 to 2016, for a) the Beaufort Sea, b) the Canadian Arctic Archipelago, c) Baffin Bay, and d) Hudson Bay (Bush and Lemmen, 2019, Fig. 5.8). The area is decreasing in all cases.

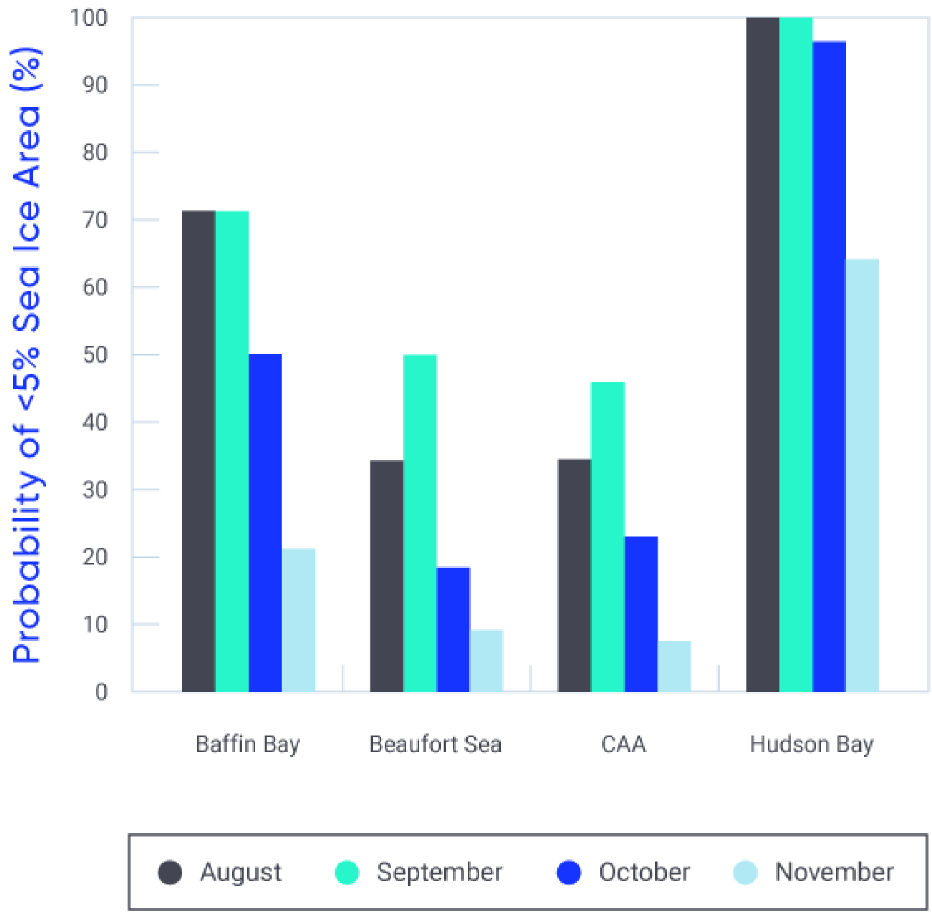


Figure 14: Probability that open water conditions will exist in from August to November 2050 in Baffin Bay, the Beaufort Sea, the Canadian Arctic Archipelago (CAA) and Hudson Bay (Bush and Lemmen, 2019, Fig. 5.11). This is under a 'high emission' scenario.

5.1. Thinning ice in the Arctic – Example of a study

For the purpose of this report, a succinct example of a study on sea ice is provided here. In that study (from Sudom et al., 2020), first-year ice thickness measurements in the Arctic were compiled and analyzed, to check for variations over a period of 60-70 years. These measurements were made at different locations, including Alert, Cambridge Bay, Coral Harbour, Eureka, Hall Beach, Iqaluit and Resolute. Measurements for Coral Harbour are presented as an example. Figure 15 shows the evolution of thickness for all years compiled into one plot – the maximum thickness is from May to June. Figure 16 shows the maximum thickness achieved at each year – a slight reduction in thickness (0.1 m) over the full time range is noted, similar to that observed at other locations. For each year of all the seven locations, the mean maximum thickness for three year ranges – 1950-2000, 2000-2010 and 2011-2016 – was determined, and is plotted in Figure 17. A decrease ranging from 0.05 m to 0.2 m is observed over the three age ranges.

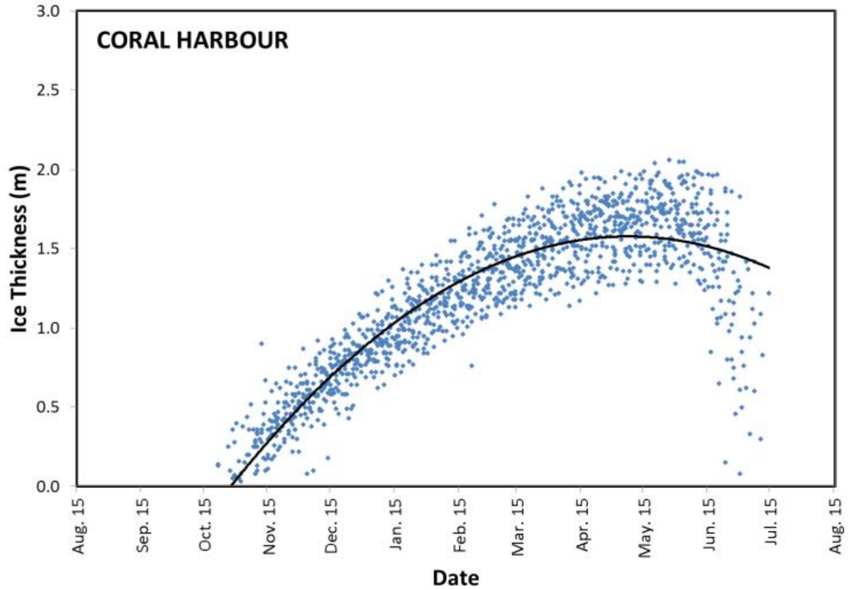


Figure 15: Seasonal variation of ice thickness from 1958 to 2016, collected at Coral Harbour in Northern Hudson Bay – each data point corresponds to one measurement taken over all years, and the trend line is a best fit (Sudom et al. , 2020).

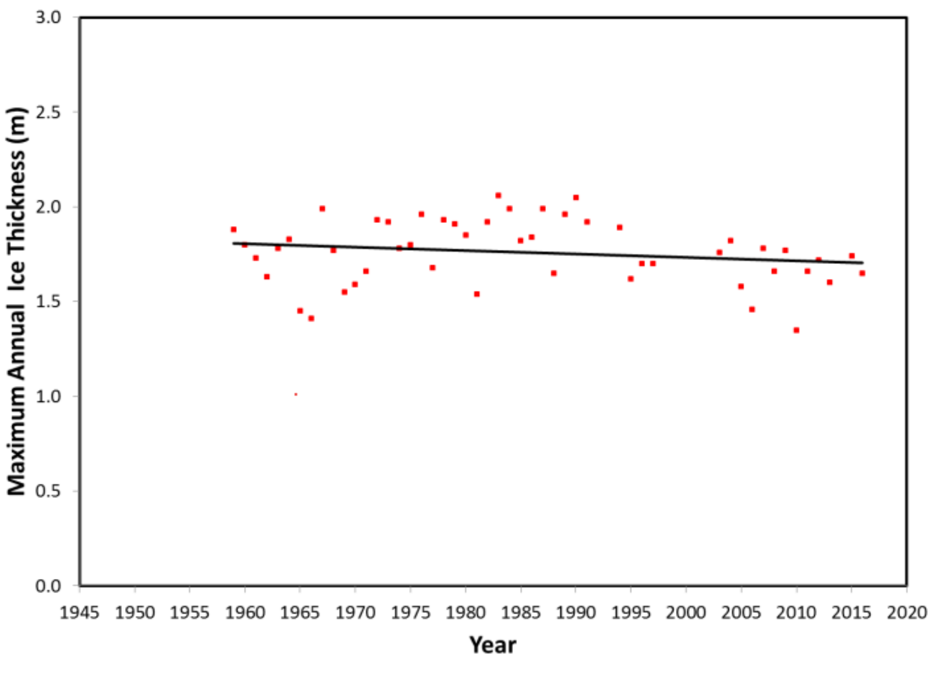


Figure 16: Maximum ice thickness measured every year at Coral Harbour – the trend line suggests a slight decrease over time (Sudom et al. , 2020).

