Chapter 15
Indigenous Knowledge and Sea Ice Science: What Can We Learn from Indigenous Ice Users?

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Abstract Drawing on examples mostly from Inupiaq and Yupik sea ice expertise in coastal Alaska, this contribution examines how local and indigenous knowledge (LIK) can inform and guide geophysical and biological sea ice research. Part of the relevance of LIK derives from its linkage to sea ice use and the services coastal communities derive from the ice cover. As a result, indigenous experts keep track of a broad range of sea ice variables at a particular location. These observations are embedded into a broader worldview that speaks to both long-term variability or change and the system of values associated with ice use. The contribution examines eight different contexts in which transmission of LIK is particularly relevant. These include the role of LIK in study site selection and assessment of a sampling campaign in the context of inter-annual variability, the identification of rare or inconspicuous phenomena or events, the contribution by indigenous experts to hazard assessment and emergency response, the record of past and present climate embedded in LIK, and the value of holistic sea ice knowledge in detecting subtle, intertwined patterns of environmental change. The relevance of local, indigenous sea ice expertise in helping advance adaptation and responses to climate change as well as its potential role in guiding research questions and hypotheses are also examined. The challenges that may have to be overcome in creating an interface for exchange between indigenous experts and sea ice researchers are considered. Promising approaches to overcome these challenges include cross-cultural, interdisciplinary education, and the fostering of Communities of Practice.

Keywords Sea ice geophysics · Sea ice use · Local indigenous knowledge · Sea ice system services · Arctic observing network

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Introduction

Over the past few years, Arctic sea ice has received increasing attention by the public, mostly in the context of climate change. Media coverage typically discusses the shrinking and thinning of Arctic sea ice by referring to scientific studies based on satellite data or computer models of the climate system. While such information is generally scientifically precise at the large scale, it provides only a limited view of the characteristics of the ice cover itself and the processes that shape its seasonal evolution and role in Arctic ecosystems. Consider the expanse of coastal sea ice and ocean shown in the photograph taken during fall freeze-up at the Alaskan community of Wales in Bering Strait (Fig. 15.1a). The different ice types, open water, and the stretch of coast visible in the photo cover only a small fraction of the area that makes up a single data point (pixel) in the satellite imagery typically used to determine ice concentration and extent for studies of sea ice climatology. Several of these pixels, 25 by 25 km in extent, are shown in Fig. 15.1b, for a satellite scene acquired on the same day, November 9, 2007, that Winton Weyapuk, Jr., a SIKU project participant from Wales took the photograph (see Chapter 14 by Krupnik and Weyapuk, this volume). In fact, the satellite imagery does not indicate any presence of ice near Wales for this same date, mostly as a result of the small width of the narrow belt of coastal ice but also due to other factors that make new ice difficult to detect in nearshore environments.

The coarse observational scale of the satellite data is sufficient for broad studies of how Arctic sea ice helps regulate Earth's climate. However, on their own such data are of lesser value if the aim is, for example, to learn more about the processes that control seasonal ice growth and decay, its role as a platform for marine mammals or its importance in the context of coastal erosion. In a changing north that experiences not only substantial sea ice retreat but also increasing

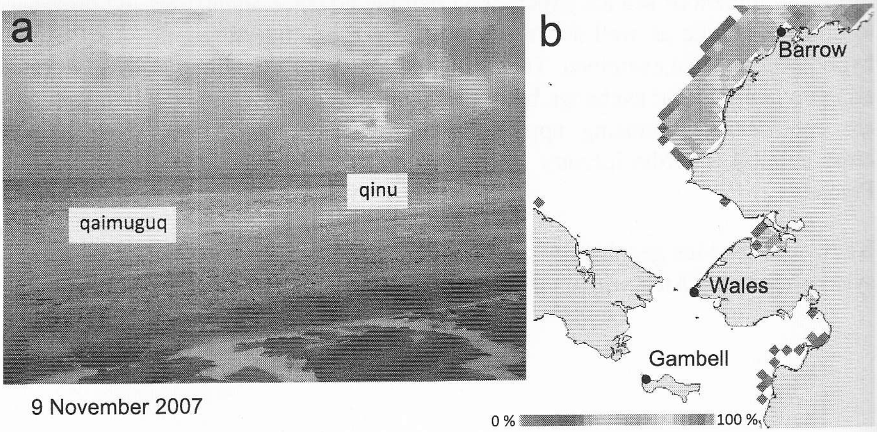

Fig. 15.1 (**a**) Ice formation along the beach at Wales, Bering Strait on November 9, 2007 (Photo: W. Weyapuk, Jr.). Note the formation of a slush ice berm (*qaimuguq*) that offers some protection to the coast from waves. (**b**) Ice concentrations for the same day obtained from passive microwave satellite data (Special Sensor Microwave/Imager, SSM/I) show no detectable ice near Wales

ship traffic and industrial activities, demand is great for more detailed information about the characteristics of the ice cover and its seasonal waxing and waning. Here, a more comprehensive, multifaceted perspective on sea ice as both a material and a process – a freezing water, or a melting, moving or deforming ice – is of value. Indigenous ice experts may provide such a perspective both through long years of detailed observation and through transmission and evaluation of knowledge from elders and peers.

