Climatic Change
DOI 10.1007/s10584-009-9587-1

Linking Inuit knowledge and meteorological station observations to understand changing wind patterns at Clyde River, Nunavut

Shari Gearheard · Matthew Pocernich · Ronald Stewart · Joelie Sanguya · Henry P. Huntington

Received: 19 November 2007 / Accepted: 30 December 2008

Abstract Connecting indigenous and scientific observations and knowledge has received much attention in the Arctic, not least in the area of climate change. On some levels, this connection can be established relatively easily, linking observations of similar phenomena or of various effects stemming from the same cause. Closer examinations of specific environmental parameters, however, can lead to far more complex and difficult attempts to make those connections. In this paper we examine observations of wind at Clyde River, Nunavut, Canada. For Inuit, many activities are governed by environmental conditions. Wind, in particular, is identified by Inuit as one of the most important environmental variables, playing a key role in driving sea ice, ocean, and weather conditions that can either enable or constrain hunting, travel, or other important activities. Inuit observe wind patterns closely, and through many means, as a result of their close connection to the land and sea. Inuit in many parts of Nunavut are reporting changes in wind patterns in recent years. At Clyde

S. Gearheard
National Snow and Ice Data Center, CIRES, University of Colorado at Boulder, Boulder, CO, USA

M. Pocernich
National Center for Atmospheric Research, Boulder, CO, USA

R. Stewart
McGill University, Montreal, Quebec, Canada

J. Sanguya
Clyde River, Nunavut, Canada

H. P. Huntington
23834 The Clearing Dr., Eagle River, AK 99577, USA
e-mail: hph@alaska.net

S. Gearheard (✉)
P.O. Box 241, Clyde River, Nunavut, X0A 0E0, Canada
e-mail: shari.gearheard@nsidc.org

Published online: 23 June 2009

River, a community on the eastern coast of Baffin Island, Inuit have observed that at least three key aspects of wind have changed over the last few decades: wind variability, wind speed, and wind direction. At the same time, wind observations are also available from an operational weather station located at Clyde River. An analysis of this information shows little change in wind parameters since the mid-1970s. Though the station data and Inuit observations correspond in some instances, overall, there is limited agreement. Although the differences in the two perspectives may point to possible biases that may exist from both sources—the weather station data may not be representative of the region, Inuit observations or explanations may be inaccurate, or the instrumental and Inuit observations may not be of the same phenomena—they also raise interesting questions about methods for observing wind and the nature of Arctic winds.

1 Introduction

For Inuit hunters in the Canadian Arctic, weather is the principal determining factor of daily activity. More than any other element, wind (*anuri* in Inuktitut,[1] the Inuit language) is often what hunters are concerned with the most. For example, winds that are too strong can constrain travel and subsistence hunting for a number of reasons including reduced visibility (blowing snow), dangerous temperatures (wind chill), and hazardous travel conditions (e.g. whiteouts, large ocean/lake waves, or shifting sea ice). Wind from certain directions can bring other hazards such as fog or open leads, and shifting wind directions can have an impact on navigation (e.g., snow forms called *uqalurait*[2]). As a result, Inuit have extensive knowledge of wind and weather patterns and many are skilled at wind and weather forecasting (e.g., Nelson 1969; MacDonald 1998; Oozeva et al. 2004; Henshaw 2006).

Clyde River (70° 28′ N, 68° 35′ W) is situated at the head of Patricia Bay, near the mouth of Clyde Inlet, a 100 km-long fjord on the eastern coast of Baffin Island in Nunavut, Canada (Fig. 1). The population of 820 is 96% Inuit (Statistics Canada 2006) and subsistence hunting is a major activity. Ringed seals are the primary food species, with arctic char, polar bear, narwhal, and caribou making up the major sources of country food (*Inuip niqingii*). Smaller amounts of bearded seal, arctic hare, and migratory waterfowl and their eggs round out the yearly diet (Wenzel 2000).

Both Inuit and scientists characterize surface winds on Baffin Island as being strongly influenced by surrounding mountains and fjords. At Clyde River, Inuit are

[1]The Inuktitut terminology used in this paper is from the Clyde River dialect. Terms and spellings may differ in other communities. We have done our best to provide spellings that are as accurate as possible and we have consulted Clyde Inuit on all the Inuktitut terms used in this paper. Any mistakes in spelling or terminology are our own.

[2]"*Uqalurait*" are tongue-like formations of snow, usually hardened by blowing snow, and are formed by the dominant wind, especially the dominant NW wind during winter months. Sometimes *uqalurait* have the likeness of a human tongue (the root word "*uqaq*" means "tongue" in Inuktitut) and sometimes they have the likeness of ripples on the water made by gentle wind. Because they are oriented to the dominant wind Inuit can use them as a navigational tool when travelling and they are especially useful in blizzard conditions or heavy snowfall when visibility is low (Sanguya, 2006, personal communication).

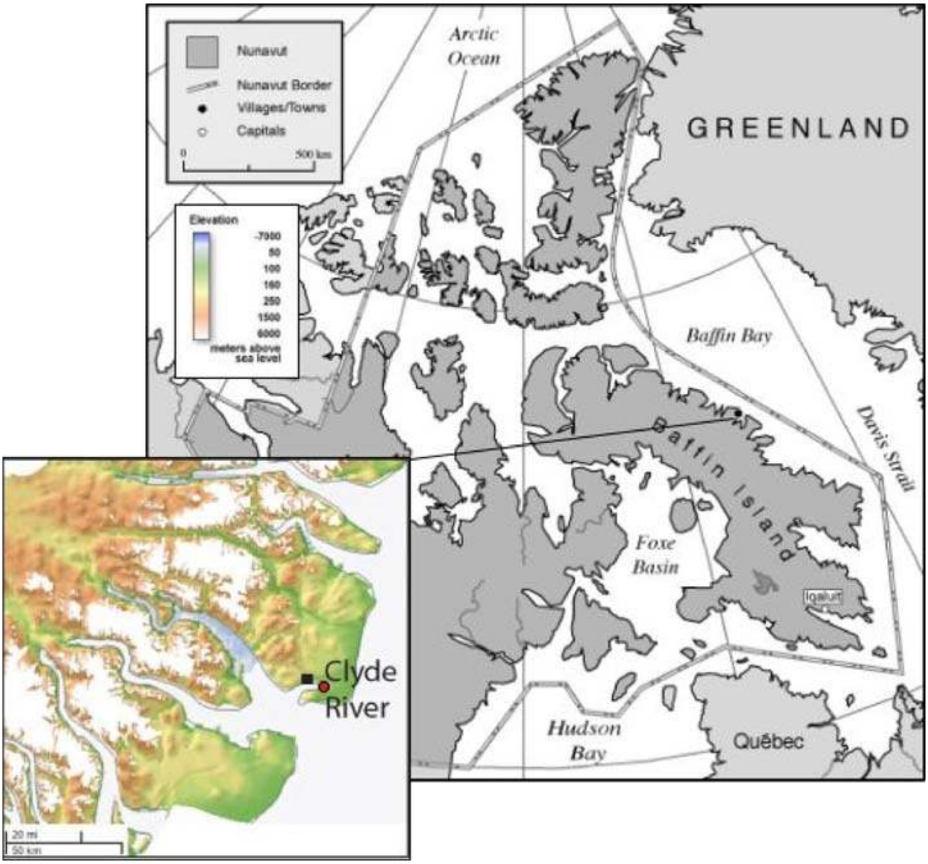


Fig. 1 Map showing Clyde River on Baffin Island, Nunavut, Canada. *Inset map* shows location of Clyde River community (*black square*), airport and weather station (*red dot*), and local relief

aware of which large mountains govern wind conditions in certain areas, how fjords channel winds, what areas of fjords are the best places to take shelter in during high winds, and how wind conditions on and near the central ice cap (Barnes Ice Cap) are different from other parts of the island (Sanguya, 2006, personal communication;[3] Angutikjuak, 2005, personal communication). For example, a landmark mountain near the community is called *Angijuqqaaraaluk* ("big boss mountain"), because of the great influence it has on weather in the area (Sanguya, 2006, personal communication; Inuit Heritage Trust 2006). When fog or low clouds are observed over *Angijuqqaaraaluk*, local Inuit know that travellers in the area should watch out for windy conditions.

[3]Sanguya is an author on the paper, however, we also cited him for certain details so that we were specific about crediting knowledge correctly to individuals.

Scientific studies of surface winds over Nunavut have been few. Essery et al. (1999) and Essery (2001) investigated strong wind events over arctic tundra with modest topography by means of linearized numerical simulations. Nawri and Stewart (2006) showed that winds are strongly affected by topographic features in the vicinity of Iqaluit. This study showed that the strongest winds are almost always from the north-west or south-east and there is often a low level jet located a few hundred meters above the surface.

Inuit, other Arctic residents, and scientists are also observing dramatic environmental and climatic changes in the Arctic (e.g. ACIA 2005; Krupnik and Jolly 2002). For many Inuit in Nunavut, some of the most concerning changes are related to winds. Local observations include more unpredictable winds (sudden shifts in wind direction, strong winds kick up or die down quickly), shifts in the dominant wind direction, more and longer windy periods, and stronger winds (e.g. Fox 2003, 2004; GN 2001; NTI 2001; NTI 2005). Inuit observers note the changing wind patterns contribute to other environmental changes such as changes in sea ice structure during freeze up, earlier sea ice break up, hard-packed snow conditions, and increased melting of *aniuvat* (permanent snow patches) and *auyuittuit* (glaciers); (e.g. Fox 2004; GN 2003). These changes in turn have had serious impacts on communities. For example at Baker Lake, a Nunavut community inland from the east coast of Hudson Bay, several accidents have been blamed on unpredictable storms and the inability to build emergency snow shelters in hard-packed snow conditions (Attungala 2003). The unpredictable storms and hard-packed conditions have direct connections to wind change; stronger and more frequent winds have packed the snow too hard for building igloos which are needed more often in unpredictable strong winds and storms. With the integral role winds play in so many environmental processes and human activities, some Inuit have suggested that perhaps too much attention has been paid to temperature in the climate change equation and that wind needs to be understood as a primary driving force in the Arctic system (Fox 2004).

