Inuit uses of weather, water, ice, and climate indicators to assess travel safety in Arctic Canada, Alaska, and Greenland: a scoping review

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Weather, water, ice, and climate indicators and summary characteristics

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
1. Weather Indicator				
Rain				
Freezing rain	Freezing rain	3	3	4
Rainfall amount, timing, intensity	The amount, timing, and/or intensity of rainfall.	26	47	44
Sky conditions	Sky conditions (general) would be assessed to predict what the weather would be	4	4	14
Cloud formation and appearance	Cloud formation/appearance, including height, form, colour, direction of movement, and location relative to geographic features (i.e. Mountain (Fox et al. 2020) all used to predict weather conditions. Unfamiliar cloud formations negatively impacting hunters ability to predict weather (Anastario et al. 2021)	18	26	38
Big long cloud	Indicator of down draft, so going to be pretty windy in the evening (Pennesi et al. 2012)	1	1	3
Cumulus cloud	Indicator that it will not get that windy or cold (Pennesi et al. 2012)	1	1	3
Double cirrus clouds	High cirrus clouds and lower ones are indicators of wind tunnel (Pennesi et al. 2012)	1	1	3
Sky colour and appearance	Glassy blue vs clear blue linked to noticing environmental change and descriptions of encountering unsafe conditions (Rathwell 2020). When the sky opens up after days of being dark (grey) good weather is on the way (Simonee et al. 2021)	2	2	4
Snow				

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Sediment in snow	Sediment in the snow is associated with less snow, which makes navigation more difficult (Panikkar et al. 2018)	1	1	1
Snow absorbing water and freezing	Occurs when the ice is worn away from currents, and the snow on top becomes slushy from water coming up. The snow absorbs the water and then freezes into a crust, and this process makes it become safe (Laidler et al. 2008)	1	1	3
Snow colour	Snow colour used to help with navigation. For example darker snow could indicate water underneath (Laidler et al. 2008; Laidler & Ikummmaq 2008).	3	3	14
Snow consistency and texture	Snow consistency/texture (e.g. light, heavy, powdery, wet, dry, smooth, shiny, soft, hard) all impacts ease of travel and access to the land.	18	27	41
Hard or soft -packed	Soft packed snow can be more difficult to travel over (Berkes & Jolly 2001), but hard packed snow (resulting from freeze-thaw cycles, or strong winds) can also be hard on snowmobiles and make building an igloo difficult (Gearheard et al. 2011; Prno et al. 2011).	7	8	27
Snow cover or extent	Extent of area covered by snow, which influences trail/land access	8	13	23
Snow depth and accumulation	How much snow is on the ground in a given place. Less snow associated with navigating routes around rocky or rough patches (Panikkar et al. 2018).	29	41	54
Snow drifts	Snow drifts are created by the prevailing wind direction, and they are used to help with navigation.	19	24	23
Snow melt	Rate/speed of melt and timing (in season) impacts the timing and ease of access to the land.	22	34	50
Snowfall amount	How much snow fell or is expected to fall. Increased snowfall can impact visibility (Ford et al., 2019) make reading the ice more difficult (Ambrose et al. 2014), and slow the thickening and stabilization of ice (Ford et al. 2009). Reduced snowfall in spring can make travelling on the land difficult (Furgal et al. 2002)	34	69	45
Sounds from walking or sledding on snow	Indicator of cold temperatures; lack of sound can indicate changing temperatures (warming)	1	2	2
Timing	The timing of snow throughout the season can impact ease of travel and hazard exposure.	21	27	27

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Water under snow on ice	Snow melt causes water to pool under the snow, but still on top of the ice. This can create slushy conditions and the ice usually becomes dangerous at this time (Laidler et al. 2008). It is extra dangerous when snow conditions at the surface appear good for travelling still (melting from underneath surface of the snow), as snow machines can become stuck (Pearce et al. 2010)	3	4	9
Storms				
Blizzard conditions, snow storms	Inherently poses a risk to safe travel. Blizzard conditions in other regions often indicate when conditions will arrive.	12	18	29
Storm strength, intensity, frequency, timing	Storms influence travel safety/decision making (either preventing, delaying, etc.). Changes to storm strength and intensity is also used to assess environmental change.	33	66	53
Visibility	Poor visibility (general) can limit the ability to assess conditions for safe travel and requires travelers to rely on other senses (and technology) to help with navigation.	9	14	26
Blowing snow	Blowing snow caused by wind can make travel very difficult and unsafe by reducing visibility.	10	12	16
Clear conditions	Able to see a certain distance to help navigate and recognize landmarks, and/or see species that are being hunted from a distance (Panikkar et al. 2018).	1	1	0
Fog	Foggy conditions impact visibility and ability to navigate using spatial referents and environmental clues.	9	21	29
Light availability	Low light or dark conditions could risk losing hunting partner (Simonee et al. 2021)	1	2	4
Reflection and glare	Reflection and glare impacting visibility, could miss seeing large holes or leads, etc. (Simonee et al. 2021)	1	2	6
Whiteout conditions - flat light	“When there is low light, snow cover with no contrast, and a stratus/leaden type of sky that blends into the horizon, often producing very light precipitation. Often you can see a long way, but there is no way to distinguish many terrain features such steep drops over which a traveler might fall” (Fox et al. 2020, p. 274)	12	17	20
Weather				
Air temperature	Air temperature, including wind temperature (e.g. warm winds from the east)	60	159	90
Freeze-thaw cycles	Freeze-thaw cycles are caused by fluctuations in temperature. This can lead to snow freezing into harder layers, which can be hard on snowmobiles. It can also cause unseasonable melt events and create hazardous travel conditions.	4	4	14

