

Linking Indigenous Knowledge and Observed Climate Change Studies

“Traditional knowledge is still under-used by science, although it is of great value and can contribute significantly to the development of humankind”

-Chief Vyacheslav Shadrin

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Abstract

We present indigenous knowledge narratives and explore their connections to documented temperature and other climate changes and observed climate change impact studies. We then propose a framework for enhancing integration of these indigenous narratives of observed climate change with global assessments. Our aim is to contribute to the thoughtful and respectful integration of indigenous knowledge with scientific data and analysis, so that this rich body of knowledge can inform science, and so that indigenous and traditional peoples can use the tools and methods of science for the benefit of their communities if they choose to do so. Enhancing ways of understanding such connections are critical as the Intergovernmental Panel on Climate Change Fifth Assessment process gets underway.

Key Words: observed impacts, climate change, indigenous knowledge, assessment, temperature change

Ironically and tragically, climate change is being experienced by indigenous communities, who have not participated in the industrial activities causing it. Climate change's negative effects on indigenous communities go beyond threats to immediate food supply (Diffenbaugh et al. 2007, IPCC 2007) to encompass long-lasting cultural disturbances and losses (Sakakibara 2008b, 2009). Their susceptibility to diseases is also projected to increase (Green D. et al. 2009a, IPCC 2001, National Assessment Synthesis Team Members 2001) as epidemiologies are affected by environmental factors such as rising temperature and increasing precipitation.

In this essay, we explore possible complementarities between indigenous and scientific knowledge systems, and discuss the potential for enhancing integration of indigenous observations of climate change with global assessments such as those of the Intergovernmental Panel on Climate Change (IPCC). Because the IPCC is subject to scrutiny, it tends to rely on information primarily from peer-reviewed scientific studies, and in the past has largely excluded traditional indigenous knowledge as a source of information for its assessment reports. Western science (here referred to as a set of statistically-analyzed data or instrumental records) rests on precise definitions of independent and dependent variables that can be empirically measured, and which demonstrate acceptable levels of reliability and validity.

Defining Indigenous Knowledge

Such quantitative rigor is not necessarily at the core of indigenous knowledge, defined as “knowledge that an indigenous or local community accumulates over generations of living in a particular environment” (www.unep.org). Indigenous knowledge often includes traditional ecological knowledge (TEK). TEK can be understood to be “a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment” (Berkes F. 1999). TEK is often an integral part of the local culture and environment, with management prescriptions adapted to the local area. Traditional systems tend to have a large moral and ethical context, and oftentimes there is no clear separation between nature and culture.

TEK can include diverse kinds of narratives or observations by an indigenous person or group (Menzies and Butler 2006). These narratives in turn can provide intergenerational observations regarding various kinds of natural resource phenomena. Since the 1980s, various kinds of TEK have come to be commonly accepted by scientists in the fields of agriculture (Warren 1995), pharmacology (Schultes R. E. 1989), water engineering (Groenfelt 1991), architecture (Fathy 1986), ethnobotany (Nebhan 1987, Schultes R. E. 1995), ethnozoology (Clement 1995), irrigation systems (Mabry 1996), soil and water conservation (Reij 1996), and ethnoastronomy (Celi 1978), and by social scientists (Allen 1998, Feld 1982, Freeman 1984, Nelson 1980). TEK can be found all over the world, particularly in indigenous traditions in diverse geographical regions from the Arctic to the Amazon and beyond, and represents various understandings of ecological relationships, spirituality, and traditional systems of resource management. The international arena has gradually begun to embrace the significance of applying TEK to contemporary resource management problems in various parts of the world in recent decades (UNDRIP 2008, WCED 1987).

There are both similarities and differences between TEK and Western science (Berkes F 1993, Berkes F. 1999 , Ingold 2000). The recent and increasing academic and scientific interest in TEK has created a new reciprocal relationship between TEK and Western science that facilitates a synthesis between the two worlds by replacing conventional wisdom through dialogues (Albert 2001, Brewster 2004, ELOKA 2010, Fox 2004, Huntington 1992). These efforts occasionally result in the formation of new indigenous cultural identities at the time of environmental unpredictability and cultural crises (Kassam and The Wainwright Traditional Council 2000, Sakakibara 2010, Watt-Cloutier 2006). Although the path of TEK integration with Western science for effective natural resource management and policy-making is a new one, we believe that we have reached the point at which indigenous communities and scientific explorations can meaningfully collaborate with one another to better understand our world as a whole.