Given the importance of winds in determining Inuit activities, community observations of recent wind changes, and the lack of attention that has been placed on this issue, this paper aims to take some initial steps in addressing the role of wind and wind changes in Nunavut from both Inuit and scientific perspectives. We focus on the community of Clyde River as a case study with the objectives to (a) explore trends/changes in wind patterns via Inuit observations and local assessments of long-term patterns; (b) explore trends/changes in wind patterns via meteorological station records; and (c) examine links between the two.

It is important to recognize that much research has been done to link indigenous and scientific observations of the environment (e.g., Johannes 1981; Ford and Martinez 2000), including observations of climate change (George et al. 2004; Huntington et al. 2004a; Huntington and Fox 2005). Several studies have emphasized that the two forms of knowledge can be reinforcing or complementary (e.g., Huntington et al. 2004b; Gearheard et al. 2006; Laidler 2006; Salomon et al. 2007). Some researchers have also pointed out the difficulties of reconciling oral traditions in the form of stories with quantitative climatological or ecological data (e.g., Cruikshank 2001). In our examination of Inuit and scientific observations of winds and changes in wind patterns, a close inspection of both sets of data reveals complementarity, as well as some apparently irreconcilable differences. We discuss the implications for further collaborative research.

2 Data sources

2.1 Inuit knowledge and observations

For generations, Inuit have lived off the land. Through activities such as hunting, fishing, preparing food and skins, and travelling the land, ice, and waters of the Arctic, Inuit have developed a complex understanding of the environment. Constant observation and experience over time accumulates to form Inuit knowledge (*Inuit Qaujimajatuqangit*), which also incorporates Inuit values and beliefs. Inuit knowledge and skills are passed down through generations through oral tradition, observation, and practice. This knowledge is dynamic, constantly evolving as each knowledge-holder engages with their environment and integrates their own experiences (Berkes 1999; Ingold and Kurtilla 2000; GN 1999).

Inuit constantly form knowledge about wind through their direct experience on the land and through a host of environmental observations including the movements of clouds, distribution and condition of snow, behaviour of animals, sea ice characteristics and dynamics, vegetation types, and ocean currents (e.g. Nelson 1969; Thorpe et al. 2001; Krupnik and Jolly 2002; George et al. 2004; Norton and Gaylord 2004; Oozeva et al. 2004; Huntington and Fox 2005; Henshaw 2006). Experienced hunters are able to keep track of wind direction and the strength of wind while travelling by dog team or snow machine, observing surface snow forms, blowing snow, clouds, and checking conditions during tea breaks. Skilled observers can also forecast wind and weather conditions (usually for the next 24 h) by using a variety of traditional indicators such as clouds, direction of winds, and animal behaviour (e.g. Nelson 1969; Fox 2004; MacDonald 1998). Some observations of wind and weather are made regularly (e.g., many elders and older Inuit immediately check the weather when they wake up each morning as they were trained to do as children, and try to predict the weather for the rest of the day) but most are made as an integral part of everyday activities. Observations of wind and other aspects of the environment are made while travelling or hunting, while walking to the store, while enjoying a coffee at the window. Observing and knowing the wind, land, animals, ice, and waters is for many Inuit a fundamental part of who they are, with knowledge being more “like a feeling” than something measurable (Arragutainaq 2005).

Today, human–environment relationships are changing in the North along with changing social, cultural, and political circumstances, but many Inuit continue to be active on the land, especially hunters. Older, active hunters and elders are those with the longest and most direct experience with the environment and have the most knowledge related to weather, climate, wildlife, and environmental processes, patterns, and changes. These are the experts community members recommended to help understand recent environmental changes and their observations are the ones used in this study.

Inuit knowledge and observations for this study was gathered primarily from research conducted by Gearheard (nee Fox) with Inuit hunters and elders in Nunavut, particularly in Clyde River. Working in partnership with local individuals and organizations, Gearheard has conducted over one hundred interviews with Inuit hunters and elders in Nunavut on their knowledge of climate and environmental changes (Fox 2002). Gearheard has worked with the community of Clyde River since 2000 and has been a resident there since 2004. Collaborative research with local Inuit has resulted in a number of reports, maps, photographs, and videos related to local environmental change, impacts, and responses (e.g. Fox 2002, 2003, 2004; Ilisaqsivik Society 2005).

Specifically for this paper, we used information gathered from 35 interviews from Clyde River that were part of Gearheard's dissertation fieldwork from 2000–2004[4] (Fox 2004). These semi-directed interviews asked Inuit hunters and elders to discuss any changes that were occurring in the environment (see Fox 2002 for details on interview methods). While the interviews were designed to let respondents identify the topics of environmental change that were important to them, and therefore cover a range of topics, we reviewed the transcripts for documented observations and knowledge related to wind and assembled information according to the themes of wind that emerged: variability, speed, and direction. Three experienced Inuit from Clyde River (Ilkoo Angutikjuak, James Qillaq, and Joelie Sanguya; Sanguya is also an author) checked the information on winds that was used for this paper and helped to update, add, and clarify the information. Other Inuit knowledge for this study comes from documented sources (reports, workshop transcripts, published literature) where Inuit are quoted.

2.2 Station data

Surface measurements are made at a meteorological station maintained by Environment Canada located at the Clyde River airport (Fig. 1). Electronic data are readily available and date back to January 1953. From 1953 to 1957, observations were recorded every 6 hours. In 1958, this frequency increased to every 3 h. Since March 1977, hourly observations have been collected. In North America, hourly wind speed is recorded as a 2-min average wind speed recorded within 10 min of the beginning of the hour (Environment Canada 2006). Note that this value is distinctly different than a peak hourly wind speed. Peak hourly wind speeds can occur at any point within the hour and are averaged over a much shorter time interval, so these values can be higher.

Over time, the height, location, and equipment used to measure wind speed at Clyde River has changed. From at least September 5, 1959 to April 30, 1964, the tower height was 6.8 m. From this time until November 11, 1970 the tower height was recorded as 7.6 m. Since then, wind measurements have been taken at the standard height of 10 m. In March, 1977, the station was moved from 70°28′, 68°33′ to 70°28′, 68°37′ (Flysak, 2006, personal communication).

In March 1977, changes were also made to the station equipment. The anemometer was changed from a mechanical 45B anemometer to a U2A anemometer. The latter instrument calculates wind speeds by converting a current generated by the moving cup weathervane to a calibrated wind speed. The resolution with which wind direction was recorded also changed at this time. Prior to 1977, wind directions were

[4]We are grateful to the Clyde River experts who were interviewed: Ilkoo Angutikjuak, Jayko Ashevak, Jacobie Iqalukjuak, Rebecca Iqalukjuak, Toopinga Inutiq, James Jaypoody, Alooloo Kautaq, Noah Kautaq, Peter Kuniliusie, Ashevak Palituq, Attakalik Palluq, Jason Palluq, Qaunaq Palluq, Peter Paneak, Jacopie Panipak, Aisa Piungituq, Apak Qaqqasiq, Uriah Qaqqasiq, Aipellee Qillaq, James Qillaq, Toopinga Qillaq, Mukpa Tassugat, Nauja Tassugat, and Abraham Tigullaraq.

recorded based on an 8-point scale (45° resolution). Since the equipment change, wind directions are recorded with a resolution of 10°. The movement of the station and equipment change seems to have had an impact on weather observations. This is evident by an abrupt increase in wind speed post 1977, as well as a sudden change in wind speed data variance.

For this paper, we use the consistent data available since 1977. We obtained this information online from the Environment Canada website and Environment Canada assisted us with clarifying aspects of the data and providing the history and qualitative information about the instrument and site.

2.3 Linking two ways of knowing about winds

Inuit and scientific observations are potentially independent sources of information that can be brought together to increase confidence and depth of knowledge, reducing overall uncertainty when the methods are combined (Agrawal 1995; Krupnik and Jolly 2002; Huntington et al. 2004a). Huntington et al. (2004a) write that the use of TEK (traditional ecological knowledge) and science together has not realized its potential in understanding the Arctic system and that one largely untapped area is the "careful comparison of specific observations from TEK with those from science". This is our aim with the wind observations presented here. We seek not to integrate the two ways of understanding, or simply to compare them with the intent to validate one or the other, but rather to use both together so that different perspectives, assessments, and lines of evidence can be examined and discrepancies investigated further. Similarities in observations and in interpretations of long-term patterns can strengthen our confidence in conclusions. Differences can lead us to identify new ideas and questions for further investigation, compare information gathered at different spatial and temporal scales, and examine potential mechanisms to explain both sets of observations thus leading to new knowledge (Huntington et al. 2004a). Our work therefore extends the work of Huntington et al. (2004a) by testing the limits of comparative and collaborative analysis. Not surprisingly, perhaps, we find that some apparently irreconcilable differences in observation may indicate a need for additional research to make sure that we are indeed comparing observations of the same phenomena, rather than attempting to connect observations that are only superficially similar.

3 Inuit observations of wind changes

Inuit observations of wind changes at Clyde River can be organized into three categories: change in variability of winds and weather, change in wind direction, and change in wind speed. In addition, Inuit also observe how wind changes interact with other environmental changes to create additional impacts on the environment and Inuit activities.

3.1 Change in variability of winds and weather

> …I can't really say that I could still predict the weather from looking at the clouds, because I try to guess and I usually get it wrong these days. I mean,

they're so changed. For instance, if I look at the clouds right now, I would think that the wind is coming from the North, but it is coming from the South instead today. (Paneak 2001)

Residents of many Arctic communities have observed that weather patterns are increasingly erratic and traditional methods of weather prediction are no longer applicable (e.g. Krupnik and Jolly 2002; Huntington and Fox 2005; Mustonen and Helander 2005; NTI 2001; NTI 2005). At Clyde River, some elders say that the change in weather patterns has been since the 1960s, but the 1990s stands out as a period when changes became more dramatic and when many experienced traditional weather forecasters lost their skills (Fox 2004).

For Clyde Inuit, one especially notable aspect of increased weather variability is changes in the wind. Wind and weather variability are strongly linked, acting together as both indicators and agents of environmental changes that have affected local activities. Increased wind variability has manifested itself in winds that come up or die down suddenly and change direction suddenly in a short period (within the same day).

