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Changes in weather persistence: Insight from Inuit knowledge

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ABSTRACT

Since the 1990s, local residents from around the Arctic have reported changes in weather predictability. Examination of environmental measurements have not, until now, helped describe what the local inhabitants have been reporting, in part because prior studies did not focus directly on the persistence aspect of weather. Here we show that there is evidence of changes in persistence in weather over the last two decades for Baker Lake, Nunavut, Canada. Hourly data indicate that for local spring, the persistence of temperature has changed dramatically in the last 15 years with some years showing a strong drop in day-to-day persistence in the local spring afternoons, somewhat at odds with changes in persistence on a more global scale. Changes in daily persistence may have implications for human health, agriculture, and ecosystems worldwide. More importantly, the approach of merging indigenous knowledge with scientific methods may offer unexpected benefits for both.

1. Introduction

All over the world, people depend on, or are influenced by, the daily weather to varying extent. For many Inuit, weather is the main determining factor of daily activity. Reading and understanding weather conditions, and how these conditions interact with other aspects of the environment (e.g. open ocean, or sea ice) is critical to safe travel and successful hunting. As a result, experienced Inuit hunters have great depth of knowledge of the environment and weather patterns, founded on generations of wisdom and combined with a lifetime of experience on the land. Because Inuit knowledge of the environment, including weather, has always been tied directly to decisions that could mean the difference between life and death, it comes with precise, descriptive language, careful observation techniques, and a focus on practice, so that knowledge is constantly tested and refined.

Scientists have recently become interested in indigenous environmental knowledge in the Arctic and in particular, observations and assessments of how the environment is changing (e.g. Krupnik and Jolly, 2002; Huntington and Fox, 2005; Riewe and Oakes, 2006; Pearce et al., 2009). Of all of the changes witnessed, increased weather variability stands out as one of the most concerning changes shared across several regions (Krupnik and Jolly, 2002; Huntington and Fox, 2005; Nickels et al., 2006). Many elders and hunters who are experienced weather forecasters are finding that they can no longer predict the weather using their traditional skills and knowledge. Though they are aware that some traditional skills are being eroded since the move from a nomadic life to sedentary communities, Inuit forecasters argue that it is the weather patterns, more than their skills, which are changing.

Climate scientists have searched for changes in weather characteristics to match reports from the Arctic with generally inconclusive results. While reports on changes in mean temperature have been consistent for surface air temperatures (e.g. studies that looked for changes in variability generally showed weak or conflicting results (Karl et al., 1995; Karl et al., 1996; Weatherhead, 1998)). Karl et al. (1995) showed day-to-day variability decreased at some sites over recent decades, but these trends did not persist over the longer records. Karl et al. (1995) among others showed little change in frequency or intensity of heat spells or cold spells lasting a few days. More recently, Alexander et al. (2006) showed some changes in the frequency of 5 consecutive days of either unusually hot or unusually cold days for less than half of the locations around the globe. Caesar et al. (2005) also showed regional changes in the top ten percent of temperature data, particularly in winter, while many Inuit reports have focused on changes in spring. Through the US Climate Change Science Program, a recent report (CCSP, 2008) highlights some changes in frequency of extreme events as the mean temperature of the Earth has risen in recent decades. Part of the reason for differences in results is due to the many different ways to look at changes in weather characteristics (Weatherhead and Tanskanen, 2005). None of these methods seem to identify changes that match Inuit reports. Without a link to scientific understanding, it is difficult to determine whether the phenomena reported by Inuit would

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continue with an increase in greenhouse gases or is related to another phenomenon changing in the Arctic, e.g. multi-decadal changes or influences of land-cover changes.