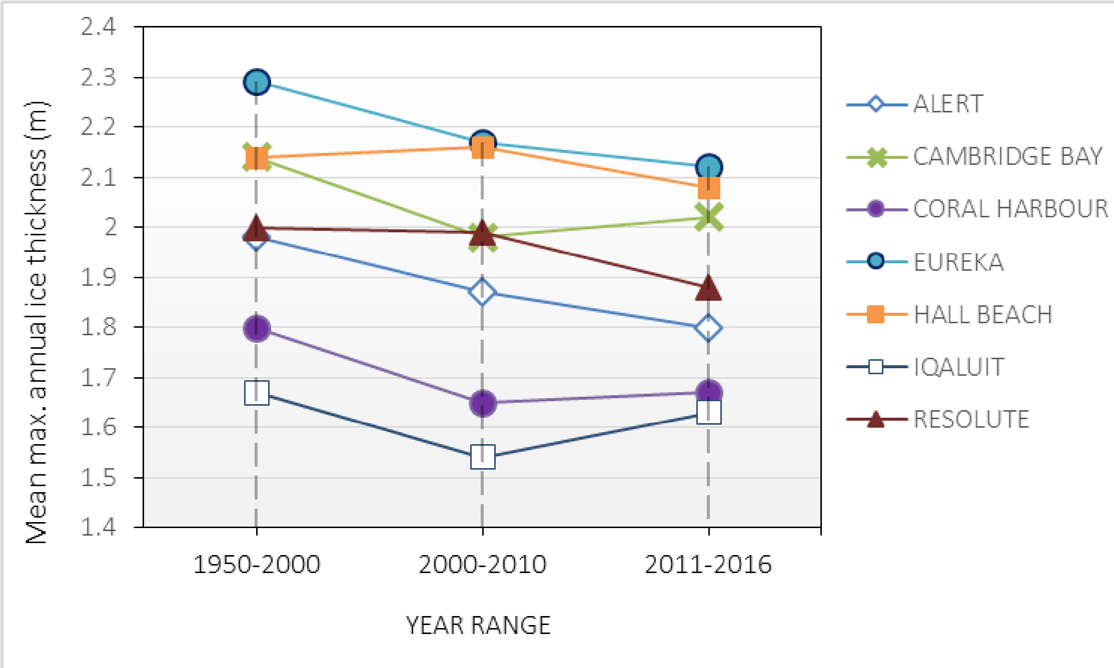


Figure 17: The maximum ice thickness averaged over time ranges, and plotted for each location (data from Sudom et al. , 2020).

6. The Inuit and sea ice

Inuit Nunaat ('land, sea and ice'), refers to the Inuit's home in the circumpolar world (Figure 18). It includes Greenland, Northern Quebec, Nunavut, Alaska and the coastal regions of Chukotka in Russia (Inuit Circumpolar Council, 2014). The term 'land' in this context represents both the solid ground and the sea ice as surfaces over which the Inuit travel, hunt and live. The Inuit Circumpolar Council (ICC) speaks on behalf of 160,000 Inuit living in that territory, "united as single people" (Inuit Circumpolar Council, 2014). Canada is home to about 65,000 Inuit, most of whom are in Inuit Nunangat, which comprises four regions: Inuvialuit Settlement Region (Northwest Territories), Nunavut, Nunavik (Northern Québec), and Nunatsiavut (Northern Labrador)(Figure 19). Inuit Nunangat represents roughly 35 percent of Canada's landmass and 50 percent of its coastline (Inuit Circumpolar Council, 2014). It is considered a young population, i.e. its median age is 23. It is also increasingly urban – for example, there are 3000 Inuit in Ottawa alone.

Figure 18: World geographical extent of Inuit Nunaat (Inuit Circumpolar Council, 2014).

Inuit used to have a semi-nomadic lifestyle – they traveled on the land and sea, following wildlife and seasonal patterns. Traveling was a way of life just as much as a way to go places – camps would be established on the ice for much of the spring season. In the mid-1900's, they settled into permanent communities and, doing so, they became constrained by imperatives such as schooling and formal employment (along with a large number of challenges)(Aporta, 2009b, Karetak, 2017b, Tester, 2017). Inuit Nunangat now includes 53 small, remote communities, the large majority of which are located on coastlines and shorelines of major waterways in the Arctic, allowing easy access to the sea. The economies of most communities are a mix of wage employment, administration, municipal services, arts and crafts, tourism, and resource extraction, namely with the mining industry (Pearce and Smit, 2013). The Inuit culture is said to be the most resilient in North America. For instance, they still rely on local country foods as they always have. A significant proportion of its population is able to converse in their language.

The Inuit Tapiriit Kanatami (ITK)[8] is the national representational organization for the Inuit in Canada. This organization is dedicated to protect and advance the rights and interests of Inuit in Canada – it maintains activities on various fronts: research, advocacy, public outreach and education.

[8] https://www.itk.ca/

Figure 19: Inuit Nunangat and the four Inuit regions inside that territory.[9]

In order to better understand Inuit's perspective on the impact of a changing climate on their lifestyle, several studies have gathered information directly or indirectly from Inuit communities on the various aspects of sea usage, including observations on the environment that are linked to a changing climate (Nickels et al. , 2005, Laidler, 2006, Laidler et al. , 2009, Pearce and Smit, 2013, Ford et al., 2019, Dufour-Beauséjour, 2020, Segal et al. , 2020, Atter, 2021, Inuit Tapiriit Kanatami, 2021).

This section draws on the above-mentioned studies – note that the evidence reported during these engagement exercises is usually site-specific. A brief review is given on way of life in Inuit Nunangat, with particular reference to the food system, its vulnerability, and the role that sea ice plays in making that system viable to communities.

6.1. The food system in Inuit Nunangat

The Inuit food system in Nunangat is unlike any other in Canada because in addition to grocery store food, i.e. what the majority of people in southern Canada rely on, it is also based on country food, i.e. that which is harvested from the land and the sea (Pearce and Smit, 2013, Durkalec et al. , 2015, Inuit Tapiriit Kanatami, 2021). This food is at the core of Inuit culture and identity; it is also an essential dietary component. It is obtained through hunting, whaling, fishing and gathering. The primary resource includes sea mammals (e.g. seals, walrus, whales), land

[9] https://indigenouspeoplesatlasofcanada.ca/article/inuit-nunangat/

mammals (e.g. muskox, caribou) and fowl (e.g. ptarmigan, geese, ducks and their eggs), a large variety of fish, shellfish and seaweeds, as well as a variety of berries. Sea ice plays a central role in accessing these resources. For instance, it is used by seals for resting, pupping, molting and feeding (Harwood et al., 2000). Other species – the walrus, the narwhal, the beluga – are found at the ice edge (Pearce and Smit, 2013).

Traveling on the ice requires different skillsets than traveling on the land, such that some hunters may specialize in one or the other (J. Karetak, writt. comm. 2021). Harvested foods, it is said, "are an essential component of [Inuit's] physical and mental health, well-being, and spiritual sustenance and are demonstrably superior in nutritional value and quality" (Inuit Tapiriit Kanatami, 2021). Resource harvesting is largely subsistence-based , i.e. it is mostly used to feed the hunter, his household and the community – it is quality food and the mainstay of their nutritional intake (Laidler et al. , 2009). These harvesting activities also contribute to the local economy, since items such as hides, skins, bones, tusks and antlers are used for clothing, crafts and art. Food sharing plays an important role in Inuit culture – it perpetuates emotional and social bonding (Pearce and Smit, 2013). It may also help households that do not have the time, skills, knowledge or equipment to feed from harvesting activities (Laidler et al. , 2009).

Commercial harvesting is also done in Inuit Nunangat, mostly by Inuit, resulting in a sizeable volume of food that is shipped out to markets abroad (Inuit Tapiriit Kanatami, 2021). Shrimp, halibut and Arctic char are some of the main exported products. Part of the catch is also commercially processed and sold directly to consumers.

Store food is shipped into the communities by air all year, and via sealifts during the ice-free months (with the exception of two communities, which have access to the road system)(Inuit Tapiriit Kanatami, 2021). These goods are handled 3 to 4 times more often than in the south before making it to the store shelves. Because of these factors and a number of others, prices can be several times that for the same product elsewhere in Canada. Access to store food remains important, given the current social and climatic context, as discussed later, and under specific circumstances, such as in the autumn, before the sea ice gets thick enough to travel on (Laidler et al. , 2009). A reduction in harvesting activities due to limited access or other reasons means the community has to rely more on store food, a lower quality, less healthy alternative, which has important repercussions on Inuit health (see also discussion in Nickels et al. , 2005).