Sudden, unpredictable changes in wind direction or the strength of winds has caused problems for travelling. Hunters can be caught in blowing snow, high waves, or have to spend unexpected extra days out on the land (Fox 2002, 2003). Because wind and weather conditions have become so variable and unpredictable in recent years, hunters have started to pack for extra days out on the land (Fox 2002, 2004). In the past, hunters could rely on forecasts that indicated good weather for a day trip, but now they anticipate a greater risk of getting caught in bad weather and take the extra gear.

Clyde Inuit make two important points regarding the recent increase in wind and weather variability. First, Inuit recognize that the rapid social and cultural changes of recent decades have eroded some Inuit knowledge and skills. However, in terms of traditional weather forecasting, elders and experienced hunters argue that traditional knowledge erosion is not the cause of faulty forecasts. Inuit have been living in a modern community setting for over 30 years and forecasting skills were reliable enough during that time to advise hunting parties and to teach until the 1990s (Fox 2004). During that decade, weather patterns changed and many local forecasters say their predictions became less reliable. Second, Inuit note that recent conditions are not unprecedented; there has always been unpredictable weather. What is unprecedented is how quickly conditions change from one to the next and the persistence of this unpredictability over time. People are careful to explain that weather (and wind) variability is an expected part of life in the Arctic. For many, weather patterns happen in cycles, some say cycles of 5 years, others 10–30 years, others still refer to a range of variability within which events or conditions inside this range are not considered unusual or worrisome. Defining or evaluating these cycles and ranges depends on the knowledge and experience of particular people. However, taken together, patterns emerge as people comment on what they perceive falls outside of the cycles or ranges they understand. For Clyde Inuit, importance is placed on the fact that the weather is always different and that variability must be carefully set apart from change. Understanding this, an important change observed at Clyde River is the increased variability of weather and wind conditions, the loss of ability to predict changes using traditional skills, and the persistence of this phenomenon particularly since the 1990s.

3.2 Changes in wind direction

Wind direction is extremely important and useful to Inuit. The way the wind blows determines many environmental conditions including movement of sea ice, clouds, snow, storms, fog, and wave action. For Inuit at Clyde River, there are eight main wind directions that correspond roughly to the directional names known in English (Table 1). In addition to these, hunters also observe winds that blow between directions. It is important to note that these names apply only in Clyde River. Other communities may refer to wind names differently, for example other North Baffin communities may use *niggiq* as southeast instead of east (Spalding 1998) or south (*nigiq*) as at Cape Dorset (Henshaw 2006).

Inuit at Clyde also recognize a seasonal pattern of winds and understand the impacts that each wind direction has on environmental conditions, as well as on Inuit activities (Table 2). Wind direction has a large role to play.

For Clyde elders, the most noticeable and concerning changes in wind direction have been (1) a shift in the prevailing northerly winds and, (2) an increase in variability of wind direction.

According to Inuit observations at Clyde, the prevailing NW winds in winter have shifted slightly clockwise, with northwesterly winds moving more to the north. In English terms, some describe this as a move from WNW to NW, others NW to N. One Clyde River elder, Nauja Tassugat, has explained that the prevailing wind direction in this area is known to be so dependable, that the change in direction must be explained by a land shift, not a wind shift (Tassugat 2001). Since the dominant wind direction is always constant, and a new direction is being observed, then the whole earth/land must have shifted to cause one to observe the new direction.

A shift in prevailing wind direction poses a number of problems. One concern is the impact to *uqalurait*, the snowdrifts that form parallel to the wind creating a directional aid (Fig. 2). In the past, travellers could depend on *uqalurait* to indicate direction, since they will be running parallel to the expected dominant wind for the season and area. Hunters today still rely on *uqalurait* to navigate while travelling, especially in bad weather conditions when visibility is poor. A change in the dominant wind, however, changes the expected direction of the *uqalurait*, and if one is not an experienced traveller who could detect the shift, one could be following the snowdrifts in the wrong direction. Hunters note *uqalurait* are still useable, but only if one is keeping track of the changes of shifting winds. The change is dangerous for younger or less experienced hunters who may be unaware of wind shifts and are expecting *uqalurait* to run in their usual direction, when in reality they may be following *uqalurait* in a different direction.

Table 1 Names of basic wind directions at Clyde River in Inuktitut and English (Qillaq, Angutikjuak, Sanguya, 2006, personal communication)

Inuktitut name	English name
Uangniq or Kuuviniut Miksaanit	North
Ikiqsuaq	Northeast
Niggiq	East
Nigirlak or Uqquata Miksipauanit	Southeast
Uqqua or Kivak	South
Uqquqsuq	Southwest
Ualiniq	West
Avangnarniq	Northwest

Table 2 Expected seasonal pattern of winds and examples of associated environmental conditions at Clyde River (Angutikjuak, Qillaq, and Sanguya, 2006, personal communication)

Month	Dominant wind direction	Conditions associated with wind
January	NW winds are dominant November through February	Sometimes a south wind during this time. A warm spell may come with some rain, forming an ice layer on the snow. Hares, ptarmigan, and caribou would go hungry as a result as they cannot access food sources through icy layer
February	NW wind	Same as January
March	End of the period when wind comes mostly from the NW.	SE wind during this time brings snow. Temperature is warmer during the day, cold at night, causing some seal pups to die during the night.
April	SE winds common in late April, bringing snow.	This type of snow is called *apummik aqiglitirijuq*; "the snow softener". A blanket of snow that settles on the ground and works as an insulation layer so that the existing snow becomes soft
May	SE winds	*Apummik aqiglitirijuq* also during this time. SE and SW winds control a large area of shorefast sea ice near the community that is heavily used for hunting and travel. SE winds can make this sea ice unstable and dangerous
June	SE winds	SE winds can still be dangerous for shorefast sea ice. Strong winds can play a role in break up during this time by helping to melt snow and ice, also by moving ice
July	E and SE	East wind will often bring fog during this time.
August	Most variable period; starting to move back to NW; some SW; SE and NE winds.	SW winds are usually warm and break up ice This period also marks the beginning of cool temperatures from the northwest
September	Winds trying to get back to NW	This wind will mix salt and fresh water in the sea, causing larger waves. Snow begins to be seen on the ground during this time
October	Mainly NW winds	Cooler temperatures than September and animals now develop thicker fur coats
November	NW wind	Sometimes a south wind during this time. A warm spell may come with some rain, forming an ice layer on the snow. Hares, ptarmigan and caribou would go hungry as a result as they cannot access food sources through icy layer
December	NW wind	Same as November

In addition to the shift in prevailing winds, local observers at Clyde note that winds change direction more rapidly and more suddenly than in the past. For example, wind may shift direction several times during a 1 or 2-day period, pick up or die down suddenly, making it difficult to predict conditions and to know if going out on the water or ice is safe.

Fig. 2 *Uqalurait* are tongue-shaped snowdrifts that form parallel to the wind and are used by Inuit as a navigational aid (photo: Shari Gearheard)

3.3 Changes in wind speed

Wind speed is very important in determining what activities Inuit can undertake on the land. Inuit characterize a variety of conditions related to wind speed (Table 3) and also use the quantitative measurements provided by Environment Canada forecasts (provided on radio, television, and Internet). Each hunter has his or her own way of judging when conditions are too windy for certain activities they would like to undertake. For example, different hunters have their own comfort levels in terms of how well they or their equipment can handle rough seas or blizzard conditions, and much of this is based on prior experience. Also, different hunters will make their own decisions about when and where it is safe to continue travel in windy conditions, or when and where to take a break or make a camp to wait out the wind (Fig. 3).

Both qualitative and quantitative information is used in assessing wind conditions and we asked hunters if there were thresholds that could be identified. Angutikjuak (2005, personal communication) explained how he incorporates forecasted wind speeds (from Environment Canada) into his decision making and we use this as one example: if the wind is (or predicted to be) 20 km/h and under, it is safe and comfortable to travel; for winds 20–30 km/h it is a personal comfort level decision depending on what activity/trip is planned; if winds are 30 km/h or more then it

Table 3 Basic categories of wind speeds in Inuktitut and their characteristics (J. Sanguya, 2006, personal communication)

Inuktitut name	Characteristics
Ikulliaqtuq	Calm
Anurajaarujuktuq	A breeze; refers to gentle wind that does not disturb any items on the ground; may cause ripples on the water
Anurajaaktuq	Gentle wind; causes ripples on the water, but no white caps
Anuraaqtuq	Windy; causes blowing snow along the ground; ripples on the water with little bit of white caps
Natiruviaqtuq	Blowing snow along the ground
Atiruttijaqtuq	Blowing snow along the ground; snow blown 15–20 m high on a clear day
Piqsiqtuq, Anuraaqtuq	Blizzard; usually cloudy, snowing, and white-out conditions; visibility varies 3 to 500 m; large white caps in summer
Piqsiqtualuk, Anuraaqtualuk	Blizzard; visibility is reduced to houses across the street (approx. 10 m or less)
Anuraajuaqtuq	Severe wind; houses shake and small cabins are blown away

is likely too uncomfortable or unsafe to travel. These thresholds are based on the affects the different wind speeds have on ocean and snow conditions (waves and blowing snow) and are applicable for both winter and summer seasons, but there are many other factors involved that make decisions much more complicated than numbers. Decision-making about travel also takes into account the type of equip-

Fig. 3 A group traveling from Clyde River finds a sheltered place in Sam Ford Fjord to take a break during a windy trip on the east coast of Baffin Island. Experienced hunters are very aware of areas that are likely to be more or less windy, so they can plan travel and seek shelter accordingly. Knowledge of these places is taught to younger hunters (photo: Henry Huntington)

ment being used by the hunter/traveller (e.g. a bigger boat can handle bigger waves), where the hunter is travelling, if the hunter is travelling alone or with family/children, what the weather is forecast to be (by local and Environment Canada sources), what activity the person is hoping to undertake, and many other considerations.

In relation to wind speeds, Inuit observe that conditions are windier than in the past. Winds are more constant and stronger (Angutikjuak, 2005, personal communication; Qillaq, 2005, personal communication; Fox 2003, 2004). One of the most noted changes in wind speed is stronger winter winds and these winds lasting longer. In addition to the slight clockwise shift in prevailing NW winds mentioned above, these winds are stronger in winter. In the past, strong winds out of the NW were not expected to last more than 3 days, however this is no longer the case, with strong winds lasting for longer periods. These stronger winds have an impact on snow conditions as they pack the snow too hard, making it difficult to build igloos, leading to the problems for finding shelter in bad weather, as described in Section 1.