2. Inuit and weather forecasting

Inuit all across the Canadian Arctic and beyond have been practicing traditional weather forecasting for generations (e.g. Nelson, 1969; Oozeva et al., 2004). Like other northerners who depend on the land and ice for their livelihoods, Inuit in Nunavut observe a variety of indicators to understand and forecast weather. Fig. 1 shows an elder carefully studying the sky for indications of future changes in weather. Wind direction and speed, cloud formations, animal behavior, and the stars, sun, and moon are all examples (e.g. Henshaw, 2006; MacDonald, 1998). For example, dogs or *tulugait* (ravens) starting to move around during high winds or a blizzard indicate that a storm is nearing its end (Angutikjuak, 2008). Or, the twinkling or colour of stars can predict temperature conditions and wind:

> “I know that *Singuuriq* (Sirius) was used to predict the weather and the severity of the temperatures. When the weather is going to be extremely cold the star turns reddish. If the star does not twinkle, milder weather will come. And when the wind is going to blow, the star behaves like a flame exposed to a draft” (Amarualik, 1992 in MacDonald, 1998:74).

Fig. 1. In Canada, Inuit elders experienced in traditional weather forecasting are unable or reluctant to use their prediction skills and hunters are packing extra travel supplies, expecting delays due to unpredictable storms and bad weather. Inuit report that changes in weather patterns are tied to many other changes in the environment including sea ice conditions, snow characteristics, and animal behavior. Here, Lasalie Joanasie checks weather and sea ice conditions during spring seal hunting near his community of Clyde River, Nunavut (photo Jakob Gearheard).

Some reports focus on certain shapes, colour, or movement of clouds that can indicate weather change:

> After a good number of clear, calm days, you see long thin black clouds forming in the north over the land just above the horizon. They would say the *Ugjunguaq* (“those that resemble the bearded seal” [possibly altocumulus lenticularis]) have appeared. Once those clouds have appeared then you shouldn’t make plans to hunt on the moving ice. The wind doesn’t begin right away [perhaps] a couple of days later, but once it does there’ll be continuous wind for a few days. That is what happens. If the black clouds I mentioned appear from *Kanangnaq* (NNE) then you know that there is going to be bad weather for some time. If you are out in a canoe during these conditions, you should make every effort to get to your destination while the weather is still good. These clouds indicate bad weather that will last for some time. Hunters of the past knew these things ahead of time (Piugaattuk 1988 in MacDonald, 2004:210).

Clouds, in particular, are useful to Inuit forecasters. Henshaw (2006:181) documents eleven distinct cloud formations that are used specifically for weather forecasting, such as *nirliviliit*, “high clouds that resemble the roof of your mouth; brings blizzard (*piqsiq*), and *kananasiktu*, a “cloud with NW wind that brings windy weather”.

Traditionally, Inuit honed their skills in weather forecasting from a very young age. Adults and children alike would “*anijaaq*”, the routine of going outside each morning as soon as possible after waking to observe the weather. Children were sent out from a very young age and expected to report the weather. When they returned inside, children were quizzed repeatedly, and sent out repeatedly, until they were able to describe in detail wind direction, cloud patterns, sky condition, and so on. In this way Inuit children were taught the skills of weather observation and forecasting, skills they would continue to develop and refine through a lifetime of living off of the land.

Inuit today have observed that their forecasts are not as accurate, or do not work at all, due to a mix of changing traditions and changing weather (e.g. Henshaw, 2006; Paneak, 2001; Qillaq, 2000, 2001; Fox, 2004). The tradition of *anijaaq* is not practiced as it once was, though many elders and older hunters still check the weather religiously each morning, if only from a window. These experienced forecasters, still active on the land, recognize that some of their traditions have weakened over the decades since moving into modern settlements in the 1950s and 1960s, but emphasize it is increasing weather behavior, not loss of skill, which makes it extremely difficult to predict the weather these days. Specifically, in Clyde River and Baker Lake Nunavut, where we focus our study, experienced forecasters point to the 1990s as the period when their skills first began to fail (Fox, 2004). Elders from each community:

> “Inuit have this traditional juggling game where you juggle three rocks and we keep changing the rocks from one hand to the other. The weather is sort of like that now; it’s like the weather is being juggled, the weather keeps changing so quickly and so dramatically” (Attungala, 2001).

