Understanding observations of selected environmental changes in communities surrounding the Bering Sea

Authors:

Paula Williams, Alaska Experimental Program to Stimulate Competitive Research

E. Jamie Trammel, Alaska Center for Conservation Science

Frank Witmer, University of Alaska Anchorage

Rieken Venema, University of Alaska Anchorage

Andy Kliskey, Center for Resilient Communities, University of Idaho

Grace Beaujean, Resilience and Adaptive Management Group, UAA

Lilian Alessa, Alaska Experimental Program to Stimulate Competitive Research

Lead author: Paula Williams pwilliams@uaa.alaska.edu

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ABSTRACT

Data in remote Arctic communities is sparse and can be unreliable. Proposals have been made to use Community-Based Observing Network and Systems (CBONS) as human sensor-arrays to increase collection of data and knowledge in the Arctic. Cognitive neuroscience suggests that natural selection has not shaped our perceptions to be an accurate representation of objective reality, but to be a species-specific guide to behaviors that we need to survive and reproduce. An understanding of which human perceptions are more or less reliable is essential if human-arrays are to be used. This study sought to investigate the correspondence between observations made by community members selected based on their length of residence or amount of time spent on the land and the sea, to local instrumented data. Interviews were conducted in communities bordering the Bering Sea in the Russian Federation: Nikolskoye, Tymlat and Kanchalan; and in Alaska: St. George, Togiak, Sand Point, Savoonga and Gambell.

Survey participants answered questions about a wide range of environmental changes. We selected environmental changes for comparison only if robust instrumented data records existed with which to compare them. The environmental variables that met those criteria were: air temperature, changes in vegetation, and freeze up and break up of sea ice surrounding St. Lawrence Island. We examined the correspondence of community-based (local) knowledge and instrumented data. The results suggest that observable stimuli that are tied to ability to gather food and to safety are more accurately perceived and that high variability in stimuli makes accurate perception difficult.

INTRODUCTION

Considerable scientific monitoring has been conducted in the Arctic; including ocean surface current sensors, buoy networks, and subsurface glider observations at sea; and terrestrial gauges, and meteorological stations on land. Instrumented records of environmental conditions in Alaska present challenges. The geographic area of Alaska and the Arctic is immense. Gauges are inadequate to reliably monitor environmental changes because they are sparse and are often placed in populated areas and near-shore locations which are easy to access and maintain. As a result, there is very little instrumented data at fine scales (Alexander et al. 2011) causing inconsistencies between instrumented data and community-based observations. Additionally, records often do not extend far back in time, or are kept for a limited time period and are then discontinued (NRC 2006).

Increasing the number of observations in the Arctic is critical since it is a bellwether of climate change. Incorporating Community-Based Observing Networks and Systems (CBONS) into a "data web"; a human sensor-array creating a network of observation stations across the Arctic, would improve data availability as well as response to change in the Arctic. Observing Networks are currently used to observe arctic events and changes as part of scientific monitoring efforts (Alessa et al. 2015). In Alaska these include, but are not limited to, the Arctic Ocean Observing System, the Global Ocean Observing System, the Arctic Observing Network, and the Sustaining Arctic Observing Network for global level efforts (Alaska Ocean Observing System 2015). There is increasing interest to augment and enhance these observing networks with CBONS, that could potentially allow observations based on scientific instruments to be coupled with local community-based observations of change.

The Bering Sea Sub-Network: A Distributed Human Sensor Array to Detect Arctic Environmental Change (BSSN) was an international community-based observation alliance for the Arctic Observing Network. This project was initiated to improve knowledge of environmental changes occurring in the Bering Sea in order to enable Arctic communities, governments and scientists to predict, plan and respond to these changes. The BSSN and its successor, the Community-based Observing Network for Adaptation and Security (CONAS), is composed of eight indigenous communities bordering the Bering Sea in the Russian Federation and Alaska, USA. In Russia participating communities are Nikolskoye (Western Aleut/Unangas), Tymlat (Koryak), and Kanchalan (Chukchi); in Alaska participating communities include Gambell, (Siberian Yupik), Savoonga (Siberian Yupik), Togiak (Central Yup'ik), St. George (Eastern Aleut/Unangan), and Sand Point (Eastern Aleut/Unangan). All communities are dependent on subsistence resources from the productive Bering Sea.

Figure 1: Map of communities surveyed and assessed for environmental change.

Knowledge contributed by CBONS is predominantly local place-based knowledge (LPBK) that, in the communities included in this study, also incorporates Indigenous Knowledge (IK). In this paper, because of the demographics of the communities included in the study, we use the terms community-based knowledge and local place-based knowledge synonymously. In a changing Arctic LPBK has much to offer, although integration with dominant Western scientific tradition can be difficult. Integration challenges have led to the underutilization of this knowledge (Huntington et al. 2004). Nonetheless, LPBK has made contributions to adaptation research by elucidating vulnerability to environmental change and exploring appropriate adaptive actions and interventions (Brubaker et al. 2011, Collings 2011, Ford & Pearce 2012, Pearce et al. 2009, Riedlinger 2001, Tremblay et al. 2007). Beyond expanding data availability, other important goals of LPBK research include: 1) shaping policies toward greater relevance to those affected (Ford et al 2010, Mahoney et al 2009, Meek et al. 2008); 2) more equitable power sharing by co-producing knowledge (Gearheard & Shirley 2007); 3) contributing to an understanding of social processes that relate to use of natural resources (Wolfe et al 2007); 4) providing alternative perspectives of ecological change (Berkes et al 2007); 5) guiding scientific inquiry (Carmack & MacDonald 2008), and; 6) capacity and relationship building (Pearce et al. 2009).

Local place-based knowledge (Indigenous Knowledge and Traditional Ecological Knowledge) and Western science instrument-derived data

Traditional Ecological Knowledge (TEK) is a subset of LPBK that relates specifically to ecology. Traditional Ecological Knowledge and Western science are similar because both are based on an accumulation of observations, but there are also differences between these two ways of knowing. Descriptions of TEK vary, but most include: 1) detailed systematic observations of the environment of a specific place through direct interaction; 2) an active process that makes use of new information and often includes elements of knowledge handed down through generations (Berkes et al. 2000; Mauro & Hardison 2000; Ramnath 2014; UNEP 2008), and; 3) a holistic understanding of ecosystems and interactions among ecosystems and human socio-economic systems (Philip 2001). Fienup-Riordan and Carmack (2011) characterize it as tacit knowledge embodied in life experiences and reproduced in everyday behavior and speech. Indigenous knowledge (IK), while encompassing cumulative place-based observations of natural phenomena that includes humans and non-human others, additionally integrates and acknowledges humans as part of the natural world and its processes (Pierotti et al. 2000). In TEK and IK, cues are rich, and observations are holistic.