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Frost formation	Not explicitly defined, but described as something you need to be attentive to address vulnerability to weather. (Middleton et al. 2020)	1	2	2
Humidity	Humidity can impact other conditions such as precipitation and temperature, or cause changes to snow composition which can impact building a snow shelter (Derry 2011; Lauder et al. 2018; Furgal & Seguin 2006)	4	4	9
Overcast conditions	Overcast conditions linked to snowfall and accumulation in the fall and impact on ice formation (thinning).	5	8	13
Precipitation (general)		10	11	27
Sounds	Sounds as indicator of specific weather conditions (e.g. the way sound travels/pitches as marker of cold temperatures) (Rathwell et al. 2020)	2	2	1
Speed and frequency of weather shifts	Increased speed and frequency of weather shifts can introduce hazards to travel, particularly if travelers are unprepared for the conditions. The general consensus from coded files is that the weather changes faster, and conditions shift with increased frequency.	16	25	21
Sunny conditions	Sunny conditions are useful for hunting and spotting whales (Waugh et al., 2018), but also risk sunburn and glare from surface conditions reducing visibility (Simonee et al. 2022)	1	2	6
Weather extremes	Weather conditions outside of the expected ‘normal’ range. Extreme weather such as cold, storms, or rain can be hazardous, especially when occurring outside of typical timing. What used to be rare and isolated extremes may no longer be anomalies (Riedlinger & Berkes 2001)	10	11	12
Weather in other areas	Weather in other areas us used as an indicator of weather to come, or that will be encountered when travelling	2	3	0
Weather patterns (general)	General descriptions of weather conditions and patterns. Used to assess travel conditions and predict future conditions.	8	24	28
Weather predictability	Weather predictability as related to expected timing of certain conditions, where increasing unpredictability is related to “unseasonal” weather” or unexpected conditions for that time of year.	35	75	46
Wind				
Duration of wind events	Longer duration of wind events can pack the snow too hard, making it difficult to build snow shelter in bad weather (Gearheard et al. 2010), can prevent boat travel due to rough	4	6	11

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	waters (Nichols et al. 2003), and overall can make travel and harvesting difficult and increasingly hazardous (Pearce et al. 2010).			
Frequency of wind events	Increased frequency of wind events can impact other conditions such as sea ice (e.g. causing more break-up events) or snow (e.g. packing the snow too hard to build snow shelters in bad weather), or rough water (making boating dangerous).	10	14	28
Sand and dust storms from extreme winds	Extreme winds causing sand and dust storms are described as causing safety concerns (Galappaththi et al. 2019).	1	1	7
Seasonality of wind direction	Prevailing wind directions at a specific times throughout the year. This can influence various sea ice conditions and are important to know about to aid in navigation.	51	165	87
Wind chill	Wind chill is important to know about when planning travel, as it can create very cold conditions.	4	5	19
Wind predictability	The "wrong" winds (Berkes & Jolly 2001), where it seems like it won't start blowing, but it does (Dowsley et al. 2011), or the direction changes suddenly which can pose a danger to hunters on the ice or on boat (Ford et al. 2008, 2010). Changes in predictable wind conditions are impacting other conditions such as freeze up (Fox et al., 2020) and so its negatively impacting peoples ability to predict conditions and know if going out on the land is safe (Gearheard et al. 2010)	14	20	26
Wind strength	Wind strength impacts sea ice, for example, through the formation of cracks and leads, causing thin ice to break up, or forming ridges and pile-ups (Barber et al. 2012), it also effects current strength and wave action, posing a hazard to travelling on ice and by boat.	57	124	79
Wind temperature	Warmer winds can lead to ice deterioration, while colder winds can help with ice formation (Galappaththi et al. 2019; Laidler et al. 2008, 2010)	6	6	15
2. Water Indicator	Inclusive of marine, river, and lake indicators			
Currents				
Current direction	The direction of currents can move the ice back and forth, bring pack ice to the floe edge, open and close leads, erode ice anchoring features, and cause pile-ups along the shore (Aporta 2002, Druckenmiller et al. 2009, 2010, Eicken et al. 2014). The dominant current can change direction certain times of the year, bringing warm water which can accelerate ice melt/break-up (Druckenmiller et al. 2010). Monitoring currents is essential for safety (Huntington et al. 2010)	16	30	40