This contribution touches on the question of what sea ice scientists, in particular geophysicists, oceanographers, and meteorologists (and to some extent biologists), can learn from indigenous sea ice experts and ice users. This question has been examined in detail in the broader context of local or indigenous knowledge and has been addressed in anthropological, geographic, or social science studies (Agrawal 1995; Berkes 1999; Krupnik and Jolly 2002). Here, I take less of a scholar's and more of a practitioner's approach and discuss how learning from indigenous ice experts may enhance, deepen, or broaden sea ice geophysical or biological research. By drawing on examples from field research or the literature this contribution aims to

- provide a perspective on the insights and understanding collaboration with indigenous ice experts may generate – mostly for those engaged in sea ice geophysical, climatological, or biological research but less familiar with local, indigenous knowledge;
- identify promising areas for further work where local, indigenous knowledge can contribute substantially to guiding observations and furthering understanding;
- develop a rough outline of what an interface between indigenous and geophysical–biological knowledge of sea ice may look like and what may be required to foster transmission and exchange across this interface.

For those interested in a comprehensive picture of sea ice knowledge in a coastal Arctic community, Richard Nelson's classic study documenting sea ice use in Wainwright, Alaska, is still highly relevant (Nelson 1969). Norton (2002) summarized insights gained from a symposium held in Barrow in 2000 that provided a good perspective on a more diversified approach to documenting and discussing indigenous and geophysical sea ice knowledge. Finally, a summary by Henry Huntington and several colleagues active in community-based observing programs is an excellent, up-to-date resource (Huntington et al. 2009).

Use of Sea Ice and Local, Indigenous Knowledge: Key Concepts and Terminology

As implied by the title of this contribution, a fundamental aspect of learning from indigenous or local ice experts is the recognition that their knowledge in large part derives from the use of sea ice. The term "use of sea ice" refers to more than simply using the ice, e.g., as a platform for travel or hunting as described by Druckenmiller and others and Gearheard and others in this book. Rather, it describes the suite of services that communities or individuals derive from the sea ice zone, including the ecosystems associated with it. Here, sea ice services include tangible and intangible benefits such as protection from waves and coastal erosion or the important place sea ice occupies in the lives of Arctic coastal residents. Moreover, the concept of sea ice system services, extending the theory of ecosystem services to the Arctic ice cover (Eicken et al. 2009), also includes the hazards and threats emanating from the ice. Within this framework, indigenous people typically observe and keep track of a range of different phenomena, processes, and animals as they relate to the specific services derived from sea ice.

This is not only apparent in the typically more than one hundred terms indigenous languages reserve for sea ice features and ice-associated phenomena (see Chapter 4, Chapter 2 by Taverniers; Chapter 14 by Krupnik and Weyapuk, this volume), from which a "map" or schematic of key ice processes and interactions can be constructed. In working with sea ice experts in the communities of Gambell, Wales, and Barrow, who are making observations of coastal ice as relevant to their communities' activities (see Chapter 4, Krupnik et al. this volume), we find references to a large number of animals observed in conjunction with the ice cover or specific ice processes. This includes not only obvious mention of ice-associated seals or walrus but also observations of fish and bird species that display preference for specific ice types and exhibit a seasonality coupled to the ice, which in turn determines how they may be harvested from the ice platform.

Intimate and long-standing familiarity with a specific place, often based on the use of resources at that location, is generally referred to as local knowledge. The power of such local knowledge was demonstrated on an icebreaker cruise with a German vessel into Siberian waters that the author participated in some years ago. Near the Franz-Josef-Land archipelago the vessel was making no progress in very heavy ice, despite non-stop ramming and breaking. A Russian icebreaker captain – onboard as an observer and familiar with the tidal currents in the region and their often barely perceptible impact on the periodic opening and closing of cracks and leads – was finally able to pick a path through cracks and narrow passageways.

Indigenous knowledge embeds local knowledge and other insights, beliefs, and values into a worldview that extends into the human and spiritual realm and is shared by a larger community. It builds on a tradition of environmental observations at a given place, providing a backdrop of greater temporal depth and topical breadth. Through ties to specific applications and uses, local and indigenous knowledge is subject to repeated critical review and reaffirmation, both in the field and by the elders and recognized experts in a community. Such knowledge is commonly also referred to as traditional (ecological) knowledge (see Agrawal 1995; Berkes 1999; Huntington et al. 2005). Both local and indigenous knowledge are relevant in this chapter and will be summarily abbreviated as LIK.

Kawagley (1995) describes how the Yupiaq worldview in western Alaska is supported by a balance between the human, natural, and spiritual realms. Since this type of knowledge or understanding cannot be compartmentalized or categorized in the manner that western (i.e., Euro-American) science ingests and evaluates information, it may be challenging or possibly discomforting for scientists to even begin to learn from sea ice users whose expertise is firmly embedded in such a holistic worldview. Hence, it is not uncommon for scientists to dismiss indigenous expertise. It often happens because the scientific method (which of course is also firmly embedded in a worldview of its own) does not come with the tools that allow one to process quantitative information about the nature of the physical environment while at the same time accepting the idea, say, that the division between the realms of people and animals is permeable and indistinct. Even though it is less rich and deep, local knowledge – such as that of the icebreaker captain referred to previously – is often easier to accept in such an LIK-skeptical context because it is divorced from any specific worldview.

The threshold that has to be crossed in order for a substantive discourse to occur is typically higher for the physical than the biological sciences. The study of ecosystems or animal physiology and behavior lends itself more readily for exchange among LIK and western science experts because of similar methodologies employed, e.g., in capturing animals, than the study of the physical environment, in particular with an increasing specialization and reliance on remote-sensing methods and model simulations. This situation is unfortunate because the latter stands as much to gain from LIK as the former.