6.2. Addressing food insecurity

The indigenous population in Canada is particularly prone to food insecurity – its prevalence is the greatest amongst Inuit communities (Huet et al., 2012, Dachner and Tarasuk, 2018)(Figure 20). According to Inuit Tapiriit Kanatami (2021), this issue is said to be the most severe amongst any indigenous people in a developed country. It is exacerbated in lower income households, i.e. in order to meet their volume requirement, they will sacrifice the more expensive quality items in favor of high sugar foods (Huet et al. , 2012, Inuit Tapiriit Kanatami, 2021). This leads to malnutrition and the consequences thereof, e.g. obesity, diabetes, heart diseases and hypertension. Harvesting activities are key to remedy to this problem. But they face three challenges (as discussed in Pearce and Smit, 2013):

- *Access*: This is the ability to safely reach the areas where these activities take place, which is made possible by the presence of a sea ice cover in the winter. In the short open water season, boats are used for transportation.
- *Availability*: The availability of the resource, e.g. the number of seals or caribous, the amount of berries, etc., translates into a successful harvest.
- *Quality*: This can refer to the health of the animals that are being hunted, and also to the availability of adequate storage, e.g. freezers.

This report is mainly concerned with the first challenge – access, which is done during much of the year using sea ice as a transportation platform. Sea ice allows Inuit access to harvesting grounds not only from the sea but also on the land (e.g. caribou hunting, lake fishing), in cases where the hunters have to cross a bay or a strait, or if their community is on an island (Laidler et al. , 2009). Not all communities are close to favorable harvesting locations – some have to travel more than others. For instance, a lower prevalence to food insecurity has been reported in households having an active hunter (Huet et al. , 2012).

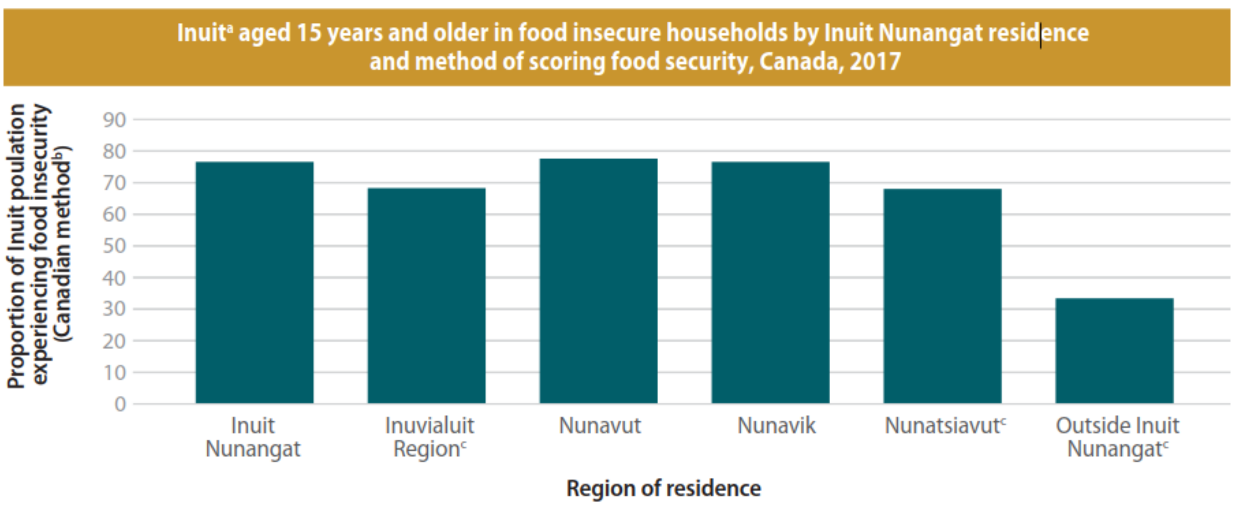


Figure 20: Food insecurity in Inuit Nunangat (Inuit Tapiriit Kanatami, 2021). [a] Inuit refers to individuals who identified only as Inuk (Inuit) or who identified as Inuk (Inuit) with other Indigenous identity(ies).[b] In addition to combining "low food security" and "very low food security," the Canadian method also includes "marginal food security" in the prevalence of food insecurity. [c] Significantly different from reference category, 95% confidence levels do not overlap.

6.3. Working with sea ice

In the Arctic, July and February tend to be the warmest and coldest months of the year, respectively. Access to sea ice, which can depend on the 'freeze-up' period (when the landfast ice begins to establish itself into a traveling platform), is in October, while break-up is in late July to early August (Laidler et al. , 2009). Inuit description of sea ice evolution incorporates many processes, e.g. 'freezing processes', 'near shore freezing', 'open water freezing', 'sea ice thickening', 'tidal cracks', 'melting processes', 'snowmelt', 'water accumulation and drainage', 'break-up', 'cracks-leads' (Laidler and Elee, 2008). Five phases of formation are recognized: 1) early ice formation, 2) development of landfast ice, 3) development of floe edge ice, 4) spring cracks; and 5) break-up (McDonald et al.,1997, in Laidler, 2006). There are also a number of sub-phases, each corresponding to particular processes.

Although ice travel may be all winter long, spring is when most of it is done. From an operational perspective, the sea ice is divided into 'stable' and 'moving' – these generally correspond, to the landfast ice and the drift ice zones, respectively (Laidler, 2006, Aporta, 2009a). Hunting activities take place on either or both, depending on location. For instance, seals are mostly found on landfast ice, while walrus are on drifting ice, next to open water expanses. However, landfast ice is where the majority of the traveling takes place, namely to reach the drift ice zone (the floe edge), but also, at least traditionally, where the living is done. The stable ice, referred to as *tusartuut*, literally means 'hearing' news from other camps, because this is when visits to other communities can be done (Inuit Circumpolar Council, 2014).

Seal hunting can be done over seal holes in the landfast ice, once spring comes around, as the animals rest on top of the ice next to their holes. Alternatively, it can be done at the floe edge.The distance from the shoreline to the floe edge can vary from a few kilometers early in the winter, to several kilometers later on. It is mostly accessed with snowmobiles, although dog sleighs and all-terrain vehicles (ATV) in the spring are also used. Air temperature, snow, wind and ice ridges are all factors that matter in these activities. New ice growth, after an opening (e.g. from the action of winds and tidal currents at the floe edge), presents risks. An adequate understanding of these conditions, and the ability to identify these zones, is critical to avoid breakthroughs. This is an important driver for implementing adequate youth training and guiding data collection in these Northern communities (S. Tagalik, writ. comm., 2021).

Because of its dynamic nature, venturing onto the drift ice can be more dangerous. A major consideration is that of being carried away on a floe that suddenly detaches itself from the stable ice (a process referred to as *uukkaqtuq*). This dynamics, however, can normally be predicted by experienced hunters, based on an understanding of prevailing winds and the currents, the latter being associated with the tide cycles. These are the two main factors that influence this dynamics (Laidler and Elee, 2008, Aporta, 2009a, Laidler et al. , 2009, Pearce and Smit, 2013, Inuit Circumpolar Council, 2014). If the wind blows toward the floe edge, it would push the moving ice against it, thereby facilitating access. If it blows in the opposite direction, then access is compromised, unless the current, the second factor, is favorable (Laidler et al. , 2009, Karetak, 2017a). Either way, minimizing the length of stay on moving ice is considered a safe measure.

The wind is helpful to predict where open water occurs, and also to anticipate the weather. Aporta (2009a) mentions that the Inuit of Igloolik identified four primary winds: *uangnaq* (WNW), *kanangnaq* (NNE), *nigiq* (ESE) and *akinnaq* (SSW). The current can be observed through holes made where ice is thinner. The moon phases can also help anticipate currents, i.e. a full moon or no (new) moon is associated with stronger currents.

These factors, the combination thereof, as well as others, such as the behavior of marine mammals, the 'sound' of the ice, and snow drifts, individually or collectively, is what allows experienced travelers to understand and anticipate sea ice behavior. For instance, the combination of factors can cause freezing rates to vary, with consequent thinner ice in places (*nigajutait*), which have to be identified and avoided. Moreover, as summarized in some detail by Laidler et al. (2009), tidal cracks are features that offer advantages but also present risks. They are often the site of seal breathing holes (because of the thinner ice at these locations) and hence constitute a choice hunting ground. The chances of landfast ice breaking off the floe edge and moving away from it are higher in the coldest months, since these events at that time of year are more common. The moon position here again provides guidance in that regard because of its link with tidal action.