A second major change in wind speed at Clyde River is increased variability, a theme that has run through the discussion so far. Winds increase their speed and die down again in short periods, within 1 day or over a matter of hours. This has been occurring at all times of the year, but especially in spring and fall seasons. Again, there are implications for Inuit activities as dangerous waves or ice conditions can develop when safe travel conditions were anticipated.

4 Station records of wind changes

Section 3 documented recent changes in wind and weather conditions based on the knowledge and assessments of Clyde River Inuit. In this section, we attempt to link this information to statistical summaries and tests based on meteorological data collected at Clyde River. Following the structure of Section 3, this section addresses wind direction, wind speed, and wind variability (speed and direction). Because of the changes introduced into the weather record by the movement and updating of the station in 1977, this section restricts its analysis to events that occurred after that date. Since the changes noticed by Inuit have been of concern primarily since the 1990s, the links in terms of time seem appropriate.

Time series data can be summarized and modelled in many ways. Here analyses are performed on a monthly basis. This allows results to be compared with conditions identified in Table 2. Where appropriate, linear regression is performed and shown with a solid black line. The initial assumption (the null hypothesis) is that there is no linear trend with respect to time. The p value indicates the probability that this hypothesis is true: the smaller the p value—the greater the likelihood of a significant trend. This conclusion assumes that the errors between the data and fitted line are independent. Linear regression fails to correctly detect non-linear patterns. To explore for non-linear patterns, a loess curve is shown on most analyses. Loess is a locally weighted polynomial regression (Cleveland et al. 1992). A low ordered polynomial model is fit to a point, with nearby points weighted most heavily. This is done for all points in a series. The resulting line allows non-linear patterns to be detected. In the following figures, loess lines are shown as red dashed lines. When the loess line and the linear line significantly depart, one may question the appropriateness of a linear model.

4.1 Wind speed

4.1.1 Trends in the magnitude of wind speed

Overall trends in mean monthly wind speeds are presented in Fig. 4. Significant linear trends are suggested in the months of June through August. From this figure, one notes that the range of wind speeds is similar.

As described in Section 3.3, with wind speeds below 20 km/h activities such as hunting may not be impeded. With winds exceeding 30 km/h, some activities such as boating or travelling on sea ice may become too dangerous. For this reason, we identified 20 and 30 km/h as thresholds for wind speeds that would affect Inuit activities and examined the proportion of time when these thresholds were exceeded. On an annual basis, the proportion of winds exceeding 30 km/h has not significantly changed (Fig. 5), however, the proportion of winds less than 20 km/h has shown a significant decrease (p value = 0.018). For example, in 1978, approximately 13% of measured

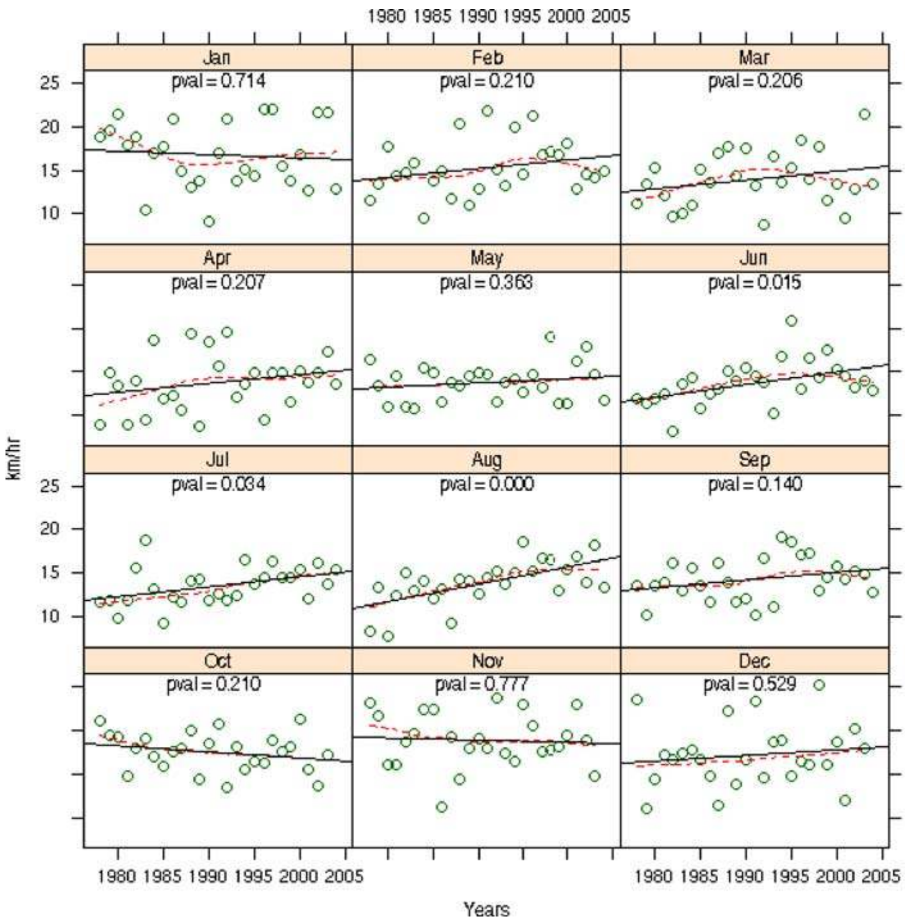


Fig. 4 Linear trends in mean monthly wind speeds. Pval indicates the likelihood of a significant linear trend. *Dashed line* indicates loess curves which suggest non-linear trends

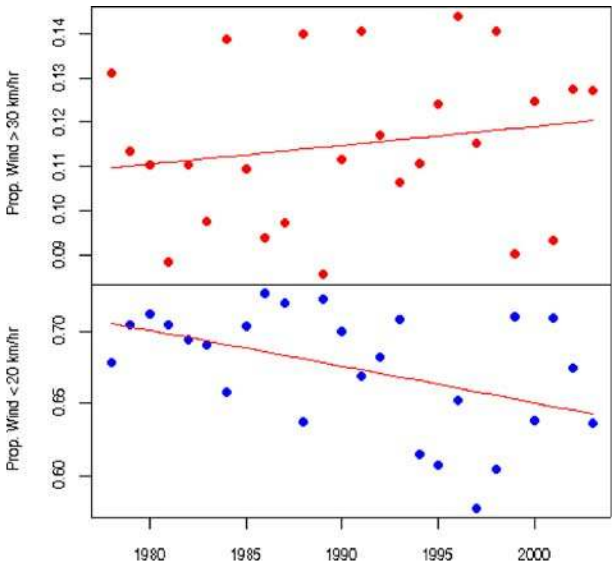


Fig. 5 Proportion of winds greater than 30 km/h and considered unfavorable for hunting (*top*) and less than 20 km/h and considered favorable for hunting (*bottom*). Linear trends shown in *red*

winds exceeded 30 km/h and consequently unfavourable for hunting, while 67% of the time winds were less than 20 km/h and more favourable for hunting. This was modelled using a generalized linear model for a binomial family of responses.

Finally, the proportion of calm observations was modelled. Because of limits in the metering equipment, "calm" describes wind speeds less than 2 km/h. Figure 6 shows monthly trends. With the exception of September and October, there appears to be significant decreases in the number of calm measurements. Therefore, both Figs. 5 and 6 align with Inuit observations of generally windier conditions.

4.1.2 Wind speed variability

The interquartile range (IQR) is the difference between the 75th and the 25th percentile values in a group of data. This statistic measures the spread in a group of values. Advantages of this statistic are that it is resistant to extremely high and low values and one does not need to assume a distribution. On a monthly basis, the IQR of wind speed values were calculated and then linear models were used to model these statistics. Both when including and excluding calm days, March was the only month showing a significant decrease in monthly IQR statistics. An increasing trend in the IQR would suggest more variable wind speeds. A decreasing trend would suggest more consistent wind speeds. The lack of a trend, suggests evidence of neither.

4.1.3 Wind speed duration

The duration of winds at several cited thresholds was examined. Figure 7 shows the distribution of the duration of winds greater than 30 km/h. While some year-to-year variation is apparent, no consistent change in the duration of high winds was apparent. This was repeated at thresholds of 10 and 20 km/h and trends or patterns were not evident.