A Survey of Indigenous Expertise and Knowledge Relevant to Sea Ice Research

One approach to help those in the physical sciences engage with indigenous sea ice experts is to identify or delineate subject areas or ways in which LIK can inform, guide, or enhance research. Eight such ways of engagement are sketched out in the brief survey below, organized to progress from specific, obvious applications to broader, potentially more complicated and less well-explored categories. It needs to be recognized, however, that by its very nature indigenous knowledge does not lend itself to compartmentalization or integration into the framework of western science (Kawagley 1995; Nadasdy 1999). Thus, the categories explored below are meant to guide the gaze as one attempts to catch a glimpse of different facets of indigenous knowledge; by no means are they intended to classify the knowledge itself. The discussion below reflects instruction by Inupiaq and Yupik sea ice experts, insights gained from field work in coastal Alaska, and discourse with colleagues working in the region. Nevertheless, similar categories have been arrived at by others, such as Berkes (2002) who recognized five potential areas of convergence between climate research and traditional knowledge that are in many ways equivalent to those delineated below.

Is This a Good Spot? LIK and Study Site Selection

A key aspect of field measurements on sea ice is the selection of an appropriate study site, which is often challenging due to the heterogeneity of sea ice as a material and the patchiness of physical and biogeochemical properties (e.g., Granskog et al. 2005). Hence, some measurements, such as the determination of ice algal biomass, may require large numbers of samples to allow statistically significant conclusions (McMinn et al. 2009). Knowledge of the ice growth history and targeting of sites with homogeneous snow cover and absence of – often hidden – deformation features can help minimize the number of samples that need to be taken and enhance insights gained from their analysis (Eicken 2009). Here, local, indigenous ice experts are in a position to offer valuable guidance. Many of the processes and ice features that complicate analysis of field data and potentially invalidate conclusions, such as ice deformation features, sediment inclusions, patchy snow cover, and anomalous growth history impacted by freshwater runoff or flooding, are familiar to local ice users in coastal communities.

As discussed by Aporta (2002), Norton (2002), Laidler and others (2009) and Druckenmiller and others (Chapter 9, this volume), use of trails over sea ice requires monitoring of ice evolution throughout the ice season to anticipate potential hazards as the season progresses. Travel and hunting on the sea ice foster close observation and tracking of snow cover and ice deformation features, potentially of great value to researchers planning a field campaign with specific requirements for the ice types that are to be sampled. A considerable challenge, however, exists in having researchers communicate their interests and then translating relevant aspects of local, indigenous knowledge that would help in the planning and execution of a field campaign. While it is common practice to hire local experts as guides, it is much less common for field parties to engage in an appropriate form of communication (see Huntington et al. 2009) with local experts during the early stages of project design and field trip planning in order to evaluate whether suitable ice types are present and if so where and how best to access them.

These difficulties are less of a challenge if the features or processes to be studied partly overlap with the interests of indigenous ice use. Let us consider two examples to illustrate this point. Multiyear sea ice (piqaluyak being an Inupiaq equivalent) helps ensure the stability of landfast ice (see Chapter 9 by Druckenmiller et al. this volume) and provides a preferred source of freshwater to hunting crews on the ice and elders in the village (Nelson 1969; George et al. 2004). Over the past two decades, access to multiyear ice in some Arctic locations, such as coastal Alaska, has become more difficult due to changes in Arctic ice circulation and dramatic loss of multiyear ice (Maslanik et al. 2007). Even small multiyear floes few tens of meters across can be of great value in a range of studies of sea ice (Eicken 2009) but are difficult to detect in satellite imagery or even on the ground. At Barrow and other Alaska coastal locations, however, many hunters and ice experts can accurately point to such old ice fragments embedded in the landfast ice over a stretch of tens of kilometers in the vicinity of town. An example of such a multiyear floe fragment is shown in Fig. 15.2. This site had been scouted from the air after Billy Adams, a seal hunter and ice expert from Barrow, had pointed it out to us. Seal hunters active in winter or whaling crews scouting potential sites for trails make note of such occurrences of piqaluyak. Typically, knowledge of even such temporary landmarks

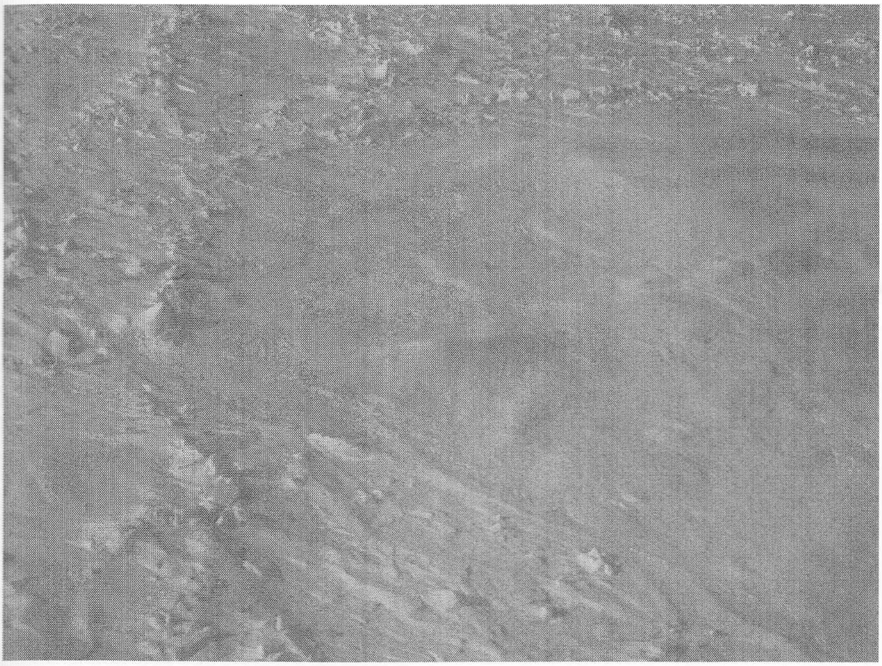

Fig. 15.2 Multiyear ice fragment (roughly 100 m wide, occupying the right-hand three-quarters of the image) in landfast sea ice north of Barrow, Alaska, in an aerial photograph taken on April 14, 2009. Note the rolling topography of hummocks in contrast with the rough, ridged, and rubbled surrounding ice. Navigating across the ice at ground level, only the most experienced of experts would be able to identify such smaller fragments of multiyear ice