> “I’m a really outdoors person and I’ve always been outdoors ever since I was a child. I’m a hunter that goes out regularly and

I've always watched the weather and it is more unpredictable than in the past. Sometimes I guess that it would be a clear day and then all of a sudden bad weather comes. My predictions used to work and I used to give advice to younger people about going out, whether to go out or stay home. But I can't do that today because it is so unpredictable" (Qaqqasiq, 2001).

3. Prior focus of climate change research

Many scientific efforts to examine climate change focus on two metrics of change: changes in mean values, such as mean temperature increase, get much of the popular attention (e.g. Trenberth and Jones, 2007; Karl et al., 1995, 1996; Serreze et al., 2000); while changes in extreme events, including hurricanes, *El Niño*, and droughts, have received increased attention in the last decade (Alexander et al., 2006; CCSP, 2008). Inspired by the observations and knowledge shared by Inuit around weather variability and predictability, this paper looks at another dimension to change that we might experience with the increase in greenhouse gases: changes in the character of weather.

Of the many scientific interpretations of weather characteristics, Inuit knowledge may best relate to the coherence of weather patterns. For meteorologists, this is described as persistence—the tendency of a warmer than normal day to be followed by another warmer than normal day. Persistence of weather patterns is a fundamental quality determined by the rotation and surface features of the Earth and the viscosity and structure of the atmosphere. Mathematically, persistence defines an entire branch of statistics, with a suite of tools for analysis, some of which are shown to be useful in this study (Box et al., 1997). Observationally, we know that persistence depends, in part, on location, with coastal areas often showing more persistence as well as lower variability in the magnitude of temperature swings for typical weather. The area examined in this paper, Baker Lake, is in the high Arctic, but far from large bodies of water (Fig. 2).

4. Quantifying persistence at Baker Lake

Inuit observe and are influenced by a variety of environmental factors when studying the weather (e.g. Henshaw, 2006; McDonald et al., 1997). Individual parameters are usually not singled out, but rather, various factors are assessed together (e.g. wind, ocean currents, animal behavior, sea ice movements, cloud formations and their movements and patterns) and there is an emphasis on relationships and interactions between various elements observed. Scientific measurements, on the other hand, capture individual parameters and scientists will often focus on wind or temperature records because they are the most often measured and have high value in numerical weather forecasting (e.g. Girz et al., 2002). In this study, we look at temperature records, not because temperature is the most important parameter, but because it can serve as a proxy for changes in weather patterns.

To examine the persistence of weather at Baker Lake, a 50-year record of hourly temperature data were examined. Following, 16 estimates of day-to-day persistence were calculated based on autocorrelation of lag 1 day:

$$\gamma \approx \left[\frac{\sum_{i=2}^{n}(T_i - T_{i,\mathrm{mean}})(T_{i-1} - T_{i-1,\mathrm{mean}})}{\sum_{i=2}^{n}(T_i - T_{i,\mathrm{mean}})(T_i - T_{i,\mathrm{mean}})}\right]^{1/2}$$

where γ is the autocorrelation for lag of 1 day, n is the number of daily datapoints, T_i is the temperature at day i, $T_{i,\mathrm{mean}}$ is the seasonally expected value for temperature on that day. This value is the correlation of the time series of daily temperature anomalies with the same time series lagged by 1 day, similar to what was presented in Weatherhead et al. (2002) for monthly values of temperature data. Results show that for much of the year, there is