Higher temperatures late in the spring causes melt puddles, at which time the ice cover begins to wear out unevenly, and the water hides opening in the ice, such as new cracks that may turn into leads (*aajurait*)(Figure 21). Many other such situations exist, which the traveler and hunter need to be aware of.

Figure 21: Inuit hunters working on a catch. Note the melt puddles – this picture was taken near Arviat, Nunavut, in the month of June. Source: James Tagalik

This overall knowledge, which is part of IQ, has been communicated from one generation to the next over the centuries, via practical engagement with the environment, and as of today, it is still instrumental in maximizing safety and improving the chances of successful hunting activities. This is especially the case for access to wildlife habitats that happen to be in riskier zones. Because sea ice is in constant evolution, new information is shared between hunters in town, or on the move over short-wave radios (Laidler, 2006).

6.4. Trails

A trail is essentially a path used by a traveler to go places and access hunting grounds. Depending on the time of the year, trails go over land, ice and/or water (e.g. Ford et al. , 2019). On an expanse of sea ice, a trail may be just a track in the snow, which is used by travelers on snowmobiles and dog sleds (Figure 22, Figure 23). They are used from year to year, at times for distances in the hundreds of kilometers, for hunting activities, to socialize and to exchange goods (food, gas, tools, etc.).

Figure 22: A 'trail' can be as inconspicuous as a set of sleigh traces on an ice cover. Source: James Tagalik

Figure 23: Looking at ice thickness near Makkovik in mid-March[10].

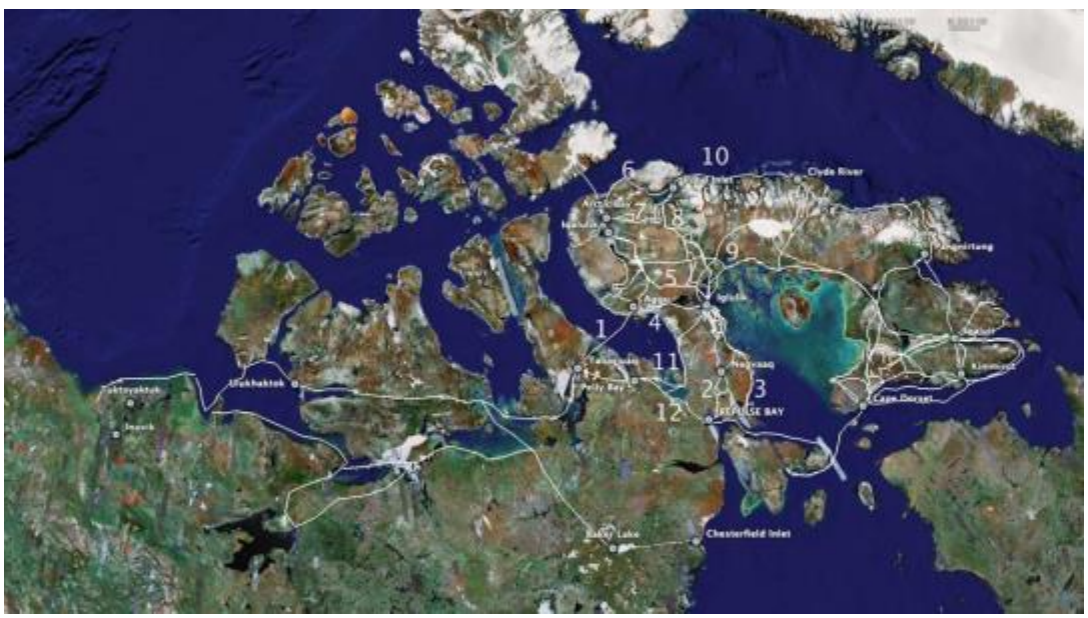


Figure 24: Pan-Arctic network of trails (Aporta, 2009b), here numbered for reference purposes. Some may not be as reliable as others, and may be used as a back-up option if the usual route is not feasible.

[10] https://www.cbc.ca/news/canada/newfoundland-labrador/labrador-nunatsiavut-sea-ice-1.5951551

Networks of trails in the Arctic are the backbone of travel over land and sea in the winter ice (Aporta, 2009b, a)(Figure 24). The trails are more of a spatial notion than a physical one. They disappear every year, or can be covered with snow drift during the winter. Although ephemeral as a structure, they are permanent in location, i.e. it is their location, not the trail itself, that is permanent, and which has been transmitted orally throughout generations. As Aporta (2009b, p. 136) points out, "[i]t is, indeed, possible to speculate that this network of trails played a role in helping Inuit spread news, and share language, cosmologies, and material culture across the Arctic." Place names are used for this purpose: landmarks, such as the shape of a hill, but also 'ice marks', such as sea ice features (ridges) that recur year after year, even in the drift ice zone. Wind direction, hunting and fishing grounds, berry spots are other features that are used as a means of communicating the location of the trails to travelers from other communities. While the networks evolve, with new names, some routes and place names have lasted several generations.

These networks are well known to the communities. They embody the principle of 'moving as a way of living', inherent to Inuit's cultural identity. That reality has evolved to incorporate new elements, such as snowmobiles, watches, GPS (global positioning systems), VHF (Very High Frequency) two-way radios and communication satellites.

7. Climate impact on usage of sea ice

7.1. Changes in natural patterns

Traveling on sea ice has never been without risks – these have been known for a long time, and the Inuit have learnt to manage them. However, in the last few decades, new challenges have arisen, which are attributed to climate change (e.g. Pearce and Smit, 2013). A combination of scientific evidence as well as ample field observations by Inuit, point out to a number of factors. The more commonly acknowledged ones, depending on location and time of year, include: a general increase in air temperature, thinner ice, less (or more) snow, the more frequent freezing of polynyas (or new ones, sometimes larger), less (or more) old ice (which, in turn, affects current patterns), an increased frequency of freezing rain and storms, changes in wind strength and directions, increased intensity of solar radiation and ocean swells. Because all these changes have been occurring over a short time span, i.e. in the order of decades, they are not understood, and are thus difficult to anticipate.

During their consultation exercise with the community members of Igloolik, Laidler et al. (2009) grouped the issues reported by the interviewees into six classes:

i. Processes associated with freeze-up and break-up of the ice cover as well as the timing at which they occur;
ii. Observations related with the thickness of the ice;
iii. The position of the floe edge, for instance, with respect to the community;
iv. The dynamics of old ice and the moving ice, for example, its ability to accelerate the establishment of an ice cover and to stabilize it or, conversely, to promote ice

accumulation and consequent thinner ice below (because of the snow's insulating properties);

v. Changes in weather patterns, namely wind and seasonal temperatures, as well as lower predictability;

vi. Wildlife – availability and health of the animals.

7.2. Predicting the environment

Northern communities generally agree that anticipating the weather has become increasingly difficult (Figure 25). The traditional weather and navigational cues are not as reliable (cloud formation, shifts in wind directions, animal behavior), i.e. these indicators are still observed but they are no longer consistent and/or the weather patterns expected from them (what the traveler reads) no longer coincides with what is actually occurring. As mentioned above, this increases the risks for traveling on the ice, either real or perceived (lack of confidence).

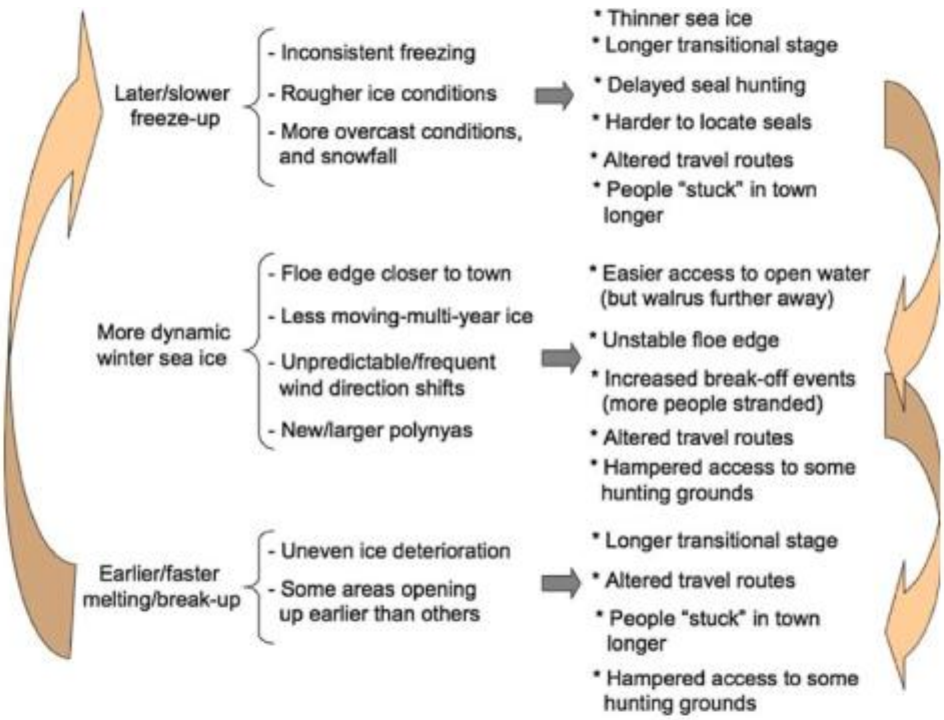


Figure 25: A summary of observations collected by Laidler et al. (2009) – this is their Figure 3 – while engaging with community members in Igloolik, namely hunters and elders. Reported changes in sea ice behavior are shown at left, and their adverse consequences on traveling and hunting activities are shown at right.