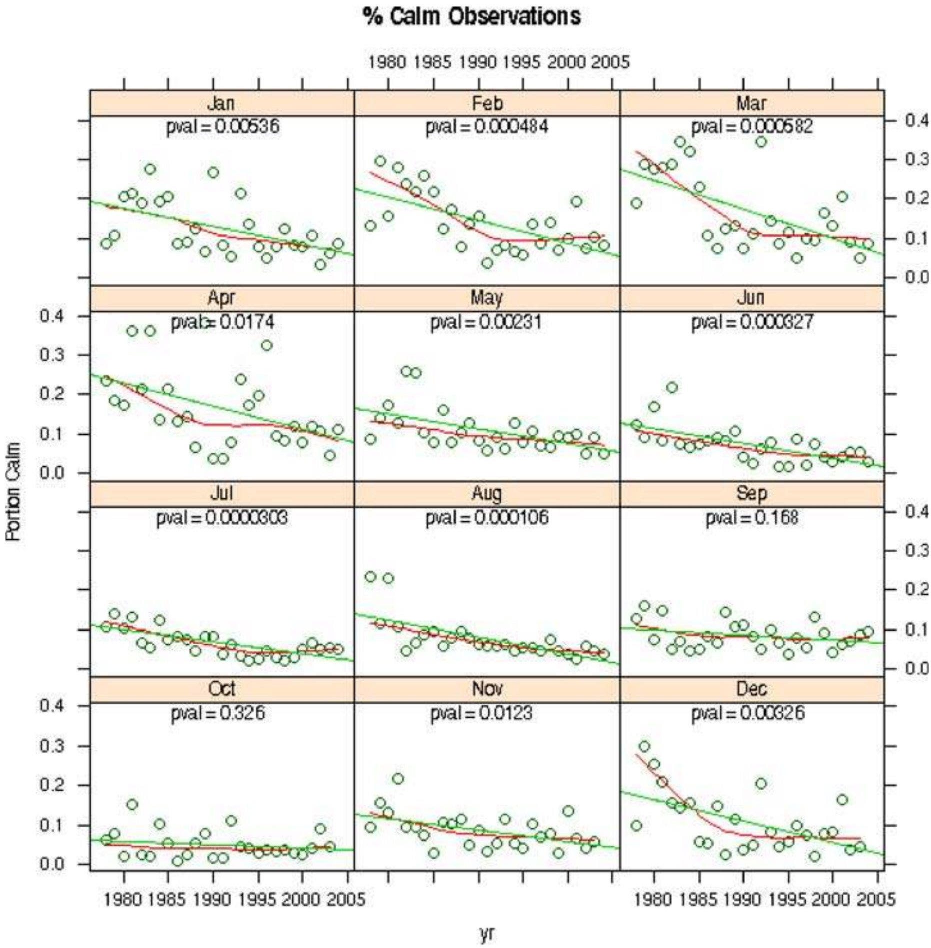


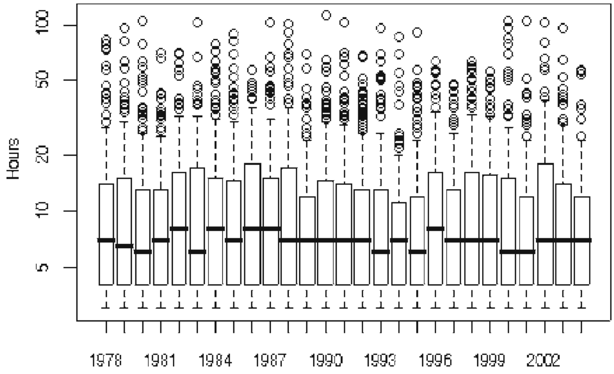
Fig. 6 Proportion of hours per month with calm winds (1977–2004). Calm is defined by wind speed less than 2 km/h. *Pval* indicates the significance of the linear trends. Loess curves depicted in *red*

4.2 Wind direction

4.2.1 Trends in mean wind direction

Inuit observers at Clyde River have noted that the predominant wind direction has shifted slightly in a clockwise direction with northwesterly winds moving more to the north. Some describe this as a move from WNW to NW, others NW to N, and mainly in the winter. Examining the monthly circular means on an annual basis (Fig. 8), we do not find significant linear changes in the wind directions. This figure indicates that the winter months are much more stable with respect to wind direction than the summer months, something also observed by Inuit. To address concerns that conclusions were affected by changes in directions in weak winds that might not be perceived, this exercise was repeated for wind with speeds greater than

Fig. 7 Boxplots summarizing the duration in hours of wind speed greater than 30 km/h



20 km/h. Again, there is not a significant change (figures not shown). Also not shown are analyses that model the monthly wind direction mode—the most commonly observed directions. Since the circular mean may become a misleading statistic in the presence of a bi-modal distribution of directions, the mode direction (most frequently observed direction) was also used to summarize monthly wind direction. Significant linear changes in wind direction were not detected using this statistic.

4.2.2 Trends in wind direction variance

Since wind directions are circular, variance as typically defined is not useful. Instead, circular variance (Fisher 1993) is calculated by adding together vectors with a length of one for each angular record and the length of the resulting vector is then divided by the number of segments. If all directions were then identical, the mean distance of this vector would be one. As the wind varies, the resulting vector is shortened and this value is less than one. By convention, circular variance is expressed as 1 - mean vector length. Therefore more consistent winds have lower variances and more variable winds have variance near 1. Figure 9 displays the monthly variance of winds greater than 10 km/h. The red line is a loess curve. Qualitatively, one notes increases in the variance during the months between April and September. This was repeated using all the wind data with less obvious increasing trends.

To quantify wind changes within a day, the maximum range of wind directions was calculated for each day. This range can vary from 180° for a wind which at some point completely changes direction to 0° for a completely consistent wind. The mean monthly values for these daily ranges are summarized in Fig. 10. This figure includes wind speeds greater than 10 km/h. Including all wind speeds generally increases the ranges. From this figure one notes some increase in the mean range of wind directions.

4.2.3 Northwest winds

In Section 3.3, the observation was also made that winds from the northwest have become stronger, particularly in winter. Figure 11 plots mean speed of winds by month from the northwest. One does not observe a notable change in wind speeds

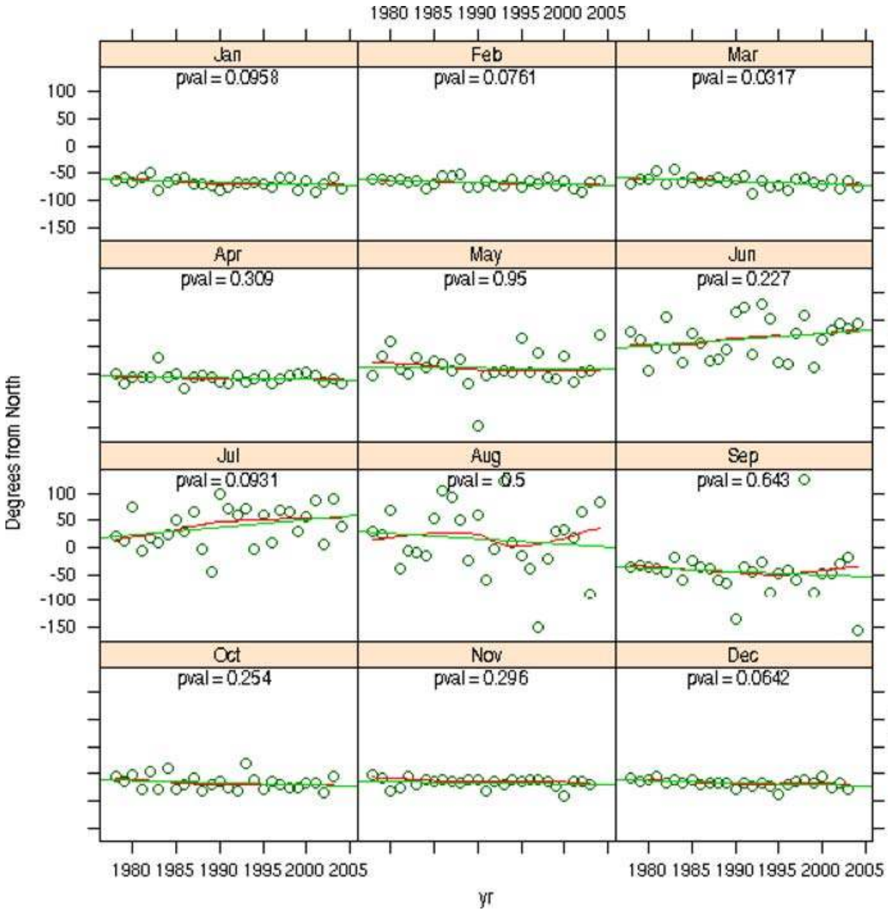


Fig. 8 Monthly mean wind directions. Zero degrees indicates north, so a positive trend indicates a shift clockwise in the mean wind direction. *Pval* indicates the significance of a linear shift in wind direction. The *red line* indicates a loess curve

and, from the previous analysis of wind directions, one can conclude that the prevalence of northwest winds has not changed according to station records.

4.3 Unpredictability of winds; increased variability

Inuit have noted that it is increasingly difficult to predict weather and, more specifically, winds. A statistical expression of predictability that is similar to the process humans use to make predictions is exceedingly difficult. One would not make a forecast of wind speed using only information about winds. In this paper we will consider two admittedly over simplified expressions of predictability. The first uses climatology—a forecast based on historical conditions. Using observations of seasonal weather has always served as a baseline for weather forecasts. People use their historical knowledge as well, and include additional information to modify this knowledge. For example, climate centres use information about ocean currents or oscillation indices

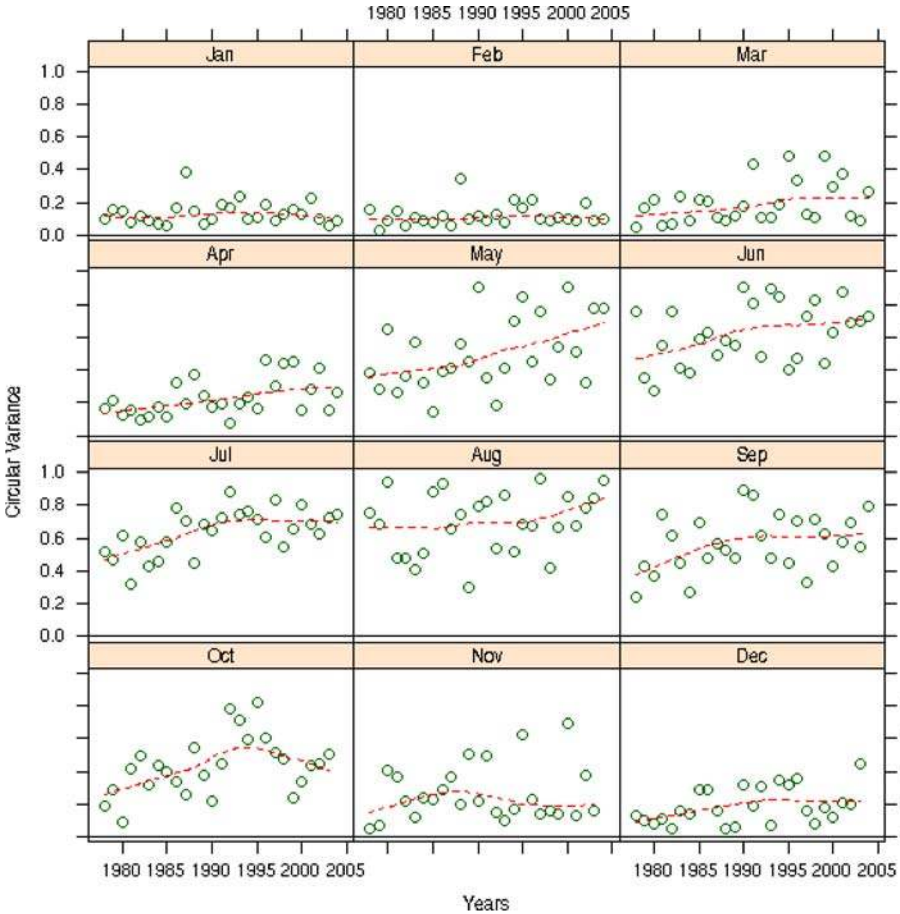


Fig. 9 Circular variance for wind direction for wind speeds greater than 10 km/h. Winds with a constant direction have a variance of 0. Larger values indicate more variance

to make seasonal forecasts for different regions. These forecasts are often expressed in terms of "warmer/colder" or "wetter/dryer" than normal seasons. Likewise, Inuit use other knowledge and observations such as snow conditions and distribution, the body condition of animals, or quantity and quality of berries or plants to modify seasonal expectations.