is so accurate that they can be visited and talked about without needing to refer to a Global Positioning System (GPS) device.

A second example of overlap in Inupiaq ice use and scientific research builds on our early work in Barrow, when we wanted to install instruments in ice that had formed locally early in the year and remained stable throughout winter. Stability and early or late access to sea ice as a platform is naturally of great interest to local hunters. Hence, Kenneth Toovak, a Barrow ice expert who through years of working at the Naval Research Laboratory had also honed his skills as a mediator between Inupiaq and geophysical ice science, was able to advise us of a location that was protected by a shoal (not evident in charts of the area) and tended to form ice early in the year with little risk of later ice break-out. This site was chosen also for its proximity to the laboratory, even though another location further away had been pointed out as being more suitable because the ice there was more stable, less heterogeneous and formed in situ in the vast majority of years. Our first deployment of sensors at the closer site was into roughly 40 cm thick sea ice on November 11, 1999. In the following seasons, it became increasingly difficult to deploy before the end of the year because of lack of (stable) ice. Now, we typically deploy instruments in late January at the second, more distant location further up the coast that Mr. Toovak had recommended as the more appropriate site. He was right – we should have deployed our instruments at that location in the first year and would have had a longer, internally consistent time series for it.

Is This Normal? Inter-annual Variability and Guidance from LIK

Many field projects may only visit for a brief period during a single ice season. Under such circumstances, conclusions of more general validity about a specific process or ice characteristic can be affected by the occurrence of anomalous events or the prevalence of atypical conditions. To be sure, process studies ultimately are linked to a specific process and not a particular site or year. However, large, expensive programs such as the Study of the Heat Budget of the Arctic Ocean (SHEBA, Perovich et al. 1999), typically only run for a single field season. Representations (so-called parameterizations) of important processes in numerical models are then based on the suite of interrelated processes and phenomena sampled at that particularly site in the given year. Here, both direct personal experience in the form of local knowledge and more so the longer-term history embedded in indigenous knowledge can be of value in placing measurements in the context of the annual cycle and inter-annual variability.

The example of landfast ice protected by a shoal quoted above is also relevant here, since Mr. Toovak was able to recommend the sampling site based on his insight into recurring features. The absence of protective ridges and grounding ice in a particular year would hence have been identified as anomalous and not representative of long-term conditions. Another, intriguing and less clear-cut case relates to the question of potentially anomalous sediment entrainment into coastal sea ice. Sediment inclusions in sea ice can have a tremendous impact on optical or biogeochemical properties and sea ice microbial communities (Light et al. 1998; Gradinger et al. 2009). However, until late in the melt season, and even then, they are not always easy to detect or are ignored in studies focusing on other aspects of the ice cover that are nevertheless potentially impacted by their presence. Fienup-Riordan and Rearden (Chapter 13, this volume) highlight how Yupik elders in the Nelson Island region pay close attention to sediments in sea ice. Similarly, two hunters in the Norton Sound and Bering Strait region commented to the author unprompted on how they had noticed an increase in the amount of sediment-laden ice, an observation that matches indications from a study in the Chukchi and Beaufort Sea (Eicken et al. 2005). Such knowledge can be key in the selection of suitable study sites that need to either preclude or include the presence of sediments in the ice. It can also provide guidance on whether a particular sampling may have been impacted by the presence or absence of sediment-laden ice, a phenomenon difficult to observe through remote sensing and notoriously patchy in time and space, and hence ideally suited for sharing of insight by indigenous, local experts.

The Hidden Whales and the One-Hundred Year Ridge: Rare or Inconspicuous Phenomena and Events

One of the more powerful ways in which LIK can help scientists or engineers gain a new level of understanding is also quite accessible to those unfamiliar with LIK. Here, two classic examples will be discussed. Both relate to significant events that are difficult to observe either because they are uncommon or because they are concealed from the eyes of casual observers or scientists relying on inappropriate methodology.

The Bowhead whale has been hunted by Iñupiat and Yupik Eskimo for centuries. When the US National Marine Fisheries Service (NMFS) threatened to close the hunt because of low whale population estimates (less than 2,000 animals), indigenous experts disputed both these numbers and the methodology used to arrive at them (Albert 2004). A long-term research program supported and guided by the Iñupiat of the North Slope of Alaska demonstrated that indigenous knowledge had been correct, asserting that whales do not shy away from ice, which they can break at 30 cm thickness or more. Hence visual counts in open leads had missed many animals. Currently the stock is well above 10,000. The application of acoustic under-ice tracking techniques prompted by Inupiaq experts has now confirmed the presence of whales other than bowheads in the winter ice pack, attributed to changing ice and ocean conditions (Stafford et al. 2007).