7.3. Impact on day-to-day living

Further to what has been mentioned above, following is a listing of consequences on day-to-day living, related with the changes in climatic patterns and in the overall sea ice (Figure 25):

- The start of the hunting season is delayed in autumn because of late freeze-up, e.g. a November start (or later) instead of October. Earlier break-up in the spring is also reported.
- More people are getting stranded on the ice, for instance because of unpredictable shift in wind patterns, storms or unexpected floe edge break-off.
- Stronger winds prevents travel, for safety reasons.
- A rougher ice surface makes traveling more hazardous and/or complicated, e.g. zigzagging across the terrain to avoid thinner ice; it is also more difficult to locate the seals.
- Less snow can make travel on snowmobiles more difficult. This may also preclude the construction of igloos.
- Melting of the ice surface occurs below the snow layer, such that while the conditions look favorable for travel on the snow, they are not because the snowmobiles sink in and become stuck in the slush.
- Bouts of mid-winter freezing rain are now observed, or becoming more frequent.
- There is an increase in the number and unpredictability of landscape hazards, which results in more damage to (or loss of) vehicles and equipment.
- The reduction in landfast ice extent and warmer temperatures in the spring are factors that reduce survival rate of seals and, as a consequence, of polar bears.
- Adjustments of traveling routes (e.g. to avoid thinner ice that now exist on the traditional ones) and types of vehicles used, e.g. an ATV (all-terrain vehicle), may now be required. This is an additional expense for a household.
- Because of their now sedentary lifestyle, i.e. they have adjusted to stable community living, Inuit no longer have the flexibility to move so as to compensate for the changes in their environment.
- Altered migratory patterns – typically those of the caribous – can translate into longer travel for the hunter, on new, unknown routes, as well as additional expenses for the households to access that resource (namely, fuel cost).
- Warmer water temperatures in rivers are reported to be causing fish caught in nets to rot more quickly.
- There is a decrease in water level and in its quality – some people switch to snow for drinking.
- Sunburn and rashes are caused by an increased exposure to ultra-violet light (UV).

7.4. Positive impacts

Not all recorded changes in the environment or climate reported by Inuit have a negative impact. For example:

- A retreating floe edge means that hunting at that location is closer to the community, e.g. a travel time of one hour as opposed to a few or several hours.
- In places, ridging intensity has decreased on the landfast ice.
- More open water means fishing areas are becoming more accessible by boat. Other activities, such as whaling and sealing can also be conducted in the summer.
- New game has become available in some places, such as the spruce hen and moose.

- Changing ice regimes presents opportunities for cruise ship tourism, with related revenue-generating prospects along the ships' route.

7.5. Adaptation to climate impact

Despite the challenge that subsistence harvesting entails, there is no indication that Inuit wish to give it up – it is quite the contrary. However, as pointed out by Nickels et al. (2005, p. 96), "associated impacts require more than a fatalistic attitude; they require clear solutions and action". Examples of those solutions are now provided, from the traveler's perspective. For the purpose of this summary, they are divided into a 'behavioral' and a 'technological' component. Higher level solutions (i.e. that can be implemented at the regional or national scale) are not included – they could be measures such as harmonizing the educational system with the Inuit culture and empowering the Inuit to conduct their own research in manners suitable to them.

Figure 26: Where water becomes excessive, the Inuit reverts to a boat to access the game. Source: James Tagalik

7.5.1. Behavioral

Behavioral adaption refers to adjustments in what people do and how, so as to compensate with the environmental changes. Included here are measures that are being used as well as those that have been proposed:

- To shift the consumption patterns of country foods, when one resources becomes less available. For instance, switching from seal hunting when ice conditions are too risky to fishing char from river shorelines, or focusing on muskox to replace dwindling availability of caribous (Figure 27).

- To alter timing, and avoid trails at a certain time of the year, and use different, more reliable trails.
- To shift quota of catches, for instance, from the on-ice spring activities (when the ice conditions are too challenging) to the open water summer hunting by boat.
- To organize structured food exchange programs and establish community freezers where this is needed.

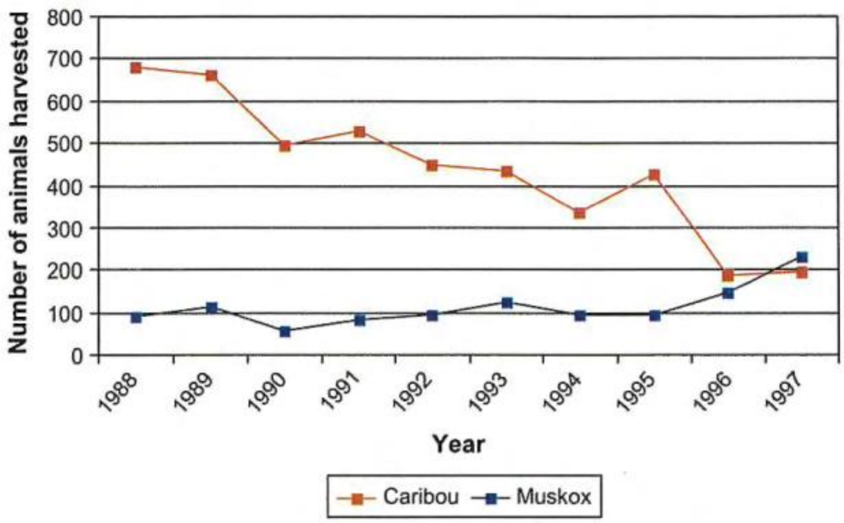


Figure 2 Number of caribou and muskox harvested by hunters in Ulukhaktok, Northwest Territories between the years 1988 and 1997. Source: IHS, 2003: *Inuvialuit Harvesters Study: Data and Methods Report, 1988–1997.* Inuvialuit Joint Secretariat. 202 pp.

Figure 27: Compensating a reduction in the number of caribous harvested with muskox (from Pearce and Smit, 2013)

- To guide hunters about how to be more selective in the caribou they hunt.
- To build cabins out nearer to the harvesting sites, so as to reduce the need to travel back and forth, and also so as to provide shelters to those who might be in need of them.
- Not to rely solely on water from natural water sources – instead, bring bottled water along while traveling.
- To start harvesting activities, such as fishing and goose hunting, earlier in the year.
- To hunt seals in summer from the water, instead of in spring from the ice, “when they are fatter and less likely to sink when shot” (Nickels et al. , 2005, p. 9).
- To exercise rigor in risk management practices, e.g. clearly identify the areas that are found or known to be dangerous, walk the route before riding it on a snowmobile, use a harpoon to test the ice.
- To better prepare for travel, with extra survival equipment, such as fuel, food and warm clothes.

- To travel closer to the community at riskier times of the year, i.e. autumn and early spring, and do it in groups.
- By default, irrespective of wind patterns, to plan on minimizing length of stay on moving ice.
- To optimize communication practices and knowledge sharing.

7.5.2. Technological

Adaptive measures also include the recourse to new tools and technologies, as mentioned earlier, which are becoming increasingly accessible for on-ice travel. Historically (i.e. irrespective of the changes in the environment), equipment has always been evolving. Contacts with the *Qallunat* (non-Inuit) over time has influenced the Inuit lifestyle and ways of doing things. Rifles replaced spears and harpoons, although the latter are still used. Motorized vehicles, namely snowmobiles, became a popular on-ice means of transportation starting in the 1950s and 1960s. These vehicles, however, are expensive and require maintenance, which is not always easily achievable in these cold and remote environments. Also, a snowmobile cannot always replace the traditional dog sleigh, which is deemed safer by some travelers, because the dogs can help pull the sleigh out of the water. It is also because it has some buoyancy. This is not the case for a snowmobile, whose footprint is also smaller, i.e. the weight is concentrated in a smaller surface area, thereby inducing higher downward deflections in the ice cover below it and promoting ice failure.