Fienup-Riordan and Carmack (2011) define Western science as: 1) investigations based on the scientific method; 2) a body of techniques for formulating and testing hypotheses, and; 3) based on systematic observation, measurement and experiment. Scientists typically view Western science as analytical, reductionist, positivist, objective, and quantitative (Berkes et al. 2000; Fienup- Riordan & Carmack 2011; Mauro & Hardison 2000; Ramnath 2014). Western scientists typically simplify and control their experiments, sometimes studying a single isolated parameter, and purposely attempt to isolate themselves from context (Fienup-Riordan & Carmack 2011). Western science is able to examine phenomena at larger scales, but often during shorter increments of time. In the Arctic, observations occur largely during the summer field season and projects are often five years or less (Eicken & Lee 2013). In this paper, following Alexander et al. (2011), we define science as “a set of statistically analyzed data or instrumental records . . . that can be empirically measured and that demonstrate acceptable levels of reliability and validity” (p. 477). We refer to the instrumented data we use in this paper as Western Science Instrument-Derived Data (WSIDD). And the place-based local observations are referred to as community-based observations. We also note that while some community-based observations may overlap with TEK or IK, for particular observers, but they are not synonymous.

Community-based observations of change in the Arctic

Natural selection has not shaped our perceptions to be an accurate representation of objective reality, but has shaped our perceptions to be species-specific guide to behaviors that we need to survive and reproduce (Hoffman 2009). Perceptions are a complex interaction among the organism, the environment, and the social context in which an organism is found (Hoffman 2009; Hoffman & Prakash 2014). We are not capable of perceiving or observing everything that surrounds us, and, similar to optimal foraging strategy, to do so would require too much energy and time for us to observe and process. Hence, natural selection has shaped our perception to attend to that which most highly relates to our survival and ability to reproduce (Hoffman et al. 2015).

Additionally, environmental conditions are an adaptive system with great variability and can be difficult to quantify (Levin 1998). We have assumed that observers who rely on the land and sea for their food may be particularly adept at observing and reporting complex ecological systems. Few studies have compared community-based observations to instrumented data. An understanding of under what circumstances community-based observations are most accurate would be beneficial in the continued use of CBONS. "The purpose of such comparison is not to 'validate' one set of observations in terms of the other. Rather, it is to combine them while taking advantage of their differences . . . ." (Huntington et al. 2004, p. 18).

Studies that have examined whether community-based observations and instrumented data have converged include: Prno et al. (2011) who found convergence between scientific literature related to trends in temperature and precipitation and observations of changes to sea ice by residents of Kugluktuk, Canada. Fienup-Riordan and Carmack (2011) documented a correspondence between Western science studies and TEK understanding of the response of sea ice to ocean waves, swells and tides, the formation of shore ice and ice piles and changes in timing of break up and freeze up in villages along the west coast of Alaska.

Inuit elders in the Foxe Basin, Canada characterized the summer ice conditions and late freeze up of 2006 as being "unprecedented in living memory" and instrumented records supported both observations (Ford et al. 2008). Weatherhead et al. (2010) examined the Clyde River/Baker Lake region of Nunavat, Canada. A 50-year record of hourly temperature data confirmed local residents' observations that weather was less predictable due to an increase in variability.

Herman-Mercer et al. (2011) compared local observations of weather, river conditions, flora and fauna in two small villages on the lower Yukon River, Alaska: St. Mary's and Pitka's Point and Huntington et al. (2004) compared local observations of plants, lichens, and insects across northern Canada and northwest Alaska found correspondence in most observations. In both of these studies, TEK observations occurred at local scales while scientific observations occurred at regional scales, primarily across the Arctic. Ambrose et al. (2012) found expert fishers in Kotzebue Alaska to be more sensitive to environmental change as compared to elders and expert hunters. This study suggests that TEK knowledge may be domain-specific.

Community-based observations, and TEK specifically, have been compared to fuzzy logic, which employs heuristic rules. Fuzzy logic enables people to successfully navigate ecological complexity (Berkes & Berkes 2009) and provides flexibility for people to adapt and thrive in natural environments (Turnbull 2000). Expert fishers have been shown to use heuristic rules to process ecological knowledge (weather, fish behavior, 'folk oceanography', etc.) to make decisions related to fishing (Grant & Berkes 2007). Nonetheless, there is likely to be some uncertainty present as understanding ecosystems is a complex process and observations of the environment are seen through the filter of human perception. While these studies make specific reference to TEK we argue that they are not unique to Indigenous populations but apply more broadly to place-based local knowledge or community-based observations generically.

Other research has found a lack of correspondence between community-based observations and instruments. Gearheard et al. compared wind data with observations at Clyde River, Nunavut, Canada and found little correspondence between observations and instrumented data (2010). Alessa et al. (2007) found differences between perceptions of change in water quality and quantity of younger observers compared to middle-aged and older observers in western Alaska, finding that accuracy increased with age. Ambrose et al. (2014) found that expert fishers were more highly attuned to environmental changes in marine species than were elders or expert hunters.

METHODS

Social Data: Community-based data were collected as part of the Bering Sea Sub-Network (BSSN) project funded by the National Science Foundation. Community Research Assistants (CRAs) were hired from within the community to conduct interviews. All interviewers were trained and provided with guidelines on interviewing. Consent was obtained from all participants in the study. The same questions were asked at all locales, albeit in languages appropriate to the survey respondents: English, Russian, Yup'ik or Siberian Yupik. Interviewers were different in each village and larger villages had two interviewers. Community experts and project personnel created a list identifying knowledgeable elders and high harvesters, defined as those who frequently harvest in their community, and had done so for 15 or more years. Directed sampling was used with the goal of capturing a majority of high harvesters and knowledgeable elders.

Survey questions assessed observed change in a variety of environmental variables including: timing of freeze-up and break-up, ice conditions, wind direction, wind velocity, air temperature, water temperature (sea, and river or lake), frequency and intensity of storms, snow conditions, rain and changes in vegetation. Surveys included multiple-choice and open-ended questions. For each environmental condition, the respondent was first asked the yes, no or don't know question, "Have you observed changes in (environmental condition) in the past 15 years or longer?" Next they were asked what changes they had observed in that time period and the direction of change specific to each season. They were then asked, "When did you first notice these changes?"

Quantitative data from the surveys in the form of yes, no, or don't know responses to the question whether participants had observed change were analyzed using SPSS 22 and 23. We aggregated spring and summer seasons and fall and winter seasons in questions about temperature change as studies predict that fall/winter temperatures will increase more than summer temperatures in the northern latitudes (Kirtman et al., 2013, p. 984). We defined spring/summer as April through August and fall/winter as September through March. For the qualitative data indicating direction of change, emergent coding in NVivo was used to categorically organize observational data.

Biophysical data: Based on papers assessing the reliability of WSIDD gauged data in Alaska written by Kane & Stuefer (2015) and by Bauret & Stuefer (2013) we eliminated instrumented precipitation records as being insufficiently reliable for comparison to human perceptions.

Instrumented data for wind had a significant percentage of missing values for all communities and it was determined that this data was not sufficiently reliable as well. We analyzed missing values in the air temperature datasets; and examined the scientific literature for studies on environmental changes in the area in which the villages are located. We assessed satellite imagery to determine whether sufficient data existed to test vegetation change in the villages. We determined that sufficiently robust air temperature data existed for Nikolskoye, Tymlat, Togiak, and Sand Point; scientific studies of ice break up and freeze up for Savoonga and Gambell; and satellite images of vegetation change for all villages except St. George.