The second example dates back to the first wave of oil and gas exploration along the North Slope of Alaska. The risk of so-called ice ride-up events presented a significant potential threat for coastal installations and infrastructure placed in shallow water on artificial islands. To allow engineers and regulators assess the hazards associated with such events and develop appropriate structural designs in order to minimize the risk to the installation, specific data on the frequency and severity of such ice ride-ups were required. With such rare but severe events as the equivalent of a storm of the century, and considering the near-complete lack of environmental engineering studies in the coastal environment at that time, this situation presented a substantial challenge. In a classic study, Lew Shapiro and Ron Metzner of the University of Alaska Fairbanks (UAF) and Kenneth Toovak of Barrow set out to interview local experts along the North Slope to record their knowledge of a range of important aspects of such events, most importantly their frequency of occurrence and severity (Shapiro and Metzner 1979). Due to the threat these events represented, they were able to compile an impressive and useful record that extended back well into the era prior to World War II. While the interviews, transcripts, and translations, residing at UAF, have proven useful in the context of the engineering design studies and hazard assessments, they represent a wealth of knowledge that remains largely untapped. In interpreting such interviews it is important to note that often the day of the year on which specific events occurred is recalled much more accurately – because it relates to the seasonal cycle of ice use – than the year itself, in particular if the event is several decades in the past (see also George et al. 2004).

Is It Safe to Go Out? Hazard Assessment and Emergency Response

The example discussed above has hinted at the potential value of LIK for engineering applications. The question of how LIK may relate to ice engineering and industrial activities in the north is one of the more difficult and important aspects of the topic at hand. Both LIK and engineering represent applied, use-driven knowledge systems. Hence it is reasonable to expect that transmission across the LIK-engineering interface would be more straightforward than exchange between climatologists and Iñupiat sea ice experts. Thus, industry commonly relies on Iñupiat guides to ensure safety of field parties and may include advice from recognized indigenous experts to arrive at major decisions concerning deployments in potentially unsafe areas. At the same time, concern by coastal communities over potential hazards associated with oil and gas development greatly complicates exchange between the different expert groups. This problem is exacerbated by the challenges encountered by indigenous experts in seeing their expertise represented in the decisions made by regulatory agencies and industry, in particular with respect to coastal and offshore development. The latter problem stems not necessarily from willful exclusion or dismissal of evidence based on LIK, but is often a result of the inability of the regulatory or scientific apparatus to come to terms with the nature of indigenous knowledge (e.g., Nadasdy 1999; Usher 2000).

Fig. 15.3 Aerial photograph from April 12, 2008, of a whaling trail (Jacob Adams crew, see also Figs. 9.11 and 9.12 in Chapter 9 by Druckenmiller et al. this volume) winding its way through pressure ridges in coastal landfast ice near Barrow, Alaska. The trail originates in the lower left corner of the image and can be seen in the center of the image as it traverses a stretch of level ice in a near-straight line. Note the band of clouds visible over the lead toward the top of the photograph

This complicated set of issues transcends the scope of this chapter and is examined in detail elsewhere (Eicken et al. 2010). However, the example of Iñupiat ice trails discussed in depth by Druckenmiller and others (Chapter 9, this volume) highlights the similarities between indigenous ice use and engineering applications. Thus, escape, evacuation, and rescue (EER) across landfast ice for coastal and offshore installations in Canada and the U.S. is a key aspect of their design and operation (Barker et al. 2006). EER also plays into safety requirements of Arctic tourism or shipping, both of which are on the rise. The expertise that enters into the operation of hunting camps and over-ice travel by the Inupiat is highly relevant in such a safety context (Eicken et al. 2010). Moreover, as pointed out by Huntington and others (2005), expertise on events that represent hazards or have threatened people in the past, like catastrophic ice break-outs (George et al. 2004; Chapter 9 by Druckenmiller et al. this volume), is particularly relevant to ice users and holders of LIK. Thus, trails placed on the ice to provide access to open water (Fig. 15.3) are specifically designed to also serve as efficient evacuation routes, hence embodying knowledge and skills relevant for EER applications as well.

Extending the Record

The discussion of local, indigenous ice experts' perspective on inter-annual variability and anomalous events leads us to the broader theme of LIK and environmental change on climatological time scales, covering several decades or more. This topic is distinct from the other two, since it requires more than the recollection of memorable events (such as the threat to life and property represented by an ice ride-up event) or the evaluation of weather and ice conditions in the current season relative to those a few years back. Moreover, objectivity and accuracy need to be considered carefully in collecting and interpreting information on constancy or change of climate variables transmitted through LIK. Cruikshank's (2005) study of oral history in the upper Yukon demonstrates just how difficult of a question this can be, partly since consideration of memories accumulated over such longtime intervals requires introspection and places greater emphasis on the human and spiritual components of indigenous knowledge (see also Huntington et al. 2009).

In the course of his analysis of historical records of weather and climate during the first International Polar Year 1882–1883, Kevin Wood has pointed to the value of indigenous expertise that allowed researchers to place their brief observation interval into the reference frame of the local indigenous community (Wood and Overland 2006). This is relevant as nineteenth century Arctic climate was emerging from the Little Ice Age. The latter period was characterized by lower temperatures and more severe ice conditions between the seventeenth and the nineteenth centuries, driven in part by insolation anomalies due to volcanism and sunspot activity (Overpeck et al. 1997). In his journal of 2 years (1852–1854) spent near the present town of Barrow, Rochfort Maguire refers to an Inupiaq ice expert's knowledge of more severe conditions, both with respect to weather and with respect to mammal harvests: "Erk-sin-ra our great authority, thinks they had worse seasons before the ship came" (Bockstoce 1988:365).

