Trails to the whale: Reflections of change and choice in an Iñupiat icescape

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Trails to the whale: Reflections of change and choice in an Iñupiat icescape

Abstract: Shorefast ice, present along Alaska’s Arctic coastline from late fall through early summer, provides a platform for subsistence hunting by coastal indigenous communities. At Barrow, Alaska, Iñupiat hunters build trails each spring across the shorefast ice to connect the community to leads in ice-choked waters where they wait to pursue migrating bowhead whales. Building on efforts initiated by Alaska’s North Slope Borough and in collaboration with the Barrow Whaling Captains Association, a systematic ice trail mapping and surveying project developed in spring 2007. Using electromagnetic induction sounding, ice thickness surveys were completed along trails just prior to whaling. Semi-directed interviews with hunters addressed the impact of ice conditions on the hunt, choice of trail and hunting locations, and safety concerns. Four years of results (2008–2011) are analyzed along three themes. First, tracking of local ice conditions reveals the interannual variability of the shorefast ice thickness distribution. Second, documenting indigenous ice knowledge and use provides a baseline and helps with assessing local impacts of change. Third, developing information resources for the community allows for interaction with hunters such that the research maintains relevance to the challenges facing the community.

Keywords: shorefast sea ice; Iñupiat; Barrow; Alaska; whaling; local and traditional knowledge

Introduction

In the Arctic, coastal indigenous peoples’ unparalleled familiarity with sea ice stems from the fact that it provides both a physical pathway and barrier to many of their most important food sources. For nine Iñupiat communities in Alaska (Fig. 1), the traditional springtime hunt of the bowhead whale remains important to their subsistence cultures. Aside from the communities of Gambell and Savoonga on St. Lawrence Island and Little Diomede, most traditional spring whaling in Alaska is done from the edge of shorefast ice. Shorefast ice is that which is seasonally anchored along the coast due to either ice freezing to the seafloor or ridges grounding in shallow waters, typically less than 20 m deep (Barry et al. 1979, Mahoney et al. 2007a). Along Alaska’s northern coastline with the Chukchi and Beaufort Seas shorefast ice remains in place from approximately early-November through mid-July (Mahoney et al. 2007a). Between late-March and early-April, ice trails—expressions of traditional knowledge, risk assessment, and hunting strategy—are built across the shorefast ice to connect the communities to leads in ice-choked waters where they wait for the migrating whales.

Barrow, with a population of approximately 4,000, is the largest Iñupiat community in Alaska and strategically positioned for hunting bowhead whales. The village sits just 15 kilometers south of the northernmost point in Alaska—Point Barrow. In spring, the whales,
which over-winter in the Bering Sea, begin their eastward migration toward summer feeding areas in the Beaufort Sea (Moore and Reeves 1993). The annual development of a persistent flaw lead system along Alaska’s Chukchi coast (Eicken et al. 2006) provides an efficient travel corridor for the whales, typically guiding them within striking distance of Barrow’s hunters. Over the last ten years Barrow has landed around 10 bowhead whales each spring, more than any other whaling community in Alaska.

The dynamic local ice environment at Barrow presents significant challenges to whaling crews who rely on shorefast ice as a platform for travel, camping, and butchering 20 to 40 ton whales to feed the community (Fig. 2; George et al. 2004a, Druckenmiller et al. 2010). Along with weather, ocean currents, and whale behavior, ice conditions largely determine where, when, and how the hunters travel, assess safety, and make decisions related to the hunt. The inherent danger and risk associated with operating from such an ephemeral and evolving icescape shapes a deep and highly nuanced body of local and traditional knowledge.

In addition to the dramatic pan-Arctic retreat of perennial sea ice extent over the last three decades (Comiso et al. 2008), studies reveal many changes in Arctic sea ice that are important on regional and local scales. These include a later onset of freeze-up (Mahoney et al. 2007a, Markus et al. 2009), decreases in multi-year ice (Maslanik et al. 2007), and general reductions in the annual mean sea ice concentration in the coastal regions (Wendler et al. 2010). After the mid-1970’s, hunters along Alaska’s Chukchi coast also began observing ice conditions unlike those experienced in previous decades (Norton 2002). These changes include a progressive decrease in the abundance of old ice, shorefast ice forming later in the year, and reduced stability of shorefast ice.

Barrow has a long history of local people partnering with researchers (Albert 1988; Brewster 1997). For example, the Barrow Symposium on Sea Ice, held in 2000, was a three-day gathering of over 30 participants, mostly whaling captains and scientists, to explore potential areas for collaborative sea ice research and understanding (Huntington et al. 2001). Local experts expressed a strong interest in seeing research address questions related to shorefast ice safety and accordingly shared recommendations for the key variables and processes to monitor in this regard. They expressed clear support for research focusing on shorefast ice break-out events, which take place when large sections of shorefast ice detach and drift away from the coast. Throughout history such events have resulted in loss of life to hunters and/or major rescue efforts (George et al. 2004a). Since 2000, several research projects have focused on break-out events near Barrow (e.g., George et al. 2004a, Mahoney et al. 2007b, Druckenmiller et al. 2009). It was in light of these types of hazards that the suggestion to map the community’s ice trails emerged, in part, to establish a more direct and identifiable link between the observations made by hunters and those made by scientists.

In the following spring of 2001, trail mapping began when Craig George, a whale biologist with the North Slope Borough (NSB), collected hand-drawn sketches of trails and ice features from Warren Matumeak, a Barrow elder, whaling captain, and retired director of the NSB Department of Wildlife Management. George also worked with other community members to map the trails using handheld GPS (global positioning system) devices. Fig. 3 presents a map based on both Matumeak’s sketches and the GPS-tracks. Through spring 2006, George kept a record of general trail locations, occasionally collecting GPS data; however a thorough and systematic approach had not yet developed. Building on existing
efforts and ideas, a refined plan for a more comprehensive trail mapping project emerged and began in spring 2008.

We propose that the placement of ice trails reflects how ice conditions guide the community’s use of ice and interaction with their local environment. In this paper, we focus on findings of the trail surveying project during its first four consecutive spring seasons, 2008 to 2011. To better understand the current state of ice conditions and efforts of the community to **cope** with a changing environment, we explore the benefits of combining geophysical-based monitoring with local knowledge and ice-use along the following themes: (1) tracking ice conditions, (2) documenting indigenous ice knowledge and use, and (3) developing information resources for the community. With intentions of continuing this project into the future, we consider ways this work may further engage the community through the involvement of young hunters.