In this paper, a simplified climatology forecast is created in the following manner. The mean daily wind speed is predicted based on the historical mean of the last 10 years of data. For example, a forecast for October 10th, 1995 would consist of the average of wind speeds measured on October 10th, 1984–94. This type of forecast could be thought to be based on peoples' recent memory of winds, but it does not include any additional information or knowledge. By month, the monthly root mean squared residual of such forecasts of wind direction is plotted in Fig. 12.

Similarly, a 10-year climatology-based forecast was created for wind speeds. A plot of the root mean squared errors suggests few significant trends (Fig. 13).

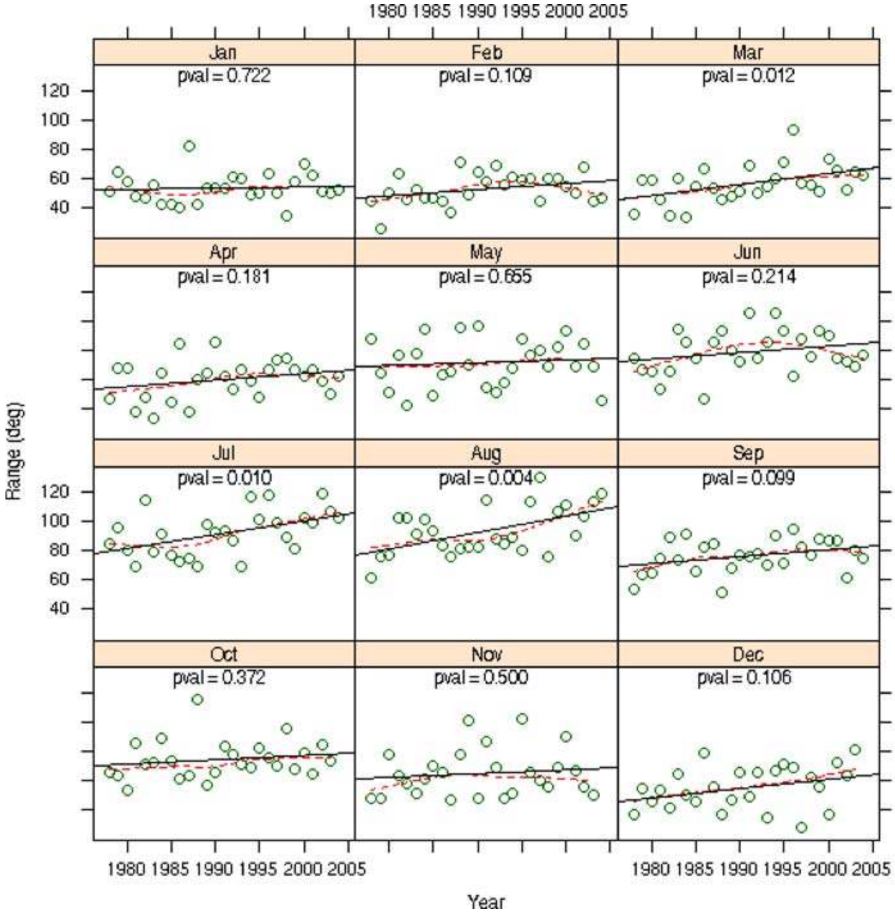


Fig. 10 Mean monthly within-day direction range for winds greater than 10 km/h. This summarizes average changes within the day of winds of modest or greater wind speeds

5 Discussion: linking Inuit and scientific observations of winds

Understanding wind is critical for Inuit who are actively hunting and travelling the land, ice, and ocean. Observations are made constantly, during daily activities, and wherever one travels, whether across town or across the tundra. The Inuktitut language has detailed terminology for winds, including speeds and directions, terminology that provides critical information needed for making decisions about what activities can be undertaken in the moment and in the near future. Knowledge about winds is inextricably tied to knowledge about sea ice, snow, weather, animal behaviour, precipitation, ocean currents, and many other environmental phenomena. This knowledge is dynamic and evolving, constantly merging knowledge passed down through generations with new experiences. Environmental knowledge is also inextricably tied to cultural knowledge and practices, which help Inuit respond to any change in their environment (Leduc 2006). With such a complex knowledge base

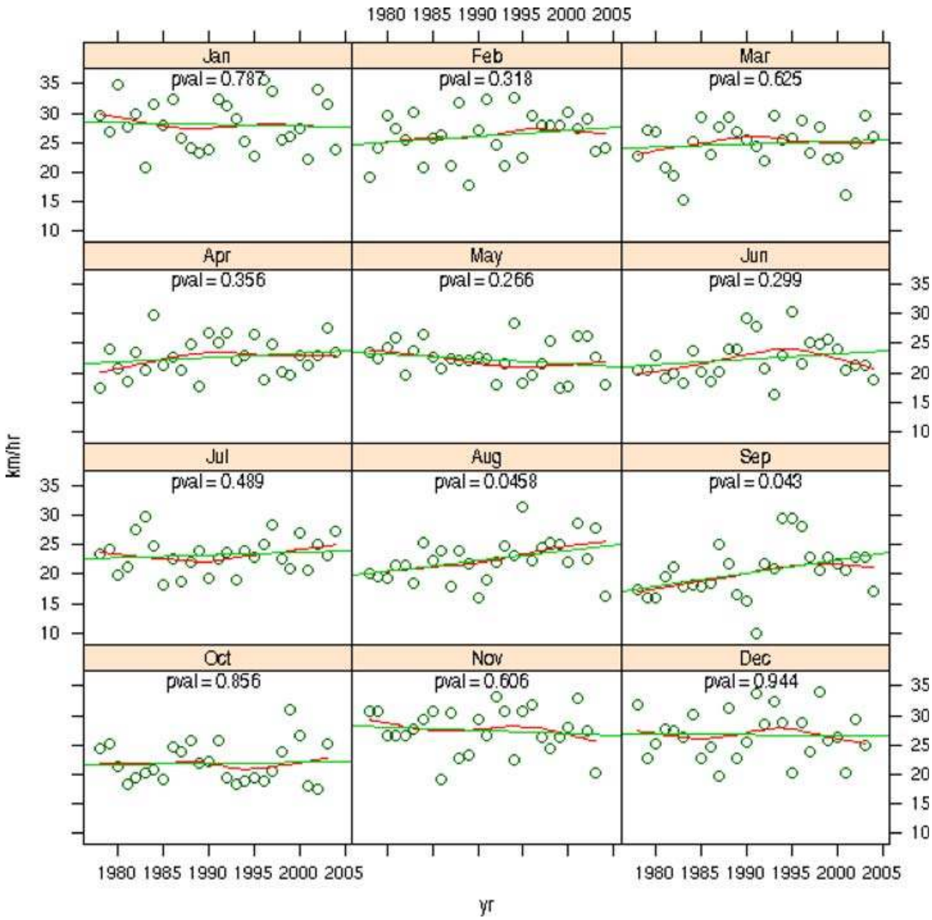


Fig. 11 Mean monthly wind speeds of winds from the northwest (between 300 and 330 degrees). Pval indicates the significance of linear changes in these wind speeds. Loess curve depict non-linear changes

in place, Inuit have many lines of evidence to draw upon when assessing changes in their environment.

Scientific observations of winds are made quite differently. Observations are gathered by instruments that individually and separately measure the variables that Inuit understand together, such as precipitation, wind speed, and temperature. The instrument used in this study is stationary and statistical methods are used to interpret conditions between instruments (distances may be hundreds of kilometres) and beyond the network of instruments. The data are valuable, but taken alone, may not match the conditions that Inuit observe when travelling in a topographically diverse region such as that surrounding Clyde River.

Using Clyde River, Nunavut as a case study, we analyzed local weather station data together with Inuit observations and assessments of wind change. Our goal was to bring two different sets of observations, two different lines of evidence, together, to examine (1) what Inuit and scientific measurements observe in regards to winds;

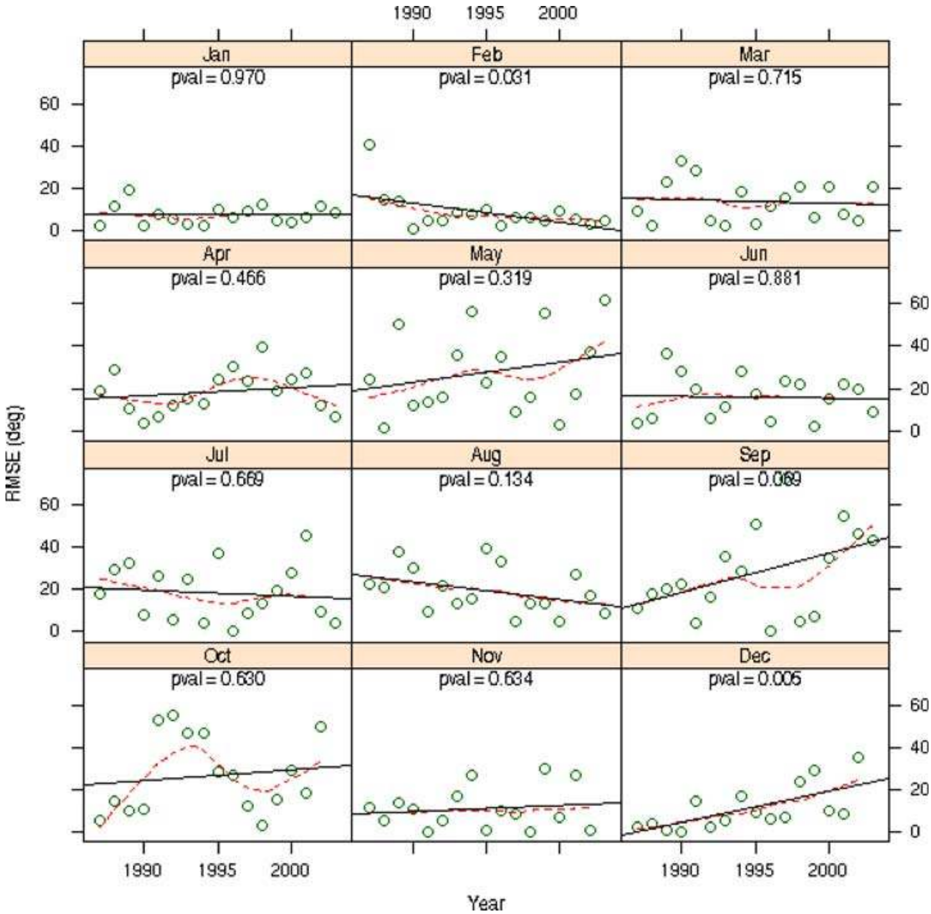


Fig. 12 Root mean squared error (deg) for wind direction forecasts based on the last 10 years of wind records. *Pval* indicates the significance of linear changes in these wind speeds. Loess curve depict non-linear changes

(2) how they compare; and (3) what we can learn from the comparison. Sections 3 and 4 addressed our first objective. In Section 3, we outlined Inuit observations and in Section 4, we analyzed station records following the themes of variability, changes in wind direction, and changes in wind speed that came through in interviews with Inuit, as these themes are of equal importance in scientific observation and study of winds. In the present section, we address our second and third objectives. We outline how these observations compare, what we can learn from this comparison, and what the comparison suggests for future research needs.