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Current strength	Current strength impacts hunting, for example strong currents may result in losing seals (Aporta 2004). Current strength dictates open water conditions, as well as the size and frequency of leads and cracks, and pile-ups and ridge formation (Barber et al. 2012). Strong currents can also impact boat travel, requiring extra precautions (Bishop et al. 2021) or cancelling the trip (Buijs 2010).	29	61	53
Current temperature	Currents bringing warmer water can wear the ice dangerously thin, lead to break-up of ungrounded ridges and the throwing up of ice into leads posing hazards to travel on ice and by boat (Druckenmiller et al. 2009, 2010).	2	5	28
Currents under ice	Currents eroding under ice surface (Druckenmiller et al. 2009), basal melt (Ford et al. 2013), wearing away the ice (linked to ablation, thermal exchanges, not only friction Laidler & Pootoogoo 2008; Druckenmiller et al. 2010). Under ice currents are important to monitor when travelling on the ice as they can lead to thinning and hazardous conditions.	15	24	37
Freshwater				
Freshwater levels	Waterbody depth, drainage, and drying. Lower water levels impacting freshwater freeze up, where increasingly shallow streams are freezing to the bottom, impacting species quality and availability. This also influences the navigability of waterbodies by boat, where shallow areas can become impassable (Fienup-Riordan 2010, Moerlin et al. 2012). This also impacts sources of reliable drinking water accessed while travelling (Furgal et al. 2002). Causes tied to permafrost loss, lack of rain and snow,	16	37	30
River flow rates	Flow rates during melt season can cause increased sea ice melt (Simonee et al. 2021). They can also impact the navigability of channels, for example by filling them with sediment (Fienup-Riordan 2010). Fast-moving rivers can create dangerous river-crossing conditions (Henri et al. 2020), or create open leads in areas of the river unable to freeze (Herman-Mercer et al. 2011)	4	6	8
Waterbody channel and bed characteristics	Changing waterbody channel composition and bed characteristics, notably increased sandbars in new areas. It is important to know the channel to travel safely, and these changing characteristics are requiring people other than take less known and more dangerous detours (Worden et al. 2020)	5	10	8
Ocean				
Bathymetry and water depth	Shallow areas are especially important to know about due to direct impacts on ice conditions and currents. Bathymetry and water depth are related to ice travel through	7	9	17

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
	grounded areas or land fast ice creating increased stability (Gearheard et al. 2006) or shallow sills where the ice could freeze rough or remain open water due to stronger currents (Barber et al., 2012, Laidler & Ikummaq 2008)). Bathymetry is also tied to boat travel and risk of getting stuck in shallower areas.			
Shoals or sandbars in water	Knowledge of the location of shoals and sandbars is required for safe navigation (Pennesi et al., 2012). The appearance of new shoals/sandbars requires travel route changes (Pannier, 2018) and can potentially cause hazards. They can act as a protective feature for areas of increased sea ice stability where ice forms early and is unlikely to break-out later (Eicken 2010). Or, in areas shoaling with high tidal range, dynamic and dangerous pressure ridges can form (Ford et al. 2013)	5	5	8
Flooding	Coastal or on ice flooding impacting camp set up or location selection when travelling On ice flooding tied to winds pushing water over top of ice	6	13	21
Frequency and severity of storm surge	Storm surges have always flooded coastal lowlands, but have become more frequent and severe (Fienup-Riordan 2010). Storm surges are more difficult to predict because they depend on the tides and wind speed and direction (Penes et al., 2012). Flooding from storm surges can pose a risk to hunting camps on the land (Worden et al. 2020).	4	5	6
Salinity levels	Salinity levels will impact where a seal will float in the water column after being killed (Gadamus & Raymond-Yakoubian 2015, Johansson 2008, Riedlinger & Berkes 2001). Increased precipitation impacts ocean salinity, and changes to salinity impacts ice conditions, including rate of freeze up, melt, and break-up processes, and thickness (Johansson 2008, Tremblay et al. 2006).	4	5	14
Sea level, coastal water levels	A strong offshore wind can locally depress sea level, causing areas of landfast ice to detach when cracks form around grounded ridges, leading to a potential break-out (Druckenmiller et al. 2009, 2010). Strong on-shore winds can bring high water, causing flooding (Fiend-Riordan 1999).	7	10	24
Water predictability	The predictability of current strength during the full moon allows people to know that the ice might break up (Aporta 2002). Tidal currents are predictable and give hunters assurance that “under the right wind conditions, even if [they] get carried away on the ice, [they] will land again” when the tide comes back in (Aporta 2002).	2	3	12
Water temperature		17	31	50
Tides	General descriptions of tides influencing travel safety and decision making, but without more specific details	9	13	29