Nowadays, GPS, VHF radios, cell phones, access to satellite imagery (and products derived from them), weather forecasts, and other sources of information on Internet, are amongst the main technologies that Inuit use to help travel.

These new adaptive measures, while being instrumental in improving travel safety and effectiveness, are not seen as a panacea. They do not replace IQ, experience and good judgement, but should supplement them. In other words, an evolving technology is a double-edged sword – it can help if used judiciously, but becomes a liability if it encourages risk-taking activities and is misconstrued as a replacement for traditional skills. Furthermore, adaptation can also take the form of a trend reversal. For instance, a boat whose shell is made from skin is light and easy to carry, and may thus be more effective in handling the new ice conditions, i.e. when the surface is too loose for a snowmobile but too icy for boats (Inuit Circumpolar Council, 2014).

7.6. Socio-economic considerations

The usage of sea ice for travel is tightly knit with socio-economic factors. Many adaptation measures come at a cost to households – fuel, repairs of vehicles and freezers are some examples. These additional expenses are also tied to community needs other than those directly related with sea ice travel. They include the acquisition of boats better equipped for the new water conditions, a better water treatment infrastructure and means of mitigating shoreline erosion. In parallel, there is a reduction in revenue from harvesting activities (for the products that are not used for subsistence). The loss of harvesting opportunities means communities will have to rely more on store-bought food, as mentioned earlier, which is expensive and not as healthy as country food.

The challenges of knowledge-sharing and IQ transfer between generations have been raised at community engagement sessions – such transfer is not done as much as it used to be (see also Aupilaarjuq, 2017). Again, relying too much on new technologies can be counter-productive, as they may cause a 'disconnect' from the environment and, thus, from the information it provides. Also, younger Inuit are faced with another form of adaption: how to make the best of both worlds and cope with this new reality. Moreover, regulatory frameworks must also consider the evolving relation between the Inuit and the ecosystems.

8. Discussion

As pointed out by Laidler (2006, p. 411), "[d]espite growing community populations, shifting demographics, and the adoption of various aspects of southern lifestyles and technologies, Inuit identity, knowledge, livelihood and survival are still strongly linked to the seasonal cycles of sea ice and wildlife harvesting". These skills are still considered essential for subsistence harvesting and traditional activities. To begin this discussion, we thus revert back to the question that was posed earlier regarding IQ's inability to handle the pace at which environmental changes are occurring: how do we collectively handle this predicament? Most of the existing literature that addressed climate impact is about phenomena such as flooding in highly populated areas, or drought in agricultural sectors, and much less about sea ice. In the following, we will look at how well-known concepts apply to sea ice usage by Inuit.

8.1. The concept of vulnerability

The concept of 'vulnerability' is a starting point. Although it is defined in several ways for scenarios affecting human populations world-wide (e.g. Cutter, 1996), it basically represents *the extent to which a system* (i.e. an Inuit community in the present context) *can be harmed by an event* (i.e. related with climate change in the present context)(Ford and Smit, 2004, Smit and Wandel, 2006, Pearce and Smit, 2013). Vulnerability, in turn, can be looked at in two ways: physical and social.

8.1.1. Physical

This is where a community is exposed to a physical phenomenon, for instance, if it is located in an area exposed to coastal erosion and permafrost degradation, i.e. it is vulnerable to ground slumping and collapse. "People are treated as being vulnerable owing to their presence in hazardous locations" (Ford and Smit, 2004, p. 392). From that perspective, factors such as magnitude, duration, impact, frequency and rapidity of onset are typical considerations (Cutter, 1996). Physical vulnerability also comprise the risks of traveling on sea ice under less predictable conditions, i.e. thinner ice, earlier break-up and later freeze-up, all of which were brought up by communities throughout the Canadian Arctic (Laidler et al. , 2009, Inuit Circumpolar Council, 2014)(see also

Figure 25). Breakthrough and getting stranded on the ice are two outcomes of physical vulnerabilities.

8.1.2. Social

Vulnerability in this case is not related with the physical phenomenon alone, but involves elements of a social, economic or cultural nature (Bohle et al., 1994). Vulnerability from that perspective is where the ability to recover from a physical phenomenon is influenced, for example, by the community's socio-economic status. Some of the better known factors are family income and the economic wealth of a community. These factors exacerbate others that have always been part of the Inuit's environment, such as geographical remoteness, limited infrastructure, low temperatures and no day light, thereby further contributing to social vulnerability.

8.1.3. Vulnerabilities related with sea ice

What, then, are the vulnerabilities related with travel on sea ice, and how to adapt to them? These vulnerabilities may vary over time and location. They can also be human-induced (Fraser et al., 2003), e.g. ship transits through sea ice, itself an outcome of climate change, and their effects on whale activity and travel on ice (Inuit Circumpolar Council, 2014). Table 2 offers a first-order classification (Pearce and Smit, 2013), in which one may appreciate the important role played by sea ice, namely in matters related with subsistence hunting, transportation and health and well-being.

Table 2: Vulnerability in Canadian Arctic communities (Pearce and Smit, 2013, Table 2). Sea ice plays an important role in subsistence hunting, transportation and health and well-being.

Broad types of vulnerability	Common elements
Subsistence hunting	Increased travel risks; access to hunting grounds; quality and availability of wildlife
Transportation	Compromised trail routes to hunting grounds
Infrastructure	Permafrost degradation affecting buildings; coastal erosion
Health and well-being	Food security - access, availability, quality
Culture and learning	Erosion of environmental knowledge and traveling skills among young Inuit
Business and economy	New shipping opportunities; compromised ice roads; negative consequences for sport hunting industry (local guides and outfitter; local businesses)

8.2. Exposure and adaptive capacity

Vulnerabilities are a function of two main parameters: e*xposure* and a*daptive capacity* (the latter term is the resort to *adaptation measures* or *adaptive strategies*). A lower exposure and/or higher adaptive capacity will reduce vulnerability.

8.2.1. Exposure

'Exposure' is the level of contact or interaction with a risky scenario or situation. In the present context, it is related with sea ice and the impact of a changing climate on its dynamics (Ford and Smit, 2004, Laidler et al. , 2009). It also includes other climate-related factors mentioned earlier (air temperatures, winds,…). Such exposure will affect Inuit that rely on sea ice for their harvesting activities, but not so much those who specialize in land hunting. The latter, however, are exposed, for instance, to thinner ice crossings on lakes (freshwater ice) related with warmer air temperatures (J. Karetak, writ. comm. 2021). *The various exposure elements for any given community have to be acknowledged so as to identify adaptation measures.*

8.2.2. Adaptation measures

Adaptation measures are intended to tackle areas in which communities are vulnerable. Hence, an initial step for communities and decision-makers is to identify who is affected by what, where and when. It is also to understand in what manner – this may have to do, for example, with a household or the local economy (e.g. unemployment), infrastructure (e.g. houses on degrading permafrost), or food insecurity (e.g. inability to procure food from harvesting activities, low quality and/or high price of store-bought food). *Adaptation measures to exposure elements have to be identified so as to understand vulnerability.*

8.3. Example of an application – Igloolik

The study described by Laidler et al. (2009) is a good example of a vulnerability assessment. It was based on combined Inuit and scientific observations for the locality of Igloolik, in Nunavut. Community engagement (e.g. interviews, site visits), as well as instrumental data (e.g. wind) and historical information on ice coverage, were used for the purpose of that assessment. Information was gathered on Inuit knowledge of sea ice and exposure to risks related with climate change – this is shown in Figure 25. The ability to adapt under these changing conditions was also documented – this is summarized in Table 3.

Laidler et al. (2009)'s assessment indicates that vulnerability to sea ice change is complex. For instance, it varies within the community. The younger generation is exposed differently to risks because they do not travel on sea ice as intensively as full-time hunters. This is particularly the case for harvesting walrus, a more dangerous endeavor (because they are found on drift ice). Youth lean toward grocery-bought food, such that they are not as concerned with the shortage of country food. On the other hand, they do access sea ice, e.g. for seal hunting or to go to a neighboring community, in the autumn and spring. Because they are less experienced and less skilled, this increases their vulnerability.

