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Contributions of traditional knowledge to understanding climate change in the Canadian Arctic

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ABSTRACT. Despite much scientific research, a considerable amount of uncertainty exists concerning the rate and extent of climate change in the Arctic, and how change will affect regional climatic processes and northern ecosystems. Can an expanded scope of knowledge and inquiry augment understandings of climate change in the north? The extensive use of the land and the coastal ocean in Inuit communities provides a unique source of local environmental expertise that is guided by generations of experience. Environmental change associated with variations in weather and climate has not gone unnoticed by communities that are experiencing change firsthand. Little research has been done to explore the contributions of traditional knowledge to climate-change research. Based in part on a collaborative research project in Sachs Harbour, western Canadian Arctic, this paper discusses five areas in which traditional knowledge may complement scientific approaches to understanding climate change in the Canadian Arctic. These are the use of traditional knowledge as local-scale expertise; as a source of climate history and baseline data; in formulating research questions and hypotheses; as insight into impacts and adaptation in Arctic communities; and for long-term, community-based monitoring. These five areas of potential convergence provide a conceptual framework for bridging the gap between traditional knowledge and western science, in the context of climate-change research.

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Introduction

There is considerable evidence of climate change, often linked to increases in atmospheric carbon dioxide. According to some estimates, this increase may cause a warming at the Earth's surface by 1 to 3.5°C during the next century (Intergovernmental Panel on Climate Change 1998). As a long-term trend, climate change is expected to have a significant impact on both the biophysical landscape of the Earth and on human life. The impacts of future warming are expected to be felt earliest and most keenly in the polar latitudes (Maxwell 1997). Many climate-change forecasts, using global circulation models (GCMs), suggest that regions of northwest Canada and Alaska will experience above average increases (Cohen 1997; Maxwell 1997; Kattenberg and others 1996).

Environmental changes observed in the Arctic in the last decade, such as melting sea ice (Rothrock and others 1999; Johannessen and others 1999; Maslanik and others 1999; Vinnikov and others 1999), rising sea levels and coastal erosion (Shaw and others 1998), permafrost thaw (Woo and others 1992; Weller and Lange 1999), and the range extension of some fish species (Babaluk and others 2000) suggest that effects of a change in climate are already recognizable. However, considerable uncertainty remains concerning the rate and extent of change, and the impact on northern ecosystems. The Arctic, for many, is the 'canary' that indicates the early warning signs of global change. However, climate science in the north is complicated by insufficient scientific knowledge and understanding of physical and ecological processes in the Arctic, and by the lack of historical baseline data against which to measure change.

Many communities in the Canadian Arctic are experiencing environmental changes that differ from normal variability. Observed differences in the seasonal extent and distribution of sea ice, fish and wildlife abundance and health, permafrost thaw, and soil erosion are considered to be without precedent (Kuptana 1996; Fox 2000; Riedlinger 2000; Johnson 1999). Community assessments of change are based on cumulative knowledge of local trends, patterns, and processes, derived from generations of reliance on the land. Can these community assessments, based on local observations and traditional knowledge, enrich and expand understandings of Arctic climate change?

This paper explores how traditional knowledge in northern communities can complement western, science-based understandings of climate and climate change in the Arctic. Traditional knowledge is defined as 'a cumulative body of knowledge, practice and belief, evolving by adaptive processes and handed down through generations by cultural transmission' (Berkes 1999: 8). The paper focuses on five areas of convergence that may facilitate the use of traditional knowledge and western science as distinctive, yet complementary, sources of knowledge in the north. The ability of Inuit knowledge to address the complexities of the Arctic environment at spatial and temporal scales that are currently under-represented in climate-change research will also be examined. The five areas of convergence are the use of traditional knowledge

1. as local-scale expertise;

2. as a source of climate history and baseline data;
3. in formulating research questions and hypotheses;
4. for insight into impacts and adaptation in Arctic communities; and
5. in long-term, community-based monitoring.

The paper is partly based on research conducted in 1999–2000 on Inuvialuit knowledge of climate-related change in the community of Sachs Harbour, Banks Island, in the Canadian western Arctic. The research was conducted as part of a larger, collaborative project between Sachs Harbour and the International Institute for Sustainable Development (IISD) on Inuvialuit perspectives on climate change (Riedlinger 1999; Ford 2000).

Background: traditional knowledge in climate-change research

Contributions of traditional knowledge have been well-documented in several areas, including biological information and ecological insights, resource management, protected areas, biodiversity conservation, environmental assessment, social development, and environmental ethics (Berkes 1999). The use of traditional knowledge is increasingly recognized as a promising means of helping to understand the Arctic environment (Duerden and Kuhn 1998). However, very little research has been done to explore the value of traditional knowledge related to climate and climate-change research.

One of the earliest examples of traditional knowledge in climate research is Spink's (1969) work showing the value of Inuit oral history in corroborating evidence for isostatic rebound and sea-level change. Cruikshank's (1984) research in the Yukon identified oral history as providing insights on past climate. The benefits of considering traditional knowledge to understand climate change has been suggested by several authors (Kassi 1993; Fast and Berkes 1998; Bielawski 1995, 1997; Chiotti 1998; Cohen 1997; Ferguson 1997; Ingold and Kurttila 2000; Maxwell 1997). But there are relatively few studies specifically on Inuit knowledge of climate change. Fox's (2000) research in the eastern Arctic demonstrated that Inuit possessed an understanding of climate change, but concluded that further research was needed before this knowledge could be integrated into climate-change assessments. The Tuktu and Nogak project in Nunavut has documented some Inuit ecological knowledge of climate-related change in relation to caribou and calving grounds (Thorpe 2000).