Climate Change

For some indigenous communities, climate change – its impacts on physical, biological, and social systems, and potential adaptations and mitigations – is an important issue. Initiatives such as the *Stories of the Raven* – which detailed the narratives set forth at a three-day meeting with

representatives from all Circumpolar nations and Indigenous peoples (Mustonen 2005) – and the Arctic Climate Impact Assessment (ACIA 2005) – which was prepared by more than 300 participants from 15 countries and includes many examples of the local traditional knowledge of Inuit, Sami, Athabaskans, Gwich'in, Aleut and other Arctic Indigenous Peoples – have demonstrated some of the possibilities for bringing diverse groups together to frame and address common problems related to this issue.

We are aware that any attempt to join scientific and indigenous knowledge systems may reflect the history of power relationships among indigenous and non-indigenous groups (Simpson 2004). We further recognize that traditional knowledge is not uniform, even within small communities, and that there can be substantial variation in the substance of traditional ecological knowledge reported in what appear to be homogenous indigenous communities. Our aim is to contribute to the thoughtful and respectful integration of indigenous knowledge and scientific data and analysis so that this rich body of knowledge can inform science, and science can in turn perhaps contribute tools and methods that will allow indigenous communities to make informed decisions about their current situation and future prospects. Capturing the people, voices, and history that hold much of the richness of indigenous knowledge is difficult, but by opening a pathway for the meaningful exchange of information, we hope that efforts to understand, adapt to, and mitigate climate change will be strengthened. This is especially true if the intent is to develop a methodology that might serve as a building block for future similar comparisons, and where findings may be eventually aggregated to build a larger body of knowledge.

The Center for Biodiversity and Conservation of the American Museum of Natural History (AMNH) brought together a panel to discuss the challenges posed by climate change to indigenous groups, and the role of indigenous knowledge in responding to climate change, as part of a larger conference titled *Sustaining Cultural and Biological Diversity in a Rapidly Changing World* (<http://symposia.cbc.amnh.org/archives/biocultural/index.html>). Panel members consisted of indigenous group leaders, scholars of indigenous knowledge, and climate change impact scientists. We present some examples of indigenous knowledge brought forward by the conference participants, and explore the connections of these observations to documented temperature and other climate changes and observed climate change impact studies from peer-

reviewed journals. Our goal is to provide some initial findings regarding the following questions:

1. Are indigenous communities experiencing and responding to climate change?
2. Do indigenous knowledge narratives relate to observed changes in temperature and other climate variables and vice versa?
3. Do indigenous knowledge narratives relate to other climate change impact studies and vice versa?

Panel participants:

Chief Clarence Alexander, Yukon River Inter-Tribal Watershed Council, USA;
Nora Bynum, American Museum of Natural History, USA;
Violet Ford, Inuit Circumpolar Council, Canada;
Liz Johnson, American Museum of Natural History, USA;
Ursula King, National Centre for Epidemiology & Population Health, Australian National University, Australia;
Tero Mustonen, The Snowchange Cooperative, Finland;
Peter Neofotis, Climate Impacts Group, Columbia University, USA;
Noel Oettle, Environmental Monitoring Group, Nieuwoudtville, South Africa;
Cynthia Rosenzweig, NASA Goddard Institute for Space Studies, USA;
Chie Sakakibara, Appalachian State University, USA;
Chief Vyacheslav Shadrin, Head, Yukagir Elders Council, Russia;
Marta Vicarelli, Columbia University, NYC;
Jon Waterhouse, Yukon River Inter-Tribal Watershed Council, USA;
Ellen Wiegandt, Graduate Institute of International and Development Studies, Geneva, Switzerland.

A research specialty of the Corresponding Author, Dr. Rosenzweig, is the impacts of climate change on physical and biological systems.

Fifty-seven indigenous narratives of climate change were gathered from sources put forth by the participants at the AMNH conference. Sources were either formal presentations or papers contributed by the some of the conference participants, representing observations from certain indigenous groups or communities (Archer E.R.M. et al. 2008b, Castillo Ameyali Ramos 2009a, Castillo Ameyali Ramos 2009b, Green D. et al. 2009b, Mustonen 2005, Oxfam American November 2007, Rhoades et al. 2008, