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Co-developing a conceptual model rooted in Inuit Knowledge of the landfast sea ice season near Makkovik, Nunatsiavut

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Abstract

Conceptual models in Western science are used to represent key processes and relationships within a system and to unify knowledge across disciplines. In this paper, we develop a conceptual model through research that spans both Western science and Indigenous Knowledge. Drawing on participatory mapping and interviews with Inuit knowledge-holders in Makkovik (*Maggovik* in Inuttitut), Nunatsiavut, Canada, we document Inuit Knowledge of the landfast sea ice season. A thematic analysis identified key environmental indicators used by Inuit to describe the drivers of local sea ice conditions and observed changes over seasonal, interannual, and climatic time scales. In collaboration with participants, we developed a conceptual model of the seasonal cycle of landfast sea ice. Grounded in an Inuit worldview, the model seeks to minimize Western scientific interpretations and biases. It depicts the seasonal progression of landfast sea ice, including the processes and drivers of environmental conditions and changes over time. This approach offers a practical method for documenting Inuit Knowledge and shows how conceptual models can serve as culturally grounded frameworks. The resulting model provides a foundation for future scientific research that is both representative of and responsive to Inuit experiences and ways of knowing the environment.

Key words: Inuit Knowledge, conceptual model, environmental indicators, sea ice, landfast ice, Nunatsiavut

1. Introduction

Nunatsiavut is an Inuit land-claim region in Northern Labrador, Canada, and has been home to Labrador Inuit for millennia. The region is characterized by the seasonal presence of landfast sea ice. Inuit in Nunatsiavut have a deep knowledge of the marine and coastal environment, including the dynamics and nature of the sea ice. This knowledge has been developed and passed down through practice and orally over many generations. For Inuit, the landfast sea ice acts as an extension of the land and enables access to important hunting and harvesting areas, other communities, and areas of cultural value including ancestral homelands.

Makkovik (*Maggovik* in Inuttitut)[1] is a small community of approximately 365 residents, located in Nunatsiavut. It is surrounded by two main inlets, Makkovik Harbour and Makkovik Bay, with two main brooks flowing into the inlets. Like all communities in Nunatsiavut, Makkovik is only accessible by boat and plane during the summer months, and by plane and snowmobile during the winter months. The seasonal presence of landfast sea ice provides a critical travel platform for Makkovimmiut (people of Makkovik) to access subsistence hunting and fishing grounds, travel to their cabins outside of the community, visit other communities, and connect with ancestral homelands. Makkovimmiut Knowledge of the sea ice has been developed and passed down over many generations, where specific environmental indicators are used to assess ice conditions, changes, and impacts to travel and travel safety. Sea ice conditions around Makkovik have changed significantly due to climate change, which has introduced more uncertainty for Makkovimmiut using traditional modes of prediction to assess the ice season and safe conditions.

Landfast sea ice has been the focus of extensive geophysical research in the Arctic. Often this research takes place at pan-Arctic or regional (e.g., basin level or ~100–1000 km) or sub-regional (e.g., coast- and shelf-level or ~10–100 km) spatial scales. While there have been assessments representing finer scale processes (e.g., Witte et al. 2021; Plante et al. 2024; Loewen et al. 2025), often landfast sea ice research

[1] We use Makkovik to refer to the community, as this was used by participants during the research. We also want to acknowledge that *Maggovik* is the Inuttitut place name, and reflects the cultural and linguistic roots of the community and *Maggovimmiut* (people of *Maggovik*). The use of Makkovik here aligns with particpants' usage and is not intended to disregard the significane of the Inuttitut place name.

does not correspond with specific processes or conditions that influence travel, hunting, and harvesting ranges of Inuit communities (e.g., metre-scale processes occurring within an ~200 km range/footprint; Laidler et al. 2011; Segal et al. 2021). Landfast ice is a critical platform of travel by snowmobile for many Inuit communities, and subtle shifts in ice stability and its relationship with weather patterns will impact travel safety (and whether people can travel at all). Inuit Knowledge of sea ice has been developed and passed down over many generations as a part of a rigorous form of systematic observation (Aporta 2002; Laidler and Elee 2008; Laidler and Ikummaq 2008; Laidler et al. 2008; Krupnik et al. 2010).

Recognizing the invaluable knowledge held by Inuit, and in response to calls to make research more relevant, impactful, and meaningful to Inuit (Inuit Tapiriit Kanatami 2018), geophysical scientists and other Western scientific researchers are increasingly seeking to co-develop research with and for Inuit. Co-development, as a framework, aims to create a space that fosters joint visioning, collaborative processes, and active information exchange to advance new knowledge (Jacob et al. 2025). Such processes emphasize equity and power-sharing through collaboration across different disciplines and cultural understandings and aim to generate useful and usable knowledge and/or information. Co-development and co-production frameworks are increasingly being used to support Arctic weather, water, and ice research (Fox et al. 2020; Herman-Mercer et al. 2023), as well as on broader scales through initiatives such as the WMO Regional Climate and National Climate Fora (Hewitt et al. 2020; World Meteorological Organization 2024). Of note, there is no "one size fits all" approach and identifying effective and relevant methods to connect culturally distinct ways of knowing remains a key challenge.

In this paper, we co-develop a conceptual model grounded in Makkovimmiut Knowledge of sea ice conditions and processes, depicting the progression of the sea ice season and how it has changed over time. We propose that conceptual models rooted in Inuit Knowledge and experiences can act as a framework to guide and inform geophysical marine research. Specifically, a conceptual model grounded in Makkovimmiut experiences and values of the sea ice can inform future ice and ocean research in Makkovik. Doing so can help generate research that supports safe travel and addresses uncertainties around traditional modes of prediction that have arisen as a result of climate change.

1.1. Background

Within geophysical sciences, conceptual models are constructed to depict (using graphical, verbal, or mathematical means) key processes and relationships within a system of study. They can include internal dynamics, external drivers, and reference theory, sometimes in a reduced or simplified form, to help convey key processes in the system the model represents (Wassmann et al. 2020). Conceptual models are used in geophysical research to describe and predict complex system dynamics, either quantitatively or qualitatively. They often deal with variability and coupling of processes across temporal and spatial scales (Chelton 2001). Further, conceptual models typically involve generalizations and abstractions of real-world processes and linkages, with the goal of simplifying complex systems to focus on key salient processes (Wassmann et al. 2020). Conceptual models have been suggested as a tool to unify and integrate oceanographic and ecological work, for example by providing a spatiotemporal framework to assess linkages between biological processes and seasonal sea ice phenology (Moore et al. 2018; Wassmann et al. 2020). Building from this, we define conceptual models as a descriptive model that can be used to represent functions, explain, or predict outcomes of complex systems, where key variables are identified, relationships and connectivity is determined, and results can be used to explain or make predictions about a system.

Indigenized conceptual models have been proposed as a means of supporting Indigenous revitalization and renewal through guiding culturally responsive science and policy (Cajete 2020; Fletcher et al. 2022). Conceptual models co-developed with Inuit have emerged in research settings where externally (Western) generated models were not considered accurate or appropriate (Fletcher et al. 2022). Developing a conceptual model grounded in Inuit Knowledge and values can help guide an exploration of scientific data. This approach offers a unique pathway to support equitable and decolonizing research processes at the interface of Inuit and Western scientific knowledge. Conceptual models have been valued in Indigenous research contexts for their ability to convey integral components of the ontological basis of Indigenous Knowledge (Littletree et al. 2020, p. 411). As such, conceptual models can be an effective tool to help connect across Western and Indigenous ways of knowing.

By its very nature Inuit Knowledge does not lend itself to compartmentalization or integration into the framework of Western science (Kawagley 1995; Nadasdy 1999). Thus, we propose the creation of a framework grounded in Inuit Knowledge, around which Western geophysical science can be developed. This is not to position one way of knowing as subservient to another, rather it is to draw on the strengths of both perspectives to advance research that is reflective of and responsive to Indigenous experiences of the environment. Using a case study of the landfast sea ice season in Makkovik, we co-develop a conceptual model grounded in Makkovimmiut Knowledge, experiences, and values tied to the sea ice. We explore potential avenues for this model to guide future geophysical research in Makkovik, which in turn can support travel safety, and help ease uncertainties when traditional modes of prediction are being challenged by ongoing climatic and oceanic changes. Ultimately, this approach can contribute to shifting the culture of Western geophysical research to one that better centres human–environment relationships (Cavaleri Gerhardinger et al. 2024).

1.2. Positionality of the research

This research spans Western science and Indigenous Knowledge and contributes to a project aiming to increase observations of sea ice and oceanographic conditions in coastal Nunatsiavut. Specifically, Western qualitative research methods are used to document and analyse Inuit Knowledge of the landfast sea ice season, shared through narratives. The resulting conceptual model is designed to complement natural scientific research in the region, and includes localized observations of sea ice changes, seasonal variability, and climatic impacts experienced by Makkovimmiut. This co-development approach emerged through collaboration within the authorship team, in response to Makkovik-based co-authors' desire to see Makkovimmiut Knowledge of sea ice change communicated to audiences outside of their community.

The authorship team brings together diverse positionalities, experiences, and ways of knowing. It includes university-based researchers: two non-Inuit co-authors (BB and CA) with longstanding experience collaborating with Inuit communities and using social scientific methods to document Inuit Knowledge of the marine environment, and an Inuk co-author (ECJO), with family roots in Nunatsiavut, who is a physical oceanographer with a focus on linking Inuit and scientific knowledge systems related to the ocean, sea ice, and climate. The team also includes community-based Inuit co-authors from Makkovik and Postville (BA and KA), who have been deeply involved in multiple research projects and bring extensive experience bridging Inuit Knowledge and Western science. We are collectively committed to support Inuit self-determination in research and to ensure that Inuit Knowledge remains central to all aspects of this research.

This research was grounded in an understanding that epistemic oppression—defined as the systemic exclusion or devaluation of certain forms of knowledge and scientific practices (Phurisamban et al. 2025)—influences geophysical sciences, including sea ice science, in both implicit and explicit ways. To better understand how Inuit Knowledge can shape sea ice science we utilized a co-development approach, which involved iterative research processes to center Inuit ways of knowing while drawing on the respective strengths of all contributors. In this context, Western-trained researchers took on supportive and facilitative roles, while Inuit participants actively shaped the model through storytelling, reflection, and feedback. The conceptual model, while rooted in Inuit perspectives, is the outcome of sustained collaboration, where our role as university-based researchers involved facilitating data collection and analysis and engaging in repeated dialogue to ensure the model reflected Inuit voices. If the model were developed without the involvement of non-Inuit team members/individuals trained in scientific methods, it might have looked very different from the version present here—one that serves as a way to connect across different ways of knowing. This approach is aligned with decolonizing methodologies that center Indigenous knowledge and community leadership in the research process (Smith 1999; Castleden et al. 2017; Whyte 2017; Latulippe and Klenk 2020), while also seeking ways to facilitate collaborative and cross-cultural sea ice research.

2. Data and methods

2.1. Participatory mapping and interviews

Participatory mapping typically involves communities creating their own maps (e.g., representing their knowledge of place via maps), and it has been used as a research methodology and powerful tool to document and assert community perspectives, values, and knowledge of the land (Laituri et al. 2023). Participatory mapping has been an effective tool for bridging Inuit and Western scientific knowledge of the sea ice and ocean environment (Laidler et al. 2010; Bishop et al. 2021). While the methodology does have limitations with respect to Inuit Knowledge that cannot be spatially rendered, when utilized in conjunction with interviews, participatory mapping offers an excellent approach to recording local knowledge of the marine environment (see Bishop et al. 2021, 2025*a*). Participatory mapping and interviews were hosted in Makkovik, Nunatsiavut during a workshop in November 2021. The research was approved by the Nunatsiavut Government Research Advisory Council as well as the Dalhousie Research Ethics Board. The goal of the research was to record Inuit Knowledge of the coastal environment and observations of change over time, and all participants provided informed consent prior to participating in the research.

A floor map was designed to match the data collection scale of Inuit Knowledge mapping studies done by the Nunatsiavut Government (1:50 000 or finer) and was printed at a size of 12 ft × 15 ft (Fig. 1, blue box). The scale and positioning of the map on the floor were intended to create a more immersive experience, where participants could "step into" and "move through" the represented landscape as they mapped. We recruited participants using the local radio and posters on community bulletin boards. Recruitment led to six (male) participants self-selecting based on their interests in the research and being known in their community for their knowledge and experience travelling on the Land. Some were born on the Land, and they have extensive experience traveling for hunting, trapping, harvesting, work, and visiting family cabins and/or other communities. Participants mapped over the course of 3 days, sometimes in groups and sometimes alone, and five of those participants elected to take part in follow-up interviews. Mapping sessions and interviews were audio recorded, and while knowledge recorded during interviews was attributed to individual participants, we agreed with participants during the informed consent process that knowledge recorded during mapping could be considered collective knowledge (attributed to the community rather than individual participants).

Participants were asked to map the sea ice and coastal ocean environment. The mapping was kept very open, prompting participants to include what they considered to be important physical features of their coastal environment, with prompts related to travel routes, sea ice features, and ocean currents. Specific features mapped in Makkovik included travel routes (by boat and snowmobile), areas of notable currents/tides, the typical location of the *sinâ* seasonally and over decades (boundary between the landfast ice and mobile ice; important hunting areas), *rattles* (areas of open water within the landfast ice, i.e., small polynyas), areas of late freeze/early thaw (areas of open water within the landfast ice that freeze-up later than the surrounding ice, and thaw out earlier than the surrounding ice), where *slob* (heavy, slushy, densely packed mass of ice fragments, snow, and freezing

Fig. 1. Makkovik map extent (blue box) shown in relation to the Nunatsiavut coast and land claim boundaries.