This project is not the first to map ice trails used by indigenous peoples in the Arctic. In the Canadian Arctic, Aporta (2009), Tremblay *et al.* (2006), and Gearheard *et al.* (2010) have mapped trails used by the Inuit to access traditional hunting and fishing sites and to travel between communities. These projects have documented routes that extend for hundreds of kilometers, mostly over level undeformed ice. Gearheard *et al.*’s (2010) work has used sophisticated geomatics devices that allow hunters to collect detailed spatially referenced information on weather, ice hazards, animal sightings and other relevant observations. Wilkinson *et al.* (2011) are collaborating with Inuit residents near Qaanaaq, Greenland, to incorporate scientific instrumentation to measure ice thickness and local weather variables (similar to that used in this study) into sleds that are pulled by local dogsled teams.

With these efforts recognized, there are four noteworthy distinguishing characteristics of the project discussed here. **First**, the approach includes detailed surveys of continuous ice thickness and topography measurements, providing a multi-year dataset for quantitative analysis of trail characteristics. **Second**, these measurements are combined with various data collected by the Barrow Sea Ice Observatory (Druckenmiller *et al.* 2009) to better understand the contributions of both ice growth and dynamics to the ice thickness distribution and to produce information resources for the community. For example, an automated mass balance site, which is installed annually in undeformed first-year shorefast ice in a small embayment SW of Pt. Barrow, uses acoustic sounders to track ice growth and provides near-real-time information on sea-level throughout the season (Druckenmiller *et al.* 2009). **Third**, relative to the spatial extent and roughness of the trails in the previously mentioned projects, the trails off Barrow traverse a very narrow stretch of shorefast ice that is highly deformed and heterogeneous. Barrow’s trails are not typically placed with precise predetermined destinations in mind. Rather, they develop in response to encountered conditions to connect the community to hunting camps at the edge. These camps are often moved throughout the season as ice conditions and the location of whale sightings change (Druckenmiller *et al.* 2010). In general, the highly dynamic nature of Barrow’s coastal ice makes for more dangerous conditions. Also, unlike ice conditions in the coastal Canadian Arctic (Aporta 2009), there is significant interannual variability. **Fourth**, in recent decades, the waters north of Alaska have experienced a greater retreat in the extent of summer- and fall-time perennial sea ice in comparison to the seas of the Canadian Arctic. This has implications for the local availability of different ice types (e.g., less multi-year ice) during the fall freeze-up of shorefast ice.
Methodology

Each spring, prior to the start of whaling, we received permission from the Barrow Whaling Captains Association (BWCA) to map and survey the trails. We agreed to stay clear of whaling activity and to perform measurements before active hunting (i.e., crews camped on the ice with their boats and hunting equipment, ready to pursue a whale) or when hunters were temporarily pulled off the ice during periods of unfavorable weather or ice conditions. The vast majority of surveys were performed in the days prior to the first arrival of passing whales (typically in mid-April; George et al. 2004b) or when no open water was present along the shorefast ice edge. Because new trails are built and old trails rerouted throughout the season as ice conditions change, it was necessary to occasionally re-survey trails during active hunting. At these times, we were especially careful to not interfere with the hunt and ended the surveys well before reaching camps at the ice edge. To the best of our knowledge, all primary trails were surveyed. However, secondary trails (i.e., poorly maintained and/or infrequently traveled trails that are used to either scout ice conditions or to connect main trails) were occasionally not surveyed due to time constraints, rough driving conditions, or lack of knowledge of trail existence or location.

The primary piece of equipment used to survey ice thickness along trails was an electromagnetic-induction device (9.8 kHz Geonics EM-31 conductivity meter), which measures apparent electrical conductivity of the underlying half-space. Because sea ice has a negligible conductivity (approx. 20 mS m\(^{-1}\)) in comparison to that of seawater (approx. 2500 mS m\(^{-1}\)), the electromagnetic-induction technique indirectly measures ice thickness (Haas et al. 1997). By placing the EM-31 on the surface of the ice (or a known distance above since air and snow also have a negligible conductivity), the distance to the ice-water interface below can be inverted from the measured apparent conductivity using an empirically derived relationship between the two. By accounting for the instrument’s distance above the ice, ice thickness can be inferred. In this study, however, measurements actually reflect the total layer thickness of ice and snow since surveys are performed along trails that have experienced heavy snowmobile traffic that significantly disturbs and depresses the snow cover. Therefore, we neglect snow depth and present total layer thickness measurements as measurements of ice thickness. The EM-31 conductivity measurements were transformed to total layer thickness using the following transformation equations for years 2008 to 2010 and 2011, respectively:

\[
Z_t = 8.72 - 1.22 \ln (\sigma_a - 12.4) \quad \text{and} \\
Z_t = 8.49 - 1.21 \ln (\sigma_a - 14.9),
\]

where \(Z_t\) is total layer thickness in m and \(\sigma_a\) is apparent conductivity in mS m\(^{-1}\). (See Druckenmiller 2011 for a description of the calibration procedures.)

The EM-31 was set to log data at 1-second intervals such that driving at speeds between 10 and 15 km hr\(^{-1}\) resulted in sampling at approximately every 3 to 4 m. Data was then subsampled to 5-m spacing. Data points were assigned a water depth (nearest 5-m contour) using a bathymetry based on GEODAS (GEOphysical DAta System) depth soundings for the Chukchi Sea acquired from the National Geophysical Data Center (NGDC). The EM-31’s footprint is roughly 3.66 m, which is the distance between its transmitting and receiving coils.
EM-31 measurements are accurate to within a few percent of total thickness when surveying level un-deformed ice up to 3 m in thickness (Haas et al. 1997). Despite accuracy decreasing over thicker ice, surveys across the entire extent of shorefast ice provide useful information regarding the ice thickness distribution, especially for the purpose of year-to-year comparisons. A differential Global Positioning System (DGPS) capable of cm-scale accuracy was also frequently used to determine the vertical location of the surface; however, this data is not presented here. In 2008, the equipment was placed on a small plastic sled, attached to a waist harness, and laboriously hauled across the ice by foot. In 2009, we used a large wooden sled pulled by a snowmobile. This setup was replaced in 2010 by a 4-m long durable Ultra High Molecular Weight (UHMW) polyethylene sled (Fig. 4), custom-designed for transporting the delicate EM-31 instrument across rough ice by snowmobile.