How accurate are such observations when examined from the perspective of geophysical or climatological research? As discussed by Nelson (1969), observations by individuals who are recognized in their community as sea ice experts are generally quite accurate, even when describing environmental phenomena that seem to contradict prevailing scientific thought, such as bowhead whales breaking 30 cm of ice. The continuous cycle of review and reaffirmation or revision of indigenous sea ice knowledge by the community, in particular elders and recognized experts, helps calibrate and provides accurate baselines for assessments of long-term change in ice conditions or local climate. Observations of gradual change are furthermore calibrated by keeping track of, e.g., changes in the treeline, permafrost, multiyear ice presence, and other longer-term integrators of subtle, but significant climate change that underscore and relate to sea ice change. While such observations of co-varying or concerted change are important in their own right (see below), they can provide a reference framework that allows indigenous experts to be cognizant of change that in the absence of instrumental records would otherwise go undetected (see Huntington 2000).

LIK and Detection of Subtle, Intertwined Patterns of Sea Ice and Environmental Change

The interaction between ice, ocean, and atmosphere results in sea ice distribution patterns that are frequently complicated and typically subject to great inter-annual variability. For example, the (then) record minimum in Arctic summer sea ice extent in 1995 (since the start of systematic satellite observations in 1979) was followed by a record maximum summer ice extent in 1996. In northern Alaska, the (then) record minimum Arctic summer ice extent of 2005 was followed by a summer in 2006 where lingering multiyear ice slowed seasonal ice retreat, fostering marine mammal harvests, and hampering summer shipping for the first time in well over a decade. Superimposed on this inter-annual variability is a trend toward decreasing summer ice extent. Local, indigenous ice experts are keenly aware of the predominance of inter-annual variability in ice conditions. The potential presence of cooling or warming trends on top of such pronounced variability may hence be examined in great detail before any LIK experts reach conclusions about observations of climate change. This is reflected in Shari Fox Gearheard's study of climate change in the Canadian Arctic in the late 1990s and early 2000s where different communities debated such questions of variability and change (Fox 2002). Similarly, on St. Lawrence Island comparison of present-day observations with records from the past indicates a more complicated picture than simple steady change (Chapter 4, Krupnik et al. this volume; Chapter 5 by Kapsch et al. this volume).

At the same time, indigenous knowledge and local expertise are in a unique position to assess even subtle changes and to separate patterns of variability from signals associated with longer-term change. This is a result of the holistic, comprehensive nature of observations that go along with a subsistence lifestyle in coastal Arctic communities. Thus, indigenous sea ice experts – and in contrast with, say, sea ice geophysicists – are not merely experts in one discipline engaging in a small set of observations. They have typically acquired expertise that spans a range of disciplines and phenomena through hunting and participating in other activities that are part of Arctic village life. In discussing climate change in the Canadian Arctic, Fox's (2002) collaborators considered a complex of 11 factors that included not just ice, but also observations of rain, insects, and birds. While LIK does not necessarily employ such observations to establish causal relationships, they allow indigenous experts to detect subtle, but coordinated change that spans a broader physical or biological system.

For St. Lawrence Island, Krupnik and co-workers (Chapter 4, this volume) refer to the utility of a range of "benchmarks" that can serve as important indicators in tracking changes in the seasonal cycle. Observations of how such indicators are linked to other physical or biological phenomena provide indigenous sea ice experts with a holistic perspective of change and variability relevant to the services they derive from their environment. Leonard Apangalook of Gambell identified roughly 30 such indicators in his log. His observations of open water in the ice pack during spring, a phenomenon referred to as *kelliighineq* (or *gelleghenak*), illustrate this point:

> April 27, 2007: West wind at 3 mph, 23F
>
> *Gelleghenak* about 3 miles offshore with pods of walrus hauled out on outer edge of ice pack. Yesterday (4/26) eight boats went out and sighted few [bowhead] whales southwest of Gambell moving north along with many beluga whales. Some loose ice packed in against shore preventing boats from getting out. Numerous walrus hauled out on ice. Mostly female walrus with juveniles hauled out. (L. Apangalook unpubl. observations)

Here, a recurring ice pattern that is closely monitored during each annual cycle and that depends on the interaction of atmosphere, sea ice, and ocean is linked to the distribution of three different species of marine mammals. Walrus and other animals like to congregate in such areas, and Mr. Apangalook provides further detail on the gender and age of walrus encountered as well as specifics on the ice conditions relevant to walrus and hunters from Gambell. Such richness of information and the identification of key processes or linkages that co-vary with this pattern cannot be extracted readily from remote sensing of ice conditions or oceanographic measurements. Hence, detection of changes in the seasonality of these patterns by indigenous communities can be a powerful indicator of systemic change that eludes disciplinary scientific approaches (see also Huntington 2000, and Krupnik et al. Chapter 4, this volume).

Adaptation to Climate Variability and Change

Indigenous sea ice knowledge derives from centuries of sea ice use at a particular location, and thus embeds in some form expertise in adaptation to a variable or potentially changing environment (Nelson 1969; Krupnik and Jolly 2002; Laidler et al. 2009). Given the magnitude of recent changes observed in Arctic sea ice and coastal environments (Rachold et al. 2000; Serreze et al. 2007), scientific research on and development of strategies for effective adaptation to a changing physical, socio-economic, and geopolitical environment is of increasing importance (e.g., Berkes 2002; Adger et al. 2007). Here, local, indigenous sea ice use and the associated body of expertise have much to offer, in particular at a time where appropriate response strategies are very much under discussion and a theoretical framework is only slowly evolving.