Some of the first attempts to understand environmental change through traditional knowledge come from the Hudson Bay Bioregion project (McDonald and others 1997) and the Northern River Basins Study (Bill and others 1996). These community-based projects documented environmental change due to large-scale developments and incidentally addressed climate-related change. They demonstrated that Aboriginal elders were able to distinguish subtle patterns, cycles, and changes in ecosystem structure (Bill and others 1996), and that accumulated knowledge of the land and environmental indicators gave Inuit the ability to interpret and understand seasonal-change processes (McDonald and others 1997). The Mackenzie Basin Impact Study was only able to skim the surface of traditional knowledge, but noted the value of such knowledge in climate-change research (Cohen 1997).

Thus, there is evidence that traditional knowledge can enhance the understanding of climate change in the Arctic. However, there are no conceptual frameworks on how to bridge the gap between Inuit knowledge and western science. Looking to Inuit perspectives on climate change requires clear identification of specific research areas that can facilitate the use of both traditional knowledge and scientific approaches. To expand the scope of conventional climate-change research to include traditional knowledge, the authors propose five areas of potential convergence to link traditional knowledge with western science (Table 1).

Five areas of convergence

Local-scale expertise

Combining the knowledge and skills of western science with local Inuit expertise can translate global processes such as climate change into local-scale understandings of potential impacts. Forecasts generated by climate and other models, while key to predicting change, typically simulate phenomena at coarse spatial and temporal scales, and thus are limited in their capacity to explain change at local or regional scales. Concepts such as climate change and global warming are nebulous until they are considered at scales at which the impacts are most likely felt (Jacobs and Bell 1998). In fact, predictions will be of most value to decision-makers on a regional basis (Intergovernmental Panel on Climate Change 1998).

As Usher (2000: 187) pointed out, traditional knowledge can contribute to a fuller understanding of local environmental processes 'at a finer and more detailed geographical scale than conventional scientific knowledge can offer...because it deals with outcomes and prediction: what people think will happen and why.' Traditional knowledge is what Harvey (1984) called 'applied peoples' geography': local geographical knowledge describing the world and providing a basis for appropriate decision-making. 'Knowledge of the land constitutes intense, highly functional local geographies' (Duerden and Kuhn 1998: 34).

The ecological and environmental expertise found in Inuit communities can highlight parameters rarely measured by scientists and help make sense of scientific findings by placing them in a local context. Such expertise can also 'groundtruth' scientific predictions and provide supporting evidence for coarse-scaled models. Traditional knowledge and local observation can elucidate complex feedback linkages between climate and the biophysical environment that are variable in time and space, and thus are difficult to quantify. Given the expected increases in regional variability associated with climate change, local observation and expertise are important components of understanding change.

Table 1. Five convergence areas that can facilitate the use of traditional knowledge and western science, in the context of Arctic climate-change research.

Local-scale expertise	The integrity of traditional knowledge at the local scale has been promoted in discussions of traditional knowledge in the north. Climate change will be first noticeable through biophysical changes in sea ice, wildlife, permafrost, and weather. These changes will not go unnoticed at the local scale in Inuit communities.
Climate history	Traditional knowledge can provide insight into past climate variability, providing an essential baseline against which to compare change. Climate history is embedded in Inuit history of wildlife populations, travels, extreme events, and harvesting records.
Research hypotheses	Traditional knowledge can contribute to the process of formulating scientific hypotheses as another way of knowing and understanding the environment. Collaboration at the initial stage of research expands the scope of inquiry and establishes a role for communities in research planning.
Community adaptation	Traditional knowledge lends insight into adaptations to changes, explaining them in the context of livelihoods and community life. How are communities responding to change? What are the social, economic, and cultural limits to adaptation in northern communities?
Community-based monitoring	Traditional knowledge reflects a cumulative system of environmental monitoring and observation. Monitoring projects have the potential to bridge the gap between science and traditional knowledge by providing a collaborative process.

One example of this local expertise is evidenced in the description of sea-ice changes by residents of Sachs Harbour, a coastal community on the Beaufort Sea. Changes related to sea ice are the most noticeable changes that the community has witnessed in recent years. Community members describe changes through a complex of interacting variables — including water temperature, currents, ice thickness, ice colour, ice phenology, pressure-ridge and lead distribution, hunting and travelling safety, polar-bear and seal distributions, animal health, and wind patterns — comparing the past and present. These descriptions capture aspects of localized change such as the increased timing and *rate* of break-up in the spring, or the intensified east winds in the fall that push ice floes away from the community and result in an absence of multiyear ice around which new ice can form. This, in turn, forces hunters to travel on new or first-year ice. Whereas weather stations and satellites provide data on wind velocity, temperature, precipitation, and ice-cover data, scientists are still unable to predict ice distribution and condition at a given location, such as Sachs Harbour, in early summer. This is because, as community members point out, ice distribution depends on the relationship between wind direction, velocity, currents, temperature, and other environmental variables.

Changes in climate are recorded; changes in the weather are experienced by local people (Ingold and Kurttila 2000). Whereas climate is an abstract scientific concept, weather is time- and place-specific, a phenomenon experienced first-hand. For example, the Inuvialuktun (western Canadian Arctic dialect) term used in Sachs Harbour, *sila*, means 'weather,' and there is no term to distinguish between weather and climate. Table 2 summarizes several examples of locally experienced changes, as described by the community of Sachs Harbour.