Trail maps were produced and provided to the community before and throughout active whaling (mid-April through late-May). The maps (similar to that shown in Fig. 5) often included labels to identify the trails of individual hunting crews and geographic coordinates to mark trailhead and camp locations. Trail locations were overlaid on the most recently available synthetic aperture radar (SAR) satellite image, provided by the Barrow Area Information Database (BAID) in cooperation with the Alaska Satellite Facility. With little required technical knowledge, SAR imagery, which is not impacted by the presence of clouds, allows hunters to discriminate between general ice types (e.g., rough ice versus smooth ice) and locate the shorefast ice edge during periods when the coastal lead is open. Hardcopy maps were then distributed to the hunters, usually through the central location of the community’s Search and Rescue Base, which serves a common meeting location for hunters and a jumping-off point for community search and rescue operations. Electronic maps (JPEG image files) were distributed through email and an internet website. In addition to providing information on trail locations and ice conditions, the maps have also greatly promoted project-recognition amongst the whaling crews.

After each whaling season, formal interviews (16 in total) and numerous informal conversations took place with whaling captains and crew members to discuss the impact of ice conditions on the hunt. These interviews were semi-directed (Huntington et al. 2009) and addressed the hunters’ choices of trail and hunting locations, safety concerns, assessments of how vulnerable the ice was to breaking-out, and observations related to weather and ocean currents. Having traveled the trails each spring over the course of several weeks, we were able to ask location- and time-specific questions about ice conditions and why the crews chose certain areas. The hardcopy trail maps and satellite imagery were used to help focus the discussion on specific trails and ice features. Furthermore, the maps provided evidence that we had been well-exposed to the range of local ice conditions in the given year, which lent credibility to our research efforts. All discussions were in English, but often used Inupiaq terminology for ice features and weather conditions.

**Tracking local ice conditions**

Interannual variability of shorefast ice thickness is assessed in thickness distributions derived from the ice thickness surveys, and serves to provide a primary basis for tracking long-term changes in ice conditions. The results of four years of ice thickness surveys are
presented in Figure 6 as a map of trail locations and in Figure 7 as probability density functions (PDFs) of ice thickness. Although the location of the shorefast ice edge during the whaling season for each year is not explicitly indicated, it can be inferred from the trail terminus locations typically located at the ice edge (except for the early season trails shown in Figure 5 as those not reaching the ice edge).

Table 1 summarizes the ice thickness measurements from the trail surveys and compares these to measurements made at the mass balance site on 12 April of each year, which is the average date for the trail surveys. The modes for “level first-year ice” thickness (i.e., the thickness of level ice that froze in-place in fall) are roughly the same for all years at between 1.5 and 1.6 m, with a slightly higher value in 2010 at between 1.7 and 1.8 m. The mass balance site measurements were at 1.3 m for years 2008 through 2010, and 1.4 m in 2011. The observed thicknesses from the trail surveys are greater by approximately 30 cm on average. This difference is explained in part by the inclusion of a compressed snow depth into the trail measurements (The average snow depth on 12 April at the mass balance site was approximately 25 cm). Moreover, the trails also traverse low-lying rubble fields with somewhat thicker ice contributing to the prevailing thickness mode. Most important, the modes for “level first-year ice” thickness show little interannual variability in both the ice trail survey and mass balance site data.

However, significant interannual differences are revealed when other aspects of the data are considered. Fig. 7 reveals ice thickness modes for ice thinner and younger than that constituting the level-ice mode in years 2008 and 2010, but not in 2009 and 2011. Satellite imagery and ground-based observations confirm that while thin ice was present at Barrow in 2009 or 2011, it was not traversed by whaling trails. Furthermore, the 2008 and 2010 thin-ice modes result from only one or two trail surveys across continuous stretches of thin ice. In other words, thin ice modes appear because hunters build a trail that either traverses a large flat pan of young ice or uses a smooth refrozen lead as a travel corridor, and not as a result of numerous disjointed thin ice sections distributed throughout the shorefast ice cover.

By linking average ice thickness from the trail surveys to the underlying water depth, Fig. 8 reveals differences in the distribution of ridges (i.e., the thickest ice) encountered along the trails. Data from years 2008 and 2009 suggest that the majority of ridges existed at the 20 and 25-m isobaths, respectively. Here, the location of ridges matches a general observation of shorefast ice near Barrow and along the north Alaskan coast, which is that large (presumably grounded) ridges are found near the 20-m isobaths (Shapiro and Barry 1978; Mahoney et al. 2007a). Years 2010 and 2011 offer contrasting ridge distributions. The 2010 data show a relatively even distribution of ice thickness across the range of water depths. In 2011, large ridges are observed near the coast and even thicker ridges at the ice edge. The former were due to a localized storm-driven ice shove event in February 2011 that resulted in large ridges (upwards of 11 m in height above sea-level) forming very close to shore. The latter was indicative of a prominent and expansive shear ridge along the lead that presented significant challenges to the hunters as the searched for suitable camp and butchering sites. In general, the absence of prominent ridges in shallower waters (i.e., up to approximately 20 or 25 m) suggests that the trails may have traversed poorly anchored and potentially unstable shorefast
ice. However, because ice stability must be assessed at higher spatial resolution than can be achieved through the trail surveys, such interpretations of the data are only useful in so far as they inform more detailed field-based measurements or interview questions to hunters regarding perceived stability along their trails.