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Direction of seaweed movement	The direction of seaweed movement is used to assess tide/current direction, particularly when the shore is not in site (Apron & Higgs, 2005). Seaweed is also studied to assess whether the winter will be bad with less animals or good with lots of animals (Anastario et al. 2021).	2	3	1
Tidal range (low-high)	Tidal range impacts movement of floating ice (Aporta 2002; Huntington et al. 2017) and can cause expansion of cracks, leads (Carmack & Macdonald 2008, Wilson et al. 2021). High tides combined with a certain wind speed and direction can cause dangerous flooding (Fienup-Riordan 1999), and large tides in the winter can create water on the ice, and cause areas to break-up (Johansson 2008). Connections between the wind and tides are important to understand when hazardous conditions might be present (Pennesi et al. 2012)	13	21	32
Tide strength	Tide strength related to phases of the moon throughout the month and year. When strong tides widen leads during the full moon, they can be used for hunting (Aporta 2002). Tide strength is used to make decision as to when it is safe for hunters to travel on the moving ice, or when the moving ice will detach from the land (Aporta 2002). Strong spring tides can impact ice deterioration and break-up (Laidler et al 2008). Strong tides can require detours when travelling by boat (Bishop et al. 2021)	8	12	25
Tide timing	Tracking the timing of tidal shifts is important for hunters on the moving ice (Aporta 2002). The timing of tidal cycles Is used by hunters and elders to evaluate the stability and safety of sea ice (Laidler et al. 2011)	2	7	14
Wave action	Broadly describing rough water, wave impacts during travel by boat, or on the ice. Waves can capsize a boat (Derry 2011), or waves from a passing ship can flood over the ice and disturb ice trails (Dawson et al. 2020). Waves under the ice can lift it, and potentially cause break-outs (Druckenmiller et al. 2009), or lead to pile-ups of broken ice that can break-out from waves (Eicken et al. 2014). New wind patterns can create more waves, preventing or changing the timing of freeze-up (Fox et al. 2020)	24	37	48
Calm surface conditions	Calm water is ideal for boating, and will reduce risk while hunting by boat, as well as help hunters avoid loss of time and fuel in rougher conditions (Waugh et al. 2018).	1	1	3
3. Ice Indicator	Inclusive of lake, river, and sea ice			
Age	Age of the ice is described, but not explicitly	5	7	14
First year ice	First year ice is considered less safe when there is no MYI or pressure ridges helping to anchor it in place (Berkes & Jolly 2001, Druckenmiller et al. 2012, Eicken et al. 2014).	7	14	27

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Multiyear ice	Presence, absence, extent, timing, and position of anchored MYI or MYI floes. Less MYI in the fall freeze-up means travel on first year ice, which is less safe (Berkes & Jolly 2001). Loss of MYI in Barrow brings concerns that ice conditions will become unfamiliar, and the hunting season will shorten (Druckenmiller et al. 2010). Thick MYI floes can help anchor and hold the landfast ice cover in place (Druckenmiller et al. 2009). MYI floes can hamper sea ice or boat travel (Laidler & Pootoogoo 2008)	20	42	40
Newly formed along solid ice-open water	It is not safe when people travel on thin, newly formed ice (Aporta 2002). Newly formed ice can eventually thicken to provide stable surface for hunting/travelling (Laidler et al. 2010). However, young ice formed along solid-ice is also vulnerable to impacts from wind and pack ice interactions, and could break-ff (Druckenmiller et al. 2010).	8	10	13
Young ice	Young ice requires testing for strength before travelling over it. Notably, it will change from a gray/blue to a near solid white, indicating it is thick enough for travel (Eicken et al. 2014). Flat young ice can be easy to travel over, but it can also get softer when the ice starts to melt in the spring (Druckenmiller et al. 2012). Without anchors (MYI) to hold young ice in place, it can be carried away when the water rises (Huntington et al. 2017)	8	14	34
Amount, timing, duration, distribution	Timing/duration/distribution of sea ice season broadly. All impacting access to the land, decision making for travel, assessment of environmental change	38	93	52
Freeze up	Timing (when freeze-up starts), speed (time taken by ice to allow safe travel once it starts forming (Ford et al., 2009)) Less references, but also progression (from start to when ice is safe to travel - different ice characteristics/features that contribute to freeze-up as freeze-up progresses (e.g. flexibility, stickiness during early freeze-up (Caramack et a.), grounding of MYI or pack ice and pressure ridges (Druckenmiller et al. 2010)	62	171	83
Early ice	Seasonal ice regime associated with freeze up; begins when ice is safe enough for travel and ends when winter conditions persist. Sea ice is thin, unstable. Formation influences ice conditions throughout the season (Segal et al. 2021)	1	4	5
Frost flowers	Surface ice conditions scrutinized during travel, frost flower formation indicates where ice will form smoothly when thickened (Laidler & Pootoogoo 2008; Laidler et al. 2011)	2	2	4
Ice freezes foamy	Ice areas that freeze up ‘foamy’ become dangerous in the springtime (Johansson 2008) - conditions upon freeze up influence conditions later in the year	1	2	5
Tear-like streaks on surface of sea	Early indicator of ocean changing in late fall - ice coming	2	2	1
Ice decay				