Air Temperature: WSIDD air temperature data were downloaded from the National Oceanic and Atmospheric Administration's (NOAA) National Climate Data Center (NCDC). Monthly or daily datasets were selected based on which was more complete (Lawrimore et al. 2011). The datasets were analyzed for missing values. The villages included in the analysis (because 90% or greater of the data was available) were: Nikolskoye, Tymlat, Togiak, and Sand Point. As with the social data, we analyzed spring/summer and fall/winter temperature data separately, defining spring/summer as April through August and fall/winter as September through March.

Trend analysis for fall/winter and spring/summer months was conducted using Minitab 17. The average temperature was calculated for the time periods available for each village. A fitted time series was determined using linear regression analysis; specifically the sum of the squared vertical distances from all observations was minimized to the fitted line. We calculated a 95% confidence interval for the slope of the line of best fit. Of particular importance, is the sign of the slope of the trend line from which we could conclude with 95% certainty that temperatures had increased (positive confidence interval) or decreased (negative confidence interval).

Because trend analysis does not indicate whether a statistically significant change has occurred, we used a two sample t-test. The purpose of the two-sample t-test, also known as the (non-pooled) independent samples t-test, is to perform a hypothesis test to compare two population means. Under the assumption that the two observed datasets are independent simple random samples from two normal populations, we tested the null hypothesis that the means are equal versus the alternative hypothesis that the means are not equal, using a fixed significance level of .05. The two-sample t-test is known to be robust to moderate violations of the normality assumption.

The time periods used to compare means for each village were determined by calculating the median year in which respondents said that they had started noticing changes in temperature (hereafter the median year). The time period from the start of data availability to the end of the year immediately preceding the median year was compared to the time period from the beginning of the median year to the end of the time that the social survey was administered in the relevant village. The comparison periods for each village are as follows: Nikolskoye (January 1979 through December 2003, and January 2004 through May 31, 2010); Tymlat (January 1981 through December 2005, and January 2006 through August 31, 2010); Togiak (July 1992 through December 2007, and January 2008 through December 31, 2012); and Sand Point (August 1983 through December 2007, and January 2008 through August 31, 2012).

Timing of ice break up and freeze up: WSIDD assessments of ice break up and freeze up times have been conducted for sea-ice surrounding St. Lawrence Island, on which the villages of Gambell and Savoonga are located. A study was conducted by Grebmeier et al. (2006) on the timing of sea ice break-up based on air temperature records. In 2012, Grebmeier examined sea ice retreat in the Chukchi Sea and Bering Sea to just south of St. Lawrence Island. Shimada et al. (2006) studied sea surface temperature and its effect on ice formation in the Chukchi and Beaufort Seas which surround St. Lawrence Island. The heat flux through the Bering Strait has steadily increased from 2001 to 2007 (Woodgate et al. 2010). These studies were used to assess community-based observations of sea ice change.

Vegetation change: We measured regional vegetation change using MODIS satellite imagery for each of the study communities. Specifically, we used the MODIS 16-day Normalized Difference Vegetation Index (NDVI) composite available through Google Earth Engine (earthengine.google.com). NDVI is regularly used to measure vegetation change and has proven particularly effective in the Arctic and subarctic (Jia et al. 2003, Stow et al. 2003, Verbyla 2008, Pattison et al. 2015). The 16-day composite is especially useful in northern coastal communities where cloud cover often reduces the utility of individual image scenes. Access to Google Earth Engine allowed us to use top of atmosphere (TOC) corrected images (Chander et al. 2009), and facilitated rapid assessment across the different study locations using the entire MODIS archive.

Average NDVI was calculated for a 50km buffer around each village location to represent the general community area of use. Buffers were then modified to remove any ocean so as to not bias the NDVI values. Average NDVI was calculated beginning in 2000 (first year of MODIS) until the survey year for each village using the modified buffers. On average, there were 283 composites available for each village, with occasional gaps during winter months.

Annual NDVI trends were analyzed using Seasonal Decomposition of Time Series by Loess (STL; Cleveland et al. 1990). STL works by removing seasonality to assess long-term trends in NDVI.

RESULTS

Air Temperature

Nikolskoye

Trend analysis indicates that there has been an increase in temperatures in Nikolskoye over the temperature record from 1979 to 2010 for both the spring/summer and fall/winter time periods. Compared to the mean temperature from 1979 through 2003, mean temperature from 2004 to 2010 was about 0.5 °C higher in fall/winter and about 0.9 °C higher in spring/summer. About equal numbers of survey participants observed that it was warmer and that it was colder in the winter and in the summer. Ten respondents indicated that it was colder in fall, whereas 16 said it was warmer. Only spring clearly had consensus, two said spring was warmer and 23 said it was colder. The t test indicated that the increases were not statistically significant, despite an almost 1 °C increase in spring/summer – an indication that air temperature is highly variable in this region.

Tymlat

Similarly, trend analysis indicates that there has been an increase in WSIDD temperatures in Tymlat, over the time period 1981 to 2010, for both the spring/summer and fall/winter time periods. Comparing the two time periods, there was a 0.9 C increase for fall/winter and 0.5 °C for spring/summer. Of 51 respondents, only 22 indicated that there had been a change in temperature. Of the 22 who responded, 7 said that winter was warmer. Responses to questions about temperature change and direction were low. No other question garnered more than four responses. The t test indicated that the increases were not statistically significant, again an indication of variability when considering the overall increase.

Togiak

In Togiak, trend analysis indicated there was a WSIDD temperature decrease in fall/winter of 1.5 °C from 1992 to 2012. Fifty-two percent of respondents in Togiak, however, reported that fall/winter was warmer and 18.6% reported these seasons as colder. In spring/summer, there was a decrease in temperature of about 0.5°C. Smaller numbers of survey participants responded to the question about spring/summer and the largest percentage (11%) indicated that summer was colder. Both trends in temperature were significant in t tests.

Sand Point

Sand Point was colder in both fall/winter (about 0.9°C decrease) and in spring/summer (about a 0.6°C decrease) over the period from 1983 through 2012 based on WSIDD records. Fifty-nine percent of respondents answered the question about air temperature change direction and of those, 36% indicated that both seasons were colder while 23% said both seasons were warmer. T tests for both seasons were significant. See Table 1 below.

Village	Time periods for which means were compared spring/summer	Mean WSIDD change in temp spring/ summer	Percent of participants noting trend shown by instrumented data	Time periods for which means were compared fall/winter	Mean WSIDD change in temp fall/winter	Percent of participants noting trend shown by instrumented data
Nikolskoye	1979-2003 2004-2009	+0.9°C	27%	1979-2003 2003-2010	+0.5°C	47%
Tymlat	1981-2005 2006-2010	+0.5°C	10%	1981-2005 2005-2010	+0.9°C	14%
Togiak	1993-2007 2008-2012	**-0.5°C***	11%	1992-2007 2007-2012	**-1.5°C****	19%
Sand Point	1983-2007 2008-2012	**-0.6°C****	36%	1983-2007 2007-2012	**-0.9°C****	36%

Table 1: Summary of mean change in temperatures, time-periods that means were compared and percent of study participants whose observations were consistent with instrumented data. Significant relationships are in bold. The levels of significance are: *$p < 0.05$, **$p < 0.01$.