**Documenting indigenous ice knowledge and ice**

If hunters placed their trails in the same locations each year, independent of ice conditions, trail surveys would provide a record of ice conditions in specific localities and could serve as a strictly physical-science approach to track interannual variability. Similarly, if the whaling crews sought a single ice type and placed their trails wherever that ice type could be found, trail surveys would yield spatial information on ice morphology without necessary consideration of the social system. Neither of these is true. Rather, trail locations vary and reflect the wide variety of choices hunters make as ice conditions differ from year to year. Since strategies do consider ice type, biases in the trail thickness data toward certain ice types are inevitable. However, these biases are meaningful. *First*, they directly relate to the hunters’ knowledge and ice use strategies. *Second*, they reveal the ice types that hunters are forced to confront each year. Hunting from sea ice requires compromising with the environment. Oftentimes, conditions are not ideal for whaling and hunters must use ice types that are considered hazardous and accordingly pay closer attention to weather and seasonal changes that may quickly lead to imminent danger (Druckenmiller *et al.* 2010, Druckenmiller 2011)

Together with the observations and assessments of hunters, the trail mapping and surveying project is generating year-to-year summaries of how specific ice conditions relate to hunting successes and challenges. The strategies employed by hunters as they construct their network of trails, monitor ice and weather conditions, and observe whale migration behavior are revealed. Hunters decide on where to place their trails according to five primary considerations (Druckenmiller *et al.* 2010): safety, access to whales, availability of preferred ice types, convenience, and tradition. These general factors, which guide where and across what types of ice hunters travel, are summarized in Table 2. In this context, the resulting documentation of how the Inupiat understand and interact with sea ice (e.g., Druckenmiller *et al.* 2009, 2010) builds upon related key pieces of literature (e.g., Nelson 1969, Lowenstein 1980, Krupnik and Jolly 2002).

*Insert Table 2 near here*

As hunters consider the factors presented in Table 2, diverse strategies emerge between the dozens of whaling crews as they seek, manage, or avoid different ice types (Druckenmiller *et al.* 2010). (It is reasonable to assume that with greater diversity in strategies, the overall sampling biases inherent in the ice trail thickness surveys are reduced.) For example, as shown previously in Fig. 7, trail surveys in years 2008 and 2010 revealed the use of relatively thin ice. In each of these years, these areas of thin ice were amongst the most productive hunting areas (Druckenmiller *et al.* 2009, Druckenmiller 2010). In 2008, several whales were caught from and harvested on a 1.5-km stretch of ice that was approximately 0.75 m thick. In 2010, the two southernmost trails (see Fig. 5), which traversed large-pans of ice with thicknesses ranging between 0.90 and 1.30 m, served as the harvest locations for the vast majority of the 14 whales the community caught that spring.
Hunters decided these stretches of thin ice were safe and stable enough for whaling based on the absence of significant cracks, the persistence of favorable weather and drift ice conditions, and their ability to quickly retreat if needed. Clearly, these were also good places for whaling, with ice thick enough to haul up a whale. In both years, whaling captains (Jacob Adams in 2008; Joe Leavitt in 2010) explained that whales were diving beneath these stretches of thin ice and coming back out to surface near the ice edge, and consequently near the whalers’ carefully placed skin boats. Furthermore, given the flatness of the ice, trail breaking was easy with abundant options for quick escape from the ice during periods of potential danger.

Fig. 9, which presents average trail ice thickness as a function of the distance between the resulting camps at the ice edge and the village center, demonstrates that whaling crews are willing to travel farther for thinner (and consequently smoother) ice. Travel time and snowmobile fuel represent significant costs to whaling captains; therefore minimizing distance to camp is weighed against access to an ice type that reduces overall trail building and navigation effort. Interestingly, these observations present thin ice (relative to the thickness of level-first year ice) as an ice type that is often sought out, rather than avoided, and are important to consider in light of popular media generalizations that thinning ice represents a threat to indigenous hunters. However, this contrast may arise mostly because such generalizations use “thinning ice” as a proxy for a whole suite of changes taking place, including decreasing multi-year ice, shorter ice seasons, less stable ice, etc.

If we focus only on the choices made toward preferred ice types, we neglect important information to be gained from those ice types that are largely avoided. This is where the documented observations of hunters become important. Their assessments reveal ice types that are often less abundant and may be underrepresented in the ice thickness surveys. For example, in 2009 and 2011 whalers faced difficulty in finding safe and suitable places at the shorefast ice edge to butcher whales. The unusual incorporation of large volumes of mubaliq (an Iñupiaq term for a conglomerate of slush, brash ice, and snow that forms during periods of shear deformation of an ice cover) at the ice edge presented significant challenges. In 2009, multiple whales had to be butchered in the water (Druckenmiller et al. 2010)—a practice not yet refined by Barrow hunters as it has been by the whalers of the Bering Strait region.

Whaler Billy Adams explained that mubaliq is very susceptible to ablation from the currents beneath, which makes it very unstable once temperatures warm in April or May. Referring to the incorporation of mubaliq at the ice edge in 2009, he stated:

It is not very stable when it melts and breaks off. There is no safe place to jump on to. Once it breaks off it disperses in all directions…Once you get into that slushy ice, it’s not a safe place to be in or to butcher a whale.

Hunters’ observations also assist in identifying multi-year ice, which is both important to hunters (e.g., as a source of fresh water) and climate scientists. When discussing the 2001 shorefast ice cover with Craig George (see Fig. 3), Warren Matumeak noted that:

We had a whole lot more multi-year ice this year than in past years…Where did all that ice come from? These were some of the biggest pieces I have ever seen, there were so many of them [consolidated into one mass]…I haven’t seen this many [piqaluyuk] sections before.
Documented observations like these are extremely valuable to consider as rapid reductions in the polar perennial ice pack are currently observed (Maslanik et al. 2007). Similarly in 2010, many multi-year floes were found scattered throughout the shorefast ice off Barrow. The hunters were not surprised. While their long-term observations overwhelmingly acknowledge the decreasing abundance of old ice (or piqaluyuk in Inupiaq), their time spent and miles traveled on the ice typically allow them to identify even trace amounts that get incorporated into the shorefast ice, and which are not easily detectable using satellite imagery.

Indigenous experts’ ability to recall the past allows for a critical perspective on how local ice conditions may be changing—one that is often difficult to communicate to those who do not share their same knowledge and experience. The recognition of an exception or an outlier relies on a massive inventory of knowledge related to the “baseline” ice condition. During interviews, whaling captains often recall challenging environmental condition they encountered during past hunts. When faced with the question of whether such conditions are unusual, they search their own experience and the stories of their elders. Their culture’s oral tradition of telling stories enables hunters to have knowledge of longer-term variability and periodic fluctuations in their physical environment (Minc 1986). Accordingly, their understanding and interaction with the environment transcends personal experience. For these reasons, it is extremely insightful when an elder whaling captain actually suggests that something is new or unusual.