Time- and place-specific empirical observations, such as those in Table 2, can help explain larger-scale phenomena. For example, the scientific evidence regarding the freshening of the Arctic Ocean (a thicker low-salinity layer in the surface waters) is inconclusive (for example, Dickson 1999). However, some Sachs Harbour hunters have noticed that seals are sinking to a deeper water level at the floe edge, a phenomenon attributed to a lowered fat content and/or the greater freshening of the ocean water from melting sea ice. In late winter, seals tend to be relatively low in fat and the spring melt results in low-density surface waters, hence seals are less buoyant and tend to sink deeper (possibly to the depth of the halocline, where the salinity changes sharply). The fact that seals in recent years are sinking deeper may be local evidence that the low-salinity surface layer has become thicker.

Climate history and baseline data

A second convergence area for the use of traditional knowledge and scientific approaches together, concerns change over historic time. Climate history of the Arctic is central to understanding future (or present) climate change. History of Arctic peoples and their activities is partly a product of past climatic change. The arrival of the Thule, ancestors of present-day Inuit, in the Canadian Arctic 1000 years ago, is believed to have been related to the expansion of the environmental zone to which the culture's maritime hunting technology was adapted (McGhee 1970).

Establishing a historical record of change utilizes a variety of scientific and non-scientific sources of information, including instrumental (for example, meteorological), documentary (Hudson's Bay Company records, expeditions), and proxy data (ice-core samples). As information sources, they can be applied with varying success to both the physical and human context of climate-change research. However, the chronological scope of data for establishing a climate record in the Canadian

Table 2. Examples of recent local environmental change related to climate, as described by Inuvialuit in Sachs Harbour, western Arctic.

Phenomena	Observed change
Sea ice	Less/no multiyear ice in July and August; more open water (and 'rougher' water) More ice movement than before Not able to see the permanent pack ice to the west Ice breaks up earlier and freezes up later Rate of ice break-up has increased Annual ice in harbour is weaker, thinner (not safe) Less and thinner landfast ice (shore ice) Changes in distribution and extent of local pressure ridges Leads (openings in ice) farther away from shore Ice pans no longer push up on shore Open water in winter is closer than before Changes in ice colour and texture
Permafrost	Land subsiding in some places Increasing slumping and landslides, both inland and along the coast Exposed ground ice (ice lenses) on hillsides Increased depth of active layer in spring Increased rate of melt in spring Water and 'ice pebbles' in the ground rather than ice in some places Increased puddles, ponds, water in pools on the flat land Pingos decreasing in size More mud on the land
Changing seasons	Longer, warmer summers More rain and wind in the summer Melts faster in the spring than it used to Spring comes earlier now than it used to Shorter, warmer winters August is warm month now; used to be 'cooling off month' Autumn comes later now than before Seasonal change is more unpredictable now
Fish and wildlife	Two species of Pacific salmon caught near the community Increased numbers of *Coregonus sardinella* (least cisco) Fewer polar bears in area because of less ice Increasing occurrence of 'skinny' seal pups at spring break-up Observations of robins; previously unknown small birds Increased forage availability for caribou and muskox Changes to timing of intra-island caribou migration
Weather	More rain in the fall; rain that should have been snow Different kind of snow, fewer rough drifts Longer duration of 'hot' days, now a whole week rather than 1–2 days Thunder and lightning – none seen before Weather more unpredictable Changes in wind velocity and direction; more intense wind storms

Arctic is limited. The systematic collection of meteorological data for the Canadian Arctic islands did not begin until 1947 (Maxwell 1980); the weather station at Sachs Harbour was not established until 1956. Prior to 1947, isolated climatic studies for the Arctic were based on historical documents and fragmentary short-term records (Maxwell 1980). Proxy sources such as ice cores and lake-sediment records can be used to reconstruct past climate events (Overpeck and others 1997), but the coarse spatial resolution makes it best suited to time scales greater than the past 100 years. McGhee (1981) used archaeological evidence to construct a picture of Arctic climate change, correlated with human occupation for the past 5000 years. Is traditional knowledge another source of climate history, providing important baseline data against which to compare change?

Traditional knowledge, through cumulative experience and oral history, provides insights into past climate variability and fluctuation; such knowledge is embedded in Inuit history of wildlife populations, travels, unusual events, harvesting records, and migrations. For example, many elders in Sachs Harbour describe extreme ice years in their stories of travelling from Banks Island to the mainland when they were trappers. Years such as 1933 are described as cold years when the ice never left and they could not travel by schooner. This kind of knowledge can

complement data gathered from instrumental, documentary, and proxy sources used to piece together climate history, and provides a more comprehensive baseline against which change can be established.

Traditional knowledge and oral tradition are validated by Inuit historical and current occupancy of the north (Freeman 1976; Weinstein 1996). In Sachs Harbour, living memory extends back to the 1920s. However, interviews conducted in the community consistently include oral history, elements of knowledge and stories passed on by parents and grandparents. The history and land use of Banks Island extends beyond the mid-1950s, when the permanent settlement was established. Inuit from the area of Victoria Island historically travelled back and forth to *Ikaahuk* – the crossing place (S. Kuptana, Sachs Harbour). Inuvialuit from the mainland began coming to the island in the 1920s to trap white fox, spending fall and winter on the island and returning to the mainland after break-up of sea ice. This history provides a context for change, as depicted in the following oral descriptions of the 'long ago' offered by elders.