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Break-up	Timing (start of break-up/melt onset - where ices no longer travelable (Laidler et al. 2010), speed (rate of melt/break-up), uniformity (non-uniformity increases risks). Break-up occurs when the ice is floating free (no longer landfast) and open enough to permit boat travel (Ford et al. 2009)	59	153	73
Early ice clearing	Ice clearing / break up event that is unseasonably early (e.g. winter) (Schist et al. 2022)	1	8	10
Late ice	Seasonal regime associated with break-up; begins when ice deteriorates (rotting) in strong current or nearshore; accumulates sea ice fractures and surface slush and water; broken by winds and tides until ice chunks float freely (Segal et al. 2021)	1	2	0
Ice melt	Melting of the ice can occur in various stages before break-up (Laidler et al. 2008. Hunters will stop travelling on melting ice when it's no longer able to support their weight safely. Non-uniform melting conditions can lead to dangerous travel and altered routes (Laidler et al. 2009)	40	69	62
Water on ice, melt ponds	Appearance of melt ponds as transition indicator of melt / break-up - travel can be dangerous as melt ponds can hide ice conditions underneath (Laidler et al. 2009; Laidler et al. 2008; Gilchrist & Robertson 2000; Ford et al. 2008; Druckenmiller et al. 2009; Bell et al., 2014). Reflection of sky on melt ponds can be blinding and hide thin ice or open water (Wilson et al. 2022)	15	32	38
Water drainage through ice	During spring melt, the process of water draining through the ice: ice can first become smoother and harder (good for travel), but eventually becomes thinner and more dangerous as it progresses towards breakup (Laidler & Ikummaq 2008; Laidler et al. 2008; Laidler et al. 2010; Laidler et al. 2009). Meltwater drainage on the other side of a lead indicates areas that are lower and safer to cross (skis will more likely clear ledge on other side of lead) (Wilson et al. 2022)	6	13	20
Ice melting from below, under ice surface erosion	Ice thinning from underneath due to melt or under ice surface erosion from warm currents. This can be particularly dangerous as it can be difficult to assess ice thickness (Derry 2011), and the ice can look all the same at the surface (Rathwell 2020). Under ice erosion or melt can contribute to break-out events or rapid spring melts (Druckenmiller et al. 2009; Gearheard et al. 2006)	10	16	23
Ice predictability	Ice predictability is described in terms of recurring features, or the changing, but predictable nature of moving ice and the floe edge (Aporta 2002). Hunters consider conditions at the start of building trails and those that will be encountered at the end of the season (Druckemiller et al. 2010). Unpredictable ice conditions make travel more	15	22	38

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	dangerous (Berkes & Jolly 2001, Bunce et al. 2016), and the reliability of traditional safety indicators is diminishing (Ford et al. 2013)			
Extreme ice years	Extreme ice years described more so as in the past, where extreme cold made the ice never leave, so boat travel was not possible (Riedlinger & Berkes 2001).	1	1	0
Floating ice				
Floe size and concentration	The presence of floes of a certain size are important in their use for hunting walrus (Furgal 2009). Floes can also pose a risk to boat travel (can cause capsizing) (Simonee et al. 2021)	3	3	9
Ice movement, drift patterns	Movement of drifting ice, or shifting of land fast ice (tied largely to wind and current patterns), notable in land fast ice interactions, stability, and hunting (on moving ice)	26	59	68
Icebergs	Presence/absence (tied to wind strength and direction, surface roughness or ice stability when anchored in ice) also tied to noting change (fewer, smaller); also a risk for travelling in boat (e.g. iceberg halved, crushing a boat (Derry 2011); play a role in shielding the ice from elements (less icebergs leading to more rough ice areas (Johansson 2008); smaller in size = unable to ground ice conditions (Schiott et al. 2022)	10	21	27
Pack ice	Presence/absence of pack ice; size/volume; drift direction; interactions with other processes (particularly at the floe edge, but also winds, currents)	16	41	39
Drift or floating ice	Ice that is not attached to the land, and is moved by ocean currents and wind (Ford 2009) Descriptions imply more dispersed floe concentration, passable with boat	15	20	26
Floe concentration and location	Concentration of ice floes impacting boater safety; “broken ice” hunting in spring	12	19	22
Floe or pan size	Tied to knowledge of walrus hunting and butchering (stability), potential stranding if blocked in by large floes, or floe edge stability and freeze up rates, large ice floes can shelter boats from wind and dampen wave effects (Laidler et al. 2010)	6	12	19
Freshwater Ice				
Freeze-up	Freeze-up of freshwater bodies allows people to travel over them during the winter season. Fall freeze-up seems to be happening later (Herman-Mercer et al. 2011), shortening the travel season	1	1	2
Melt and break-up	Important for springtime conditions and timing as freshwater bodies are used to access hunting and fishing camps (Berkes & Jolly 2001). Rivers and lakes are notes as having a shorter ice travel season (Brubaker et al. 2011), in part due to earlier break-up (Cuerrier et	12	19	29