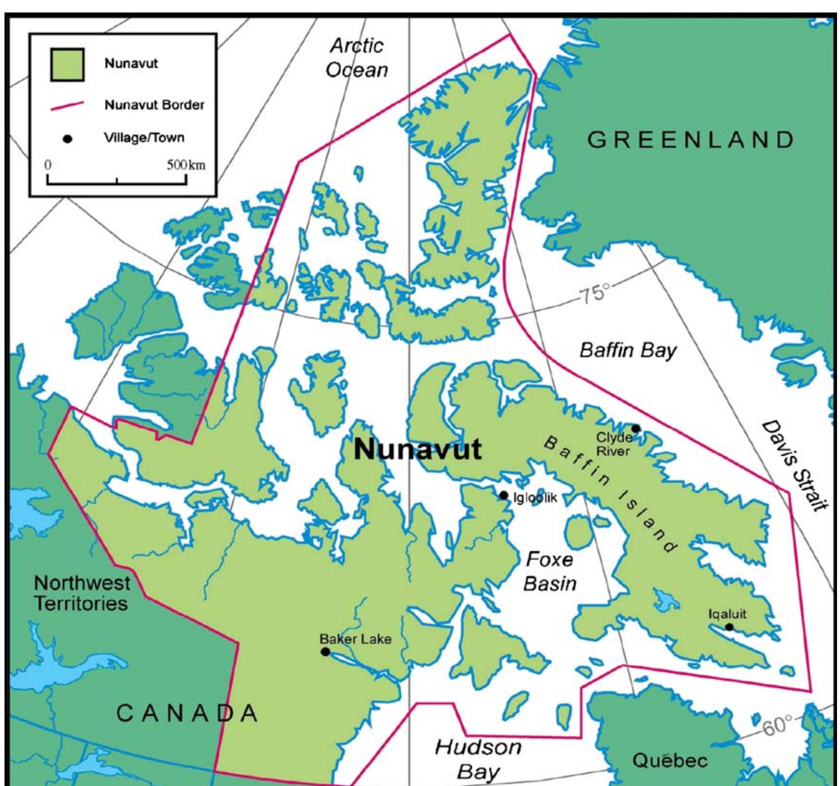

Fig. 2. Baker Lake and Clyde River, Nunavut, Canada, are communities where Inuit reports were recorded and have long-term meteorological data for examination. Baker Lake, the focus of this study, is fairly removed from the highly variable Arctic sea ice.

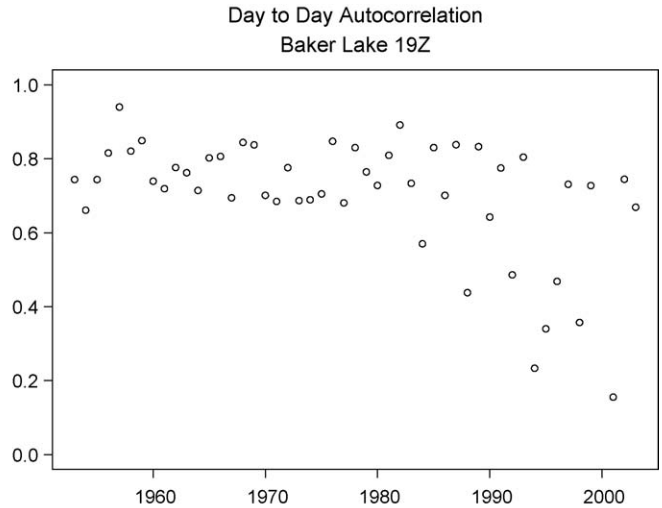

Fig. 3. Day-to-day autocorrelation was computed for the daily afternoon (2 pm local time standard time) temperature for each June from 1953 through 2004. The autocorrelation represents how persistent temperature variations are. It is not yet understood why some years show near-historical levels of persistence, while other years show a strong change towards less persistence.

no significant change in autocorrelation. However, during spring, the time of year most frequently cited by local Inuit as being increasingly unpredictable, a significant change was noted in the autocorrelation when we look at afternoon temperatures (Fig. 3). For the first several decades, the persistence is stable, near 0.8. For the last 20 years, the persistence has dropped implying more chaotic daily variability, although not necessarily larger temperature swings. This finding is consistent with local reports that the weather is more difficult to predict and that this difficulty started in the early 1990s. This approach of looking at daily autocorrelation was first used by Barry (1986) to understand weather persistence in mountainous conditions. Walsh et al. (2005) used a related approach for analyzing data in the Arctic but did not find a significant change in persistence using daytime values. In contrast, this study used a different statistical method that isolates short-term persistence and focuses on the time period of local spring, which was identified by Inuit observations to be the time of most change in weather predictability. For Inuit at these far northern locations, local spring occurs in June, when seasonal snow melt may be complete or nearly complete.