> In the early days, we used to have a schooner and we used to go back and forth every summer [to the mainland]. We would spent the winter here and go back every summer. But we always can't get out of here until around August. We tried to get out of here in July and one time we had to go by Holman Island just to get to mainland. Now in July it is clear across. (A. Carpenter, Sachs Harbour, NWT)
>
> My mom said that a long, long time ago before I was born, there always used to be such good weather on Banks Island — when they used to live on Victoria Island. Those *angatkuq* (shaman), they used to go and get good weather from Banks Island to [bring to] Victoria Island. A long, long time ago before I was born my mom used to tell me this. Now we blame the *angatkuq* for taking our good weather away! That is how my mom used to talk and it's true. Banks Island used to be really good weather long ago. (L. Wolki, Sachs Harbour, NWT)
>
> When there is no old ice, there is not very much seals too. They [seals] travel on the big old ice. Long ago when the old ice used to come in, we head for the big ice out there. We would just stop and seals would start coming. Nowadays it is not like that anymore. Those small ice — there is hardly any seals on them. They are too small. It is the warmer summers — I think those thin ice melted right down. That is why there is hardly any more ice. There used to be old ice coming from the north all the time, and when it freezes up with old ice, there seems to be more bears all the time. When it [the old ice] has leads, around March, boy there are lots of bears when you go out. I used to feel safe when I would camp on the old ice. Just like islands, that old ice. Good for tea! The old ice, it always opens up too, and there are all kinds of seals. Because that old ice is smooth, good for seal holes. (G. Wolki, Sachs Harbour, NWT)

As Usher (2000) described, the time depth of Inuit knowledge provides a diachronic perspective, creating a baseline for expected deviations from 'normal' conditions. This baseline is fluid and evolving, rather than static. Elders in Sachs Harbour state that 'long ago the weather was not the same as it is now.' They describe it in terms of seasons; that the 'seasons are getting crazy now.' There has always been change; the timing of seasons, freeze-up, break-up, and wildlife migrations have always fluctuated. The difference in recent years, however, is that changes are beyond the range of expected variability and fluctuation. Many people say, 'things are happening at the wrong time now.' As one elder described, 'there used to be hardly any summer [here], and in the winter you needed two parkas; two caribou skins back to back' (S. Kuptana, Sachs Harbour).

Researchers have shown the accuracy, consistency, and precision of Inuit historical recall with respect to studies of caribou populations in the Arctic (Ferguson and Messier 1997; Ferguson and others 1998), and land use and occupancy (Arima 1976). Inuit knowledge is a valuable source of climate history for many parts of the Canadian Arctic, providing a record for the north that in some cases may exceed that of other sources, particularly during the last century.

Formulating research questions and hypotheses

A third convergence area is the contribution of traditional knowledge to the process of formulating research questions and hypotheses. The method of empirical science is hypothetico-deductive; constructing hypotheses and testing them by observation and experience (Popper 1959; Peters 1991). Even if it were known *how* to measure climate change in the Arctic, first it would need to be known what to measure. Traditional knowledge may expand the range of concepts and possibilities upon which to base research questions and formulate hypotheses.

Knowledge systems, or ways of knowing the world, provide the boundaries that either constrain or enhance the process of asking questions, observing, testing, and understanding. Formulating hypotheses is considered the most important part of the research process in determining the research that follows. It can also be the most subjective step in the research process. Researchers formulate hypotheses based on the range of questions of which they are aware (Keddy 1989). The kinds of questions asked are a function of the concepts available; they originate within a culturally specific picture of the world. The western scientific tradition holds a particular concept of the world, which is usually considered 'the correct' picture of the world (Feyerabend 1987).

However, limiting research to one 'correct' view of the world may constrain the understanding of complex environmental phenomena such as global change. Both Inuit and scientists choose what to observe over time, whether based on the need to travel safely and hunt successfully, or the need to study those phenomena deemed relevant for specific research goals. Inuit knowledge can

Table 3. Hypotheses generated from interviews with community members in Sachs Harbour.

Hypothesis	Explanation
Observed changes are beyond the natural range of variation.	People describe trends, such as earlier ice break-up and warmer temperatures, but emphasize the importance of 'variability.' Recently observed changes are considered without precedent and beyond natural variability.
Observed changes result in increased unpredictability in environmental phenomena.	Related to increased variability, Inuvialuit notice that it has become more difficult to predict or anticipate weather, seasons, ice conditions, game availability, or the timing of animal migrations.
Increased variability and unpredictability are most noticeable in the spring and fall months.	Changes are observed in winter and summer, but the most noticeable changes occur in the transition months.
Rare and extreme weather phenomena are becoming more frequent.	What used to be considered rare and isolated events such as ice-free summers in ocean waters near Sachs Harbour, extended hot spells in summer and thunder storms, people note, may no longer be anomalies.

contribute to the process of formulating scientific hypotheses as an alternative way of understanding the environment. Time-tested observations can expand the scope of inquiry through insight into ecological relationships and provide a starting point for research (Berkes and Folke 1998; Thorpe 2000).

A good example of how Inuit observations can lead to scientific questions comes from the Hudson Bay Bioregion project, in which Sanikiluaq hunters reported major changes in currents and regional sea-ice conditions (McDonald and others 1997). They related these changes to increases in winterkill of common eiders (*Somateria mollissima*). The hunters' observations were later corroborated in scientific studies (Robertson and Gilchrist 1998). A second example is Ferguson's (1997) research on caribou migrations and severe weather events. Ferguson found that in many cases, Inuit knowledge of caribou ecology and subsequent hypotheses relating to caribou density, movement, and forage resources provided a better fit than did conventional science in both explaining and predicting caribou behaviour related to adverse weather conditions.