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
	al. 2015). While break-up used to be really loud and exciting, today it seems to just melt off, and lacks high water pressure behind it to cause violent break-ups (Herman-Mercer et al. 2011).			
River explosions	Caused from built up water and ice from quickly melting rivers (Johansson 2008)	2	3	11
Open ice leads	Areas in freshwater bodies that don't freeze over, and people can fall through (Herman-Mercer et al. 2011)	1	2	1
Slush on freshwater ice	Slush on lakes or rivers from rapid periods of melting affecting on-land travel routes and spring ice fishing (Pearce et al. 2010). Risk of getting stuck in slush when traveling on the land / over slush forming in melting rivers (Simonee et al. 2021)	2	4	15
Splinter ice, crystals, icicles	Forms upriver, becomes jumbled with saltwater ice in spring downriver. Dangerous and unstable to walk on (can cut you if you fall in) (Heyes 2011)	2	2	3
Thickness	Frozen rives and lakes are used as a main transportation route in winter using snow machines, and thinning ice shortens the winter travel season and it can make travel more dangerous (Herman-Mercer 2011, Tremblay et al. 2006)	2	3	8
Ice internal properties				
Ice layers	Layered ice, such as an ice cap on water on ice underneath can allows for travel on ice but with possibility of ice failure where a snowmobile could become trapped (Bell et al. 2014)	3	5	16
Points of attachment or fusion	As indicator of ice stability, potential areas for break-off to occur or areas of increased thickness/stability depending on the make-up of ice at the point of attachment (e.g. thin add on vs large thick pans)	5	11	26
Rotten ice	Not described explicitly beyond 'unsafe' ice conditions, but rotten ice is linked to the ice about to break-up (Wilson et al. 2021)	4	5	10
Candle ice	"Rotten ice that develops in columns perpendicular to the surface" where people have lost their lives by travelling over it (Prno et al. 2011)	1	1	6
Salt content	Salt free ice as a source of drinking water, but can shatter upon impact so also potentially dangerous in dynamic conditions (Durckenmiller et al 2010). Saltwater ice can be softer and more flexible than freshwater ice (allowing for travel when it's relatively thin, soon after freeze-up).	6	10	16
Sediment in ice	Sediment in ridges as clue to ice formation (scraped and grounded to seabed during formation. Helps understand make-up/attachment of ice and potential for break out to	1	1	0

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
	occur later in season (Druckenmiller et al. 2010)			
Temperature	Not explicitly defined, beyond noting that sea ice is warmer than it used to be (Rathwell 2020)	1	1	0
Ice strength and stability	Assessed within the land fast ice or at the floe edge based on a variety of other indicators (e.g. ice thickness, ridges, anchoring and grounding) in its ability to support travel. Weakened sea ice risks hunters breaking through (Durkalek et al. 2015) and calls for "additional navigational and safety roles" (Derry 2011). 'Destabilization' via drift ice impacting floe edge, or stabilization via onshore ice movement building ridges = stable platform (Eicken et al. 2014)	89	478	119
Ice bridge	Areas of stable ice between leads that are safer for travel, and can be crossed when leads get too wide. Although these can eventually break off (Wilson et al., 2022)	1	2	3
Ice pile formation and location	Ice piled up on reefs or shallower areas are ice stability indicators (Laidler et al. 2010)	6	11	25
Ice ridges	Abundance, location, height, grounded vs ungrounded, all impacting sea ice stability; ridges as travel routes (Eisner et al. 2009), patterns of formation (regular patterns = reliance on same routes; irregular patterns (env change) = difficulty relying on same routes) (Panikkar et al. 2018). Ridges can be formed from closing of cracks creating a pile or ridge where it was (Wilson et al. 2022)	23	75	63
Ice thickness	Thin ice breaks/melts sooner/easier than thick ice and poses increased risk to travel over the ice. Important to know of areas that remain thin ice year round, or that thin out more quickly in the spring (e.g. from spring river / glacier run off (Wilson et al. 2022)	80	273	99
Location of anchoring, grounding features	Anchored / grounded MYI, pressure ridges as an indicator of stability holding landfast ice in place	12	29	37
Openings and edges				
Cracks	Location of re-occurring cracks in the ice (spatial reference), or areas that could potentially crack (related to time of year, particularly when assessing where break out will occur during break-up in spring) indicative of weakness or potential danger, also used for hunting. Cracks forming in different areas than the past is challenging TK of local ice conditions (Pro et al. 2011)	31	71	67
Caverns between cracks	Used to harvest from ice, accessing species on seabed (clams and seaweed collected at low tide) (Heyes 2011)	1	2	1