Ice Break Up and Freeze Up (Gambell/Savoonga)

Fifty-two percent of Gambell survey participants indicated that ice freeze up was later, and 61% indicated that ice break up was earlier. In Savoonga 52% indicated that ice freeze up was later and 50% indicated that break up was earlier. Grebmeier et al. (2006) calculated the timing of sea ice break-up as occurring 3 weeks earlier just south of St. Lawrence Island based on WSIDD air temperature records, although this was calculated during a warm period in the Bering Sea (2001-2005) which was followed by a cold period (2007-2010) (Stabeno et al. 2012). Just north of the Bering Strait, the Chukchi Sea has consistently had earlier spring sea ice retreat (Grebmeier 2012). Shimada et al. (2006) demonstrated that WSIDD sea surface temperature around St. Lawrence Island increased from 1978-2004, which affected ice formation in the Chukchi and Beaufort Seas surrounding St. Lawrence Island, accelerating break up time. The heat flux through the Bering Strait has steadily increased from 2001 to 2007 (Woodgate et al. 2010). The observations of the majority of St. Lawrence Island residents that break up is occurring earlier and freeze up later support these WSIDD records.

Changes in Vegetation: A majority of survey participants across all villages except Togiak reported that there had not been a change in vegetation. Sixty-nine percent of participants in Gambell, 83% in Savoonga, 72% in Kanchalan, 62% in Nikolskoye, 80% in Tymlat, and 69% of participants in Sand Point answered no to the question whether there had been changes to vegetation. In Togiak, 42% answered that there had been no changes, 41% answered that there had been changes. Statistical analysis of vegetation change shows that there is considerable seasonal and inter-annual variability in NDVI (Figure 2). Decomposing the time-series into seasonal and trend components reveals no long-term trends in NDVI for any location. Figure 2 shows NDVI trends for each of the villages surveyed using the MODIS 16-day composite. To further quantify this result, linear regression models were fit to each time series, with no statistically significant trends detected.

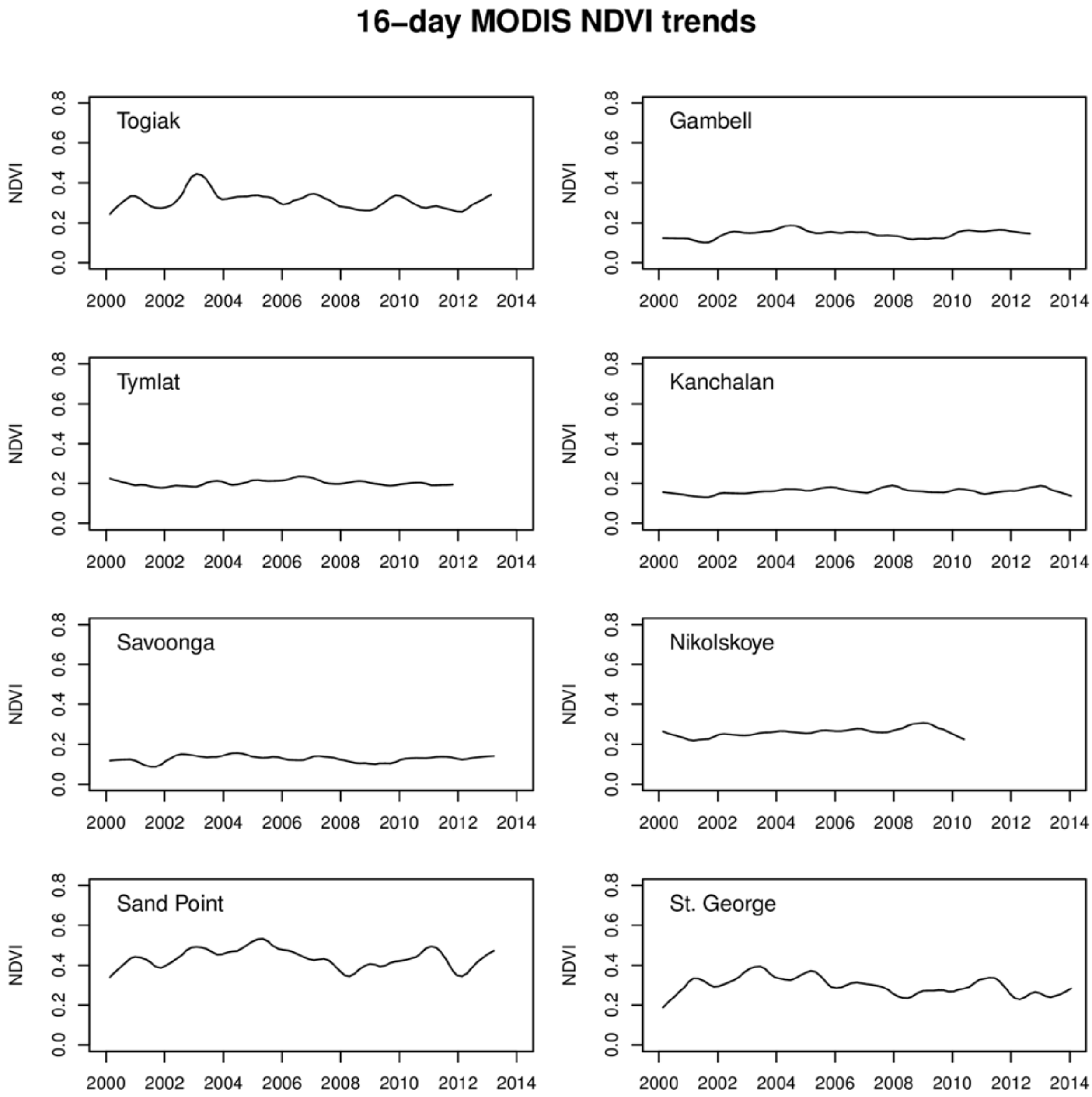

Figure 2: NDVI trends for each of the villages surveyed using the MODIS 16-day composite. Trend analysis was ended on the last survey date (Appendix 1).

DISCUSSION

Air temperature observations

The majority of survey responses in all communities did not correspond closely with WSIDD air temperature trends in either spring/summer or fall/winter. The closest to a majority of corresponding observations occurred in Nikolskoye in which 47% of respondents reported increasingly warm fall/winters in that area (Table 1). It is interesting to note that, with the exception of the relatively larger decrease in spring/summer temperatures in Togiak (~-1.5°C), the mean temperature increases in Nikolskoye and Tymlat were very similar, as were the mean temperature decreases in Togiak and Sand Point. Only Togiak and Sand Point, however, had statistically significant change, indicating that temperatures in Nikolskoye and Tymlat had greater variability.

Despite the overall mean change in temperature in Togiak in the fall/winter of -1.5 °C, the change was not perceived and this relatively large change was not statistically significant because of variability in temperatures. Fifty-seven percent of Togiak residents stated that fall/winter temperatures were warmer, 19% stated it was colder. This suggests that variability may impact community perceptions of changes in air temperature when compared to WSIDD. This is supported by prior research in which respondents of northern communities in Nunavat, Canada reported that weather was less predictable, and this observation was statistically supported by analyzing the increase in variability of the weather in that area based on WSIDD (Weatherhead et al. 2010). At 60˚ North latitude, the rounded latitude of the communities included in this study, mean annual variation in temperature is 30˚C /54˚F. Mean annual variation in temperature increases with increased latitude. (Brigham Young University n.d.). In addition to annual variation, there is pronounced temperature variation from season to season.

Humans may be poor observers of temperature overall when compared to WSIDD. Air temperature and trends in air temperature over time is arguably a much more important environmental variable for people living in lower latitude urban areas than in upper latitude rural areas. Deschenes and Moretti (2007) studied deaths from heat and cold waves and found “mortality rates are significantly higher on both cold and hot weather days, but that the excess mortality on hot days is substantially larger (e.g. 3-6 times larger) than on cold days.” p. 13.

The Urban Heat Island effect accelerates temperature changes in cities (Arnfield 2003; Lowry 1967; Taha 1997; Voogt 2002). In large cities such as Chicago (Semenza et al. 1996), Cincinnati (CDC 2000), Philadelphia (Mirchandani et al. 1996), and Paris, France (Vandentorren et al. 2004), among many others, thousands of deaths each year are caused by summer heat waves. The Maricopa County Department of Public Health (in which Phoenix is located) concluded that heat or heat exposure was a direct or contributing cause of 215 deaths from 2005 to 2007 (MCDPH 2008). In a study conducted in metropolitan Phoenix Arizona in 2006, a year after an unprecedented heat wave in 2005, researchers analyzed the correspondence between a climate model that had shown accurate results on finer scales, and hence the ability to assess microclimates, and people’s perceptions of changes to regional and neighborhood air temperatures. Tests indicated only “a modest positive association between daily average, high, and low neighborhood temperatures and respondents’ aggregated perceptions of change in regional temperatures over time (r=0.26 to 0.33).” Statistics were stronger, but still statistically modest, for aggregated perceptions of temperature at finer scales of neighborhood relative to other neighborhoods (r=0.47 to 0.50). The correlation at the neighborhood level was statistically significant, although below r=0.50 (Rudell et al. 2012, p. 596).

Given the direct safety concerns from higher temperatures in Phoenix, it is surprising that perception is not more accurate at both neighborhood and regional scales. Variation in temperatures is not as significant a factor in Phoenix, which is located at 33˚ North latitude where mean annual temperature variation is 13˚C/23˚F (at 30˚ North latitude) (Brigham Young

University n.d.). Despite less variation, perceptions even a year following the heat wave were poor. Another factor impacting perceptions might be technological protection from the elements (Technologically-induced environmental distancing) (Alessa et al. 2010) in the form of air-conditioned houses and vehicles, which mute the extremes of environmental temperatures.

Why might perceptions not track more closely to instrumented air temperature data in the communities in this study? First, air temperature change that has occurred over the time periods used in this study is not a direct threat to survival or reproduction. That is, temperature increases and decreases have not reached extremes that have caused deaths. Daily air temperature certainly has a direct effect on survival when making decisions of what clothing to wear, but when daily temperatures can vary by 15 to 20˚C, attire must always be adaptable.

Indirect effects of increases in air temperature certainly impact survival in these communities, including making travel on ice more risky, and access to food resources more difficult. It is these more direct effects of changes in ice and snow cover that affect survival and people in northern regions perceive these changes more accurately. Another explanation may be that people more accurately perceive microclimates where they live and hunt. Placement of gauges in northern communities is sparse and related to ease of access. Neither gauges, nor climate models, accurately account for microclimates in northern regions, which might explain a great deal of the difference between perception and instrumented data. We also did not analyze perceptions at finer time scales, as the study allowed participants to decide at what time scales change had occurred. Such an analysis might also decrease the difference between the perceived and instrumented change. Although one would anticipate that because of increased time on the land of many of the study participants, the effect of having a warm house to retreat to would have a lower impact on perception of air temperature change than in large cities, technology-induced distancing may have affected perception in these communities as well.

Ice break up and freeze up

Observations of changes in sea ice are interesting because, although general trends are well-documented (thinning, decrease in extent, change in timing of freeze and thaw), changes vary regionally with some areas not experiencing change (Meier et al. 2011) even within the Bering Sea (Stabeno et al. 2012). An effort was made to verify observations with literature as close as possible to the local scale. As these are large scale changes, and Savoonga is only 63 km from Gambell, both villages were considered together. In this case, a relatively large body of scientific research conducted in the area of St. Lawrence Island supported the observations that break up was occurring earlier and freeze up later in these villages. Ice break up and freeze up have been confirmed by a number of other studies as being phenomena that are accurately observed (Prno et al. 2011; Fienup-Riordan & Carmack 2011; Ford et al. 2008).

The timing of ice events significant to survival by respondents was accurately perceived. These changes directly impact the ability of people living in these communities to travel safely and to gather food. Cognitive neuroscience suggests that natural selection has not shaped our perceptions to be an accurate representation of objective reality, but has shaped our perceptions to be species-specific guide to behaviors that we need to survive and reproduce (Hoffman 2009; Hoffman & Prakash 2014). Studies also suggest that people are more likely to perceive risks after catastrophic events than changes that are slowly evolving (Rudell et al. 2012). As noted above, changes in ice conditions have resulted in increased deaths from travel on ice, a catastrophic event. More accurate perceptions of ice changes, which have a direct effect on survival, are consistent with the theories of Hoffman and Prakash.

Vegetation changes

Analysis of annual NDVI suggests that there has been no significant vegetation change in any village. Respondents from all of the villages, except Togiak, correctly reported that no vegetation changes had occurred. Togiak respondents were equally split in their opinions that vegetation had and had not changed. As shown in graph 1 and graph 2 below, maximum NDVI over time is highly variable. Although variability could impair the accurate observation of vegetation change, as it appears to have in air temperature change, vegetation change is much less variable than air temperature change and more villages accurately observed that vegetation had not significantly changed.

As well, changes to vegetation relate more closely to ability to survive in these communities as all communities gather greens for food. If greens had increased, which would be represented in NDVI, it would make sense that these communities would perceive this since it would likely increase their access to a food source.

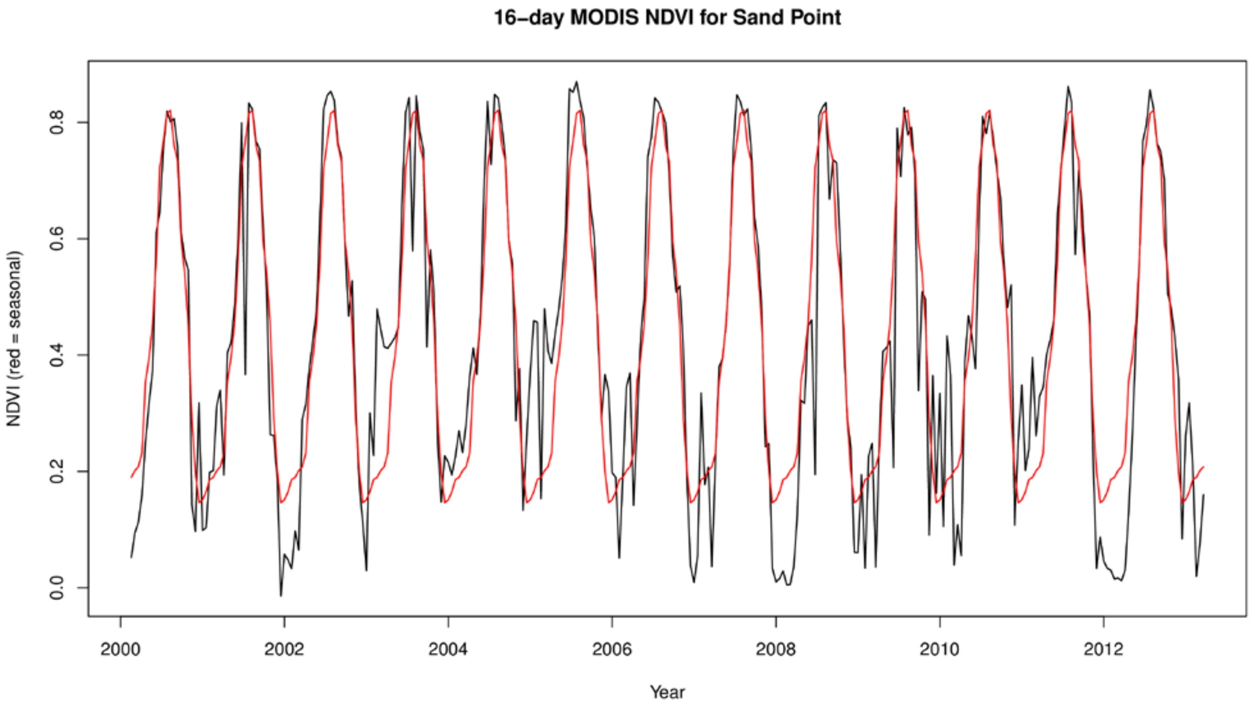

Figure 3: Plot of annual variation in NDVI for Sand Point, Alaska. The red line indicates expected seasonal NDVI values (using the STL method), while the black line indicates observed NDVI values. This shows both the annual magnitude of NDVI change as well as the lack of change in green-up or length of season over the time period.

CONCLUSION:

Research into how and under what circumstances people's perceptions of the environmental are veridical to WSIDD environmental conditions is sparse. Cognitive neuroscientists have suggested that perception that closely tracks actual conditions does not increase adaptive capacity, a surprising result (Hoffman 2009; Hoffman & Prakash 2014). This may be partly explained in terms of the amount of information available from the environment and the amount of energy and time needed to process this information. Perception that is attuned to increasing our fitness to survive and reproduce will be selected (Hoffman 2009; Hoffman & Prakash 2014). Perceptions that reduce the amount of information we process to that which is most relevant to the particular environment, social conditions and circumstances of the observer are those that will most likely increase our survival. Our perceptions are likely place-based and function as complex adaptive systems.

Researchers have compared the techniques used by local place-based observers to characterize their environment as "fuzzy logic" (Berkes & Berkes 2009). Other research suggests that people do not limit their observations to single variables, but combine them to discern patterns in the environment (Berkes et al. 2007). Asking survey participants whether temperature, rain or wind direction had increased may have imposed Western science ways of observing on an Indigenous system and may have assured inaccurate responses, because those questions were not related to other variables in a meaningful way that relates to increased survival or ability to reproduce. Berkes et al. (2007) suggested that questions related to topics of safety, access to resources, species health and availability, and predictability result in keener observations. These suggestions are consistent with research in cognitive neuroscience and are supported by this study. Ambrose and colleagues (2014) found the following five questions to be most predictive of climate change knowledge in their study: temperature of water compared to 10 years ago, arrival of salmon, migration of trout, amount of flounders caught in nets, and water temperature increase resulting in an increase in crabs; all phenomena concerned with species health and availability, and access to subsistence resources.

Importantly, this study suggests that large variability in environmental conditions reduces the correspondence of community-based observations, this is true of even people who are, arguably, most attuned to environmental change, compared to WSIDD measurements of change. Climate scientists predict more variable climate, which may create situations where change is very difficult to predict. Other studies have supported the observations of people living in northern latitudes that climate is becoming less predictable.

REFERENCES

Alessa, L., Kliskey, A., Gamble, J., Fidel, M., Beaujean, G., Gosz, J. 2015. The role of indigenous science and local knowledge in integrated observing systems: moving toward adaptive capacity indices and early warning systems. Sustainability Science, 10:2. DOI: 10.1007/s11625-015-0295-7.

Alessa L. N., Kliskey, A., Williams, P. 2010. Forgetting Freshwater: Technology, Values, and Distancing in Remote Arctic Communities, Society & Natural Resources, 23:3, 254-268, DOI: 10.1080/08941920802454813.

Alessa, L.N., Kliskey, A., Williams, P., Barton, M. 2007. Perceptions of change in freshwater in remote resource-dependent Arctic communities. Global Environmental Change. 18:153-164.

Alexander, C., Bynum, N. Johnson, E., King, U., Mustonen, T., Neofotis, P. Oettle, N., et al. 2011. Linking indigenous knowledge and scientific knowledge of climate change. BioScience 61 (6), 477-484.

Alaska Ocean Observing System (AOOS), http://portal.aoos.org/real-time-sensors.php#module- search?lg=8c5dd704-59ad-11e1-bb67-0019b9dae22b&p=proj3857&b=google_hybrid&page=1&tagId=&q=chukchi%2Bsea.

Ambrose, William G., Clough, Lisa M., Johnson, Jeffrey C., Greenacre, Michael, Griffith, David C., Carroll, Michael L., & Whiting, Alex. 2014. Interpreting environmental change in coastal Alaska using traditional and scientific ecological knowledge. Frontiers in Marine Science, Vol. 1, article 40, doi: 10.3389/fmars.2014.00040.

Arnfield, A. J. 2003. Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. Int J Climatol 23:1–26.

Bauret, S. & Stuefer, S.L. 2013. Kenai Peninsula Precipitation and Air Temperature Trend Analysis, 19th International Northern Research Basins Symposium and Workshop Southcentral Alaska, 35 - 44.

Berkes, F., Berkes, M.K. 2009. Ecological complexity, fuzzy logic, and holism in indigenous knowledge. *Futures.* 41 (1):6-12, doi. 10.1016/j.futures.2008.07.003.

Berkes, F., Berkes, M., Fast, H. 2007. Collaborative Integrated Management in Canada’s North: The Role of Local and Traditional Knowledge and Community-Based Monitoring. Coastal Management 35(1):143-162.

Berkes, F., Colding, J., & Folke, C. 2000. Rediscovery of Traditional Ecological Knowledge as adaptive management. Ecological Applications. 10(5), 1251-1262.

Brigham Young University, n.d. Retrieved from: http://www.physics.byu.edu/faculty/christensen/physics%20137/Figures/Temperature/Effects%20of%20Latitude%20on%20Annual%20Temperature%20Range.htm.

Brubaker, M.Y., Bell, J.N., Berner, J.E., Warren, J.A. 2011. Climate change health assessment: a novel approach for Alaska Native communities. International Journal of Circumpolar Health. 70(3):266-273.

Carmack, E., MacDonald, R. 2008. Water and ice-related phenomena in the coastal region of the Beaufort Sea: Some parallels between Native experience and Western science. Arctic.

61(3) 265-280.

(CDC) Centers for Disease Control. 2000. Heat-related illnesses, deaths, and risk factors—Cincinnati and Dayton, Ohio, 1999 and United States, 1979–1997. Morb Mortal Wkly Rep 49:470–473.

Chander, G., B. L. Markham, and D. L. Helder. 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sensing of Environment 113:893-903.

Collings, Peter 2011. Economic strategies, community, and food networks in Ulukhaktok, Northwest Territories Canada. *Arctic*. 64(2):207-219.

Deschenes, Oliver, Moretti, Enrico. 2007. Extreme weather events, mortality and migration. National Bureau of Economic Research Working Papers. Available at http://www.nber.org/papers/w13227.

Eicken, H., Lee, O. 2013. Status of current observing system, white paper synthesis brief of the Arctic Observing Summit, Vancouver, BC, Canada. Accessed on-line on 10/24/13 at http://www.arcticobservingsummit.org/users/white_papers.php.

Fienup-Riordan, A., Carmack, E. 2011. "The ocean is always changing": Nearshore and farshore perspectives on Arctic coastal seas. Oceanography. 24(3):266-279, doi org/10.5670/oceanog.2011.78.

Ford, J. D. & Pearce, T. 2012. Climate change vulnerability and adaptation research focusing on the Inuit subsistence sector in Canada: Directions for future research. The Canadian Geographer. 56(2):275-287.

Ford, J.D., Pearce, T., Duerden, F., Furgal C., Smit, B. 2010. Climate change policy responses for Canada's Inuit population: The importance of and opportunities for adaptation. Global Environmental Change. 20:177-191.

Ford, J.D., Pearce, T., Gilligan, J., Smit, B., & Oakes, J. 2008. Climate change and hazards associated with ice use in northern Canada. Arctic, Antarctic & Alpine Research. 40(4): 647-649.

Gearheard, S., Pocernich, M., Stewart, R., Sanguya, J., Huntington, H.P. 2010. Linking Inuit knowledge and meteorological station observations to understand changing wind patterns at Clyde River, Nunavut. Climatic Change. 100:267-294. Doi. 10.1007/s10584-009-9587-1.

Gearheard, S., Shirley, J. 2007. Challenges in community-research relationships: Learning from natural science in Nunavut. Arctic. 60(1):62-74.

Grant, S., & Berkes, F. 2007. Fisher knowledge as expert system: A case from the longline fishery of Grenada, the Eastern Caribbean. Fisheries Research. 84:162-170, doi. 10.1016/j.fishres.2006.10.012.

Grebmeier, J.M. 2012. Shifting patterns of life in the Pacific Arctic and Sub-Arctic seas. Annual Review of Marine Science. 4:63-78.

Grebmeier, Jacqueline M., Overland, James E., Moore, Sue E., Farley, Ed V., Carmack, Eddy C., Cooper, Lee W., Frey, Karen E., Helle, John H., McLaughlin, Fiona A., & McNutt, S. Lyn. A major ecosystem shift in the Northern Bering Sea. Science, 311, 1461, DOI: 10.1126/science.1121365.

Herman-Mercer, N., Schuster, P.F., Maracle, B.K. 2011. Indigenous observations of climate change in the lower Yukon River Basin, Alaska. Human Organization. 70(3):244-252.

Hoffman, Donald D. 2009. The Interface Theory of Perception. In *Object Categorization: Computer and Human Vision Perspectives*, edited by Sven Dickinson, Michael Tarr, Ales Leonardis and Bernt Schiele. Cambridge University Press, pages 148-265.

Hoffman, Donald D., Prakash, Chetan. 2014. Objects of consciousness. Frontiers in Psychology, 5, article 577. doi: 10.3389/fpsyg.2014.00577.

Hoffman, Donald D., Singh, Manish, Prakash, Chetan. 2015. Psychonomic Bulletin & Review. 22(6):1480-1506.

Huntington, H.P., Callaghan, T., Fox, S., Krupnik, I. 2004. Matching traditional and scientific observations to detect environmental change: A discussion on Arctic terrestrial ecosystems. *Ambio.* Special report #13:18-23.

Jia, G. S. J., H. E. Epstein, and D. A. Walker. 2003. Greening of Arctic Alaska, 1981-2001. Geophysical Research Letters 30.

Kane, D.L. & Stuefer, S. L. 2015. Reflecting on the status of precipitation data collection in Alaska: a case study, Hydrology Research, 46(4), 478-493.

Kirtman, B., S.B. Power, J.A. Adedoyin, G.J. Boer, R. Bojariu, I. Camilloni, F.J. Doblas-Reyes, A.M. Fiore, M. Kimoto, G.A. Meehl, M. Prather, A. Sarr, C. Schär, R. Sutton, G.J. van Oldenborgh, G. Vecchi and H.J. Wang, 2013: Near-term Climate Change: Projections and Predictability. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Lawrimore, J.H., Menne, M. J., Gleason, B. E., Williams, C. N., Wuertz, D. B., Vose, R. S., & Rennie, J. 2011. An overview of the Global Historical Climatology Network monthly mean temperature data set, version 3, Journal of Geophysical Research. 116. D19121, doi:10.1029/2011JD016187.

Levine, S. 1998. Ecosystems and the biosphere as complex adaptive systems. Ecosystems.

1(5); 431-436.

Lowry W. 1967. The climate of cities. Scientific Amercian, 217:15–23.

Mahoney, A., Gearheard, S., Oshima, T., Qillaq, T. 2009. Sea Ice Thickness Measurements from a Community-Based Observing Network. Bulletin of the American Meteorological Society. 90(3):370-377.

Mauro, F., & Hardison, P. D. 2000. Traditional knowledge of indigenous and local communities: International debate and policy initiatives. Ecological Applications. 10(50: 1263-1269.

(MCDPH) Maricopa County Department of Public Health, Division of Disease Control, Office of Epidemiology and Data Services. 2008. Heat caused and heat related death occurrences in Maricopa County. (August 12). Phoenix, AZ.

Meek, C.L., Lovecraft, A.L, Robards, M.D., & Kofinas, G.P. 2008. Building resilience through interlocal relations: Case studies of polar bear and walrus management in the Bering Strait. *Marine Policy*. 32:1080-1089

Meier, W.N., Gerland, S., Granskog, M.A. Key, J.R. 2011. Sea Ice. Chap. 9 In Snow, water, ice and permafrost in the Arctic (SWIPA): Climate change and the cryosphere. Arctic Monitoring and Assessment Programme, Oslo, Norway. 9.1-9.87.

Mirchandani H, McDonald G, Hood I, Fonseca C. 1996. Heat-related deaths in Philadelphia—1993. American Journal of Forensic Medical Patholology, 17:106–108.

National Oceanic & Atmospheric Association, National Climate Data Center at http://www.ncdc.noaa.gov/cdo-web/datasets#GHCND

National Research Council, Toward an Integrated Arctic Observing Network 2006., at 85; Alaska Ocean Observing System, AOOS: A tool for tracking, predicting, managing, and adapting to changes in our marine environment, 2015. available at www.aoos.org.

Pattison, R. R., J. C. Jorgenson, M. K. Raynolds, and J. M. Welker. 2015. Trends in NDVI and Tundra Community Composition in the Arctic of NE Alaska Between 1984 and 2009. Ecosystems 18:707-719.

Pearce, T.D., Ford, F.D., Laidler, G.J., Smit, B., Duerden, F., Allarut, M., Andrachuck, M., Baryluk, S., Dialla, A., Elee, P., Goose, A., Ikummaq, T., Joamie, E., Kataoyak, F., Loring, E., Meakin, S., Nickels, S., Shappa, K., Shirley, J., Wandel, J. 2009. Community collaboration and climate change research in the Canadian Arctic. *Polar Research.* 28:10-27.

Philip, K. S. 2001. Indigenous knowledge: science and technology studies. In, Smelser, N. J., & Bates, P. B. eds. International Encyclopedia of the Social & Behavioral Sciences. Amsterdam and New York:Elsevier.

Pierotti R, & Wildcat D. 2000. Traditional Ecological Knowledge: The third alternative (commentary). Ecological Applications. 10(5): 1333-1340, DOI: 137.229.184.15.

Prno, J., Bradshaw, B., Wandel, J., Pearce, T., Smit, B., Tozer, L. 2011. Community vulnerability to climate change in the context of other exposure-sensitivities in Kugluktuk, Nunavut. Polar Research. 30:7363, doi 10.3402/polar.v30i0.7363.

Ramnath, A. 2014. 'Indigenous knowledge' and 'science' in the age of globalization. IIM Kozhikode Society & Management Review. 3(1): 101-107.

Riedlinger, Dyanna 2001. Responding to climate change in Northern communities: Impacts and adaptations. Arctic. 54(1):96-98.

Rudell, Darren, Harlan, Sharon l., Grossman-Clarke, Susanne, & Chowell, Gerardo. 2012. Scales of perception: public awareness of regional and neighborhood climates. Climatic Change, 111:581–607, DOI 10.1007/s10584-011-0165-y.

Semenza JC, Rubin CH, Falter KH, Selanikio JD, Flanders WD, How HL, Wilhelm JL 1996. Heat-related deaths during the July 1995 heat wave in Chicago. Am J Prev Med 16:269–277.

Shimada, K., Kamoshida, T., Itoh, M., Nishino, S., Carmack, E., McLaughlin, F., Zimmermann, S., Proshutinsky, A. 2006. Pacific Ocean inflow: Influence on catastrophic reduction of sea ice cover in the Arctic Ocean. Geophysical Research Letters. 33(L08605), doi 10.1029/2005GL025624.

Stabeno, P.J., Farley, E.V., Kachel, N.B., Moore, S., Mordy, C.W., Napp, J.M., Overland, J.E., Pinchuk, A.I., Sigler, M.F. 2012. A comparison of the physics of the northern and southern shelves of the eastern Bering Sea and some implications for the ecosystem. Deep Sea Research II. 65-70:14-30.

Stow, D., S. Daeschner, A. Hope, D. Douglas, A. Petersen, R. Myneni, L. Zhou, and W. Oechel. 2003. Variability of the seasonally integrated normalized difference vegetation index across the north slope of Alaska in the 1990s. International Journal of Remote Sensing 24:1111-1117.

Taha H. 1997. Urban climates and heat islands: albedo, evapotranspiration, and anthropogenic heat. Energy and Buildings, 25:99–103.

Tremblay, M., Furgal, C., Larrivee, C., Annanack, T., Tookalook, P., Qiisik, M., Angiyou, E., Swappie, N., Savard, J., Barrett, M. 2007. Climate change in North Quebec: Adaptation strategies from community-based research. Arctic. 61(Suppl. 1):27-34

Turnbull, D. 2000. Masons, tricksters and cartographers: Makers of knowledge and space. Amsterdam, Harwood Academic; Abingdon: Marston.

United Nations. 2008. United Nations Declaration on the Rights of Indigenous Peoples. Resolution adopted by the General Assembly, March 2008. United Nations.

Usher, P. 2000. Traditional and Ecological Knowledge in Environmental Assessment and Management. Arctic 53(2):183-193.

Vandentorren S, Suzan F, Medina S, Pascal M, Maulpoix A, Cohen J-C (2004) Mortality in 13 French cities during the August 2003 heat wave. Am J Public Health 94:1518–1520.

Verbyla, D. 2008. The greening and browning of Alaska based on 1982-2003 satellite data. Global Ecology and Biogeography 17:547-555.

Voogt JA (2002) Urban Heat Island. In: Douglas I (ed) Encyclopedia of global environmental change. Wiley & Sons, Chichester, pp 660–666.

Weatherhead, E., Gearheard, S., Barry R.G. 2010. Changes in weather persistence: Insight from Inuit knowledge. Global Environmental Change. 20(3):523-528

Wolfe, B. Armitage, D., Wesche, S., Brock, B., Sokal, M., Clogg-Write, K., Mongeon, C., Adam, M., Hall, R., Edwards, T. 2007. From isotopes to TK interviews: Towards interdisciplinary research in Fort Resolution and Slave River Delta, Northwest Territories. Arctic. 60(1):75-87.

Woodgate RA, Weingartner T, Lindsay R. 2010. The 2007 Bering Strait oceanic heat flux and anomalous Arctic sea-ice retreat. Geophys. Res. Lett. 37:L01602

APPENDIX

Table 2. Some demographic and survey information for the Environment Survey

Village	Population	Number of Respondents	Response Rate	% Male	Average Age	Years hunting and/or fishing	Survey administered
Nikolskoye	~800	85	73%	88%	52	31	03/2010 – 05/2010
Tymlat	~500	51	33%	80%	51	30	06/2010 – 10/2011
Kanchalan		50			51		05/2010-06/2010
Gambell	681	77	37%	86%	52	38	01/2011-8/2012
Sand Point	976	70	65%	84%	52	35	01/2010 – 03/2013
Savoonga	671	52	35%	87%	55	40	5/2012 – 3/2013
Togiak	821	151	71%	51%	47	30	01/2010 – 02/2013
St. George		9			57		07/2011-07/2012