Indigenous communities, though hard hit by some of the negative impacts of climate change, in particular by those limiting access to sea ice, are quick to adapt. They are responding by relying on different technologies or through modifications of their lifestyle. The rapidity of such adaptation, evident, e.g., in some of the shifts in hunting patterns or hunting methodology (George et al. 2004; Chapter 4 by Krupnik et al. this volume; Chapter 5 by Kapsch et al. this volume), may be due in part to the ability of indigenous environmental experts to keep a finger on the pulse of variability and change. Moreover, LIK is very much both a fundamental and an applied knowledge, thus placing its holders in a uniquely qualified position to respond to change (see Eicken et al. 2009). This opens the door for rich exchange of information and synthesis of indigenous and western scientific approaches to increase community resilience in the face of change and improve people's ability to respond to a broader range of challenges associated with a rapid transition.

Building on the work by Druckenmiller and others (Chapter 9, this volume), the photograph showing an Iñupiat whaling trail on landfast sea ice (Fig. 15.3) illustrates how the combination of LIK and geophysics can benefit both scientists and a range of sea ice users. Trail routing is based on a comprehensive assessment of a range of factors that determine the ease of travel, safety, stability, and persistence of the trail throughout the season. These factors, as pointed out by Druckenmiller and others, may be related to key geophysical variables such as the thickness distribution, morphology, and physical properties of the ice. Repeat annual surveys of the trail systems thus represent a form of highly integrated information that may serve as an indicator of both the nature of environmental change and the indigenous community's response to such change. Building on the concept of benchmarks or indicators discussed by Krupnik and others (Chapter 4, this volume), I postulate that such use-based indicators represent a higher level of integration that may help sea ice science in grappling with the difficult question of how to move from observations of climate change to an understanding of the underlying processes and the development of response strategies.

Indigenous ice expertise has something else to offer that is often lacking in large-scale studies of climate variability and change: The detailed understanding of how large-scale processes work in concert to produce impacts at the local scale. Returning to Fig. 15.1 and Winton Weyapuk's observations of ice formation in the coastal environment, such records of fall freeze-up can help validate and improve remote-sensing approaches, which may not necessarily capture the relevant processes or phenomena. Moreover, such local observations can also help with downscaling from observations or projections of climate variability and change, typically registered at a much coarser scale (Fig. 15.1).

LIK and the Development of Research Questions and Hypotheses

Those willing to engage with local, indigenous ice experts from the very outset of a scientific study can gain much from having these experts and the knowledge shared by them and their community define or inform the development of research questions and hypotheses. As different scientific programs and nations focus on the development of an Arctic Observing Network, much emphasis is placed on not merely satisfying the interests of the researchers relying on such a system to answer fundamental science questions, but to consider the information needs of those impacted by or in some way linked to Arctic change (e.g., Committee on Designing an Arctic Observing Network 2006; Eicken et al. 2009). These goals can be achieved through the joint development of research questions and hypotheses by sea ice users and sea ice scientists. While such approaches are only in their infancy, past experience suggests that they hold much promise. Here, the classic case of building on Inupiaq traditional knowledge of the bowhead whale's use of the ice environment to develop and test novel (at least to western science) hypotheses that led to a revision of western scientific thought is a good example (Albert 2004). Along similar lines, George et al. (2004) explored different Inupiaq and western science postulates explaining the causes of large landfast ice break-out events. Carmack and Macdonald (2008) adapted their hydrographic measurement program to explore local environmental knowledge in the Mackenzie Delta region from a geophysical perspective. However, as pointed out by indigenous experts (Gearheard et al. 2006), often "it's not that simple." Rigorous and thorough exchange across the interface between LIK and the biological–geophysical sciences is as challenging, if not more, than complex, highly involved interdisciplinary research and may not necessarily yield nuggets of insight that can be directly translated into research questions or hypotheses. Here, perseverance and innovative approaches are needed. This book highlights such perseverance that bears the fruits of substantial exchange between different knowledge systems.

Conclusions

In concluding this survey of ways sea ice science can learn from local, indigenous sea ice users, I hope at least some benefits have become clear. This contribution has glossed over some of the challenges that may await those who are willing to explore the interface between LIK and western sea ice science.

While written about anthropological work with indigenous historians, I consider the following summary by Ernest S. Burch, Jr., as highly relevant to the issues discussed above:

> Thirty years ago, my view was that all narrative history which challenged my notions of common sense should be regarded as false until confirmed as true. Unfortunately, what

> originally passed for common sense proved to be little more than nonsense. In 1991, I would restate my position as follows: information that is provided by people whom the Iñupiat consider competent historians should be regarded as true until proven false, no matter how extraordinary what they say may first appear. [. . .]
>
> I include the caveat "whom the Natives consider competent historians" because there are incompetents and charlatans, as well as genuine experts, among Alaska Native peoples, just as there are among all peoples. The Natives know who is which, although, out of politeness, they generally listen to every elder who expounds on legendary or historical matters, regardless of the truth value of that person's remarks. In any event, oral accounts, like written accounts, must be subjected to rigorous historiographic evaluation and critical analysis. (Burch 1991:13)

Replace "historian" with "ice expert" in this quote and there are arguably few other summaries of the issue that make the pertinent points as succinctly and eloquently. An important issue implicit in Burch's remarks and highly relevant for audiences in the physical and biological sciences is that work at the interface between LIK and western science is most effective and rewarding in a truly interdisciplinary setting that pairs the natural sciences with the social sciences in order to open up an unobstructed channel for communication and transmission between knowledge systems. Cruikshank's (2005) work – building on the highly relevant study of glacier history in the Yukon – illustrates just how complex and sophisticated of an endeavor is required to achieve such goals, but also suggests that similar work in the realm of oral histories of sea ice holds much promise.