Full-time hunters and elders are at the opposite end of that spectrum. While they have the expertise and understanding of the sea ice environment, they also conduct riskier operations, such as accessing the drift ice. They also are on the ice in autumn, winter and spring.

In all cases, less predictable sea ice dynamics caused by climate change increase the traveler's vulnerability. Because communities depend on country food and the income derived from it, they face mutually conflicting conditions: a lower income means buying food is less of an option, but that income would come from their harvesting activities, which they cannot perform.

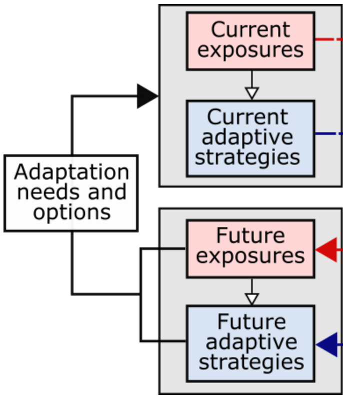
Table 3: Outcome of the assessment reported in Laidler et al. (2009) for the Igloolik sector on exposure, adaptive strategies and what is required to implement the strategies.

Exposure	Adaptive strategies	Prerequisite
Nigajutait/putlaujaraq (Non-uniform freezing rates) and early freezing conditions	• Regular use of harpoon to test ice thickness during autumn • Vigilance during ice freeze-up • Detour from regular routes to avoid thin ice • Avoid areas with strong currents • Use of immersion suits when using ice	• Knowledge of sea ice formation processes • Knowledge of areas that are usually dangerous • Ability to identify indicators • Access to money or sharing networks
Qaattuq/uukkaqtuq (break-off events at the floe edge)	• Avoid pack ice/floe edge during northwesterly (NW) winds and low tide • Return quickly if NW wind comes up • Hunt on moving ice as quickly as possible, and then return quickly • Plan for what to do if stranded	• Ability to use indicators to predict wind direction/shifts (e.g. interpreting walrus movement) • Knowledge of timing of high and low tides
Snow on ice	• Vigilance when traveling on snow-covered ice, particularly in areas where ice is usually thin	• Knowledge of how snow can create thin ice
Inability to access hunting areas due to state of ice	• Hunt seal on/near Igloolik Island • Country food flown in from Hall Beach • Eat store food	• Sharing networks important for access of country food • Access to income
Generic sea ice risks – potential to fall in, get stranded, etc.	• Take along extra clothing, food, supplies • Use of VHF radios in case of accident • Risk planning – knowledge of what to do in emergency situation	• Access to income to purchase technology • Access to networks to borrow technology • Knowledge of survival skills (e.g. ability to build a snow shelter)

8.4. Way forward – Future vulnerability

The example above on the Igloolik community emphasizes the importance of the ‘bottom-up’ approach, i.e. where both the issues and the remedies are raised by the community (Smit and Wandel, 2006). These can then be correlated with what is known about environmental changes to this date, and what is expected in the future. The information in the ‘Prerequisite’ column of Table 3, known as ‘determinants’ in the academic literature, is central because it can *guide decision-making about how to prepare*, and to evaluate what can be done, in a practical sense, to address vulnerability.

Figure 28 summarizes this principle. In essence, based on what is known today about how communities cope with adversity, community decision-makers and policy analysts, with the input from scientists, can identify potential future exposures, then plan for adequate adaptive capacity. Figure 29 is a notional depiction of the expected outcome of that framework with time. In that figure, four factors, of a qualitative nature (no ‘amount’ associated with them), are shown.



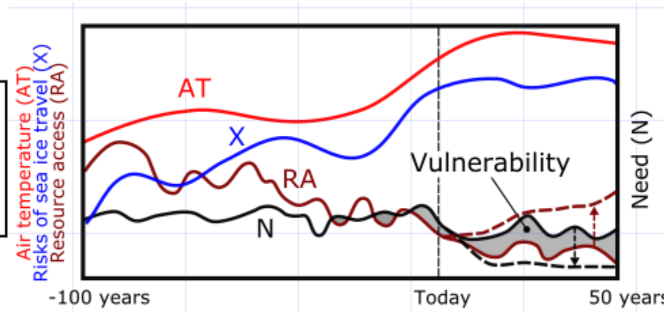


Figure 28: A conceptual framework where current vulnerability assessment and adaptive strategies are extended into the future, based on expected changes in natural and social systems (Smit and Wandel, 2006, Fig. 3).

Figure 29: Hypothetical evolution of four inter-related factors over time (from 150 years before present to 50 years into the future). Vulnerability (shaded areas) can be reduced (or eliminated) by increasing access to a particular resource (brown arrow pointing upward), and/or reducing community needs for that resource (black arrow pointing downward).

The factors in that figure are as follows:

- *Air temperature (AT):* A rising air temperature is probably the most influential parameter – it is used here as an example, bearing in mind challenges for on-ice activities are typically due to a variety of environmental parameters and combination thereof, which are also location/time-dependent.
- *Risks of on-ice travel (X)*: These risks are tied with the dynamics of sea ice and represents the 'physical' exposure described earlier, e.g. breakthroughs, getting stranded on the ice, which are increasing as a consequence of a changing climate.
- *Resource access (RA)*: A reduction in the amount of catch (e.g. seals, walrus, fish, caribou,…) can be due to any number of reasons, i.e. less resource per se (e.g. limited access to hunting grounds, a reduction in the number of animals, poorer quality of the meat, etc.), and societal aspects (i.e. settling in permanent locations, employment, low income, etc.)
- *Need (N)*: The community or household requirements for a particular resource from hunting activities, which varies over time (e.g. if more seals are available one year, this can make up for a reduction on walrus).

The 'vulnerability' in Figure 29 (shaded areas) is when the resource does not meet the need. This can be rectified either by increasing the community's adaptive capacity, thereby allowing for a better access to the resources, and/or by reducing its need, through community sharing agreements, replacement with alternative resource, etc. It is that sort of long-range planning that could be entertained by community leaders and policy analysts, in collaboration with scientists.

8.5. Inuit and scientific perspectives

An adequate understanding of the difference in perspective between Inuit and scientists is essential before envisaging any form of joint effort or collaboration. This has been pointed out by previous investigators, who have endeavored to optimize two-way communication (e.g. Nickels et al. , 2005, Laidler, 2006, Dufour-Beauséjour, 2020).

8.5.1. The difference in perspective

The table in APPENDIX – Inuit and scientists' standpoints on sea ice – is an insightful comparison (from Laidler, 2006) between how Inuit and scientists address various concepts related with sea ice. The reader is invited to have a close look at that compilation. The concept of 'sustainability' could also be added to that listing. For Inuit, "an action that can continue for ten or twenty, or even fifty years before its damaging effects are seen does not qualify as sustainable. A way of doing things, a way of living and behaving, must be done in such a way that it could continue for hundreds and thousands of years without harming the natural way of things in order for it to meet the Inuit standard of sustainability" (Inuit Circumpolar Council, 2014, p. 24). The difference in preferred means of communication should also be carefully considered. Internet-based tools such as email and chatting platforms may not be as effective as the more traditional telephone communications. Similarly, the conventional 'conference' format, coveted by the scientific community for face-to-face gatherings, may not be ideal for meeting with members of the Arctic communities. Instead, timely visits to these communities by the scientists may better align with Inuit perspective, as this is also an opportunity to get acquainted with an age-old synergy between humans and these environments.

8.5.1. Collaboration and way forward

Scientists, policy-makers and Northerners agree that collaboration is in order. The Inuit have been expressing the importance of being involved in research (Nickels et al. , 2005, Inuit Circumpolar Council, 2014). Inuit knowledge has contributed a wealth of information to these endeavors already. One necessary pre-requisite, however, is that they should be consistent with the National Inuit Strategy on Research (Inuit Tapiriit Kanatami, 2018). That is, to foster a self-determined and sustainable food system which reflects Inuit societal values and supports Inuit well-being[11].

For collaboration to happen effectively, two-way communication could be improved. As pointed out by Laidler (2006, p. 434),"[t]he physical sciences need to explore ways of communicating highly technical research results into accessible forms for the use of social scientists and community or governmental decision-makers." The recent account by Dufour-Beauséjour (2020) seems to reflect this state of affairs – while the researcher was able to communicate the overall scientific outcome of her work, this was more of a challenge for the technical data per se. Interestingly, community involvement via social media, namely Facebook, was found by Dufour-Beauséjour to be very helpful in learning about Inuit culture, and also as an engagement instrument.