Figures 7–10 illustrate different approaches to quantifying wind variance at Clyde River, focussing on wind speed and direction. Unlike the changes noticed by Inuit, including unexpected shifts in wind speeds and direction and stronger winds, the station has recorded relatively little change. Climatology-based forecasts, and other quantifications of variance, show no significant trends. There were some changes in the variance of wind direction, changes that link to Inuit observations that in

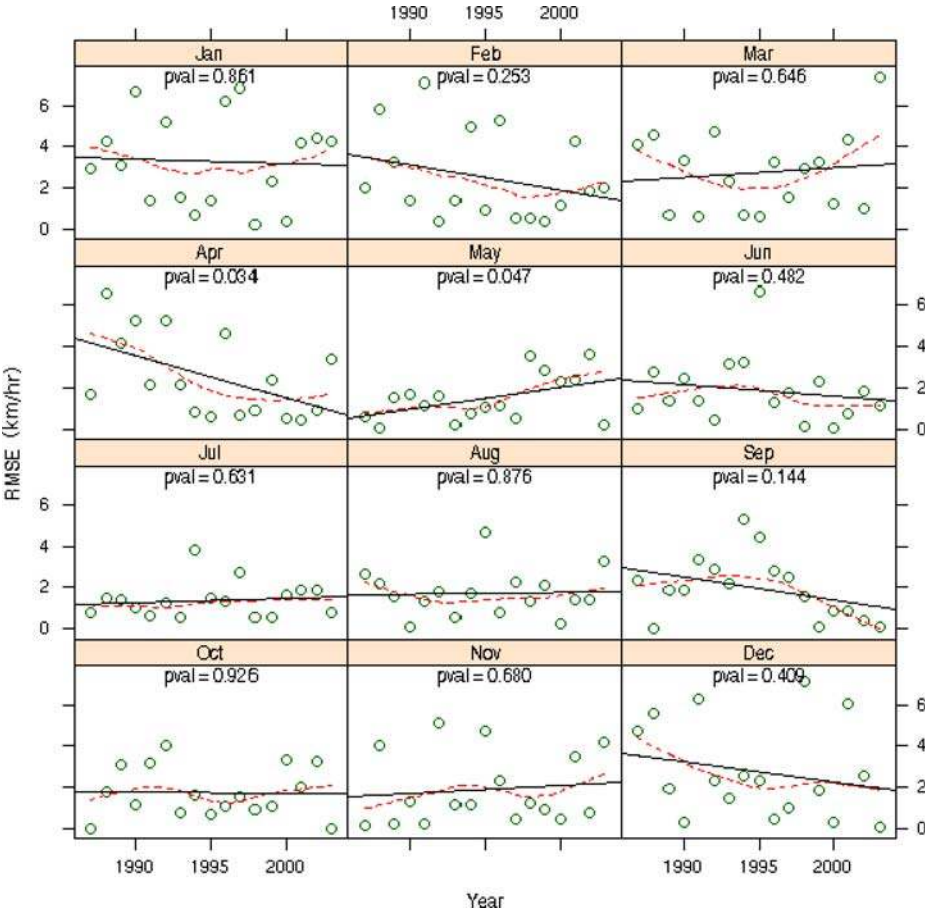


Fig. 13 Root mean squared error for wind speed forecast based on climatology. *Pval* indicates the significance of linear changes in these wind speeds. Loess curve depict non-linear changes

recent years wind directions change more frequently over short periods (e.g. wind direction changes several times over a 1-day period). In the past, Inuit and scientific observations agree that wind direction was more stable in the past.

Also with respect to wind direction, station observations link well with Inuit understandings of annual/monthly wind patterns; wind direction being more stable in winter months than summer months. According to the weather station, however, there has been no change in the dominant (NW) wind direction (no change in the prevalence of NW winds), and NW winds did not appear to be stronger in recent years compared with the past. With respect to wind speed, Inuit and station observations do show some agreement. Summer wind speeds have increased (Fig. 4) and in Figs. 5 and 6 we see that the proportion of winds less than 20 km/h have decreased and, except for September and October, there are fewer periods of calm winds (winds less than 2 km/h). These results all align with Inuit observations at Clyde River that conditions have been windier than normal in recent years.

These areas of agreement notwithstanding, overall there is limited agreement between Inuit and station observations of wind change at Clyde River. As Huntington et al. (2004a) note, however, divergences can be particularly illuminating. The fact that Inuit observations include several key changes that are not matched by the meteorological station data suggests three possible explanations to consider, none of which excludes the others.

First, the weather station records are not representative of the areas in which Inuit travel. Although several changes have taken place in the weather station itself, none appears to have had a major impact on the parameters analysed here. Instead, the question is the degree to which the measurements reflect what Inuit experience. Given the topographical complexity of the region, considerable variation in conditions is to be expected. The community of Clyde River, and the weather station, is located near the sea in relatively flat terrain, whereas hunters often travel in the fjords, which are bordered by high cliffs and mountains. The weather station at Clyde is thus likely to record different conditions than those experienced by Inuit travelling in other areas, even areas nearby. Nonetheless, one might expect general patterns to hold throughout the region with some degree of correlation between conditions at the weather station and conditions elsewhere. That is, changes in winds at Clyde may manifest themselves differently than changes in the fjords, but some degree of change would be expected in both locations rather than only in one place. Additional studies of wind variability, including the collection of more data from various locations in the Clyde River area, might help determine the extent to which the station actually records wind events of significance to hunters. More work with hunters about the degree to which they rely on information from the weather station, and what information or parameters specifically, might also be illuminating.

Second, Inuit observations (or perhaps more accurately the explanation for the observations) are inaccurate. These observations rely on personal recollection, potentially over longer periods than the observers have lived in Clyde River itself. The importance of wind parameters may vary with technology and activity. For example, wind is likely to affect dog teams differently than it affects snowmobiles, so that a change in technology might yield different reports of wind, even if wind stays the same. Some additional investigation of the specific details of Inuit–wind interactions and other changes over time might shed additional light on this possibility.

Third, the comparisons of Inuit and meteorological records are invalid because the observations are not of the same phenomena. Inuit are concerned primarily with sudden changes and with high winds that inhibit travel or reduce safety. The weather station records events over different time scales, at a fixed location, and with no sensitivity to other environmental factors (e.g., blowing snow) that might increase the perceived severity of wind at a given speed. Different variables might be developed to more directly quantify the attribute being described, similar to the way windchill was developed to describe the temperature as felt by a person. Some additional attention to exactly what Inuit are concerned about in terms of various wind events and whether these events are likely to be captured in the weather station records are worth examining. Even a perceived change in wind direction may reflect secondary phenomena such as ice movements or snowdrifts, which in turn may respond to other influences (currents, snow quality, previous storms, etc.)

A prospective study to compare observations and records of the same events might help shed light on differences in perspective. For example, Inuit reporting a sudden change at a given time could compare their observation with the weather record for that time to see if the weather station captured the same change. The comparison of specific events could complement the analysis of general patterns given here. Similarly, the frequency of the events reported by Inuit may not be statistically significant, but could be personally significant. An analysis of the sensitivity of the weather records analysis could help determine how many additional events are required to be statistically significant, which could then be compared with descriptions by Inuit of the frequency with which they have observed wind events that diverged from the expected pattern.

Regardless of the explanation for the divergence, there are several avenues for further collaboration and study. For example, further study of specific patterns of land use and weather observation may shed light on the reasons why Inuit perceive changes in wind. Similarly, further investigation of specific patterns of winds over time and space may help better connect Inuit and weather station observations over the greater Clyde River area. Future studies and instrumentation could focus on both the same observation methods and on the same parameters.

It is essential to recognize that these questions are not only of academic interest. For Inuit living in a variable and changing environment, and depending for their lives and livelihoods on an accurate understanding thereof, the nature and extent of change is of vital importance. Research to connect large-scale patterns with effects on individuals is essential both to understanding the true impacts of global climate change and to providing useful information to Inuit and others adapting to a changing world.

The results of this analysis demonstrate that connecting Inuit and scientific observations is not always straightforward. Similarly, assessing the impacts to Inuit of observed or projected environmental changes is likely to be complex at best. The idea that indigenous and scientific observations can be mutually instructive is well established. Further study is needed, however, to move beyond that basic observation to examine the ways in which divergence, complexity, and uncertainty can be addressed in collaborative studies that link complex environmental phenomena such as global climate change with the equally complex social phenomena of human perception, behaviour, and practice.

6 Conclusions

In regards to wind changes at Clyde River, the local meteorological station shows relatively little change since the 1970s. Inuit, however, note key changes in wind patterns that have had a direct impact on the environment and human activities. Both perspectives are critical to understanding wind and wind changes at Clyde River and the combination of scientific and indigenous knowledge is critical for understanding the wind and the environment Arctic-wide. Each line of evidence can provide important information for the other, both with regard to actual observations and, perhaps even more importantly, with regard to the interpretation of those observations and the application of resulting new knowledge.