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Previously refrozen cracks melting to open water	Indicator of ice melt/break out event coming and too risky to remain on ice (Druckenmiller et al. 2009)	1	1	8
Erosion or break-off, break-out events	Potential for erosion or break-off events can strand hunters on drifting ice, can provide access to marine mammal hunting areas (can be caused by winds, dropping sea level causing ice to break, tides, pack ice colliding with floe edge causing break off) Similarly, potential for break-out events throughout the ice season Coded text includes floe edge and polynya erosion or break-off events	29	59	69
Floe edge				
Dynamic ice conditions	Dynamic ice conditions are described in relation to the floe edge, and can result in unpredictable hazards (Ford et al. 2019).	5	6	20
Floe edge condition	Shape, orientation, stability, make-up all impact the location where hunting actives take place (Druckenmiller et al. 2012)	8	18	30
Floe edge location, extent	Accessibility to hunting areas; travel safety impacted by floe edge conditions and ice dynamics in this area; floe edge location as indicator of stability of marine environment overall (Henshaw 2003)	32	94	52
Floes separating from ice edge	Floes separating from ice edge as dictated by tides and the natural movements of ice floes, rather than erosion or break-off events. Awareness of this is critical for hunter positions/safety when hunting at floe edge (Lee & Wenzel 2006; Huntington et al. 2016)	2	3	8
Shear zone with landfast ice	Separating pack ice and land fast ice - noted as important for travel on sea ice (Bell et al. 2014)	1	2	6
Holes in the ice	Seal breathing hole and melt hole characteristics used to assess ice thickness (Laidler et al. 2010), and changing ice conditions (Johansson 2008)	4	5	13
Leads	"Linear" open water between the drift/pack ice and the fast ice. Location, size and time of opening tied to other indicators and important for hunting. Patterns of formation (regular patterns = reliance on same routes; irregular patterns (env change) = difficulty relying on same routes) (Panikkar et al. 2018)	29	65	59
Broken ice throwing-up into leads	If trapped under closed lead, when lead opens up can throw up the ice posing hazard to boats (Druckenmiller et al. 2010)	1	1	6
Open water	Location of open water beyond floe edge or within land fast ice (text not explicitly stating "polynya" was coded to open water), or open water that is free of ice - all tied to	33	57	57

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
	subsistence hunting, navigation, ice formation trends, ocean currents and winds			
Polynyas	Polynya (where the ice never freezes within the sea ice) size, location, characteristics used for navigation, hunting and harvesting	10	23	32
Sensory indicators of ice conditions				
Ice lifted by wave motion	As indicator of potential breakout event (Druckenmiller et al. 2009). Weight of snowmobile travelling over flexible ice can also cause waves under ice, causing it to crack (Wilson et al. 2022)	2	2	11
Ice quality	Quality tied to safety of ice, or 'bad ice', but not explicitly described beyond "decreased ice quality".	5	7	16
Seals popping up but not resting on ice	Visual indicator of seals popping up in first thin solid layer of sea ice, but not strong enough for seals to rest on the ice (Wilson et al. 2021)	1	1	3
Sounds	Sounds of dynamic conditions: crashes as the ice breaks apart and rafts, or opening of cracks due to tides and winds sounding like boiling (qulluaq) (Aporta 2002). Quiet break-up dangerous, as sounds for cracking and ridging are usual warnings of threatening conditions (Druckenmiller et al. 2010). Freshwater ice break-up - solid ice was really loud, vs needle ice is not as loud (Herman-Mercer et al. 2011). Cold temperatures reflected in sound of the lake cracking (Nichols et al. 2003)	6	8	12
Grinding	Areas of moving ice where grinding occurs can cause ice to turn into slushy water that people could risk falling through. This happens very quickly (Laidler & Ikummaq 2008; Laidler et al. 2009)	2	2	4
Steam, vapour, fog	Used to evaluate state of ice formation in fall (Aporta 2002) as tied to (extreme) cold temperatures (Laidler et al. 2009; 2010)	3	3	8
Water sky - dark band along horizon indicating open water	Reflection of open water in sky as indicator of proximity of open water, a way to monitor pack ice that could threaten the floe edge, and as a way to navigate through fog when visibility at eye level is limited (Aporta 2002; Druckenmiller et al. 2010; & Huntington et al. 2016)	3	5	8
Shoreline conditions and characteristics				
Beached ice	Ice beached in shallow areas indicator of areas that were deep are now shallow, and sandbars newly appearing (Fienup-Riordan 2010), or of strong winds driving ice onto the	2	4	10