However, hunters very often preface their personal observations and understanding of traditional knowledge by acknowledging that it may be different from a response offered by another hunter. Because local and traditional knowledge is highly nuanced, it is expected that there will be slight differences between how individual hunters may describe a particular detail, especially since many hunters may not be as clear as others in translating their practical and experiential knowledge into words. Typically, hunters place great importance on accurate explanations and are often hesitant to speculate or to even generally discuss impacts from climate change.

**Developing information resources for the community**

Since 2005, the coastal radar of the Barrow Sea Ice Observatory has provided the community with an internet-based near-real-time animation of coastal ice dynamics (Druckenmiller et al. 2009). Since 2003, the Barrow Area Information Database has provided an online interactive mapping service that in recent years has hosted satellite imagery of sea ice for the Barrow region in springtime. Both of these efforts have contributed in some degree to hunters being more accustomed to using science-based data products to supplement their knowledge of present ice conditions. However, such resources currently see little use by the hunting community in comparison to information sources they are more accustomed to, such as the National Weather Service’s 5-day Marine Forecast of wind conditions.

The introduction of ice trail maps to the hunters has offered a new approach for gauging interest in science-based resources and improving their understanding of potential value. Accordingly, this project represents an ongoing experiment to explore how research can better provide useful information to the community.

The ice trail maps produced and distributed to the community have included GPS-tracked trail locations, recent satellite imagery (usually from 1–10 days before present), and a
coastline with traditional place names and commonly used location names. The spatial coverage of the maps has been chosen to include all trails in the given year, as well as the nearby shorefast ice edge. Maps have been largely considered by the community as useful for on-ice navigation, general ice-type discrimination (e.g., flat ice versus rough ice), a resource for search and rescue, and as a tool for communication between whaling crews, for example, in directing people to butchering sites.

Some hunters have also noted that the maps provide a tool for people learning to use a GPS device. As handheld GPS devices are increasingly used, elders and more experienced hunters have expressed concerns over this trend. The technology both provides a great advantage to hunters, enabling them to navigate efficiently to previously visited sites, locate trails that have been covered in snow, and to find their way in poor visibility. However, reliance on this technology comes with a price (Aporta 2005)—traditional navigation skills and attention to local landmarks and place names are quickly fading and are already mostly non-existent amongst the youth. As a result, we acknowledge that satellite imagery and trail maps are not always used to supplement local and traditional knowledge and may in some cases detract an inexperienced hunter from learning traditional skills.

On several occasions, trail maps with ice thickness values provided in color (similar to Fig. 5 but with units of feet instead of meters) have been distributed amongst the hunters. Surprisingly, the thickness information in such products stimulated little feedback or interest, which led to further consideration regarding the appropriate level of detail and the types of information that are useful. Potentially misleading or too specific information must be avoided. As stated earlier, EM-derived ice thickness measurements are not able to resolve the actual thickness of ridges thicker than 3–5 m, and therefore cannot be used to reliably infer grounding, at least not without detailed assumptions and knowledge of water depth.

Furthermore, regarding Inuit indigenous knowledge, Berkes and Berkes (2009) made the general claim that numerical precision is not highly valued or often used. They argue that local and traditional knowledge maintains real-word relevance because precise categorizations are specifically avoided. An informal survey of whaling captains on the minimum ice thickness sufficient to haul up a whale, would likely generate a wide range of answers. However, evaluating a potential whale haul-out site out on the ice, these experts would likely come to consensus regarding whether the ice was suitable, and certainly their assessment would consider much more than ice thickness. The hunters would evaluate the ice for cracks and consider other factors that could compromise the integrity of the ice in addition to the weight of the whale. For example, is the haul-out site sufficiently sheltered from potential direct impact from pack ice? When on the ice the nuanced-nature of their knowledge is most evident when specific uses of ice are considered.

When Warren Matumeak traveled the trails in 2001 describing the types of ice he encountered (see Fig. 3), he was essentially noting features and ice types that he deemed important. He likely considered ice type as a useful indication of ice anchoring strength ("pressure ridges"), trafficability ("smooth" versus "jumbled ice"), potentially dangerous conditions ("new ice"), and specific ice uses ("multi-year ice" as a solid platform for camp or as a source of fresh water). In 2002, the NSB School District published Abviqsiubnikun Whaling Standards (Harcharek 2002) as an educational resource for young hunters from the villages of Barrow and Wainwright. The handbook summarizes local and traditional knowledge of winds and ocean currents, bowhead whale morphological types, hunting equipment, and butchering methods. It includes a checklist for the things a whaling captain

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must pay close attention to when making decisions on the ice. Interestingly, it encourages the young whalers to travel their crews’ trails in springtime and to sketch the different ice types they encounter.

As we consider an improved trail mapping product, a refined method for ice type classification is needed. Ice thickness is not the sole determinant of ice type. Age, floe size, roughness, and thermal state must all be considered. Therefore, ice thickness information alone is not adequate to inform hunters’ decisions.

In this context, we calculated a z-score (using the cluster analysis tools provided by ArcGIS software) for each thickness data point in order to allow ice thickness values to exist in more than one class. The z-score is based on how many standard deviations an observation is from the mean within a moving window of specified length. For example, a z-score of -2.0 means that the data value is 2.0 standard deviations below the mean of the values within the moving window. Fig. 10 presents an example of this approach applied to ice thickness from a single trail in 2010. Using geo-located photos taking during the trail survey, the classification of z-scores was semi-arbitrarily adjusted such that different ice types fell within mostly different classes. For example, light blue represents either rough ice or multi-year ice, dark blue represents prominent ridges, red represents thin ice that was wet on the surface, and orange represents either flat ice near the coast or very smooth ice in the refrozen lead. While the difference between the information presented by the two colored trails in Fig. 5.18 is not dramatic, it presents an improved contrast between ice types compared to classifying by ice thickness alone.

Recognizing that the most informative classification scheme must incorporate expert knowledge and direct visual observations made while on the ice, we see greater opportunity for this project to collaborate with the community. A future goal for this project is to provide young hunters with cameras and handheld GPS devices so that they may travel the trails to document encountered ice types in the manner that Warren Matumeak did and that the school district’s Whaling Standards (Harcharek 2002) proposed. While being exposed to science and technology, young hunters will be contributing to a process of classifying the ice trail thickness surveys. The experience may improve their ability to make ice observations and inform their later conversations with elders regarding ice conditions.