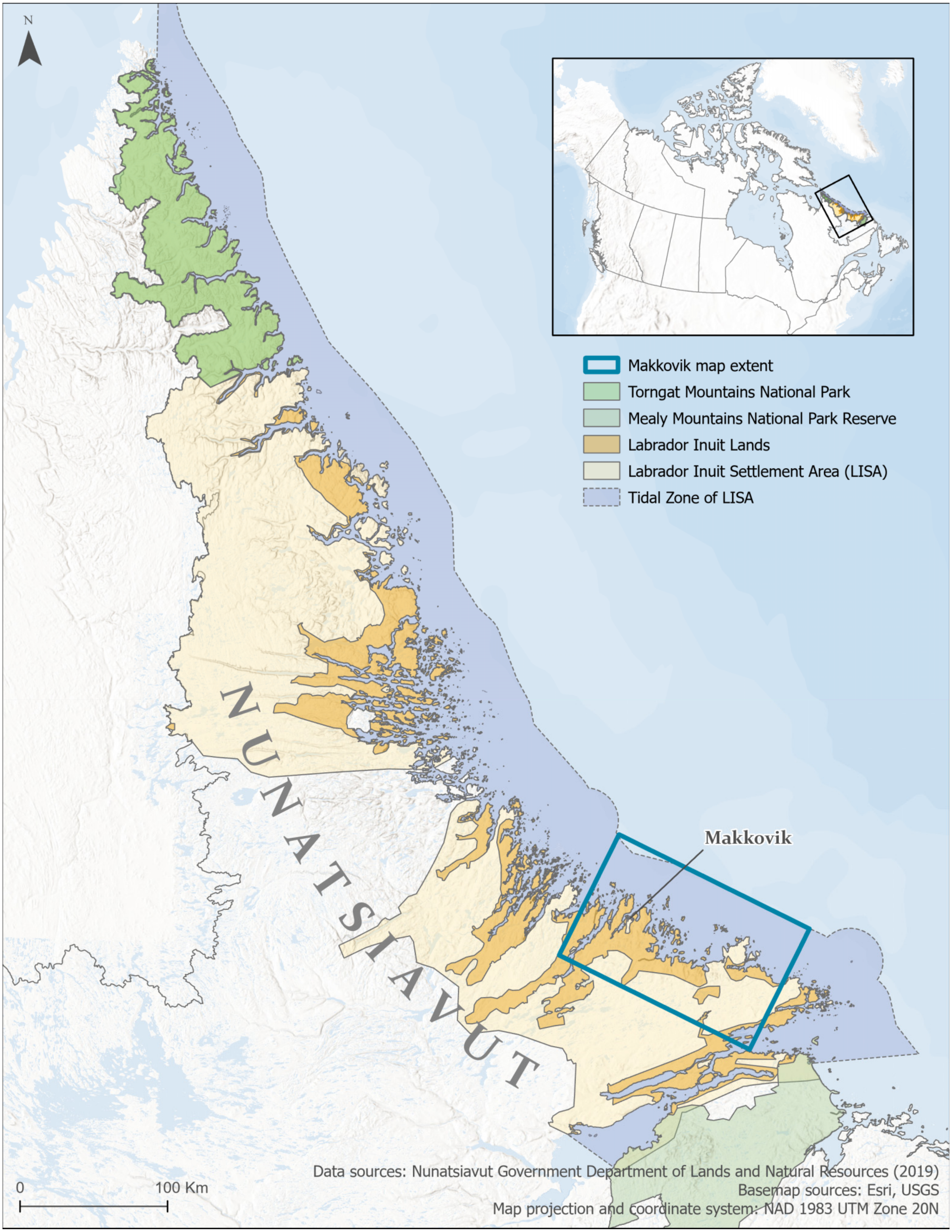


Table 1. Local terminology used in association with seasonal sea ice conditions around Makkovik, Nunatsiavut.

Local term	Description
rattle	Areas of open water within the landfast ice (i.e., small polynyas)
sea-on	Wind generated sea swells
sinâ	Edge of the landfast ice
slob	Heavy, slushy, densely packed mass of ice fragments, snow, and freezing water that drifts with the winds and tides
taluk	Seal hunting blind
ukiak	Fall
ukiatsâk	Early fall
upinngak	Spring
upinngasâk	Early spring
ukiuk	Winter
vapour/kisuk	Vapour or steam rising from the water when air temperatures are cold enough to contribute to sea ice freeze-up

water that drifts with the winds and tides) freezes in the bays, the direction of drifting *slob* coming from the north, as well as the direction of drifting pack ice (both offshore, and when it can come in and block the bays after the landfast ice breaks up). Participants also wanted to map a key hunting area that has been impacted by changing ice conditions. Follow-up interviews were semi-structured and asked participants to share more details related to the features that were mapped, as well as the processes that influenced them such as how the seasons and weather changed throughout the year and over decades. We use local terminology throughout the paper, which is emphasized by italics and defined upon first use (summarized in Table 1; also see Sikusiutet Committee et al. 2023 for visualizations of some of these terms).

During the mapping and interviews, participants shared extensive knowledge of the expected conditions leading into a "good" ice season, characterized by stable sea ice and longer periods of access/travel over the ice (conditions more common in the past), as well as a "bad" ice season, characterized by more unsafe ice and less stable conditions, and a shorter period of access/travel over the ice (conditions more common in recent years). Participants also described the types and timing of weather events and other conditions or phenomena that might impact the ice. Interviews and recordings from the mapping session were transcribed to facilitate a text-based analysis. The resulting floor map was scanned and uploaded into a geographic information system (ArcPro), where it was georeferenced and digitized. The mapping and interviews allowed us to identify key environmental indicators, seasons, and change over time that impact the sea ice season in Makkovik.

2.2. Developing a conceptual model

We created a draft conceptual model based on the most salient processes discussed during the participatory mapping and interviews. The model visualized the key indicators and relationships that participants described as influencing the ice throughout the season and over the years. In March 2023, the draft conceptual model was shared with co-author AngajuKak (mayor) Barry Andersen (who was also a participant) to discuss the possibility of developing it further to depict how the sea ice season is experienced in Makkovik. After gauging broader interest, we secured additional funding to pursue this work in collaboration with AngajuKak Andersen. The goal was to develop a conceptual model that depicts how Makkovimmiut experience the sea ice season and how it has changed over time.

Grounded theory is used in qualitative research to identify concepts (codes) and build models based on a close reading of texts (Bernard 2006). This approach guided development of the conceptual model and involved reading the interviews and mapping workshop transcripts to inductively identify concepts (codes) representing prominent themes and how they are linked to each other (Glaser and Strauss 2017). Using NVivo 1.7.1, sections of text were grouped to generate and refine themes. Coding identified themes around how the sea ice season is experienced, including various conditions that influence safe travel and access to the land, and notable changes observed over time (throughout the season and over years). The linkages across themes were revealed by cross-coding sections of text containing multiple themes to identify key environmental indicators, the relationships of influence among indicators, and how they impact safe travel and access to the Land in Makkovik. This analysis allowed us to develop a more detailed conceptual model building on the preliminary draft that was brought to Makkovik in March 2023. This model highlighted two different sea ice season scenarios that were prevalent in the interviews and transcripts, depicting the conditions and events that might take place during the sea ice season (from early fall to spring) for (i) a cold temperature scenario and (ii) a mild temperature scenario (cold and mild in an anomalous sense; both temperatures are still cold enough for ice to form).

The conceptual model was printed and brought to Makkovik along with the sea ice map that was made in 2021 to discuss with participants and other interested community members during a verification workshop in December 2023. Feedback was solicited to see if there were any more influential factors impacting the sea ice season and changes over time, and to discuss any other themes or ideas in more detail. The model prompted lots of storytelling in response to the process or feature being depicted, and the model was updated based on what participants described.

The results outlined in Section 3 detail the 2021 sea ice map, a summary of participants' individual descriptions and collective narratives of the sea ice season in Makkovik, and the resulting conceptual model. We do this to show the depth of participant narratives, and the process of reduction required to translate those narratives into a conceptual model. Participants are directly cited where their individual knowledge is described in the results; however, knowledge summarized from the mapping was collectively rendered and is presented without attributions to individuals, where any text without citations is derived from collective knowledge shared during the mapping.

3. Results

The following results provide an overview of the Makkovik sea ice season, with descriptions of the sea ice system, dynamics, and growth/melt trends. Section 3.1 includes an overview of the sea ice in Makkovik and a sea ice map depicting the general climatology. Sections 3.2–3.6 include detailed narratives of the sea ice season, including conditions that are observed between *ukiatsâk* (early fall) and *upinngak* (spring). While participants used English terminology to describe the seasons, the primary temporal demarcation of conditions aligned with the Inuit seasons determined elsewhere in Nunatsiavut and corresponding Inuttitut terminology (Cadman et al. 2025; Virtual Museum of Labrador n.d.), and thus both English and Inuttitut terms are used to structure the results. The results are also structured around a secondary temporal distinction of typical conditions in the past (experienced within the lifetime of participants; 61–76 years at the time of research) and conditions experienced more commonly today (observed changes shared during 2021 and 2023 workshops). Section 3.7 presents the conceptual model that was created based on the narratives articulated in Sections 3.2–3.6, depicting conditions expected for each season, and the changes observed in the past versus present day.

3.1. Makkovik sea ice overview

Makkovik experiences a lot of variability in the stability of the landfast sea ice and the position of the sinâ throughout the sea ice season, which has seemingly increased over the last few decades. The coastal environment is relatively exposed to the open ocean (see Fig. 2), making it vulnerable to the impacts of storms, wind, and *sea-on* (wind generated waves). When landfast sea ice forms, because there are limited offshore islands (compared to some other communities), there has always been potential for break-up events to occur throughout the sea ice season. However, under cold temperatures, the sea ice consolidating and re-freezing after a break-up event would not take long (typically 2–3 days). Participants described how the *sinâ* has changed over decades, specifically that it has been forming closer to the coastline compared to where it would be expected to establish over 20 years ago (Fig. 2, dashed lines). As the *sinâ* moves closer to the land, the landfast ice extent is reduced, meaning snowmobile routes and hunting areas are becoming more difficult to access due to ice conditions. This was highlighted by participants who described memories of regularly travelling near the outward most islands over 30 years ago and mapping the associated snowmobile routes once used to reach those islands (Fig. 2, red and yellow lines). Participants also described increased variability in the *sinâ* location because of the increased frequency of storm, wind, and *sea-on*. This has led to a once common hunting area being impacted, insofar as it cannot be accessed reliably anymore (Fig. 2, hatching, "Impacted Hunting Area"). Most on-ice snowmobile routes that were mapped cross through areas of changed ice conditions. This shows the extent of reduced (or no) access to areas that had been travelled to regularly in the past.

3.2. Ukiatsâk (early fall)

3.2.1. Typical conditions

Ukiatsâk was "always bird hunting—geese, ducks, that kind of thing, as well as seal hunting" (Andersen 2021*a*). The start of the season was marked by the arrival of cooler temperatures compared to the previous season, and "anytime past the 20th of September, you get snow on the hills and it would generally stay on the hills after that, and the weather would get gradually colder into October and November" (Broomfield 2021). The arrival of the cool air temperatures in *ukiatsâk* would overlap with cooling water temperatures, so that "by the time the ice making months came along, the water was already chilled enough to freeze" (Broomfield 2021). Broomfield recalled that the snow during *ukiatsâk* was always variable and described one year: "I went goose hunting at the end of September and when I came home people were going around on [the land on] snowmobiles […] a big snowstorm and we were stuck for about a week […]. That was always normal. You didn't know what was going to happen [with snow] after September" (2021).

3.2.2. Changes observed

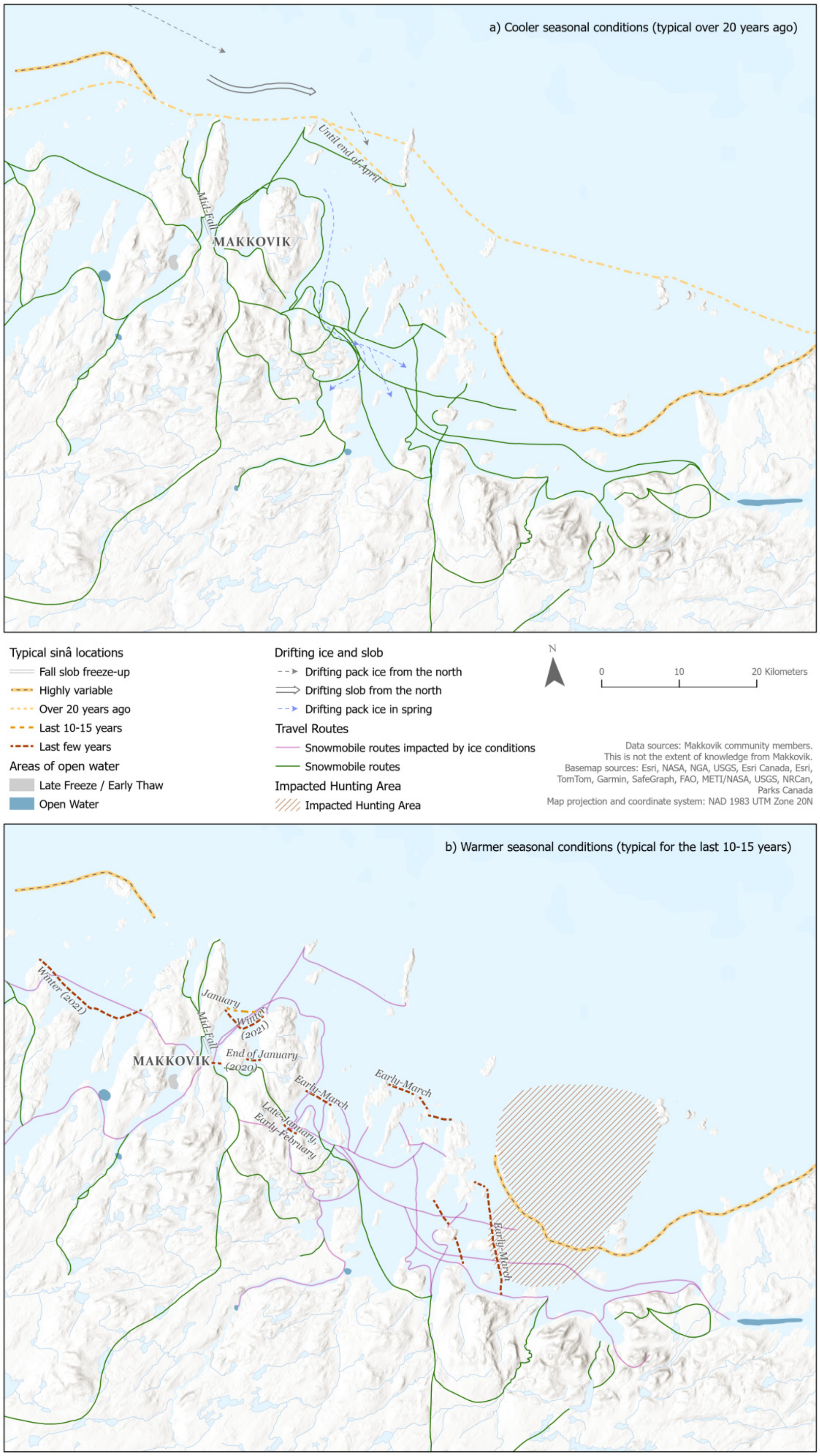
Warmer temperatures from summer have been staying around for much longer than in the past, leading to a later start of cooler weather. For example, "nowadays with the later freeze ups, like we're into late October and it's almost like summer conditions. So, the water should be getting cold this time of year for it to freeze in December and January but, you know, that's being delayed. It seems like it's getting later every year. Yep, so it's more unpredictable. You just don't know what's going to happen" (Broomfield 2021).