This contribution has been concerned mostly with *what* sea ice science can learn from sea ice users, less so with *how* such knowledge can be transmitted. Huntington and others (2009) have recently made the methodology of community-based ice observations more accessible to a broader audience. Here, I wish to conclude with a few remarks on how to promote two-way transmission of local, indigenous knowledge and physical–biological expertise. An effective way to progress is to bring together recognized LIK and sea ice geophysics or biology experts in a teaching and learning environment to share their expertise with students. Field courses, typically an integral part of many polar geophysics and biology curricula, can play a major role by including indigenous ice experts among the instructors and allowing them to share their knowledge in a culturally appropriate setting. Figure 15.4 highlights the role of experts, such as Richard Glenn from Barrow, Alaska, who are versed in the language, ways, and methodology of both indigenous and western sea ice science. The openness of students toward new approaches and their ability to side-step many of the traps that have plagued transmission of relevant knowledge across cultural divides in the past should not be underestimated.

The example of Richard Glenn also points to the important role of mediators or experts versed in both knowledge systems for transmission across a cultural interface. One of the most effective means of enhancing the role of such mediators is to entrain indigenous students into academia, allowing them to develop skills that are relevant to both the LIK and western science spheres. A promising arena to entrain local talent and promote exchange and learning is the nascent Arctic Observing Network, with its component projects of community-based observations. Several chapters in this book highlight the benefits gained from observations made within

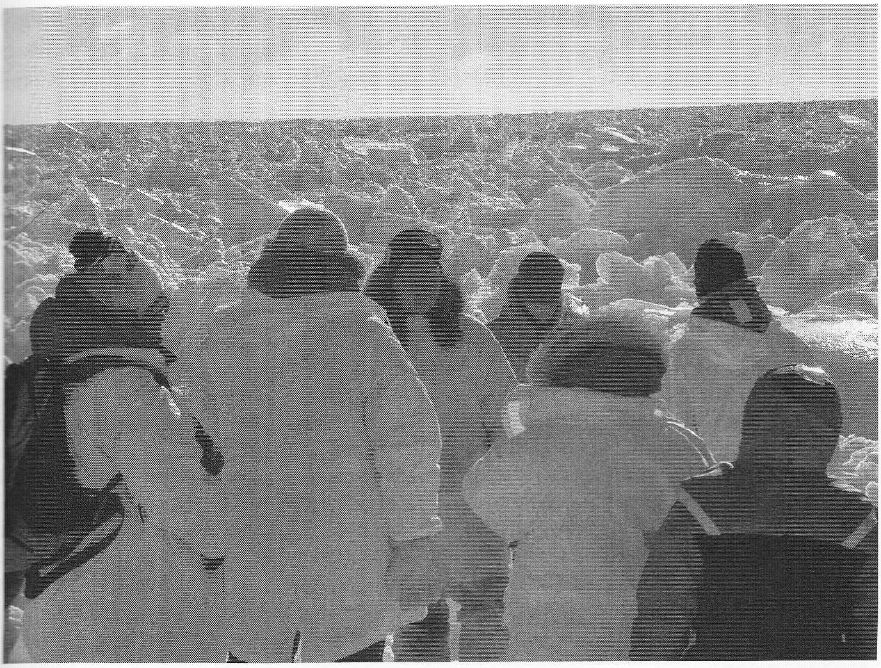

Fig. 15.4 Richard Glenn (*center*), Inupiaq sea ice expert and academically trained geoscientist, teaching students in an international sea ice field course held at Barrow in May 2004

the community by recognized experts as well as the younger generation (see also Huntington et al. 2009). While the community-based components of these studies are increasingly robust and effective, further work is needed to improve the integration of such projects into the overall network in a meaningful way.

A concept and practical approach that holds much promise in weaving together these different activities and perspectives is to foster the development of the so-called Communities of Practice. Wenger and others (2002) have highlighted the importance of such informal groups of experts sharing a common interest or passion in advancing both theoretical understanding and practical progress with respect to pressing, difficult problems. A similar approach has been identified as highly promising in fostering exchange between engineers, regulators, and indigenous environmental experts in the context of offshore and coastal oil and gas development (Eicken et al. 2010). The challenges facing the establishment of such Communities of Practice are mostly geographic and cultural separation (both indigenous vs. western and academic vs. non-academic cultures). However, the field courses referred to above, community-based ice observations (Huntington et al. 2009) and efforts such as the Barrow Sea Ice Symposium that brought together a diverse group of sea ice experts (Norton 2002) have demonstrated their promise and potential value.

A highly promising topic area that arguably has already benefited greatly from the emergence of Communities of Practice is the problem of coastal dynamics and coastal retreat. As highlighted above, a range of geological, geophysical, biologic, and human processes conjoin along the Arctic coastline. With enhanced rates of coastal retreat furthered by declining sea ice and thawing permafrost, indigenous expertise, with a holistic perspective on coastal dynamics that still eludes academic and engineering approaches, has much to offer. Efforts such as the relocation of the Alaska coastal community of Newtok where native elders, young community leaders, scientists, and engineers from academia and state and federal agencies and countless others are taking a pragmatic, hands-on approach to the problem hold significant promise for a new era in Arctic fundamental and applied research.

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