In addition to more data, there is an urgent need for more collaborative research. This paper represents an opportunistic study. We took existing sources to try and link data and perform our analysis. More projects are needed that bring scientists and

Inuit together directly in research, from conceptualization, to analysis, to reporting. In this way data can be collected with the understanding that they will be linked. This can lead to innovative methods in observation, analysis, and information sharing. Moreover, multi-cultural, interdisciplinary teams of Arctic residents and researchers can lead to key exchanges in knowledge and in life experience, so that more common ground can be established (Gearheard et al. 2006). When this mutual understanding occurs, it creates the best context within which to bridge perspectives, data, methods, and ultimately, understanding of the Arctic system.

Acknowledgements Gearheard would like to thank all the Inuit hunters and elders in Clyde River who have been so generous with their collaboration in research. Thanks in particular to Ilkoo Angutikjuak and James Qillaq for advice directly related to this paper. Gearheard is also grateful to Nunavut Tunngavik Inc. for the invitation to attend the workshop, “Inuit Perspectives on Climate Change Adaptation Challenges in Nunavut” in March, 2005. Discussions at that workshop provided useful information for this paper. Gearheard’s research was supported with funding from the National Science Foundation (OPP-9906740), the Cooperative Institute for Research in Environmental Sciences (CU-Boulder), the Social Sciences and Humanities Research Council of Canada, and ArcticNet. Stewart would like to thank ArcticNet, Environment Canada, and the Natural Sciences and Engineering Research Council of Canada for support. The authors would all like to thank Niklolaj Nawri for his helpful comments on earlier versions of this paper, and Larry Flysak at the Meteorological Service of Canada for assistance in obtaining historical station data and records for Clyde River.

References

ACIA (2005) Arctic climate impact assessment. Cambridge University Press, Cambridge, UK

Agrawal A (1995) Dismantling the divide between indigenous and scientific knowledge. Dev Change 26(3):413–439

Arragutainaq L (2005) Comments made at the Nunavut Tunngavik Inc workshop. In: Inuit perspectives on climate change adaptation challenges in Nunavut, Iqaluit

Attungala N (2003) Interview in Fox S (2003) when the weather is uggianaqtuq: inuit observations of environmental change. A multi-media, interactive CD-ROM. Produced at the Cartography Lab, Department of Geography, University of Colorado at Boulder. Distributed by the National Snow and Ice Data Center (NSIDC) and Arctic System Sciences (ARCSS), National Science Foundation

Berkes F (1999) Sacred ecology: traditional ecological knowledge and resource management. Taylor & Francis, New York

Cleveland WS, Grosse E, Shyu WM (1992) Local regression models, chapter 8. In: Chambers JM, Hastie TJ (eds) Statistical models in S. Wadsworth: Pacific Grove, CA

Cruikshank J (2001) Glaciers and climate change: perspectives from oral tradition. Arctic 54(4): 377–393

Environment Canada (2006) Observation site data inspection report for clyde a station. (Site ID YCY, Climate ID 2400800). Inspection data 4/13/2006. Published by Environment Canada and obtained by request

Essery R (2001) Spatial statistics of windflow and blowing-snow fluxes over complex topography. Boundary-Layer Meteorol 100:131–147

Essery R, Li L, Pomeroy J (1999) A distributed model of blowing snow over complex terrain. Hydrol Process 13:2423–2438

Fisher NI (1993) Statistical analysis of circular data. Cambridge University Press, Cambridge

Ford J, Martinez D (2000) Traditional ecological knowledge, ecosystem science, and environmental management. Ecol Appl 10(5):1249–1340 (invited feature)

Fox S (2002) These are things that are really happening: inuit perspectives on the evidence and impacts of climate change in nunavut. In: Krupnik I, Jolly D (eds) The earth is faster now: indigenous observations of arctic environmental change. Arctic Research Consortium of the United States, Fairbanks, AK, pp 12–53

Fox S (2003) When the weather is uggianaqtuq: Inuit observations of environmental change. A multimedia, interactive CD-ROM. Produced at the Cartography Lab, Department of Geography, University of Colorado at Boulder. Distributed by the National Snow and Ice Data Center (NSIDC) and Arctic System Sciences (ARCSS), National Science Foundation

Fox S (2004) When the weather is uggianaqtuq: linking inuit and scientific observations of environmental change in Nunavut, Canada. Dissertation, University of Colorado at Boulder

Gearheard S, Matumeak W, Angutikjuak I, Maslanik J, Huntington HP, Leavitt J, Matumeak-Kagak D, Tigullaraq G, Barry RG (2006) "It's not that simple": a comparison of sea ice environments, uses of sea ice, and vulnerability to change in barrow, Alaska, USA, and Clyde River, Nunavut, Canada. Ambio 35(4):203–211

George JC, Huntington HP, Brewster K, Eicken H, Norton DW, Glenn R (2004) Observations on shorefast ice failures in Arctic Alaska and the responses of the Inupiat hunting community. Arctic 57(4):363–374

Government of Nunavut (1999) Report from the September Inuit Qaujimajatuqangit workshop, Niaqunngnut, Nunavut, 29–20 September 1999. Sponsored by the Government of Nunavut Department of Culture, Language, Elders and Youth

Government of Nunavut, Department of Sustainable Development, Environmental Protection Services (2001) Inuit knowledge of climate change: a sample of inuit experiences of climate change in Nunavut, Baker Lake and Arviat, Nunavut. Government of Nunavut, Iqaluit

Government of Nunavut, Department of Sustainable Development, Environmental Protection Services (2003) Inuit Knowledge of climate change: a sample of inuit experiences of recent climate and environmental changes in Clyde River, Pond Inlet, Resolute, Grise Fjord, Pangnirtung and Iqaluit Nunavut. Two Volumes, North Baffin and South Baffin. Government of Nunavut, Iqaluit

Henshaw A (2006) Winds of change: weather knowledge amongst the Sikusilarmiut. In: Riewe R, Oakes J (eds) Climate change: linking traditional and scientific knowledge. Aboriginal Issues Press, University of Manitoba, Winnipeg pp 177–186

Huntington HP, Fox S (2005) The changing arctic: indigenous perspectives. In: Arctic climate impact assessment. Cambridge University Press, Cambridge, pp 61–98

Huntington HP, Callaghan T, Fox S, Krupnik I (2004a) Matching traditional and scientific observations to detect environmental change: a discussion on Arctic terrestrial ecosystems. Ambio 33(7):18–23

Huntington HP, Suydam RS, Rosenberg DH (2004b) Traditional knowledge and satellite tracking as complementary approaches to ecological understanding. Environ Conserv 31(3): 177–180

Ilisaqsivik Society (2005) Healthy land, healthy ice, healthy life: understanding environment-health relationships at Clyde River, Nunavut. Ilisaqsivik Society, Clyde River

Ingold T, Kurtilla T (2000) Perceiving the environment in Finnish Lapland. Body Soc 6(3–4):183–196

Inuit Heritage Trust (2006) Notes accompanying Clyde River place name maps. Map sheet 27F.

Johannes RE (1981) Words of the Lagoon: fishing and marine lore in the Palau District of Micronesia. University of California Press, Berkeley, CA.

Krupnik I, Jolly D (eds) (2002) The earth is faster now: indigenous observations of arctic environmental change. Arctic Research Consortium of the United States, Fairbanks, Alaska

Laidler GJ (2006) Inuit and scientific perspectives on the relationships between sea ice and climate change: the ideal compliment? Clim Change 78:407–444

Leduc TB (2006) Inuit economic adaptations for a changing global climate. Ecol Econ 60:27–35

MacDonald J (1998) The arctic sky: inuit astronomy, star lore, and legend. Royal Ontario Museum and Nunavut Research Institute, Toronto and Iqaluit

Mustonen T, Helander E (2005) Snowscapes, dreamscapes: snowchange book on community voices of change. Tampere Polytechnic Publications, Tampere

Nawri N, Stewart RE (2006) Climatological features of orographic low-level jets within Frobisher Bay. Atmos Ocean 44:397–413

Nelson R (1969) Hunters of the Northern Ice. University of Chicago Press, Chicago, Xxiv+429 pp

Norton DW, Gaylord AG (2004) Drift velocities of ice floes in Alaska's northern Chukchi Sea flaw zone: determinants of success by spring subsistence whalers in 2000 and 2001. Arctic 57(4): 347–362

NTI (Nunavut Tunngavik Inc) (2001) Elder's conference on climate change: final report. Cambridge Bay, Nunavut. Nunavut Tunngavik Inc.

NTI (Nunavut Tunngavik Inc) (2005) What if the winter doesn't come? Inuit Perspectives on Climate Change Adaptation Challenges in Nunavut. In: Summary workshop report, 15–17 March 2005. Iqaluit, Nunavut. Nunavut Tunngavik Inc

Oozeva C, Noongwook C, Alowa G, Krupnik I (2004) Watching ice and weather our way. Arctic Studies Center, Smithsonian Institution, Washington, DC
Paneak P (2001) Interview by Shari Fox and Geela Tigullaraq. 29 June 2001. Clyde River
Salomon AK, Tanape NM, Huntington HP (2007) Synergistic serial depletion of marine invertebrates leads to the decline of a strongly interacting grazer in Alaska. Ecol Appl 17(6):1752–1770
Spalding A (1998) Inuktitut: A multi-dialectical outline dictionary. Nunavut Arctic College, Iqaluit, Xi+195 pp
Statistics Canada (2006) http://www12.statcan.ca/english/census06/data/profiles/aboriginal/. Cited 30 June 2008
Tassugat N (2001) Interview by Shari Fox and Geela Tigullaraq. 25 June 2001. Clyde River
Thorpe N, Hakongak N, Eyegetok S, the Kitikmeot Elders (2001) Thunder on the Tundra: Inuit Qaujimajatuqangit of the Bathurst Caribou. Generation Printing, Vancouver, British Columbia
Wenzel GW (2000) Sharing, money, and modern inuit subsitence: obligation and reciprocity at Clyde River, Nunavut. In: Wenzel GW, Hovelsrud-Broda G, Kishigami N (eds) The social economy of sharing: resource allocation and modern hunter-gatherers. Senri ethnological studies, vol 53, pp 61–87