3.3. Ukiak (fall)

3.3.1. Typical conditions

After mid-October, the snow would fall and typically stick around—with many people having memories of spending their Halloweens trick-or-treating on snowmobile. The cold temperatures would arrive, marking the onset of freeze up. Freshwater brooks and ponds would freeze first, allowing people to travel by snowmobile over the land. People would put their boats away by mid- to late-October or early-November, and it would be about a week until they could be

Fig. 2. Mapped landfast ice state around Makkovik including variations throughout the season (typical sinâ locations, dashed lines), and over decades. Panel a) shows cooler seasonal conditions (typical over 20 years ago), and panel b) shows warmer seasonal conditions (more common in the last 10–15 years).



out on the ice on snowmobile (Broomfield 2021). Once the air temperature would hit −15 to −20 °C for 4–5 days or longer, vapour would be seen on the ocean, indicating the start of sea ice freeze up (often during November). The vapour (sometimes called steam, or *kisuk*) could be so active that some years, you could barely see the tops of the hills across the harbour (Broomfield 2021) and it could reach "halfway up the hill here in the harbour, vapour flying. Looks like the kettles boiling, and it's all steam coming off the water when it's freezing up" (Andersen 2021*b*). It would not take very long to freeze-up once the cold temperatures arrived, and "once they came, they never really left" (Broomfield 2021).

At the start of freeze-up in *ukiak*, participants described typically seeing ice around the shore by late October, early November. Ice pans would begin to freeze together in the bays. Winds during this time would break up the newly frozen pans, and the process of freezing together would have to start all over again. However, if cold temperatures persisted, after a few nights of no wind (calm conditions) the harbour and the bays would catch over (freeze). This could be safe for travel within a few days. While the ice is forming, it might be thicker close to shore, and thinner closer towards the *sinâ*. Thin saltwater ice is flexible, and you could see waves in the ice when travelling over newly formed, young ice (Winters 2021), but "you chop a hole, few chops with the axe and if it doesn't break through then you know it's safe" (Andersen 2021*a*). People "make sure it's at least 5 inches thick or, or 15 cm before you venture out. Just to be on the safe [side], because the [snow] machines are much heavier now than they used to be" (Andersen 2021*a*).

When heavy snowfall occurred during this time, it would sink the ice, and flooding of seawater mixing with snow would form a slushy layer on top of the ice. Cold temperatures would allow this layer to freeze and help the ice thicken. Snowfall would also bring *slob* down from more northern parts of the coast, which would get pushed in from offshore and help protect the newly forming ice by buffering it from wind and *sea-on*. If a fall storm were to occur, the ice could break up from the *sea-on*, and the wind could blow it all away. However, with cold temperatures, the ice would re-freeze within a few days.

During fall, once the snow stuck around on the land and the ice in the bays and harbours became safe enough to travel, it would be time for seal hunting, trapping, cutting wood, and preparing for winter (Andersen 2021*a*; Broomfield 2021; Winters 2021).

3.3.2. Changes observed

In the last 20 years, the temperatures have become warmer throughout the fall months, and it is staying mild for much longer, so it does not freeze up as quickly as it used to (Andersen 2021*a*). The ponds, lakes, rivers, and brooks are not freezing either and so people cannot really get away from the community (Broomfield 2021). In Makkovik, the typical indicators of *ukiak* are being pushed back by about a month or more (from mid-October to at least mid-November or later). Lately, "it's pretty much November and we're just walking around in thin jackets, sneakers… no *slob* on the roads, no ice" (Andersen 2021*a*). It could be December before you get any snow (Broomfield 2021). November is no longer seeing as much vapour as in the past, if at all. Now, it's about six weeks or more between when people put their boat away, to when they're able to get out on snowmobile.

Generally, it seems like it's harder for the ice to freeze in the fall (Andersen 2021*c*). The ice may begin to form, but the process is slower under relatively mild conditions—"mild" here meaning anomalously warm, though still cold enough for early stages of ice formation. If it does get cold enough for ice to freeze and begin to thicken, "[we've] been getting more wind storms, and it's making it harder for the ice to form up. The prevailing winds have changed from the northwest, which used to bring colder winds from the west, to a lot of wind off the easterly point, which is milder wind" (Andersen 2021*a*). The dominance of northeast winds as opposed to northwest is keeping it warmer (Andersen 2021*a*, 2021*c*; Broomfield 2021).

There has been increased snowfall on the ice during freeze-up (amounts that would not be expected until spring). Having this much snow in the fall can sink any newly formed ice, and the mix of snow and water on top of the ice can cause *slob* to form. With warmer temperatures than in the past, this *slob*/slushy layer does not freeze solid, and can be easy for snowmobiles to get stuck in, especially when from the surface it looks like snow on solid ice. With more mild temperatures, snowfall during freeze-up insulates the ice and delays or prevents proper freezing (Andersen 2021*b*). This means that the ice might look safe, but it's not as reliable to travel on because of warmer temperatures. At the same time, due to changes in prevailing wind, there seems to be less *slob* coming down from the north, which is leaving the *sinâ* more open and vulnerable to the impacts of wind and *sea-on*.

As a result of warmer temperature and changing wind direction, sea ice freeze-up timing is delayed, since sustained cold temperatures are not occurring until January/February, and only then does it stay cold enough for the sea ice to form and stay. Windstorms can still come through during this time and smash up the young ice trying to thicken and consolidate, and when the temperatures are too mild to re-freeze, the freezing process has to start all over again once temperatures become cold enough. While this has always been the case, when cold temperatures are present the re-freezing process will happen within a few days, while under warmer temperature this process can take much longer. When the ice does form, there is not as much of it, and it is not as hard as it used to be (instead of the rigid, freshwater-like ice of the past, it is now softer and more prone to buckling).

3.4. Ukiuk (winter)

3.4.1. Typical conditions

Towards the start of *ukiuk*, the sea ice extent slowly increases from the bays outward towards the islands. The season was characterized by very cold temperatures, with only 1–2 mild days (warmer than expected for that time of the year, and often approaching melting temperatures near 0 °C) across the whole season and very little snowfall. The cold temperatures could set in by December and not break until

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February—you'd get an occasional warm day, but it would not stay warm for any period of time, and "when it warmed up to −20 °C, that was [considered] warm" (Broomfield 2021) given that temperatures of −25 °C, −30 °C, or colder could be typical during this time (Andersen 2021*a*). About 30–50 years ago, by mid- to late-December, you could go anywhere on the ice in the bays and harbours and by January you could go pretty much anywhere to the islands as well.

December and January have always been known as the ice making months (Andersen 2021*a*; Broomfield 2021). During these months, westerly winds were common, bringing cold temperatures and calm seas. However, storms would pass by, and if easterlies blew, they would create sea swells that could cause the sea ice to move like a wave. Under these conditions, people would not travel in case the ice were to break up. When the weather was cold, "even when the ice broke up and it would go off, then the wind would bring it back in, it would freeze together, like, in probably two or three days, you'd be able to go on it again" (Andersen 2021*b*). This process, plus the impact of sea swells causing the ice to move up and down would create rough ice at the *sinâ*, sometimes piled 10–12 feet high, which would be really good for hunting seals later on, as the rough ice could act as a *taluk* (blind) (Andersen 2021*b*, 2021*c*; Winters 2021).

Continuing from fall, *slob* coming from the north would drift along the *sinâ*. It would form from snow blowing off the land into the sea, drifting southwards with the currents and winds, and would accumulate to become very thick along the sinâ. Participants recalled a year where a shrimp troller had to turn around because of the *slob* in early January, which was 9 m thick. If easterly winds blew, the *slob* would help dampen the impacts of sea swells on the *sinâ*. As *ukiuk* progressed, heavier pack ice coming down from up north would get pushed in by the tides and freeze into the *sinâ*. In December and January, it would pile up too much to get through to hunt and retrieve seals, so you would not travel out there until early spring. But the pack ice would help protect the *sinâ* from winter storms, and into the spring it would be better because it would delay the melt process as well (Andersen 2021*c*).

3.4.2. Changes observed

The prevailing winds seem to have shifted from westerlies to easterlies, bringing milder temperatures from offshore and causing more frequent sea swells. This leads to the ice-breaking up, "and we're seeing that all through the winter, through the last few years anyways" (Andersen 2021*a*). There seems to be less *slob* and pack ice coming down from the north, leaving the outside more open and vulnerable to the impacts of easterly winds. In response to this, it is increasingly important for people to check the ice from shore and listen for any groaning, and to see or feel if the ice is moving up and down. If any movement is noticed or a groaning sound is coming from the ice, it is deemed not safe for travel as this indicates sea swells which can cause cracks to form, and pans of ice can break off. Because in early *ukiuk* the weather is not as cold as it was back then, when a storm comes through and causes the sea ice to break up, the process of re-freezing takes much longer. In recent years, while the bays might freeze up by late-December, these changes have led to open water remaining out towards the islands all winter long in some years.

As *ukiuk* progresses, the cold temperatures that used to set in by December or January have shifted towards longer periods of mild temperatures, lasting up to a few weeks at a time. This has significantly impacted winter travel, preventing on-ice travel in many cases, with participants recalling mild temperature events that included rainfall and extremely thin ice conditions. A winter storm can still come through and break-up what ice is there during this time, but because of mild temperatures it takes much longer for the ice to re-freeze. Because December and January are considered the ice making months, "if we don't get ice then, we are not going to get ice. […] You can get cold weather in March, but December and January are the ice months, because the sun, in March the sun is way up in the sky again" (Andersen 2021*a*). Because there are longer daylight hours, ice growth is seemingly stunted if it has not thickened sufficiently in December/January, and what does form can be very thin, and very dangerous. What is especially challenging is that people do not know what kind of winter they are going to have. While they know it will be shorter and not the same as in the past, they just do not know what it will be like, and it is hard to plan anything.

3.5. Upinngasâk (early spring)

3.5.1. Typical conditions

Upinngasâk was known for snow. Around March, the temperatures would become more mild (still remaining below 0 °C) and lots of snow would arrive. The ice would be at its thickest, and out towards the *sinâ* it could be around 3–5 ft (0.9–1.5 m) thick, depending on the height of ridging and rafted pans. As the days became longer, the snow would become hard-packed, "then it was relatively easy to travel over because it was kind of compact, as opposed to jumping off your snowmobile and going up to your waist and having to use snowshoes the whole time" (Andersen 2021*a*). People would travel to cut their firewood and go for much longer distances to hunt for caribou. Winds from offshore would push drifting pack ice in towards the *sinâ*, causing ridges to pile up. These would create great conditions for seal hunting and also protect the landfast ice from any offshore wind and sea swells. At times, the *sinâ* could be so thick (vertically, due to ridging and rafted ice) that participants described having to cut through it to get a boat in the water to retrieve a seal. While these areas would not be commonly accessed in *ukiuk*, snowfall in early spring was known to fill in and smooth over areas of rough ice formed by break-up events or from pack ice anchored into the *sinâ*.

3.5.2. Changes observed

Warmer temperatures still arrive at the start of *upinngasâk*, as well as snowfall. However, the landfast sea ice is not nearly as thick as it used to be out towards the *sinâ*. This is because such a late freeze-up process can prevent it from thickening as it used to during the ice forming months. The pack ice that used to come down and get pushed into the landfast ice seems to have reduced in volume, leaving the *sinâ* more open and vulnerable to sea swells and wind coming from the offshore. Now, for the most part, the ice that forms locally is the only ice that the Makkovik region gets—there seems to be no more piled high multiyear ice coming down from the north. If the pack ice does come through, it is much less, and the wind can come through and break it off easily—people cannot predict stable enough conditions to rely on it for hunting anymore.

Milder weather (compared to 20–30 years ago and at times reaching above 0 °C) is now being associated with *upinngasâk*, and this has led to outflow from the rivers cutting the ice away from underneath at the mouth of the river. Some years the milder temperatures are leading to rain events as opposed to snow. Rain contributes to snow melt which, in addition to exposing the rougher ice surface below, is reducing the shelter available for jar seals who den and pup underneath the snow cover on the ice (Andersen 2021*a*).

3.6. Upinngak (spring)

3.6.1. Typical conditions

During *upinngak*, Makkovimmiut would travel on the ice to go fishing and hunting seals. As the season progressed, the ice melt would start. Participants described influences from above and below the sea ice as contributing to ice melt. Underneath the ice in the spring, algae would form, and Elders would always say that it would contribute to the ice melt from below, and this is still said by people today (Andersen 2021*a*). At the surface, longer days and warmer temperatures would cause melt ponds to form on the surface, which could accumulate a lot of water. People would still travel through the melt ponds, as "we knew we were still on good ice, but there was a lot of water all around" (Andersen 2021*c*). The melt was described to as a two-layer melt process, where the first layer of ice would melt and the water would drain off through holes in the ice, leaving beyond what was termed the "last ice", a solid layer of ice, which was always very hard and good for travelling over for a few more weeks. This last ice could be "full of holes, but it was hard as a rock [...] we used to have a little boat [that was towed over the ice to retrieve seals from the water], but you could go anywhere around [on snowmobile on the ice], even around the holes! It was good ice [...]. We used to always go around on the last ice. It used to be hard and good for seal hunting then [...], it was good going on the last ice (Winters 2021). People would travel on the last ice in the spring because it was predictable. Some years, 30–50 years ago, it would be early- to mid-June and people would still be travelling on snowmobile. The snow could be melted off the land, but the ice would still be around and good to travel on, and not until the end of June would Makkovimmiut be going out on boat.

As the season continued and the landfast ice would start to break-up, drifting pack ice from the north would get pushed into the bays and harbours, and it could get jammed in and block up some of the harbours or bays. So much so that under favourable conditions, people would take their snowmobile and a punt out onto these ice floes and hunt for seals. During this time, people might travel by boat as well. John Winters recalled,

> "We had a speed boat. We used to go out there and go over to Kaipokok Bay in the boat and it would be all still big ol' pans over there. We used to haul our boat up on the ice and go to sleep! In June. We used to haul it out with no worries. Go to sleep and wake up the next morning and go seal hunting. Yep. And we used to leave our boat way out here, and walk way out on to the ice. We wasn't scared it was going to break up and go away. Yeah, it was a lot of ice. You know, we trusted the ice, eh? You could leave your boat and walk away, it was so thick. Sometimes you'd think it was never gonna thaw out, hey. That's what we used to think! We used to come in from out there, we says "it's going to be July this year, portage!" (Winters 2021)

3.6.2. Changes observed

Sea ice melt and break-up has changed in *upinngak*. Generally, it was described as happening quicker, and earlier than in the past, and especially in the last 10 years, has been slowly getting worse, and very bad (becoming less stable and therefore unsafe to access/travel over) within the last few years. As the ice starts to thaw, in some hunting areas people are seeing seals on the ice earlier than they used to, especially in the last few years (Andersen 2021*a*, 2021*b*). In the last 4–5 years, the sea ice on the inside closer to the land seems to be getting thinner faster than the sea ice at the *sinâ*, and people are coming out to the outside islands in the spring, because they do not trust the ice on the inside (Andersen 2021*b*). The two-layer melt process was described as having changed as well. Specifically, people are not seeing the first layer ice melt in the same way as it did in the past, where the water would pool on the ice before draining through holes, now, the melt water seems to just seep through the ice. While the last layer of ice will still remain after the melt water drains, the last ice was described by participants as seeming like *candle ice* (comparable to rotten ice with a columnar structure) and it just falls apart. This is not safe to travel over, as people can break through and are unable to pull themselves back up.

The pack ice in spring has also changed. While it used to be anchored at the *sinâ* and help protect the landfast ice from wind- and wave-induced break-up events, it also would prolong the break-up process after the landfast ice had started to melt, as it would get pushed in with the tides and block the bays for quite a long time. Now, it does not come through as it did before (Winters 2021). Specifically, "the pack ice comes through fast. And I think last spring it was a month and we were out in the boat. And like, you didn't have to worry about that ice jamming you in. It used to be sheets of ice back then, but we don't get that as much anymore. Still some, but not much" (Andersen 2021*b*).

3.7. The conceptual model

A conceptual model was co-developed based on the processes and features that were most salient and consistently described by participants. The model frames sea ice or ocean access (by snowmobile vs boat travel, depicted pictorially) through expected ice conditions under a cold temperature scenario (equated to conditions more common in past decades—or "historical" but within the lifetime of participants; Fig. 3, left column) and a warm temperature scenario (equated to conditions more common in recent years; Fig. 3, right column). The model includes other key events that have the potential to impact ice conditions throughout the season in Makkovik—including snowfall, storms, vapour/*kisuk* (cold temperatures), *sea-on*, *slob*, and pack ice (Fig. 3, top row). Figure 3 includes text descriptions of key environmental indicators are coloured blue or red based on if they contribute to good ice (contribute positively to ice stability and therefore access) or contribute to bad ice (contribute negatively to ice stability and therefore access), respectively.

3.7.1. Cooler seasonal conditions

Under cooler seasonal conditions, the conceptual model depicts sea ice formation and decay throughout five seasons as follows: *Ukiatsâk* (early fall; Fig. 4*a*) is marked by cool air and water temperatures setting in, with snow falling and staying on the hills. At this time, Makkovimmiut are accessing the ocean by boat. *Ukiak* (fall; Fig. 4*b*) was marked by cold temperatures (−15 to −20 °C) staying for 4–5 days or longer, causing vapour to form, indicating the start of freeze-up. Within a few days the ice forms, and the flexible (as opposed to brittle) nature of saltwater ice enables access by snowmobile. Under these conditions, it would take about a week between putting the boat away and being able to travel by snowmobile. As *ukiak* (fall) progresses (Fig. 4*c*), any snowfall coinciding with cold temperatures can sink the ice, forming a slushy layer that freezes and contributes to the sea ice thickening. Drifting *slob* can get pushed into the sea ice and helps dampen the impacts of wind and *sea-on*. Fall storms might occur, and *sea-on* can cause a break-up event, with wind pushing the ice away from the coast (preventing access to the sea ice). However, under cold temperatures (associated with westerly winds), the ice will re-freeze and access to the ice can resume after 4–5 days. *Ukiuk* (winter; Fig. 4*d*) was associated with cold temperatures, ice thickening, and very little snowfall. At this time, cold temperatures would be the main deterrent to access, but ice conditions were typically favourable for travel. Offshore pack ice would be pushed in by winds, building up as rough ice anchored into the *sinâ*. This would make accessing the *sinâ* more difficult due to a rough and high piled travel surface, but also was good for hunting. Winter storms would always occur, and easterly winds could cause ice to break-off, but cold temperatures would allow the ice to re-freeze within a few days. *Slob* during this time would also help dampen sea swells impacting the *sinâ*. *Slob* and pack ice at the sinâ function in a very similar way to how the landfast ice acts as a buffer against coastal erosion from storms and waves (Hošeková et al. 2021; Henke et al. 2024).

Upinngasâk (early spring; Fig. 5*e*) was always known for snowfall and the landfast ice reaching its thickest point. These were ideal conditions to access the ice, which was protected from wind and sea due to pack ice frozen in at the *sinâ*. As *upinggak* (spring) progressed (Fig. 5*f*), warming temperatures and longer days would lead to the start of snow and ice melt, while break-up would be slowed by the presence of frozen in pack ice at the *sinâ*. The top layer of ice and snow would form melt ponds, eventually draining off through holes in the sea ice, leaving the last ice layer remaining, which was very hard and would extend ice access for a few more weeks after the melt had begun. Later in *upinngak* (spring; Fig. 5*g*) once the landfast ice had melted, drifting pack ice would get pushed in, blocking up the bays. During this time, people would access the ocean by both boat and snowmobile, and eventually just by boat once the ice cleared out.

3.7.2. Warmer seasonal conditions

Under warmer seasonal conditions, the conceptual model depicts sea ice formation and decay throughout five seasons as follows: *Ukiatsâk* (early fall; Fig 6*h*) is now characterized by warmer air and water temperatures persisting for longer into the season, and snowfall being delayed, allowing people to travel by boat for longer. *Ukiak* (fall; Fig. 6*i*) arrives later than before, and ice might start to form, but mild temperatures cause this process to take much longer, delaying snowmobile travel by weeks, if not months. If heavy snowfall occurs, it will still sink the ice, but mild temperatures prevent it from refreezing, and instead it insulates the ice and further delays ice growth. If a fall storm were to happen during *ukiak* (fall; Fig 6*j*), the *sea-on* and wind will break up and take away the ice, and under mild conditions it takes much longer to re-freeze. Due to the later, longer freeze-up in *ukiak*, access is delayed by a month or more. People start accessing the sea ice by *ukiuk* (Fig. 6*k*), and while it might thicken closer to shore, it gets thinner out towards the *sinâ* as a result of the late freeze-up. Across the Arctic there have been reductions in the volume of pack ice, including multiyear ice (Tivy et al. 2011; Babb et al. 2021). Furthermore, a generalized shift in precipitation patterns in Nunatsiavut, with a decreased fraction of precipitation falling as snow (Barrette et al. 2020), leaving less snow in general to contribute to *slob* development offshore. These trends are evident around Makkovik, where less *slob* and pack ice drifting from the north make the *sinâ* more exposed and vulnerable to break-up under the action of wind and sea-on. Storms occur more frequently, with easterly winds bringing mild temperatures and break-up events. Sustained mild temperatures extend the length of time it takes for the ice to refreeze after a break-up event. Ice access can be quite variable during this time, but generally there is reduced access as compared to the past (cooler temperatures).

Upinngasâk (early spring; Fig. 7*l*) is still associated with milder temperatures, however they are warmer than in the past, and precipitation that once fell as snow can also bring rainfall, which contributes to snowmelt. At this time, the rivers and brooks have been thawing out early and freshwater outflow begins to cut the ice out from underneath. The landfast ice is not as thick as it used to be which makes it more vulnerable to breaking off at the *sinâ*. This vulnerabil-

Fig. 3. Simplified conceptual model of the sea ice season (from early fall, through winter, to spring) in Makkovik, Nunatsiavut. The model shows, graphically, the temporal progression of the seasons(y axis, time increasing from top to bottom) and a transition from cold to warm conditions over decades (left vs. right panels). The model can be interpreted by reading down the columns to assess sea ice progression over the course of the seasons, or by reading across the rows to contrast the cooler vs warmer seasonal conditions (to assess how the sea ice season in Makkovik has changed over decades, largely influenced by warming temperatures). This figure is divided into four with more detailed descriptions in Figs. 4–7.

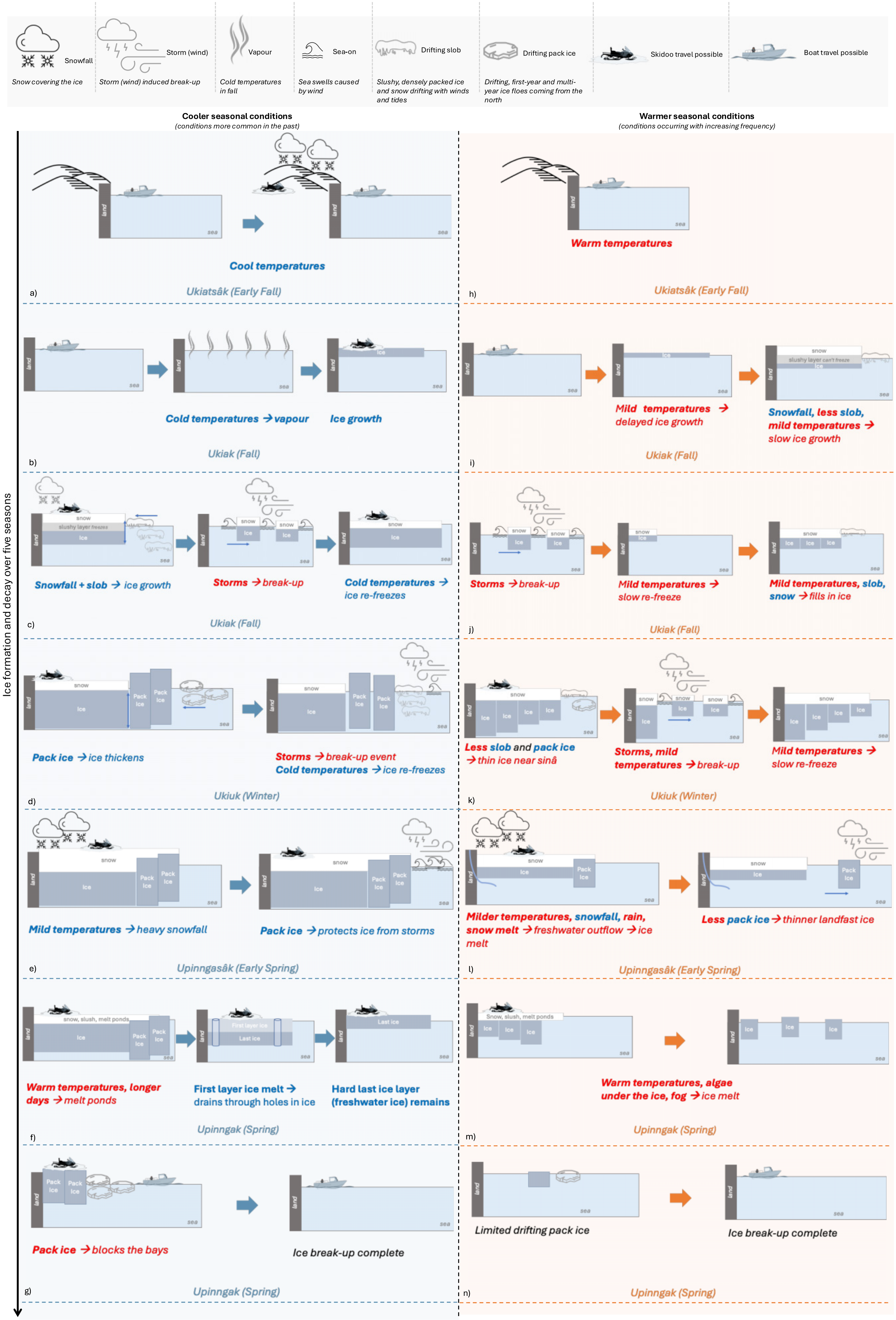


Fig. 4. Segment of the conceptual model showing ice growth and decay under a cold temperature scenario between Ukiatsâk and Ukiuk.