Discussion and conclusions

A four-year interannual comparison of the shorefast ice thickness distribution sampled along hunting trails has revealed a fairly consistent modal thickness corresponding to level first-year ice (as confirmed by measurements at the fixed-location mass balance site). This suggests that surveys provide a meaningful and consistent approach to monitoring long-term changes in shorefast ice mass balance since the “level first-year ice” thickness mode is a signature of thermodynamic ice growth. Moreover, the geographic spread of trails and the diversity of strategies that enter into the routing of a trail ensure that a very broad spectrum of ice types is sampled. Clearly, biases in the ice thickness surveys due to oversampling of certain ice types, such as thin ice (i.e., ice thinner than expected level first-year ice), must be considered. These biases, however, represent the choices made by hunters and are reflective of ice use. For example, whaling crews will travel a greater distance from the village when the required effort to establish a trail is minimized by the presence of flat and relatively
thinner ice. Hence, the raw ice thickness data from the trail surveys represent a convolution of information relating to the ice mass budget (ice growth/ablation and deformation) and the strategic use of the ice cover. This information is valuable and important in its own right. However, further data analysis, such as the grouping of trail section data into “clusters” as shown in Fig. 10 or the classification of trail data based on other criteria allow for a disaggregation of thickness measurements into categories that are unbiased and lend themselves to further scientific analysis.

Trail surveys have also revealed significant interannual differences in several variables relating to trail thickness and morphology, such as the water depth at which the primary grounded zone(s) and prominent roughness conditions developed and the incorporation of favorable and unfavorable ice types (e.g., mubaliq). Such features are tracked by hunters throughout the entire ice season and have important implications for ice stability and therefore the safety of hunters. In this context, the interannual variability that is important to hunters is not driven by season-scale thermodynamic ice growth as much as it is by the deformation and accession history of the ice cover and the occurrence of short-lived thawing events.

Relating trail surveys to the experiences of the whaling community relies on the observations and assessments of individual hunters. Interviews allow trail locations and thickness data to be spatially co-located with their specific observations of noteworthy ice features. As an important feedback, efforts to document and understand the sophistication, depth, and context of their local knowledge increases the involvement of local experts in the research process. This not only creates local opportunities but also improves community acceptance of the research and ensures a more accountable approach toward maintaining research that is relevant to the community.

In terms of improving the usefulness of science-based resources for the community, data products must be developed such that they are compatible with the ways hunters already use information to evaluate ice conditions. Consideration for the proper level of detail is essential. Success is likely to be achieved through multiple iterations of a data product and continued community feedback. The usefulness of trail maps by the community may be improved by discriminating ice types based not only on ice thickness, but also on the spatial clustering of ice thickness observations and visual-based expert knowledge of the specific ice types encountered along the trails. This represents a unique prospect to involve young hunters and to indirectly support opportunities for traditional learning. However, we recognize that such community involvement is often difficult to maintain, and thus may not provide a realistic mechanism for sustaining this project in the long-term.

This project is not only documenting natural and social variables, but tracking variables that link the natural system to the social system, which Liu et al. (2007) present as a major common feature of integrated efforts to understand human-environment systems. In this system, there is a well-defined priority, which is to harvest whales safely and in a manner respectful to tradition and culture. Although the main activities of the hunt are performed by individual hunting crews (or small groups of several crews), the Inupiat practices of self-organization and working together certainly transcend the level of the hunting crew to include the entire community. In this sense, the distribution of trails is not necessarily always an accurate representation of where active and successful hunting takes place since many crews will often abandon the majority of established trails to concentrate into relatively small
areas to take advantage of suitable ice conditions (e.g., during ice deterioration late in the hunting season).

In comparison to the shorefast sea ice environment elsewhere in the Arctic, such as near the coastal communities in northern Canada and Greenland, conditions at Barrow are more variable, which is largely related to its location at a regional-scale promontory of land and its steep coastal bathymetry. Barrow also experiences greater local heterogeneity in ice conditions; within only a few kilometers from the coast, a large range in ice types and morphologies can be found throughout much of the year. This project is documenting the persistence, mobility, and ingenuity employed by the hunters to deal with such variability. The range in strategies employed by the community defines the “decision space” in which they can maneuver to deal with this challenging environment. As this work continues into the future, it may begin to answer the question of whether Arctic communities, like Barrow, that have and continue to cope with such change and variability may be more adaptive to future environmental change than communities located in less dynamic, less variable environments. At the same time, future work will have to establish whether studies at sites such as Barrow that sample a broader range of ice conditions may provide insights into processes and temporal change that is relevant for communities elsewhere.

One potential counterargument relating to Barrow’s demonstrated resilience to significant environmental change relates to the delicate timing of spring whaling. In recent years, the average arrival of thawing air temperatures has been the third week in May, which is approximately the time when spring whaling comes to an end. The timing of these two events is somewhat related as hunters routinely attribute the development of unstable ice and dangerous spots along trails to both warming air and water temperatures. However, this has not significantly impacted the harvest of whales since the majority of the migrating whales pass by this time. Furthermore, the last whales to pass Barrow are mostly comprised of large older whales, which are much less preferred by hunters than the small younger whales. Currently, evidence supports this when considering local spring temperatures and harvest data. Fig. 11 shows the dates for the first thaw and for the onset of seasonal thaw (defined as the first day with a mean average temperature above 0°C that is also the beginning of a 15 day period with an average temperature above 0°C) for the last three decades alongside the average harvest dates and the dates for the last harvested whale each spring. These data do not correlate on an annual basis and show no significant indication that these are becoming earlier over this period (except for the date of first thaw).

However, even slight warming experienced during the time of whaling if coupled with decreases in ice thickness and stability (i.e., the degree to which anchored ridges keep the shorefast ice from breaking-out) may present important challenges to hunters even if the timing of the harvest has not yet been affected. Fig. 11 does show that the date of first thaw is arriving early over the last 30 years. Short-lived warming periods (thawing temperatures lasting less than 1 day) contribute to rapid trail deterioration, especially in areas of high traffic were snow machines have worn the snow and ice thin. Trails traversing areas of refrozen cracks or solidified piles of brash ice (mubaliq) can quickly break up while the typical level undeformed ice shows little sign of change (Druckenmillner et al. 2010). Additionally, annual coastal temperatures on Alaska’s North Slope show an increasing trend over recent decades (Wendler et al. 2010) and studies have shown shorefast ice to be breaking up earlier in summer (Mahoney et al. 2007a). Therefore, there is cause for concern
that the delicate timing between the abundance of stable ice and the arrival of the majority of whales to the region may be disrupted in the future. This would likely challenge the traditional bowhead whale hunt to a degree not yet experienced by the present day whaling community.