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
	beach (Druckenmiller et al. 2010)			
Ice pile platform formed along shore or cliff edge	Ice pile platforms formed along shore or cliff edge are used for spring travel along the coast by snowmobile	1	2	3
Ice shoves, push events	Ice shoving over each other and piling up (on ice or on land) and can damage camps/structures.	3	4	5
Icy shores	Icy shores as a potentially significant hazard towards the end of the boating season; makes it difficult to pull boats in, is slippery with risk of falling (Simonee et al. 2021)	3	3	7
Surface conditions				
Colour	Indicator of ice thickness, age, overall safety	15	22	45
Ice texture and consistency	Hard, soft, flexible, jumbled, sticky, roughness…surface ice conditions as well as consistency of the ice overall - all indicators of ease of travel, ice stability, thickness, age, and safety (Nichols et al. 2003)	35	166	82
Brittle - flexible	Flexible ice formed from saltier water bends before breaking, providing time to turn back (Carmack & Macdonald. 2008), MYI is more brittle than first-year ice and can shatter upon impact - dangerous to camp on (Druckenmiller et al. 2010). Colder moths can increase brittleness of ice, more prone to cracking/breaking off (Laidler & Ikummaq 2008; Laidler et al. 2009)	8	9	18
Compact-Dense - less compact-dense	No specific definition / implication available based on description in coded literature (Laidler et al. 2011)	2	2	9
Rough - flat or smooth	Ice roughness as an obstacle for travel, impacts routes chosen; smooth ice easier, but can be affiliated with less stability. Rough ice = rubble ice, or rough ice due to snow frozen by wind to create rough surface (Bell et al. 2014) These are relative terms, what can be dangerous for one could be an inconvenience for another (Bell et al. 2014)	27	70	60
Soft - hard	Soft as indicator of salinity levels in ice; but also linked to weaker ice (easier to break through when testing for strength with a harpoon, and or when travelling over) (Gearheard et al. 2006; Laidler et al. 2010)	7	10	23
Sticky	Stickiness associated with ice formed from saltier water (Carmack & Macdonald 2008)	1	1	6
Location of recurrent features and structures	Recurrent features as important to know for safe travel, for example recurring areas of dangerous ice (Ford et al. 2006), or ice marks used for navigation (Aporta 2002; Hayes 2011)	4	5	9

	Description	Indiv. Pubs.	Unique Refs	No. of cross-coded indicators
Moisture and condensation insulating ice	Moisture on surface of ice (condensation or rime "kaneq" builds on ice) due to warmer water below, prevents ice from getting thick - risks hunter safety (Derry 2011)	2	2	7
Rafted ice	Rafted ice is used by hunters looking for seal lairs (Furgal et al. 2002)	1	1	3
Slush ice (shear formation)	Slush ice (formed through shear and incorporating of snow and lacks salt water drainage of 'typical' ice production); can be incorporated into the land fast ice, and while it can freeze (not always), when it warms even slightly it can rapidly lose its integrity and break quietly (Druckenmller et al. 2010; 2012). Grinding of ice as its moving causing it to become soft slush (Laidler & Ikkumaq 2008). High tide at floe edge bringing slush up over sea ice (Heyes 2011). Danger of falling through	5	10	22
Slush ice (thermodynamic)	Slushy layer formed either due to early stages of ice formation/ snow and ice melt when slush (thin, not stable ice) is hidden by snow (Ford et al., 2008; Laidler et al., 2008). Danger of falling through; can disguise areas of thin ice (Segal et al., 2021)	6	14	22
Snow on ice	Slows freeze-up by insulating ice (Ford et al. 2008; Huntington et al. 2016; Laidler et al. 2008; Laidler & Ikummaq 2008; Laidler et al. 2009; Laidler et al. 2011). Hide or contribute to dangerous ice (e.g. thick snow on thin ice or open water (Bujis, 2010; Ford et al. 2009; Panikkar et al. 2018), or significant drop in surface height (Segal et al. 2021). Can make travel more difficult (e.g. low-snow - snowmobiles collide with rocks) (Durkalec et al. 2015), or easier - covering rough ice (Segal et al. 2021)	24	44	47
Under ice conditions and characteristics				
Air pockets under the ice	Caused by waves under ice preventing ice freezing through - thin ice, potential to fall through (Laidler et al. 2009)	1	1	2
Algae under the ice	Indicator of thin or dangerous ice, as it contributes to earlier spring melt when on (or within) the sea ice (Laidler et al. 2011)	1	1	0
Ice accumulation under ice from currents	Creates ice that looks solid but is not frozen through and people can sink through if travelling on it. Cracks can be soft all the way down (Laidler & Ikummaq 2008)	1	1	4
Rocks under ice	Hazard associated with on-ice travel (Panikkar et al. 2018)	1	1	4
Underwater ice topography	The topography of ice underwater interacts with currents, creating turbulence which can wear the ice out from underneath, while the surface looks unchanged. This can create particularly dangerous travel conditions (Laidler & Ikummaq 2008).	1	2	5