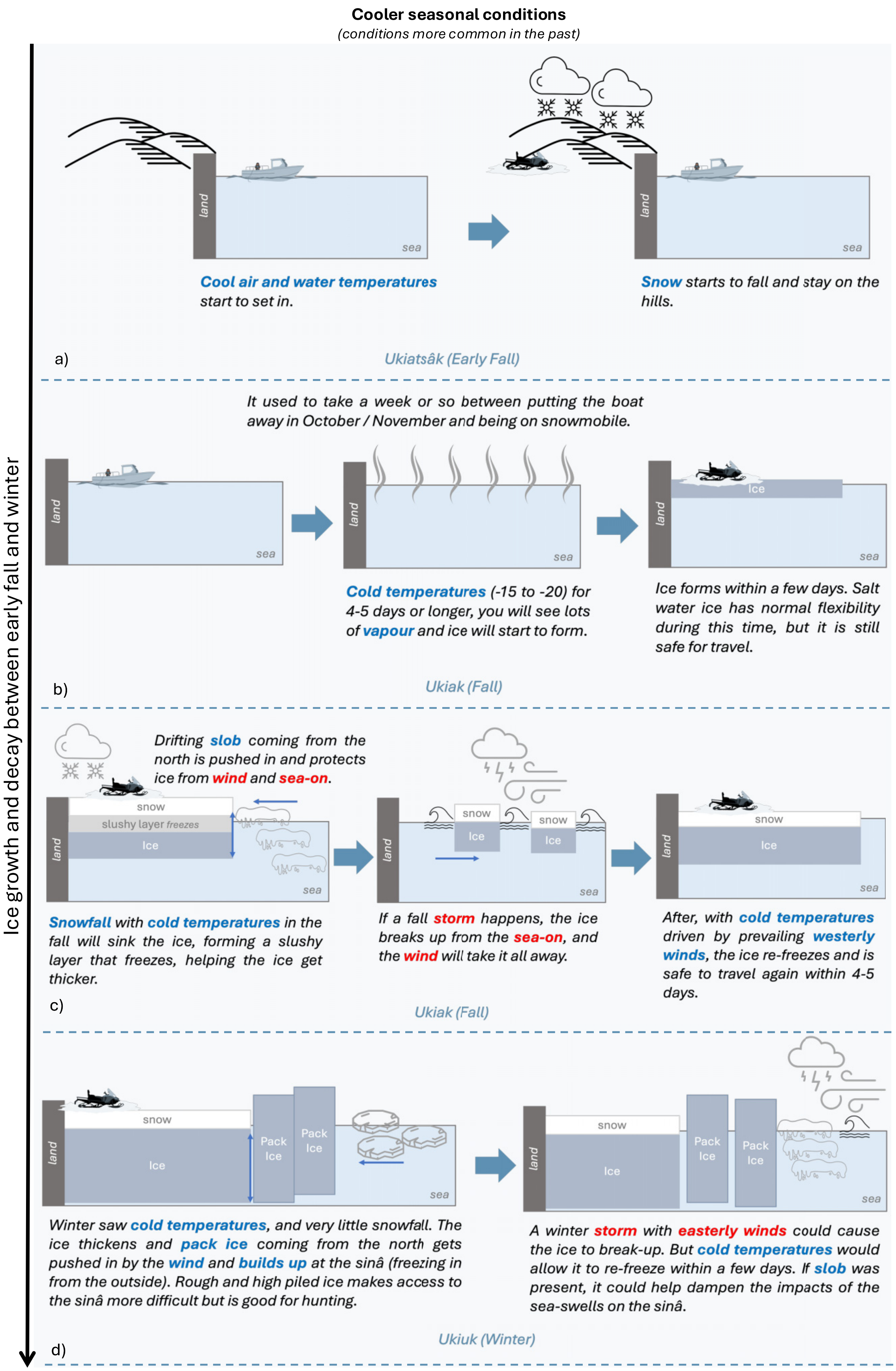


Fig. 5. Segment of the conceptual model showing ice growth and decay under a cold temperature scenario between Upinngasâk and Upinngak.

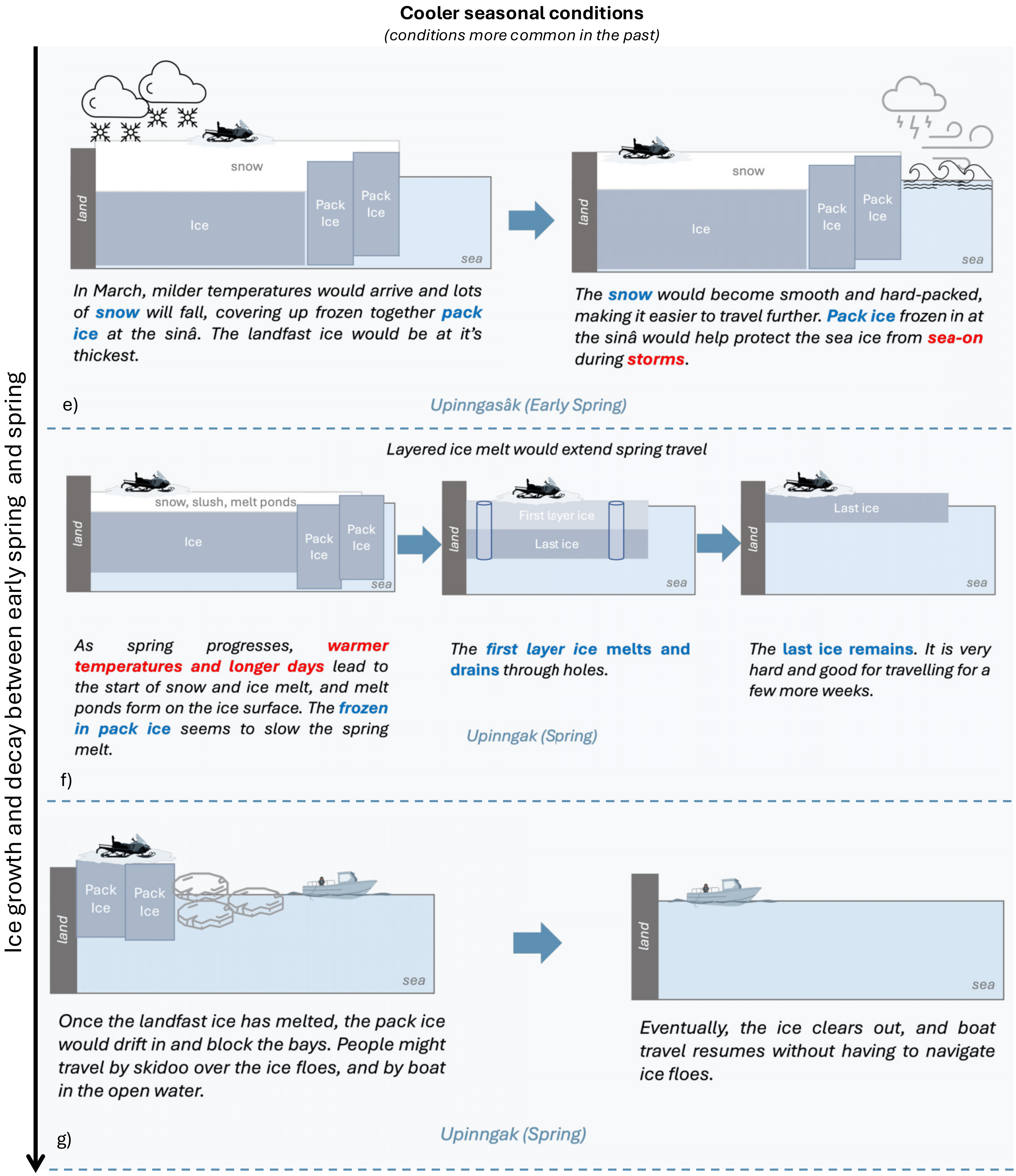


Fig. 6. Segment of the conceptual model showing ice growth and decay under a warm temperature scenario between Ukiatsâk and Ukiuk.

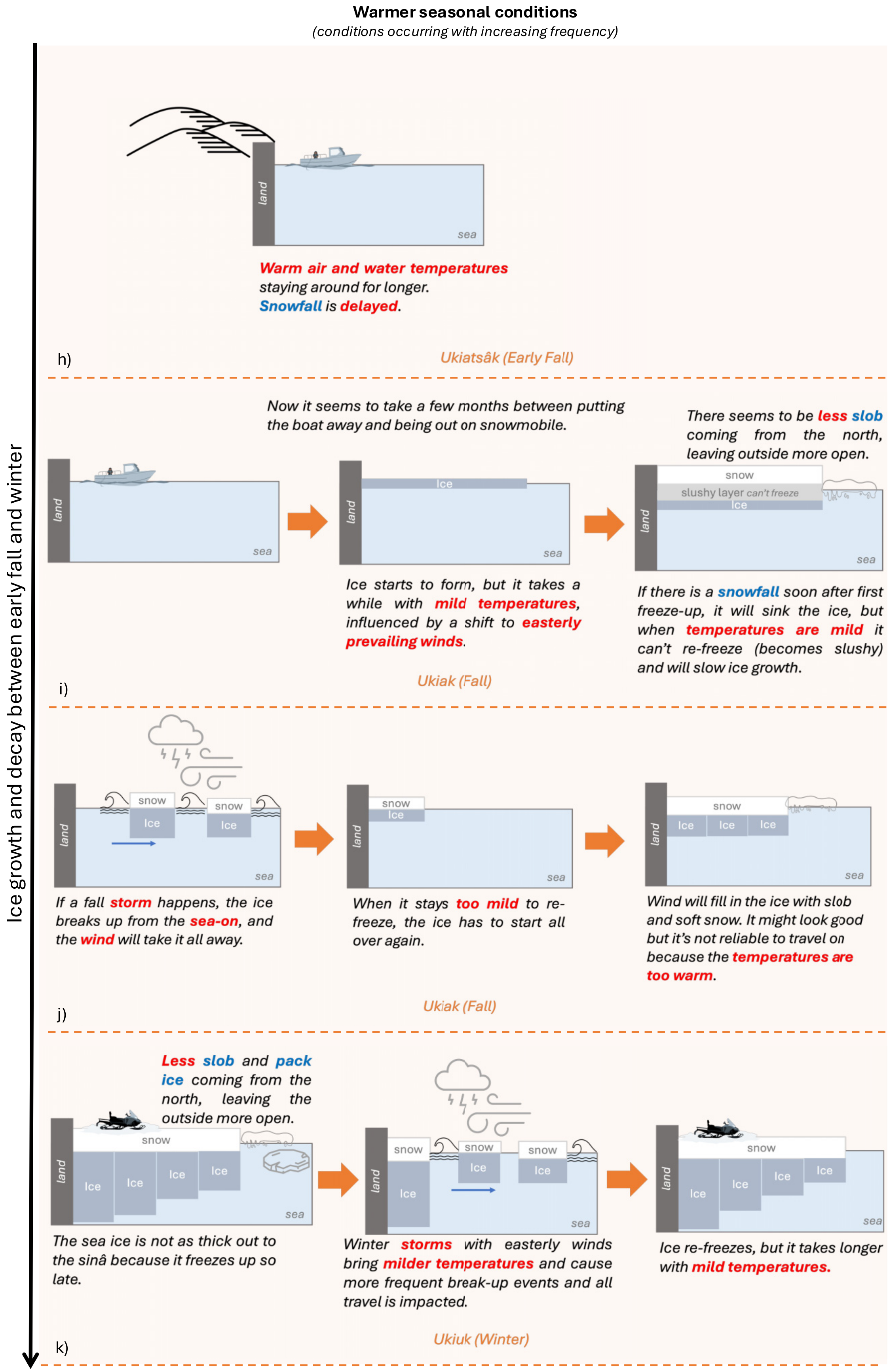
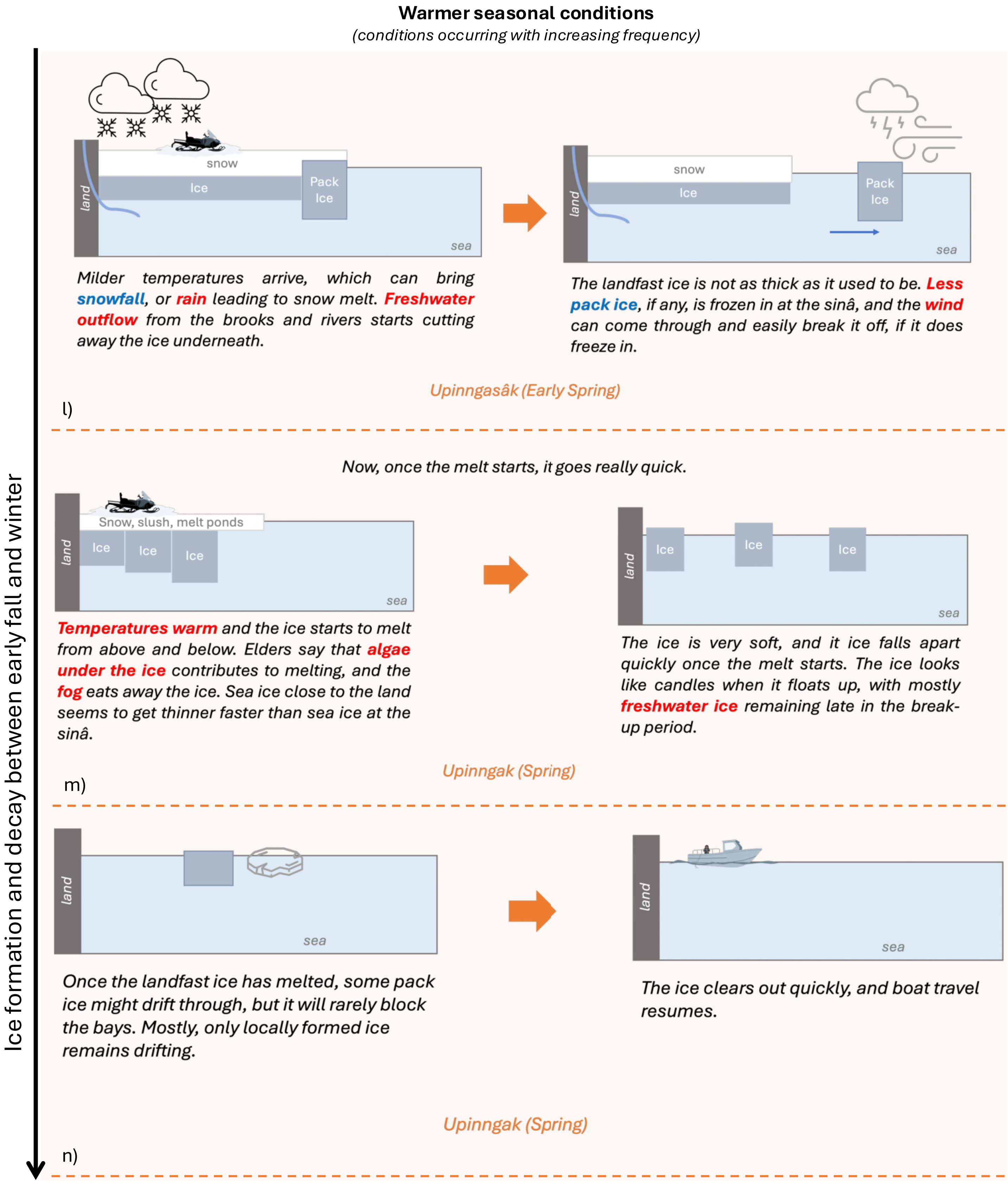


Fig. 7. Segment of the conceptual model showing ice growth and decay under a warm temperature scenario between Upinngasâk and Upinngak.



ity is amplified by reduced pack ice frozen in at the *sinâ*. As temperatures warm in *upinngak* (spring; Fig. 7*m*), the ice melts from above and below, and sea ice closer to the land seems to get thinner faster than sea ice at the *sinâ*, causing people to change the route they take to access spring hunting areas (and if they are able to access those areas at all). Once the melt starts, it seems to go very quickly, and access is prevented as the ice is very soft and falls apart quickly, looking like candles as it floats up, indicating that it is mostly freshwater ice remaining. Once the landfast ice has melted (Fig. 7*n*) pack ice might drift through, but it rarely will block the bays, and boat travel can resume once the ice has cleared.

4. Discussion

Developing a conceptual model is necessarily reductionist, focusing on key concepts that capture and convey the rich understandings embedded in Inuit narratives of the sea ice season. The narratives in Sections 3.2–3.6 illustrate what Herman-Mercer et al. (2023) describe as episodic and semantic knowledge—encompassing past stories, qualitative, and quantitative observations of climate change impacts. The blending of specific temperature and timing references with memories of seal hunting and travel across different types and textures of ice reflects a bio-socio-cultural framing of environmental change (Herman-Mercer et al. 2023). Translating this into a conceptual model required simplification and refinement. Given the cross-cultural nature of this research, it was important that the model could serve as a foundation to guide future western scientific research while also upholding core aspects of participants' narratives, such as the emphasis on sea ice access and factors leading to good or bad ice conditions. While participants sometimes provided specific parameters for timing or temperature, these quantitative details were not their focus. Instead, they were used as references to help convey what was being described to university-based researchers unfamiliar with those specific conditions. In the context of Inuit Knowledge, the absence of specific and consistent parameters should not be understood as a lack of information. Rather, the information provided is sufficient—within local knowledge systems—to define what is being described. Participants emphasized the relationships among environmental indicators and their influence on sea ice access and safe travel, whether enabled or constrained by good or bad ice. These descriptions are meaningful in the local context, where terms such as *mild* or *cold* express locally relevant conditions without reliance on quantification. The conceptual model was therefore designed to reflect these relational processes.

Throughout Labrador, including Nunatsiavut, rapid warming has occurred from the late 1990s to present (Way and Viau 2015; Barrette et al. 2020). Participants in Makkovik described this warming trend as the key causal factor leading to poor and less reliable ice conditions and ice access (increased prevalence of "bad" ice conditions). This temperature trend, together with seasonality, became the core framing of the conceptual model, centered on sea ice access through conditions that contribute to good ice (contribute positively to ice stability and therefore access) or contribute to bad ice (contribute negatively to ice stability and therefore access), respectively. Within this framing, all indicators included in the model function as determinants of ice access. This approach allows the model to retain cultural contextualization (landfast sea ice access) while maintaining flexibility to inform scientific analysis (through key indicators and their relationships), underscoring its uniqueness in having a dual role: a community-informed representation of sea ice knowledge and a tool emerging from and intended to support cross-cultural research.

The conceptual model details key processes among weather, water, and ice indicators that convey different relationships of influence: causal (directly impacts ice conditions and ice access), conditional (impacts ice conditions and ice access through the confluence of other conditions that may or may not be present), or predictive (can be used to predict ice conditions and ice access; Table 2; see also Bishop et al. 2025*b*). For example, certain indicators were framed as influencing how the sea ice season progresses (conditional, predictive). Participants described that if freeze-up during *ukiak* was characterized by snowfall sinking the ice and insulating it (preventing freezing), and ice growth being delayed until late *ukiuk* and *upinngasâk*, the ice melt during *upinngak* would be rapid, and the two-layer melt would not be observed.

Additional relationships in the model convey the influence temperature, snowfall, storms, winds, and *sea-on* (among others), which throughout the season can lead to ice growth and/or break-up events which impacts ice access. These relationships, which exert influence beyond the seasonal temporal framing conveyed in Fig. 3, are summarized in Fig. 8. The causal, conditional, and predictive relationships that influence ice access in Makkovik represent various thermodynamic and dynamic factors that can improve understanding the mechanisms that impact landfast sea ice growth, decay, and overall stability (Druckenmiller et al. 2009). Of note, the indicators and their relationality reflect the interests and needs of ice users in Makkovik and as such may not be suitable for broader applications at different scales or in other locations (Walsh et al. 2022).

4.1. Centring Inuit Knowledge in sea ice research

The conceptual model conveys Inuit community insights that are highly relevant at local and regional scales. In contrast, geophysical models of landfast sea ice often focus on pan-Arctic, regional, or sub-regional scales. These models are designed for specific purposes, such as characterizing sea ice properties, examining how sea ice influences oceanic and atmospheric conditions, or predicting future changes that may affect vessels navigating seasonally ice-covered waters (De Silva et al. 2015; Olason 2016; Sterlin et al. 2024). Geophysical sea ice models are a critical source of information for Arctic climate change assessments, which in turn inform policy and decision-making contexts, including those in Nunatsiavut (AMAP 2021; Nunatsiavut Government 2025). While geophysical models are designed for specific purposes and at particular temporal and spatial scales, use of model outputs can extend beyond the control of the researchers who developed

Table 2. Environmental indicators described in Makkovik as influencing sea ice conditions and sea ice access classed as casual, conditional, or predictive.

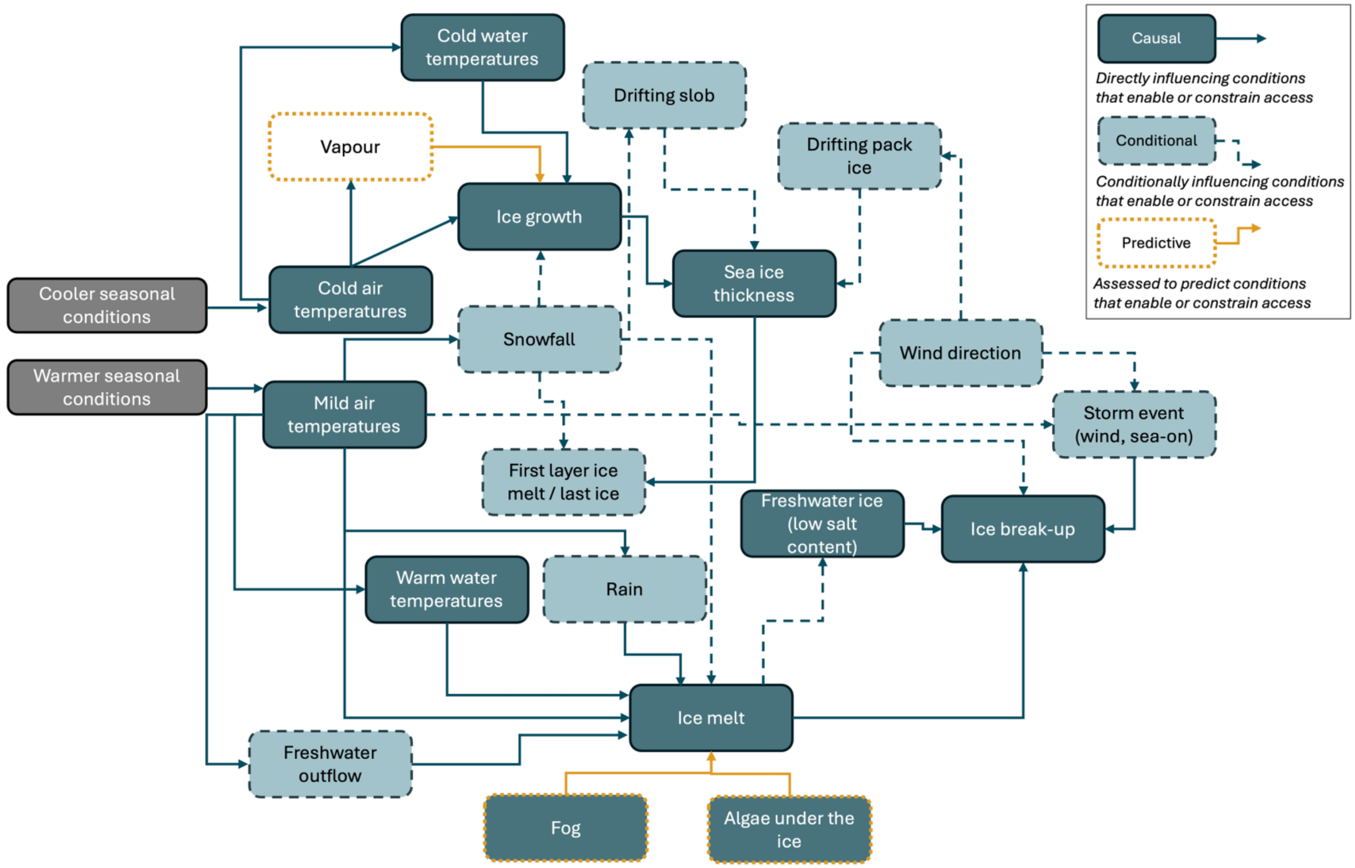
Indicator	Indicator type	Relationality to sea ice conditions and access
Air temperature	Causal	Directly enables or constrains ice formation and melt, thereby the timing of access
	Conditional	The duration of sustained air temperatures influences the time and efficiency of sea ice re-freezing after a break-up event, enabling or constraining access
	Predictive	Air temperatures are the primary predictor of ice conditions and access
Algae under the ice	Causal, predictive	Algae under the ice in the spring contributes to ice melt below the surface, and is a precursor to ending access by snowmobile in the spring
Drifting pack ice	Conditional	The presence or absence of pack ice and the volume of pack ice can help buffer the *sinâ* against impacts from storms, winds, and *sea-on*, helping strengthen or protect the landfast ice conditions, sustaining access
Drifting *slob*	Conditional	The presence or absence of *slob* and the volume of *slob* can help buffer the *sinâ* against impacts from storms, winds, and *sea-on*, helping strengthen or protect the landfast ice conditions, sustaining access
First layer ice melt/last ice	Conditional	If first layer ice melt occurs and leaves behind the last (hard) layer of ice, ice access can be prolonged during the melt
Fog	Causal, predictive	Fog during spring eats away at the ice (contributes to thinning), and is a precursor to ending access by snowmobile in the spring
Freshwater ice (low salt content)	Causal	Freshwater ice with low salt content that remains in the spring will fall apart quickly (*candle ice*)
Freshwater outflow	Conditional	Freshwater outflow caused by brooks and rivers thawing can thin the ice from below the surface, leading to areas of unsafe ice and/or contributing to melt
Ice thickness	Causal	Ice thickness will determine whether or not ice can be accessed
	Conditional	Ice thickness is influenced by temperature and timing of ice growth
Snowfall	Conditional	The timing and amount of snowfall will help the ice freeze up solid or prevent the ice from freezing solid depending on air temperatures, helping or hindering access as a result
	Causal	The amount of snowfall will help smooth out rough ice, making access easier
Storm event (wind, *sea-on*)	Conditional	A storm event including wind and *sea-on* can cause a break-up event, prohibiting access, but the duration that access is prevented depends on air temperatures and the presence or absence of *slob* and pack ice beyond (or anchored into) the *sinâ*
Vapour	Predictive	Vapour in fall is a sign of air temperatures being cold and sustained long enough for freeze-up to occur within a few days
Water temperature	Causal	Water temperatures must reach a certain temperature in the fall in order for freeze-up to occur
Wind direction	Conditional	The timing and duration of wind from a certain direction can help the ice form or cause a break-up event

them. Users may apply model outputs (e.g., sea ice or climate predictions) in contexts or at scales for which they were not originally intended (e.g., sea ice travel safety; Cooley et al. 2020), creating potential gaps between model design and real-world applications. By centring Inuit Knowledge and experiences in the conceptual model presented here, we are proposing a framework anchored in local-scale observations and applications to guide future geophysical sea ice models and sea ice research more broadly.

The conceptual model emphasizes relationality among environmental indicators over time, a perspective that could be translated into geophysical sea ice research in Nunatsiavut. For example, many sea ice studies use a certain percentage of ice concentration to assess the start and end of the freeze-up and break-up process (Bliss et al. 2019; Walsh et al. 2022). While such parameters can inform real-time and retrospective analysis of the ice season, they do not always indicate what conditions might be expected throughout the season; an essential consideration for Inuit travelling over the ice. The model identifies the temporal relationships among indicators that shape the seasonality of landfast sea ice near Makkovik. For instance, cool temperatures (marked by vapour), snowfall and offshore slob all contribute to ice growth and access in Ukiak, whereas the absence of these indicators can delay ice growth and access. These indicators could be further explored and parameterized, building on prior work where Inuit observations were quantified and successfully used to define the start and end of freeze-up and break-up processes in geophysical research (Eicken and Johnson 2016). The novelty of this approach stems from centering observations related to ocean access for subsistence hunters, including the ability to travel over the sea ice as a key indicator to inform community-based geophysical sea ice studies (ibid.). Moving from documenting and representing Inuit sea ice knowledge via the conceptual model to collaborating on its uptake and application in western geophysical sciences will require future research. This research should assess whether consistent quantification and parameterization is appropriate and, if so, identify metrics that reflect Inuit indicators of safe travel and access.

When designed to forecast the timing and likelihood of seasonal sea ice stability and trafficability (and communicated in terms ice access), such applications of the conceptual model could support ice travel planning throughout the

Fig. 8. Causal, conditional, and predictive relational processes among key environmental indicators that influence landfast sea ice access and dynamics near Makkovik, Nunatsiavut.



season. This, in turn, can help support coastal livelihoods and socio-economic decision-making (Eicken et al. 2021) such as when to take time off work to travel, when to collect firewood for the season, or when and where to plan a hunting trip. Using the model as a framework to guide geophysical sea ice research could generate more locally relevant information for climate change adaptation planning and decision-making, particularly for anticipating future sea ice conditions. These examples demonstrate clear applications for Inuit communities while also underscoring the need for novel geophysical research that is responsive to human–environment relationships (Cavaleri Gerhardinger et al. 2024). Such research can increase the usefulness and usability of sea ice studies at local scales, in turn supporting self-determination in climate change planning and decision-making.

4.1.1. Conceptual and practical considerations

While the conceptual model offers a meaningful approach to connect diverse understandings of sea ice, it also raises important conceptual and practical considerations. Developing a model involves ontological assumptions and epistemological values that influence what variables and processes are included or excluded, ultimately leading to a researcher-determined simplified representation of real world phenomena (So 2017). It is essential to acknowledge biases and power imbalances that can influence cross-cultural research, particularly in settings such as geophysical sea ice research, where Western scientific priorities often dominate.

The conceptual model presented here differs from typical Western geophysical sea ice science in several ways: (1) its focus on sea ice access rather than physical properties; (2) its temporal framing of four Inuit seasons marked by the presence or absence of indicators rather than specific dates; (3) its emphasis on causal, conditional, and predictive relationships centered on Inuit–ice interactions rather than physical processes isolated from human use; and (4) its grounding in a local/community-focused scale rather than a broader or more generalizable scale. These differing approaches can be complimentary however, it is important to consider how to engage with uncertainty and variability across different knowledge systems and observational frameworks.

Tensions may arise when Inuit Knowledge and Western scientific observations diverge. For example, participants described experiencing a shift in prevailing winds from the west (which would blow snow off the land) to more frequent winds from the east. Yet, when co-author Oliver conducted a preliminary scientific analysis of local weather station data, the analysis did not reflect the shift in dominant wind patterns expressed by participants. Similar discrepancies have been noted elsewhere in Inuit Nunangat (Gearheard et al. 2010; Barrette et al. 2020). Such differences may stem from distinct approaches to experiencing, observing, and measuring key variables. Western science measures relies on fixed, location-based measurements which are sensitive to site conditions (Barrette et al. 2020). In contrast, Inuit descriptions of changing wind patterns reflect lived experiences of how Inuit interact with the wind during on-ice travel. Furthermore, Inuit knowledge spans generations of personal engagements and shared oral histories, highlighting the elastic and highly experiential nature as compared to the fixed timescales and locations in-situ natural scientific observations (Gearheard et al. 2010).

Another tension may emerge around how sea ice processes are conveyed in cross cultural research. For example, the narratives and conceptual model include a mix of experiential descriptions with specific parameters such as temperatures or dates. In contrast, geophysical sea ice science requires standardized parameterizations to ensure replicability, generalizability, and validity. This difference highlights an important ontological distinction: the conceptual model is centered on human–environment interactions and culturally grounded indicators, whereas Western scientific approaches treat sea ice processes as external, quantifiable variables. Recognizing this distinction is critical for cross-cultural research if the aim is to avoid privileging Western scientific frameworks and to ensure that locally relevant knowledge (such as the relational indicators of safe ice access) remains central.

Finally, the model is contextualized through the ways in which Makkovimmiut interact with and experience their environment. Factors such as cultural values, employment schedules, access to technologies such as snowmobiles or GPS, and community knowledge-sharing networks all share how the landfast sea ice is engaged with. Given the depth of this contextualization, further development of the model to bridge with specific Western scientific applications must be done in collaboration with Makkovimmiut to better understand how it can be interpreted, parameterized (if desired), and applied. Local participation is crucial to ensure rigour, accuracy, and credibility to the results of any research endeavors (Barber and Jackson 2015).

5. Conclusion

The conceptual model presented in this study offers a framework to guide the development of geophysical research that relates and is responsive to Makkovimmiut knowledge and experiences of the sea ice. This includes providing observations of phenomena of importance to Makkovimmiut at both the geographic scale of mobility on the land, sea, and ice, as well as climatic phenomena occurring at local and regional scales such as temperature trends and wind patterns. Similarly, the temporal framing of seasons marked by the presence/absence of environmental indicators that determine access to the sea ice (as opposed to seasons marked by specific dates) and indicators of change over decades provide a multiscalar basis for analysis and framing future predictions. The relationships presented among the environmental indicators described provide a basis around which hypotheses might be developed and the conceptual model can help validate hypotheses testing. Furthermore, the conceptual model provides an important framework around which results can be communicated, presenting key indicators and relationships of importance to Makkovimmiut. Ultimately, while the model presents key variables that can translate into geophysical research, the values that underpin the conceptual model are essential to consider as well, specifically *access* to sea ice. As a bridging tool, conceptual models can lead to a deeper and more nuanced understanding of sea ice achieved through drawing on both the larger scales of geophysical science models and the local conditions of sea ice that emerge in relation to how Makkovimmiut experience their environment.

Inuit Knowledge of sea ice offers different spatial scales, environmental indicators, and relationships to consider in geophysical research (Eicken 2010; Gearheard et al. 2011; Huntington et al. 2011). The narratives we include here highlight how Makkovimmiut Knowledge inherently has the capacity to convey seasonal and climatic information (Itchuaqiyaq 2023). Importantly, this is underpinned by and structured around cultural values and in this case the value of *access* to the sea ice. Thus, future research could focus on parameterizing concepts conveyed within the model, or use the model to guide and interpretate a quantitative data analysis of seasonal and climatic trends (Pfister 2018; Ouellet-Bernier and de Vernal 2020) that impact Inuit access to the landfast sea ice in Nunatsiavut. While beyond the scope of this current study, future work will utilize the conceptual model presented here to guide an analysis of temperature, precipitation, and wind speed data in Nunatsiavut. This conceptual model can act as the basis from which testable hypotheses could be developed, data collection (field campaigns) could be planned and modified, and results could be communicated to broader audiences (Wassmann et al. 2020). Importantly, this future research building from this model would be shaped by and centre the Inuit value of *access* to the land. This approach has the potential to address multi-scalar bio-socio-cultural-ecological linkages while informing transcultural environmental research with and for Indigenous communities (Laidler et al. 2011; Cooley et al. 2020; Fox et al. 2020; Hauser et al. 2021).

Involving Indigenous communities in the research process fosters a participatory model of science that respects and incorporates diverse worldviews. This can lead to more accurate and culturally relevant scientific findings. Co-developing community-based geophysical research can foster meaningful engagement, improve how community-relevant processes are understood, increase the relevance and use of research outputs. An Indigenized conceptual model such as the one presented here can serve as a boundary object (Bishop et al. 2021), offering an approach to shift the culture of geophysical research to one that is responsive to human–ocean relationships, generating research that is inclusive, equitable, and relational in praxis.

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Data availability

In support of Inuit data sovereignty, data that support the findings of this study are owned by and remain with the knowledge holders and communities where the research took place. The Nunatsiavut Government Research Advisory acts as stewards of these data on behalf those knowledge holders and their communities.

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References

AMAP. 2021. AMAP Arctic Climate Change Update 2021: Key Trends and Impacts. Arctic Monitoring and Assessment Programme (AMAP). p. 148. Available from https://www.amap.no/documents/download/6890/inline [accessed January 2023].

Andersen, B. 2021a. Interview 27 October 2021. Makkovik, Nunatsiavut.

Andersen, J. 2021b. Interview 28 October 2021. Makkovik, Nunatsiavut.

Andersen, T. 2021c. Interview 27 October 2021. Makkovik, Nunatsiavut.

Aporta, C. 2002. Life on the ice: understanding the codes of a changing environment. Polar Record, **38**(207): 341–354. doi:10.1017/S0032247400018039.

Babb, D.G., Kirillov, S., Galley, R.J., Straneo, F., Ehn, J.K., Howell, S.E.L., et al. 2021. Sea ice dynamics in Hudson Strait and its impact on winter shipping operations. Journal of Geophysical Research: Oceans, **126**(12). doi:10.1029/2021JC018024.

Barber, M., and Jackson, S. 2015. 'Knowledge making': issues in modelling local and indigenous ecological knowledge. Human Ecology, **43**(1): 119–130. doi:10.1007/s10745-015-9726-4.

Barrette, C., Brown, R., Way, R., Mailhot, A., Diaconescu, E., Grenier, P., et al. 2020. Chapter 2: Nunavik and Nunatsiavut regional climate information update. *In* Nunavik and Nunatsiavut: from science to policy, an integrated regional impact study (IRIS) of climate change and modernization, second iteration. *Edited by* P. Ropars, M. Allard and M. Lemay, ArcticNet Inc. p. 58.

Bernard, R.H. 2006. Research methods in anthropology: qualitative and quantitative approaches. 4th ed. AltaMira Press.

Bishop, B., Denniston, M., Oliver, E.C.J., and Aporta, C. 2025a. An iterative and participatory method for mapping inuit knowledge of ice and ocean in Nunatsiavut. Human Ecology, **53**: 843–864. doi:10.1007/s10745-025-00631-8.

Bishop, B., Oliver, E.C.J., and Aporta, C. 2021. Co-producing maps as boundary objects: bridging Labrador Inuit knowledge and oceanographic research. Journal of Cultural Geography, **39**(1): 55–89. doi:10.1080/08873631.2021.1998992.

Bishop, B., Paquette, E., Carter, N., Ljubicic, G., Oliver, E.C.J., and Aporta, C. 2025b. Inuit uses of weather, water, ice, and climate indicators to assess travel safety in Arctic Canada, Alaska, and Greenland: a scoping review. FACETS, **10**: 1–25. doi:10.1139/facets-2024-0107.

Bliss, A.C., Steele, M., Peng, G., Meier, W.N., and Dickinson, S. 2019. Regional variability of Arctic sea ice seasonal change climate indicators from a passive microwave climate data record. Environmental Research Letters, **14**(4): 045003. doi:10.1088/1748-9326/aafb84.

Broomfield, T. 2021. Interview 28 October 2021. Makkovik, Nunatsiavut.

Cadman, R., Saunders, M., Andersen, C., Bishop, B., Pamak, M.C., Pijogge, M.L., et al. 2025. All kinds of seasons: articulating Labrador Inuit governance through crafting a seasonal calendar. Arctic Science, **11**: 1–13. doi:10.1139/as-2025-0037.

Cajete, G.A. 2020. Indigenous science, climate change, and indigenous community building: a framework of foundational perspectives for indigenous community resilience and revitalization. Sustainability, **12**(22): 9569. doi:10.3390/su12229569.

Castleden, H.E., Martin, D., Cunsolo, A., Harper, S., Hart, C., Sylvestre, P., et al. 2017. Implementing Indigenous and Western Knowledge Systems (Part 2): "you have to take a backseat" and abandon the arrogance of expertise. International Indigenous Policy Journal, **8**(4). doi:10.18584/iipj.2017.8.4.8.

Cavaleri Gerhardinger, L., Moreira Moura, G.G., McKinley, E., Christie, P., Narchi, N.E., Colonese, A.C., et al. 2024. A call for a cultural shift in oceanography. Coastal Management, 1–13. doi:10.1080/08920753.2024.2370214.

Chelton, D.B. 2001. Report of the high-resolution ocean topography science working group meeting. College of Oceanic and Atmospheric Sciences Oregon State University. Available from https://ceoas.oregonstate.edu/hotswg [accessed November 2024].

Cooley, S.W., Ryan, J.C., Smith, L.C., Horvat, C., Pearson, B., Dale, B., and Lynch, A.H. 2020. Coldest Canadian Arctic communities face greatest reductions in shorefast sea ice. Nature Climate Change, **10**(6): 533–538. doi:10.1038/s41558-020-0757-5.

De Silva, L.W.A., Yamaguchi, H., and Ono, J. 2015. Ice–ocean coupled computations for sea-ice prediction to support ice navigation in Arctic sea routes. Polar Research, **34**(1): 25008. doi:10.3402/polar.v34.25008.