Speaking of ice conditions in 2009, which was a year with the relatively very early first thaw date of 27 April (see Fig. 11), whaler Billy Adams stated:

It was no good. We had a bad season because of all that young ice coming in all the time and staying in [at the ice edge]... …There was a lot of slush-ice...Even if there were whales we were kind of hesitant to go out there because of the unsafe ice conditions. We're not trying to take chances to kill a whale for loss of [human] life...It was May 12 when we went home...It had gotten hot and for many days straight. It melted everything and we just didn't want to stay out there with a lot of water all around...It just took a few days of warm weather from on top and, I think, [also] from the current on the bottom. The young ice had gotten soft. We wouldn't be able to pull up a whale on it. Once we know we can't pull up a whale then [whaling] is done for us.

Whether the strategies employed by hunters have significantly changed in recent decades due to climate change remains mostly an unanswered question. However, as environmental change continues, it is reasonable to assume that coping strategies will become more apparent. For example, in a scenario of thinner and less stable ice, the following types of measures may be taken by the hunters:

- increasing their mobility and spending less time on the ice,
- developing a trail network with increasing options for quick escape routes to land,
- hauling caught whales a greater distance to find suitable locations for hauling whales onto the ice for butchering,
- increasing the interaction between elders and youth to retain traditional knowledge and as a way to discover new knowledge (e.g., internet and science-based resources), or
- shifting investments from equipment necessary for the ice-based spring hunt toward suitable boats for the open-water fall hunt.

Continuing this work into the future may not only reveal how the community adapts but also eventually identify thresholds in the system (i.e., where changing environmental conditions prompt whalers to make a fundamental shift in strategy). For example, when does the presence of young thin flat ice shift from being considered an ice type that provides for easy and efficient trail building as well a good place to see whales to an ice type that must be avoided at all costs due to earlier and more persistent thawing temperatures?

Any effort to identify thresholds must consider the other factors that in some way influence the human-environment system of traditional whaling. Fig. 12 summarizes these five major inter-connected components: environment, whales, governance, local community, and whaling crews. For example, changes in the sea ice environment on one side impacts the relevance of local and traditional knowledge and the associated confidence of local experts, and on the other side may impact whale population health and the timing and location of its migration, which will in turn be considered by the International Whaling Commission as it sets the subsistence quota for Alaska’s whaling communities. While examining these interconnections in the context of social and environmental change is beyond the scope of this paper, general consideration is necessary to provide a broader perspective to our work.
Fig. 12 is not all-inclusive; each component could be expanded upon and more components added. For example, within the whaling crew, local and traditional knowledge depends on elder-youth interaction, time spend on the ice, and the access to traditional means of education.

[Insert Figure 12 near here]

Sea ice provides an important ecosystem service to Arctic coastal communities by connecting them to hunting opportunities (Eicken et al. 2009). In order to gain greater insight into how future changes in ice conditions may impact the hunt, it is necessary to continue focusing on how ice conditions along specific trails relate to hunting success, or alternatively to major hazards that divert hunting effort. Sustaining this project into the future and continuing to partner with the community remains a priority. In local human-environment systems in the Arctic, there is a need for well-understood ecosystem services as a strategy to assess vulnerability to environmental change and to assist in adaptation.

References


Aporta, C., 2005. From map to horizons; from trail to journey: The challenges of documenting Inuit geographic knowledge. Études Inuit Studies, 29 (1–2), 221–231.


URL: http://mc.manuscriptcentral.com/tpog


### Table 1. Ice trail and mass balance site thickness modes

<table>
<thead>
<tr>
<th>Year</th>
<th>Thin ice mode&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Level first-year ice mode&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Mass balance site&lt;sup&gt;c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ice thickness (m)</td>
<td>PDF value (m&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>ice thickness (m)</td>
</tr>
<tr>
<td>2008</td>
<td>0.7–0.8</td>
<td>0.31</td>
<td>1.5–1.6</td>
</tr>
<tr>
<td>2009</td>
<td>-</td>
<td>-</td>
<td>1.5–1.6</td>
</tr>
<tr>
<td>2010</td>
<td>1.0–1.1</td>
<td>0.38</td>
<td>1.7–1.8</td>
</tr>
<tr>
<td>2011</td>
<td>-</td>
<td>-</td>
<td>1.5–1.6</td>
</tr>
</tbody>
</table>

<sup>a</sup> Ice thickness mode less than level first-year ice thickness.

<sup>b</sup> Nearest mode to expected level first-year ice thickness.

<sup>c</sup> Measurements from 12 April, which is the average ice trail survey date. See the site location in Fig. 6.
<table>
<thead>
<tr>
<th>General considerations</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessments of safety</td>
<td>- Is the ice well anchored?</td>
</tr>
<tr>
<td></td>
<td>- Is the trail quickly navigated in case of an emergency?</td>
</tr>
<tr>
<td></td>
<td>- Is the trail wide enough for two snowmobiles to pass?</td>
</tr>
<tr>
<td></td>
<td>- Is there potential for secondary access/escape trails?</td>
</tr>
<tr>
<td></td>
<td>- Is there a good location for the Nafiaqtubvik (safe camp)?</td>
</tr>
<tr>
<td></td>
<td>- Can dangerous areas (e.g., cracks or thin ice) be avoided?</td>
</tr>
<tr>
<td>Access to whales</td>
<td>- Is the camp in a good location to see surfacing whales (e.g., in an embayment at the ice edge)?</td>
</tr>
<tr>
<td></td>
<td>- Will the ice edge shape funnel or deflect whales to or from camp?</td>
</tr>
<tr>
<td></td>
<td>- Does camp provide a good view of the water in the direction of the arriving whales?</td>
</tr>
<tr>
<td></td>
<td>- Is the water deep enough for whales to dive?</td>
</tr>
<tr>
<td></td>
<td>- Is the camp remote enough to prevent village noise from disturbing the whales?</td>
</tr>
<tr>
<td>Availability of</td>
<td>- Is there multi-year ice for drinking water?</td>
</tr>
<tr>
<td>preferred ice types</td>
<td>- Is the ice edge level and thick enough to haul up a whale?</td>
</tr>
<tr>
<td></td>
<td>- Is the ice edge suitable for launching a boat?</td>
</tr>
<tr>
<td></td>
<td>- Are high ridges nearby to serve as whale lookouts and landmarks when returning to camp in a boat?</td>
</tr>
<tr>
<td>Convenience</td>
<td>- How much trail construction effort is required?</td>
</tr>
<tr>
<td></td>
<td>- What is the travel time between camp and the village?</td>
</tr>
<tr>
<td></td>
<td>- Are other crews nearby in case of needed assistance?</td>
</tr>
<tr>
<td>Tradition</td>
<td>- Where are traditional hunting locations (e.g., good places to see whales)?</td>
</tr>
<tr>
<td></td>
<td>- What crews often build trail and establish camps together?</td>
</tr>
<tr>
<td></td>
<td>- What areas does traditional knowledge consider more dangerous (e.g., north of Point Barrow)?</td>
</tr>
</tbody>
</table>
Figure Captions

Figure 1. Alaska’s indigenous whaling communities, whale migration, and summer sea ice extent. Barrow is the only community to practice both spring and fall whaling. AWMP (2006) provided the approximate migration path for the Bering-Chukchi-Beaufort bowhead whale stock. The September median (1979-2000) and the September 2007 (the lowest on record) ice extents are derived from passive microwave satellite imagery and obtained from the National Snow and Ice Data Center.

Figure 2. A Barrow whaling crew moves their boat out to their safe camp, nafiaqtubvik, where crews will retreat to when conditions are dangerous. The shorefast ice and lead system off the community of Barrow (bottom). Photos by M.L. Druckenmiller taken in mid-April 2010.

Figure 3. Warren Matumeak’s 2001 trail map. Warren Matumeak (top left; photo by Shari Gearheard). Sample trail sketch (top right). A reconstructed trail map using Matumeak’s sketches and trail GPS tracks (bottom).

Figure 4. Ice survey sled with EM-31 and DGPS.

Figure 5. Ice trail map from spring 2010 with ice thickness values. Colors represent different ranges in ice thickness values according to a classification scheme based on 1 standard deviation from the mean of the entire dataset. Data points are presented at a 5-m subsampled resolution.

Figure 6. Trail and ice thickness survey locations (2008 to 2011).

Figure 7. Probability density functions (PDF) of ice thickness from trail surveys for years 2008 to 2011. The last bin in each PDF represents all thickness values greater than 5 m. The vertical dotted lines represent the ice thickness at the mass balance site on 12 April (Fig. 6) of each year. *Data does not include the early season trails, which can be seen in Fig. 5 as those not extending to the shorefast ice edge.

Figure 8. Average ice thickness along the trails in relation to water depth (binned into 5 m depth intervals).

Figure 9. Average ice trail thickness as a function of the remoteness of the trail terminus. The average ice thickness for trails that terminate at or very near the shorefast ice edge used during whaling is plotted against the distance from the trail’s endpoint to the village center (71.2972° N, 156.7783° W). A linear regression of the entire dataset (solid line) yields a correlation coefficient of -0.80.

Figure 10. Ice trail morphology classification according to both thickness and type. Top left: Colors along the trail indicate ice thickness according to the classification scheme of Fig. 5. Bathymetry is shown with 5-m contours. Top middle: Colors along the trail indicate z-score (using a moving window of a fixed Euclidian threshold distance of 50 m) according to the
classification shown in the graph at bottom left. The numbers along the trail represent the different ice types shown in the column of numbered photos on the right. The trail used in this Fig. is the second trail from the NE in Fig. 5.

Figure 11. Whale harvest dates (top) and thawing dates (bottom) between 1972 and 2011. Harvest dates were provided by the North Slope Borough Department of Wildlife Management. A harvest on 13 July 1986, the latest “spring” whale on record, has been omitted as an anomalous event. Surface temperatures obtained from the National Climatic Data Center for the Barrow W. Post-W. Rogers Airport (GSOD ID: 70026027502). Linear regressions for the last harvest date, average harvest date, onset of seasonal thaw, and first thaw date yield correlation coefficients of -0.06, -0.08, -0.12, and -0.33, respectively, and negative slopes of 0.05, 0.06, 0.06, and 0.33 days yr⁻¹, respectively.

Figure 12. Five controlling factors of the Inupiat’s traditional spring whale hunt.
Figure 1. Alaska’s indigenous whaling communities, whale migration, and summer sea ice extent. Barrow is the only community to practice both spring and fall whaling. AWMP (2006) provided the approximate migration path for the Bering-Chukchi-Beaufort bowhead whale stock. The September median (1979-2000) and the September 2007 (the lowest on record) ice extents are derived from passive microwave satellite imagery and obtained from the National Snow and Ice Data Center.
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186x272mm (300 x 300 DPI)
Figure 4. Ice survey sled with EM-31 and DGPS.
61x30mm (300 x 300 DPI)
Figure 5. Ice trail map from spring 2010 with ice thickness values. Colors represent different ranges in ice thickness values according to a classification scheme based on 1 standard deviation from the mean of the entire dataset. Data points are presented at a 5-m subsampled resolution. 127x159mm (300 x 300 DPI)
Figure 6. Trail and ice thickness survey locations (2008 to 2011).

117x107mm (600 x 600 DPI)
Figure 7. Probability density functions (PDF) of ice thickness from trail surveys for years 2008 to 2011. The last bin in each PDF represents all thickness values greater than 5 m. The vertical dotted lines represent the ice thickness at the mass balance site on 12 April (Fig. 6) of each year. *Data does not include the early season trails, which can be seen in Fig. 5 as those not extending to the shorefast ice edge.
Figure 8. Average ice thickness along the trails in relation to water depth (binned into 5 m depth intervals).

78x48mm (600 x 600 DPI)
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87x60mm (600 x 600 DPI)
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101x80mm (600 x 600 DPI)
Figure 12. Five controlling factors of the Iñupiat’s traditional spring whale hunt.

114x102mm (600 x 600 DPI)