The contribution of traditional knowledge to hypothesis development is important in bridging the gap between community concerns and research efforts. Communities that are directly experiencing change can better identify research priorities. The Sachs Harbour Community Conservation Plan (Anonymous 1992) identifies two species, *ugyuk* (*Erignathus barbatus*, bearded seal) and *natchiq* (*Phoca hispida*, ringed seal), as requiring research into the occurrence of 'skinny' animals on spring sea ice. The community observed the increased occurrence of abandoned seal pups related to early break-up and general lack of sea ice. These kinds of observations provide community-based directions to formulate research questions. Table 3 provides additional hypotheses from Sachs Harbour. Such hypotheses articulate a community-based assessment of climate change.

Increasingly, Inuit communities are questioning conventional research processes and demanding more involvement at the design stage and the implementation of research that affects their communities and livelihoods. Arctic communities, as the 'canaries' of global climate change, are already seeing the effects of such change. Collaboration between communities and scientists at the initial stage of research expands the scope of inquiry and also ensures meaningful involvement of communities in research planning.

Impacts and adaptations: how Inuit see change

Human dimensions of change, including planning for and understanding human adaptation, is an important aspect of climate-change research, but is poorly understood (Intergovernmental Panel on Climate Change 1995; Maxwell 1997; Smithers and Smit 1997). Including traditional knowledge in adaptation research can establish the changes that members of the communities see, how they perceive them, and how they explain these changes in the context of livelihoods.

How does a temperature increase of 1 to 3.5°C during the next 100 years (Intergovernmental Panel on Climate Change 1998) translate at the community level in the western Arctic? The geographical location and resource dependency of Arctic communities means that small increases in global temperatures will be more noticeable than in other regions. Humans and the environment are closely linked in the Arctic (Roots 1994), and societies dependent on Arctic resources are more sensitive to environmental change (Krupnik 1993). Northern livelihoods are resource-based, and hunting and fishing remain important aspects of social and economic life (for example, Fabijan 1998).

The relationship between Inuit and the Arctic environment is closely tied to cycles of seasonal activity and resource use. To the Inuit, environmental change is an expected part of the daily life and a capacity to adapt to

change is a part of livelihood systems. However, unexpected or extreme events and unusual fluctuations create hardships because they interfere with the ability of people to access the various resources on the land, and make resource availability itself less predictable (Fast and Berkes 1998). In some cases, early freeze-up of the sea ice has shortened the walrus-hunting season in some communities, causing meat supplies to run low (Fox 1998). Increased coastal erosion in places such as Tuktoyaktuk in the western Canadian Arctic risk making parts of the community uninhabitable (Shaw and others 1998).

Climate change, at rates outside of the historical experience, may also make some aspects of traditional knowledge unreliable (Fast and Berkes 1998). For example, Inuvialuit elders in Sachs Harbour say, 'long ago when it was going to be a big storm, there was a sign, and then the hunters would prepare for the storm. Now it is increasingly difficult to predict the weather' (P. Esau, Sachs Harbour). Such signs usually include physical changes, such as the appearance of clouds on the horizon, and subtle changes in the temperature or wind. Fox (1998) commented on the role of 'reading' the Sun and Moon in predicting weather among eastern Arctic Inuit. Such environmental cues become difficult to interpret under conditions of climate change.

At the 1998 Circle of Wisdom Native Peoples/Native Homelands climate-change workshop, a Siberian Yup'ik elder described the change as 'The Earth is so fast now; we can't predict the weather anymore' (Gonzales and Rodriguez 1999). How much change can be accommodated by the current system of traditional knowledge and practice? The amount of perturbation that a system can absorb and to which it can adapt is a measure of the resilience (or flexibility) of that system (Berkes and Folke 1998). The question of resilience is important because little is known about the cultural, social, and economic limits to adaptability.

Changes observed in Sachs Harbour are not beyond the range of the community's ability to respond and cope with them, predominantly through adjusting subsistence activity to accommodate seasonal fluctuation and change. However, these changes are relatively recent events, and how Inuvialuit are coping and responding up to now may not be a reliable indication of the community's ability to adapt in the future.

The key to understanding the impacts of climate change on northern communities is through the perspective of northern people. Gaining insight into the adaptability and resilience of northern economies to future change can be achieved through working with communities to understand how they perceive the change. Awareness of climate change in the Arctic, as described and explained by Arctic communities, may provide the necessary impetus to policy-makers and governments to plan more effectively in addressing impacts of climate change.

Community-based environmental monitoring

A primary difference between western science and traditional knowledge is that traditional knowledge holders are the resources users themselves, and their knowledge is grounded in the observation of environment and resources over an extended period of time (Berkes 1999). Environmental monitoring occurs in the context of seasonal rounds of resource harvesting activities; it is closely tied to travel routes, and the times and places of harvesting. This kind of community-based monitoring ensures that ecological relationships are noted, as in the case of possible competition between caribou and muskox for forage (D. Riedlinger, unpublished field notes, Sachs Harbour). Such monitoring recognizes and uses environmental indicators, as in the case of Sachs Harbour residents noting 'signs' of an impending storm.