Druckenmiller, M.L., Eicken, H., Johnson, M.A., Pringle, D.J., and Williams, C.C. 2009. Toward an integrated coastal sea-ice observatory: system components and a case study at Barrow, Alaska. Cold Regions Science and Technology, **56**(2–3): 61–72. doi:10.1016/j.coldregions.2008.12.003.

Eicken, H. 2010. Indigenous knowledge and sea ice science: what can we learn from indigenous ice users? *In* SIKU: knowing our ice. *Edited by* I. Krupnik, C. Aporta, S. Gearheard, G. J. Laidler and L. Kielsen Holm. Springer, Netherlands. pp. 357–376. doi:10.1007/978-90-481-8587-0_15.

Eicken, H., and Johnson, M. 2016. Estimating Arctic sea-ice freeze-up and break-up from the satellite record: a comparison of different approaches in the Chukchi and Beaufort Seas. Elementa: Science of the Anthropocene, **4**: 000124. doi:10.12952/journal.elementa.000124.

Eicken, H., Danielsen, F., Sam, J.-M., Fidel, M., Johnson, N., Poulsen, M.K., et al. 2021. Connecting top-down and bottom-up approaches in environmental observing. Bioscience, **71**(5): 467–483. doi:10.1093/biosci/biab018.

Fletcher, C., Riva, M., Lyonnais, M.-C., Baron, A., Saunders, I., Lynch, M., and Baron, M. 2022. Epistemic inclusion in the Qanuilirpitaa? Nunavik Inuit health survey: developing an Inuit model and determinants of health and well-being. Canadian Journal of Public Health. doi:10.17269/s41997-022-00719-4.

Fox, S., Qillaq, E., Angutikjuak, I., Tigullaraq, D.J., Kautuk, R., Huntington, H., et al. 2020. Connecting understandings of weather and climate: steps towards co-production of knowledge and collaborative environmental management in Inuit Nunangat. Arctic Science, **6**(3): 267–278. doi:10.1139/as-2019-0010.

Gearheard, S., Aporta, C., Aipellee, G., and O'Keefe, K. 2011. The Igliniit project: Inuit hunters document life on the trail to map and monitor arctic change. Canadian Geographies/Géographies Canadiennes, **55**(1): 42–55. doi:10.1111/j.1541-0064.2010.00344.x.

Gearheard, S., Pocernich, M., Stewart, R., Sanguya, J., and Huntington, H.P. 2010. Linking Inuit knowledge and meteorological station observations to understand changing wind patterns at Clyde River, Nunavut. Climatic Change, **100**(2): 267–294. doi:10.1007/s10584-009-9587-1.

Glaser, B.G., and Strauss, A.L. 2017. The discovery of grounded theory: strategies for qualitative research. Routledge. doi:10.4324/9780203793206.

Hauser, D.D., Whiting, A.V., Mahoney, A.R., Goodwin, J., Harris, C., Schaeffer, R.J., Schaeffer, R., Laxague, N.J., Subramaniam, A., Witte, C.R., et al. 2021. Co-production of knowledge reveals loss of Indigenous hunting opportunities in the face of accelerating Arctic climate change. Environmental Research Letters, **16**(9): 095003. doi:10.1088/1748-9326/ac1a36.

Henke, M., Miesse, T., De Lima, A.D.S., Ferreira, C.M., and Ravens, T.M. 2024. Increasing coastal exposure to extreme wave events in the Alaskan Arctic as the open water season expands. Communications Earth & Environment, **5**(1): 165. doi:10.1038/s43247-024-01323-9.

Herman-Mercer, N., Andre, A., Buschman, V., Blaskey, D., Brooks, C., Cheng, Y., et al. 2023. The arctic rivers project: using an equitable co-production framework for integrating meaningful community engagement and science to understand climate impacts. Community Science, **2**(4): e2022CSJ000024. doi:10.1029/2022CSJ000024.

Hewitt, C.D., Allis, E., Mason, S.J., Muth, M., Pulwarty, R., Shumake-Guillemot, J., et al. 2020. Making society climate resilient: international progress under the global framework for climate services. Bulletin of the American Meteorological Society, **101**(2): E237–E252. doi:10.1175/BAMS-D-18-0211.1.

Hošeková, L., Eidam, E., Panteleev, G., Rainville, L., Rogers, W.E., and Thomson, J. 2021. Landfast ice and coastal wave exposure in Northern Alaska. Geophysical Research Letters, **48**(22): e2021GL095103. doi:10.1029/2021GL095103.

Huntington, H.P., Gearheard, S., Mahoney, A.R., and Salomon, A.K. 2011. Integrating traditional and scientific knowledge through collaborative natural science field research: identifying elements for success. ARCTIC, **64**(4): 437–445. doi:10.14430/arctic4143.

Inuit Tapiriit Kanatami. 2018. National Inuit strategy on research. Inuit Tapiriit Kanatami. Available from https://eppdscrmssa01.blob.core.windows.net/cmhcprodcontainer/sf/project/archive/housing_organizations/itk_nisr-report_english_low_res.pdf.

Itchuaqiyaq, C.U. 2023. When the sound is frozen": extracting climate data from traditional Inuit narratives. *In* Technical communication for environmental action. *Edited by* S. D. Williams. pp. 19–38.

Jacob, D., St, L., Clair, A., Mahon, R., Marsland, S., Ndebele Murisa, M., et al. 2025. Co-production of climate services: challenges and enablers. Frontiers in Climate, **7**: 1507759. doi:10.3389/fclim.2025.1507759.

Kawagley, A.O. 1995. A Yupiak worldview. *In* A Yupiaq worldview: a pathway to ecology and spirit. Waveland Press, Inc.

Krupnik, I., Aporta, C., Gearheard, S., Laidler, G.J., and Kielsen Holm, L. (*Editors*). 2010. SIKU: knowing our ice: documenting inuit sea ice knowledge and use. Springer, Netherlands. doi:10.1007/978-90-481-8587-0.

Laidler, G.J., and Elee, P. 2008. Human geographies of sea ice: freeze/thaw processes around Cape Dorset, Nunavut, Canada. Polar Record, **44**(1): 51–76. doi:10.1017/S0032247407007061.

Laidler, G.J., and Ikummaq, T. 2008. Human geographies of sea ice: freeze/thaw processes around Igloolik, Nunavut, Canada. Polar Record, **44**(2): 127–153. doi:10.1017/S0032247407007152.

Laidler, G.J., Dialla, A., and Joamie, E. 2008. Human geographies of sea ice: freeze/thaw processes around Pangnirtung, Nunavut, Canada. Polar Record, **44**(4): 335–361. doi:10.1017/S003224740800750X.

Laidler, G.J., Elee, P., Ikummaq, T., Joamie, E., and Aporta, C. 2010. Mapping Inuit sea ice knowledge, use, and change in Nunavut, Canada (Cape Dorset, Igloolik, Pangnirtung). *In* SIKU: knowing our ice. *Edited by* I. Krupnik, C. Aporta, S. Gearheard, G. J. Laidler and L. K Holm. Springer, Netherlands. pp. 45–80. doi:10.1007/978-90-481-8587-0_3.

Laidler, G.J., Hirose, T., Kapfer, M., Ikummaq, T., Joamie, E., and Elee, P. 2011. Evaluating the Floe Edge Service: How well can SAR imagery address Inuit community concerns around sea ice change and travel safety? Canadian Geographies/Géographies Canadiennes, **55**(1): 91–107. doi:10.1111/j.1541-0064.2010.00347.x.

Laituri, M., Luizza, M.W., Hoover, J.D., and Allegretti, A.M. 2023. Questioning the practice of participation: critical reflections on participatory mapping as a research tool. Applied Geography, **152**: 102900. doi:10.1016/j.apgeog.2023.102900.

Latulippe, N., and Klenk, N. 2020. Making room and moving over: knowledge co-production, Indigenous knowledge sovereignty and the politics of global environmental change decision-making. Current Opinion in Environmental Sustainability, **42**: 7–14. doi:10.1016/j.cosust.2019.10.010.

Littletree, S., Belarde-Lewis, M., and Duarte, M. 2020. Centering relationality: a conceptual model to advance indigenous knowledge organization practices. Knowledge Organization, **47**(5): 410–426. doi:10.5771/0943-7444-2020-5-410.

Loewen, A., Crocker, G., Mueller, D., and McKenna, R. 2025. The role of preconditioning on landfast sea ice break-off processes in admiralty Inlet, Nunavut. Arctic Science, **11**: 1–21. doi:10.1139/as-2024-0053.

Moore, S.E., Stabeno, P.J., Grebmeier, J.M., and Okkonen, S.R. 2018. The arctic marine pulses model: linking annual oceanographic processes to contiguous ecological domains in the Pacific Arctic. Deep Sea Research Part II: Topical Studies in Oceanography, **152**: 8–21. doi:10.1016/j.dsr2.2016.10.011.

Nadasdy, P. 1999. The politics of tek: power and the "integration" of knowledge. Arctic Anthropology, **36**(1/2): 19.

Nunatsiavut Government. 2025. Sungiutisannik Nunatsiavummi—an inuit approach to climate change mitigation and adaptation in Nunatsiavut. Available from https://nunatsiavut.com/wp-content/uploads/2025/03/ADAPT-NUNATSIAVUT.pdf [accessed March 2025].

Olason, E. 2016. A dynamical model of Kara Sea land-fast ice. Journal of Geophysical Research: Oceans, **121**(5): 3141–3158. doi:10.1002/2016JC011638.

Ouellet-Bernier, M.-M., and de Vernal, A. 2020. Winter freeze-up and summer break-up in Nunatsiavut, Canada, from 1770 to 1910. Pages Magazine, **28**(2): 52–53. doi:doi.org/10.22498/pages.28.2.52.

Pfister, C. 2018. Evidence from the archives of societies: documentary evidence—overview. *In* The Palgrave handbook of climate history. *Edited by* F. Mauelshagen, C. Pfister and S. White. Palgrave Macmillan. pp. 37–47. doi:10.1057/978-1-137-43020-5.

Phurisamban, R., Luna, E., Eyster, H.N., Chignell, S., and Koppes, M. 2025. Shedding the cloak of neutrality: a guide for reflexive practices to make the sciences more inclusive and just. Ecosphere, **16**(4): e70168. doi:10.1002/ecs2.70168.

Plante, M., Lemieux, J.-F., Tremblay, L.B., Tivy, A., Angnatok, J., Roy, F., et al. 2024. Using Icepack to reproduce ice mass balance buoy observations in landfast ice: improvements from the mushy-layer thermodynamics. The Cryosphere, **18**(4): 1685–1708. doi:10.5194/tc-18-1685-2024.

Segal, R.A., Scharien, R.K., Duerden, F., and Tam, C.-L. 2021. The best of both worlds: connecting remote sensing and arctic communities for safe sea ice travel. Arctic, **73**(4): 461–484. doi:10.14430/arctic71896.

Sikusiutet Committee, Dicker, S., Holwell, R., and Wilson, K. 2023. Sikusiutet sea ice terminology for Nain, Nunatsiavut. SmartICE Sea Ice Monitoring and Information ServicesInc., Nain, Canada. 82p. Available from https://smartice.org/ice-safety-nain-2024/ [accessed December 2024].

Smith, L.T. 1999. Decolonizing methodologies: research and indigenous peoples. Zed Books, University of Otago Press, Distributed in the USA exclusively by St. Martin's Press.

So, R.J. 2017. All models are wrong. PMLA, **132**(3): 668–673. doi:10.1632/pmla.2017.132.3.668.

Sterlin, J., Orval, T., Lemieux, J.-F., Rousset, C., Fichefet, T., Massonnet, F., and Raulier, J. 2024. Influence of the representation of landfast ice on the simulation of the Arctic sea ice and Arctic Ocean halocline. Ocean Dynamics, **74**(5): 407–437. doi:10.1007/s10236-024-01611-0.

Tivy, A., Howell, S.E.L., Alt, B., McCourt, S., Chagnon, R., Crocker, G., et al. 2011. Trends and variability in summer sea ice cover in the Canadian Arctic based on the Canadian Ice Service Digital Archive, 1960–2008 and 1968–2008. Journal of Geophysical Research, **116**(C3): C03007. doi:10.1029/2009JC005855.

Virtual Museum of Labrador. n.d. Labrador Inuttut Dictionary. Available from http://www.labradorvirtualmuseum.ca/home/inuttut_dictionary.htm [accessed November 2023].

Walsh, J.E., Eicken, H., Redilla, K., and Johnson, M. 2022. Sea ice breakup and freeze-up indicators for users of the Arctic coastal environment. The Cryosphere, **16**(11): 4617–4635. doi:10.5194/tc-16-4617-2022.

Wassmann, P., Carmack, E.C., Bluhm, B.A., Duarte, C.M., Berge, J., Brown, K., et al. 2020. Towards a unifying pan-arctic perspective: a conceptual modelling toolkit. Progress in Oceanography, **189**: 102455. doi:10.1016/j.pocean.2020.102455.

Way, R.G., and Viau, A.E. 2015. Natural and forced air temperature variability in the Labrador region of Canada during the past century. Theoretical and Applied Climatology, **121**(3–4): 413–424. doi:10.1007/s00704-014-1248-2.

Whyte, K. 2017. Indigenous climate change studies: indigenizing futures, decolonizing the anthropocene. English Language Notes, **55**(1–2): 153–162. doi:10.1215/00138282-55.1-2.153.

Winters, J. 2021. Interview 29 October 2021. Makkovik, Nunatsiavut.

Witte, C.R., Zappa, C.J., Mahoney, A.R., Goodwin, J., Harris, C., Schaeffer, R.J., et al. 2021. The winter heat budget of sea ice in kotzebue sound: residual ocean heat and the seasonal roles of river outflow. Journal of Geophysical Research: Oceans, **126**(9): e2020JC016784. doi:10.1029/2020JC016784.

World Meteorological Organization. 2024. 2024 State of Climate Services: Five-year Progress Report (2019–2024). United Nations.