5. Physical interpretation

Baker Lake shows an interesting change in daily persistence of temperature, which has a unique signature. It occurs most strongly in the local spring, June, and is strongest in the late afternoon. Several possible explanations exist, including changes in surface albedo and weather patterns. The time signature of these changes imply that the boundary layer, the lowest few kilometers that is generally highly convective and to some extent isolated from the upper atmospheric layers, is disrupted during the years of low persistence. This disruption may be caused by the high radiative emissions at the surface when the snow melts off. The diurnal and seasonal signatures of this change support this theory, along with the observation that the years of low persistence are generally the years that show the higher mean temperatures. If this explanation is correct, then as temperatures continue to increase, we may expect further decreases in the persistence of weather systems. However, confounding this result, is that the observation of changes in persistence were not well supported by temperature data at Clyde River, Nunavut, another Arctic station from a different region analyzed in a similar manner but a location where local Inuit also report increasingly unpredictable weather (Fox, 2004). An analysis of Arctic stations for which only daily minimum and maximum temperature were available confirm that these changes in persistence can be highly local in effect, perhaps related to very local land changes or very local cloud changes. However, strong changes in the boundary layer structure at one location can have significant regional implications. As the relatively dry upper air mixes with the boundary layer air, the net result can have a large drying effect on the entire region depending on the level of mixing that takes place.

6. A global perspective of persistence

To test whether the results observed at the Baker Lake station are indicative of changes around the world, the daily temperature record from channel 2 of the Microwave Satellite Unit (MSU) sensors, which is a proxy for daily tropospheric temperature values, was examined for changes in day-to-day persistence (Fig. 4). The daily record exists for latitudinally averaged sections of the Earth and therefore is not completely comparable to the single station analysis. To put these values in perspective, most single stations at mid-latitudes exhibit day-to-day autocorrelation of between 0.4 and 0.8; while the autocorrelation for latitudinally averaged datasets with most latitudes showing autocorrelation values of between 0.90 and 0.95. These observed changes in autocorrelation from MSU are notably large, given that the trends span almost three decades and that typical changes of 0.010 per decade indicate autocorrelation values may be changing from 0.92 to 0.95, nearing the mathematical limit, although physically unachievable, for autocorrelation as defined here as ranging up to 1.0.

The plots show trends in derived autocorrelation from latitudinally averaged temperature data. The solid dots show when the observed trend is significant at the 95% confidence level, assuming an AR(1) behavior, where in this case, the time step for the AR process is 1 year. Unlike the Baker Lake station shown in Fig. 2, most of the Earth, when examined in a latitudinally averaged view, has shown an increase in day-to-day persistence. However, the high northern latitudes, where Baker Lake is situated (64°N) show slightly negative trends in autocorrelation even for regionally averaged values allowing for some consistency for

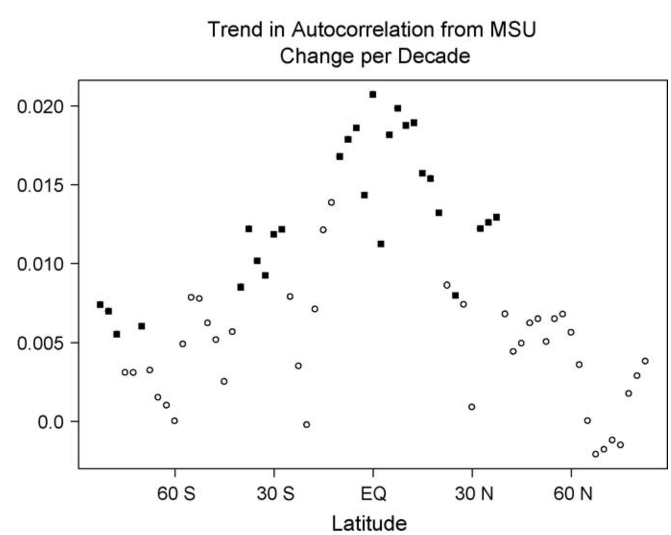

Fig. 4. Latitudinally averaged temperature values from satellite are examined for changes in day-to-day persistence. Typical autocorrelation values for all latitudes range between 0.90 and 0.95 for most locations. Over the past 30 years there has been a tendency for an increase in persistence. The solid dots indicate that the observed trend is significant at the 95% confidence level.

what is observed at the individual stations and what is observed in the broader region encompassed by the latitudinal averages. These results are supported by reports from Kyselŷ and Domonkos (2006), Cassano et al. (2006) and Kyselŷ and Huth (2008) which indicate systematic changes in weather patterns for the northern hemisphere.

7. Implications for the future

There is some indication from previous studies that weather systems may last longer as greenhouse gases increase. Mickley et al. (2004) examined GCM output and showed that weather systems that can result in pollution events damaging to human health might increase in duration from roughly 2 days to over 3 days (supported by Cassano et al., 2006). This result is in qualitative agreement with the mid-latitude results presented here.

The results from this study show that while individual stations may show a decrease in persistence, the Earth, for the most part, has shown an increase in persistence. The implications for changes in persistence of weather are not well studied. However, one can extrapolate from changes in temperature persistence to changes in other weather related phenomena. Just as Inuit hunters traveling on the sea ice need persistence in order to complete a long journey, biological systems need rain at semi-regular intervals for survival: changes in the distribution of how often precipitation occurs may be well more important than changes in the annual totals of precipitation. Efforts to examine persistence in precipitation struggle similarly to find an appropriate metric to describe persistence but can be even more challenging than temperature because of the binary nature of precipitation (e.g. Brubaker and Entekhabi, 1996; Taylor and Lebel, 1998; Carvalho et al., 2004).

8. Further bridges between indigenous and scientific knowledge of climate change

If this initial work proves relevant to climate change and climate effects, it can serve as a lesson of how we choose and examine science questions. In this case, Inuit hunters and elders raised an issue that had not been fully addressed in the scientific literature—the increased variability and unpredictability of weather. Connecting indigenous knowledge and science is useful and valuable, but most projects in the Arctic have focused on conceptual links or challenges (e.g. Nadasdy, 1999; Huntington et al., 2004; Laidler, 2006) with less work on practical applications (e.g. Gearheard et al., in press). Future projects that bring scientists and Inuit together at the project design stage and follow through with collaborative analysis and reporting are likely to reveal even more detailed findings.

As weather characteristics continue to change in the Arctic, Inuit continue to adapt. Hunters take precautions such as carrying extra supplies in anticipation of bad weather (Gearheard et al., in press). The changing weather conditions are intricately linked to other changes in the environment including those in sea ice, snow, animal populations, and vegetation. Continued weather changes will offer new challenges for those living in the Arctic, with physical, chemical and biological effects that have yet to be explored.

Merging different sources of knowledge and linking specific observations is a complex task but can lead to important insights into the changing Earth. This paper is one example where specific observations of Inuit hunters and elders led to specific data analyses and discoveries by scientists. As efforts in making full use of indigenous knowledge continue, several points are clear. First, indigenous knowledge is distinct from scientific knowledge—neither should be used as a superior form of understanding. Indigenous knowledge must be documented with care and in collaboration with indigenous partners to assure unbiased and full accounts and proper interpretation, analysis, and application. And, perhaps most importantly, some knowledge such as Inuit weather forecasting techniques is disappearing and collaborative efforts in research can help to preserve this knowledge through documentation and especially field research and education that help to facilitate practice, and the passing on of knowledge in situ. Traditional insights and understandings are a resource that can offer unexpected benefits if properly preserved and understood.

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Contribution. Shari Gearheard interviewed Inuit hunters and elders and recorded their observations. Betsy Weatherhead performed the statistical analysis and developed the technique for quantifying persistence. Roger Barry oversaw and guided the project.

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