In the community of Sachs Harbour, many families maintain camps at inland lakes to which they travel regularly, often at the same time every year. These trips provide a time series of observations that can be recalled years later, on such things as inland snow conditions, sea ice, and the appearance of migratory animals such as the lesser snow goose. Such observations provide an in-depth, cumulative, relational, diachronic set of information for a given area. By contrast, scientific monitoring techniques often focus on individual environmental phenomena in isolation from other factors, and are best suited for synchronic (simultaneously observed) data collection.

Climate-related environmental-change monitoring can use the capacity of local people to add site-specific information, bring attention to signs or indicators, and highlight relational information. It can also capture anomalous observations, such as the two species of Pacific salmon (*Oncorhynchus nerka* and *O. gorbuscha*) caught in Sachs Harbour in 1993. The occurrence of these species represents significant extensions of known, normal distributions (Babaluk and others 2000).

Monitoring can be collaborative, bridging the gap between scientists and communities by combining synchronic and diachronic information. Such projects enable local input into the environmental variables to be monitored. Community-based projects can provide cost-effective means of establishing baseline data and monitoring change. Within regional-scale monitoring projects, traditional knowledge can also help to distinguish natural variability from 'non-natural' or unexpected changes. For example, Sachs Harbour community members describe land and coastal erosion as a result of the thawing of permafrost. This is a natural process that can been seen all around Banks Island. But in recent years, the rate and extent of permafrost thaw have increased, resulting in unnaturally high amounts of erosion. Community members describe soil erosion, slumping, and mudslides as being 'all over now, not just in certain areas. People have seen them before, but there is more now. Before it was once in a while, mostly coastline. Now, [there are] more inland' (A. Carpenter and L. Carpenter, Sachs Harbour).

Thus, community-based monitoring projects can help link traditional knowledge and scientific approaches.

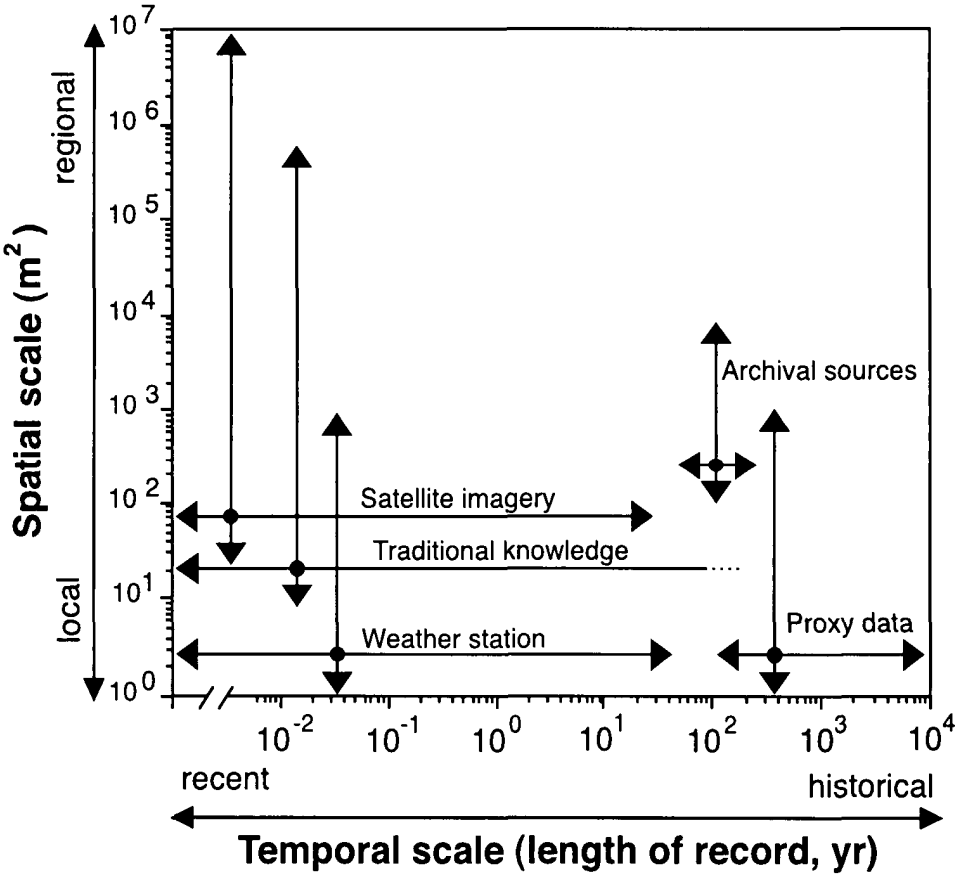


Fig. 1. Spatial (resolution) and temporal (length of record) scales of various approaches to investigating climate change in the Canadian Arctic. The spatial scale of a given approach indicates the extent to which it is best suited to providing local or regional information. The temporal scale of a given approach illustrates the temporal depth of information coverage, from recent to historical.

However, attempts to combine traditional knowledge and science often raise the question of the decontextualization of local knowledge, to fit it into an established scientific framework (see Nadasdy 1999). Collaborative community-based monitoring projects have good potential to retain traditional knowledge in its cultural context, rather than reifying it as an information source separate from its local applicability. The Arctic Borderlands Ecological Knowledge Co-op (2000) is one project example of an attempt to link communities and scientists to monitor northern resources such as caribou, in this instance the Porcupine Caribou herd.

Scale, context, and Arctic climate-change research

Inuit knowledge can be an accurate and sophisticated source for understanding climate change and variability in the Canadian Arctic. The five convergence areas presented as a conceptual framework for facilitating the linkage of traditional knowledge with western science illustrate the potential for collaborative research into climate change. Even though the five areas were presented as separate items, they contain a common theme: that traditional knowledge can complement western scientific approaches to climate-change research through understanding change in contexts and at scales currently under-represented in this research. This section expands on the discussion of scale, context, and climate-change research in the Arctic.