[11] https://www.itk.ca/inuit-nunangat-food-security-strategy/

It should also be pointed out that tangible collaboration efforts and joint research projects between southern scientists and northern Indigenous groups have been happening for a number of years. The SmartIce initiative is the outcome of such an association with local Inuit expertise – because of their year-round availability, they are able to implement their own in situ monitoring programs to address their own requirements (Bell et al., 2015, Safer, 2016). Another example, of a different form, are the Atlases from the Geomatics and Cartographic Research Centre (GCRC) at Carleton University, namely the Sea Ice Knowledge and Use (SIKU) Ice Atlas[12]. These document specialized Inuit knowledge about sea ice, through a collaboration between Inuit experts, community researchers, and university researchers. The Pan Inuit Trails Atlas[13] is another such example. Validating and ground-truthing remotely-collected data and satellite imagery, particularly at locations and time period relevant to their activities (Laidler, 2006, Laidler and Elee, 2008).

In order to further improve the integration of both sources of knowledge – north and south, it was proposed that a central office could be instituted so as to facilitate communication, consolidate all data from communities and collect community concerns related with climate impact (Nickels et al. , 2005). Guidance in the use of new technology, weather forecasts and usage of satellite imagery (and derived products) could be coordinated through such a platform. All of this would feed into the development of policies, programs and strategies. They could participate in the interpretation of the ice dynamics (e.g. Dufour-Beauséjour, 2020). This level of coordination would also help decipher training requirements and inter-generational knowledge transfer, as well as a judicious appreciation of both sides of 'Two ways of knowing'.

For instance, Ford et al. (2019) provide evidence that experience and knowledge *is more important than the changes in environmental parameters* in determining whether or not an Inuk chooses to travel (either on ice, land or water), pointing out to the importance of education in conveying the required skill sets. Investing in program models that develop Inuit harvesting knowledge and skills has been called for[11].

Figure 30 is an attempt to capture these various components and other considerations covered in this report.

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[12] https://sikuatlas.ca/index.html

[13] Introduction (paninuittrails.org)

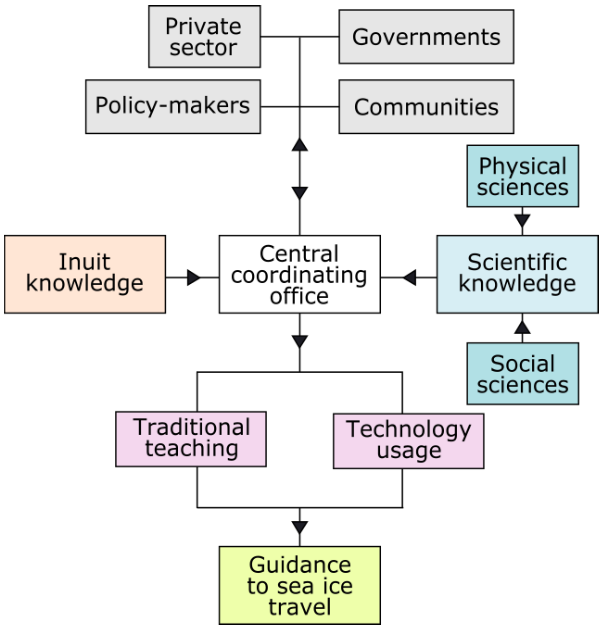

Figure 30: 'Two-ways of Knowing' – *summary of the interaction between the various actors involved in the generation and transfer of knowledge.*

9. Conclusion

Food insecurity amongst Inuit communities is an outcome of the high cost-of-living and poverty rates in those communities. People with low income spend most of it on food and accommodation. A solution to this situation can be found via country food harvesting, which has always been Inuit's primary resource. For this purpose, sea ice plays a central role.

Even if climate change were not happening, sea ice formation and dynamics would remain a very complicated story, one that Inuit have been accustomed to deal with, up until the last several decades. Since then, a rapidly evolving climate has been introducing unfamiliar challenges. An example of climate impact assessment is given herein, focusing on the Arctic Archipelago. More frequent, well targeted and better guided data production are required to decipher the effects of the changes that have occurred until now and those that can be expected in the future. The involvement of Inuit, who are now experiencing these phenomena, in achieving that level of granularity in gathering the existing evidence has never been as relevant as it is today.

For fruitful collaboration to take place, the differences in perspective have to be acknowledged and factored in communications. In Inuit Nunangat, sea ice is a transportation infrastructure, albeit owned by no one, an unusual concept amongst non-indigenous people:

> *"[t]o outsiders, ice is an impediment to transportation and access, something that must be broken or bypassed. It is seen as a barrier, blocking rather than enabling human activity." We view sea ice as enabling.* Duane Ningaqsiq Smith, in Inuit Circumpolar Council (2014).

The objectives of the present report was to provide a glimpse of the various aspects that come into play when approaching sea ice as a traveling platform for Inuit. The authors are aware that such a cursory overview may not do justice to the large amount of information that exists on these aspects. The reader is encouraged to pursue this exploration further.

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APPENDIX – Inuit and scientists' standpoints on sea ice

Aspect	Inuit	Scientists
Perspective	***Holistic**, highly **contextual**, aiming to understand local human-environment **relationships***	***Reductionist**, aiming for **objectivity** and **generalization***
Sea ice	*A **platform** to travel, hunt, and/or live on*	*A **topic** of study*
Sea ice links to climate change	***Interest in how changing ice regimes will affect sea ice** as an important travel platform, the quality of wildlife habitat, wildlife availability, and personal safety*	***Interest in the physical processes and feedbacks** relating to how sea ice can influence ocean/atmosphere energy exchanges, and thus climate*
Sea ice observations	*Acquired through **daily interaction** with sea ice, as well as weather, winds, currents, and tides that affect sea ice conditions, accessibility to wildlife, weather predictability, and travel safety*	*Predominantly based on **remotely acquired** data or point sampling*
Importance of understanding links between sea ice and climate change	***Practical consequences** – sea ice change can undermine personal safety, access to marine wildlife, the ability to travel, and notions of personal/cultural identity; survival may be in jeopardy from mistakes or misinterpretations*	***Theoretical consequences** – inadequate modeling parameters may be re-evaluated or re-calculated; scientific reputation or credibility may be in jeopardy from mistakes or misinterpretations*
'The big picture'	***Broad** and **holistic** focus on all related components which may affect ice conditions, and subsequent influences on distribution, behaviour, or well-being of marine wildlife, as well as community members*	***Technical** and **detailed** focus on physical processes and parameters of sea ice, and related interactions with global climate and circulation*
Human position in climate change context	***Embedded***	***External***
Relationships with sea ice	***Personal** relationships with the marine system constructed out of personal interactions, beliefs, and practical necessity*	***Distanced** from sea ice, relationship with an object of study through remote observations and/or theoretical and empirical simulations*
Life experience	***Live** in the Arctic, **experience** sea ice conditions and change daily, typically in subsistence-, commercial-, tradition-, or leisure-related activities*	***Study** the sea ice environment, **model** ice links to weather or climate variation, typically in work-related activities*

'Data' capture	*Years of* ***personal interaction*** *with,* ***observation*** *of, and* ***use*** *of the marine environment*	***Short-term****,* ***fragmentary*** *records, predominantly based on satellite* ***remote sensing****, with some paleo-environmental, archeological, and point sampling records*
Scale	*Local (****mainly at fine scales****) and regional, spanning living memory to the past, through historical recall (varies greatly between communities)*	*Local, regional, and global (****mainly at coarse scales****), but generally short historical record or relatively recent use of technologies*
Temporality	***Experience-focused****, based on first-hand interaction with sea ice environments and reliability based on age or experiences of person making observations/predictions; predominantly concerned with* ***extreme events***	***Time-focused****, based on yearly chronology and statistical reliability; predominantly concerned with averages over time*
Goals	*Knowledge that promotes* ***personal safety****,* ***harvesting success****, and* ***reliable weather prediction***	*Comprehensive understanding of* ***physical and internal ice processes****, identification of long-term sea ice trends, and reliable* ***modeling*** *of future climates*
Terminology	*Refers to ice states, processes, and* ***human interaction with sea ice****, verb-based language structure recognizes* ***human/environment interactions*** *reflected in Inuktitut sea ice terminology;* ***highly contextual***	***Technical, specialized, jargon-laden****, notoriously hard for the layperson to comprehend; holds* ***universal meaning*** *for those with access to the appropriate literature*

Modified after Laidler (2006, Table 1) – bold font is from the source.