Climate-change research relies on comparing what is happening at present to what has happened in the past. To this end, western science has employed several approaches, from palaeoclimatic investigation to modelling temperature records. Each approach is best suited to certain spatial and temporal scales, as well as contexts (Ingram and others 1981). As put forth in this paper, traditional knowledge represents another approach to investigating climate change. Figure 1 summarizes the spatial and temporal extent of these various approaches to investigating climate change in the Arctic.

As Figure 1 illustrates, weather-station data provide a relatively short historical record, and consist of measurements made at one point in space. Thus, even though temporal resolution is high (that is, hourly records), the length of record is relatively short (last 50 years) and the data provide a limited spatial scale, some 1–1000 m. A second information source, satellite imagery, is capable of providing land- and ice-surface data over large and small scales, but its use is relatively recent. Third, archival sources such as expedition records, whaling logs, or

Hudson's Bay Company annals may provide more historical depth than other sources, but are often isolated records (that is, spatially limited). Fourth, proxy data, such as ice cores and lake-sediment cores, provide a climate history for one locality; they are most useful for recognizing historical patterns, that is, they have a temporal scale that spans some 100–10,000 years. Fifth and last, traditional knowledge can be applied to a range of spatial scales (local to regional) for the region of occupancy. In terms of temporal scale, it spans from the present and living memory to the past through historical recall and oral tradition. For the purpose of Figure 1, it is difficult to assign a temporal scale to traditional knowledge, given that it is representative of a knowledge system as a whole, and not a specific technique, as with the other approaches. The temporal depth attributed to traditional knowledge is variable, as it is dependent on the community itself, and on what kind of knowledge/history is being shared.

Figure 1 and the discussion of scale demonstrates how Inuit knowledge can complement other approaches. For example, the availability of three sources of climate knowledge (traditional knowledge, weather data, and satellite imagery) have overlapping time and spatial scales, suggesting the potential for using multiple approaches, cross-verification, and groundtruthing.

An examination of the spatial and temporal extent of various approaches to understanding climate change is useful in conveying the complementary nature of traditional and scientific knowledge. However, the discussion would be incomplete without a detailed examination of the attributes, or context, of each approach. For example, on the basis of the spatial scale alone, satellite imagery appears to be the most extensive. But its use is limited to spectral signatures of land- and ice-surface cover. The specific attributes of each approach can be expressed using general criteria such as available record, type of information, consistency, reliability, ease of information transfer, and accessibility, as well as the kinds of questions that can be asked using the approach.

Table 4 provides an evaluation of the attributes of selected approaches to climate-change research. 'Available record – temporal scale' refers to how long data have been available from each information source. 'Available record – spatial resolution' refers to the extent to which the given source provides local and regional coverage. 'Available record – temporal resolution' describes the 'fineness' of temporal coverage, or how often the information is measured. 'Type of information' identifies whether the data are quantitative, qualitative, or both. 'Consistency' is a measure of the evenness of information and whether the data are continuous or interrupted. 'Reliability' refers to the objectivity/subjectivity of data, and whether they can be independently verified. 'Ease of information transfer' addresses the facility by which one source can be combined with another, and 'accessibility' is meant to measure the amount of money, time, or labour required to extract and use the information. Finally, 'kinds of questions that can be asked' clarifies the type of information that a source most suitably provides.

As with Figure 1, this assessment highlights how traditional knowledge compares with other approaches. While these comparisons are not intended to be comprehensive, Figure 1 and Table 4 together demonstrate that the best approach to understanding climate change and the potential impacts on northern ecosystems and communities is through a combination of approaches. The five areas of convergence discussed in the previous section provide a conceptual framework within which to address temporal- and spatial-scale issues, from both Inuit and scientific perspectives.

Conclusion

This paper concentrates on areas of convergence and complementarity between western science and traditional knowledge. The five convergence areas provide a starting point for building relationships between communities and scientists. However, it is important to recognize that traditional knowledge does not necessarily fit with scientific models or research frameworks in all cases. As a number of authors have pointed out, there are cases in which scientific models do not adequately account for local observations (Nadasdy 1999). Part of the reason for this divergence is that the two kinds of knowledge are based on different world views (Cruikshank 1998; Berkes 1999). For example, Fienup-Riordan (1999: 1) found that scientific understandings and Alaska indigenous understandings of changes in the behaviour of brant geese generally agree on what is occurring, but 'they do not always agree on why these changes are taking place.' There may be other areas outside of a conventional climate research framework in which traditional knowledge can inform science. B. Riffenburgh (personal communication) commented that 'conceivably local models may actually suggest reframing some of the larger questions about how humans are to come to terms with climate change — a phenomena that science may monitor very effectively but certainly not fix.'

Neither western science nor traditional knowledge is sufficient in isolation to address all the complexities of global climate change. Scientists are increasingly recognizing the value of traditional knowledge in climate science (for example, Cohen 1997). Local communities, conscious of natural cycles, are finding that recent changes in weather are beyond the range of expected variability, and they are searching for answers. Climate-change research provides a rich setting for the study of the dynamic relationship between northern communities and ecosystems. A study of this relationship, as expressed through the medium of traditional knowledge, can be used to complement and enrich scientific understandings of the impacts of climate change on the Arctic environment and communities.

Environmental change associated with variations in weather and climate has not gone unnoticed by Inuit who are experiencing change first-hand (Riedlinger 1999). At the Beaufort Sea 2000 Conference in Inuvik, Inuvialuit

Table 4. Evaluating the attributes of various approaches to investigating Arctic climate change. This is not intended to be a comprehensive summary, but rather an indication of the general characteristics of various approaches.

Source	Instrumental data from weather stations	Satellite imagery	Archival (documentary sources)	Proxy data (ice cores)	Traditional knowledge
Available record – temporal scale (monthly record)	1947 in most of the Arctic	Some types of imagery starting in early 1970s, others more recently	150 years in many parts of the Arctic	Hundreds of years to many thousands of years	Living memory; extended through oral history; monthly and seasonal changes represented well. Dependent on individual communities
Available record – spatial resolution	Local: measures variables at one point in space and time; regional: data from several stations, but may not give regional picture if regional variability is high	Local: variable resolution from about 10 m (RADARSAT) to 30 m (SPOT); regional: approx. 25 m pixels from some sensors; image mosaics can provide extensive coverage	Local: can cover individual expedition routes; regional: region in which an HBC post/store was located	Local: measures one or a few points in space; regional: aggregating several independent measures	Diachronic information of a locale or region over time
Available record – temporal resolution	Fine resolution – hourly, daily, monthly summaries	Constant record, with constraints (such as cloud cover for optical and thermal wavelengths)	Fine resolution – daily, weekly logs	Coarse resolution	Best suited to relatively coarse measures such as monthly and seasonal change
Type of information/ observation	Quantitative; measures temperature, precipitation, wind, etc.	Quantitative; land- and ice-surface cover only; often restricted to signatures of spectral reflectance	Mostly qualitative (records, journals); some quantitative (date of ice break up, temperature); observations of land use, wildlife, weather events	Quantitative palaeo-records of climate or atmospheric composition	Mainly qualitative but can be quantitative. Knowledge of weather, land, sea ice, animals, etc. based on resource use
Consistency	Data can be fragmented; missing variables; isolated network of stations not all collecting same variables; changes in technology over time	Can be consistent, but often interrupted because of cloud cover. Consistency will vary dependent on dataset. Limited in temporal depth	Fragmented record in time and space	Relatively few sites used	Cumulative observations over time; consistency can be evaluated through cross-referencing within and between communities
Reliability	Objective; but unknown how reliably isolated stations represent surrounding area	Objective data but requires user expertise. Limited in what can be monitored; problems with data archiving and retrieval	Subjective; often of unknown context; difficult to verify	Objective; relatively high reliability; depends on analytical techniques used	Subjective; validated through land use, history and occupancy; by triangulation and by local expert verification

Ease of information transfer	Relatively easy; can be used to calibrate models	Compatible with other sources	Difficult to use with other sources; isolated records	Relatively easy to use with other sources	May be difficult to incorporate into scientific approaches, requires working with communities
Accessibility	Relatively inexpensive in money, time and labour; easily obtained	Easily obtained, but relatively expensive for imagery. Some datasets better than others	Relatively inexpensive in money, but expensive in time and labour	Relatively expensive logistics	Time- and labour-intensive; requires community participation and partnership
Kinds of questions that can be asked	Amounts, highs and lows, means, difference from normal, extremes, trends in regional climate and weather	Concentration (extent) of sea ice and snow cover over time, vegetation and productivity change over time, seasonal patterns, landforms	Extremes, past weather events, impacts of severe weather on human or wildlife populations, weather patterns in the context of a particular place	Past, historical climate information; distinguishing long-term trends from cycles	Indicators; rates of change; impact on wildlife, natural variability compared to unexpected change; extremes; human adaptation to change

delegates from six western Arctic communities rated climate change as one of two primary areas of concern (the other being contaminants) facing their communities.

Western science represents only one set of approaches to knowledge and inquiry. An exclusive focus on science may restrict the understandings of climate change, and the impacts of change on northern ecosystems and the communities that depend on them. For understanding a phenomenon as unpredictable and far-reaching as climate change, the wise approach is one that takes a pluralistic view. As articulated by a past Inuit Circumpolar Conference president at a United Nations convention on climate change, 'Your science cannot tell you how fast climate change will happen and your science can not tell you what and when the surprises will be—just that they will happen' (Kuptana 1996).

Arctic science is becoming more pluralistic and participatory, evidenced by areas such as wildlife co-management, coastal-zone management and environmental assessment (Berkes and others, in press). Traditional knowledge is identified as one of the mechanisms by which participatory approaches can be developed. Research partnerships between scientists and communities are not uncommon in the north. For many scientists, their knowledge already incorporates what has been learned from Inuit communities. However, at the same time, communities still express frustration over the lack of useful feedback from scientists or input into research and decision-making. There is room for more progress in accepting traditional knowledge as a source of knowledge and understanding, not in the abstract, but in practice.

The evolution of an Arctic science that looks to both traditional and scientific knowledge will be achieved by determining how to include traditional knowledge in a research paradigm that, in the Arctic, is largely influenced and constrained by external budgets, logistics, methods, and values. This paper addresses the 'how' question, not as a methodological discussion, but by suggesting a framework for the contributions of traditional knowledge to climate-change research. The 'how' question is also addressed by demonstrating, through the example of Sachs Harbour, how different ways of perceiving the physical and biological environment can complement each other. In the framework proposed, the five clusters of potential complementary relationships may help make Arctic research more participatory and pluralistic.

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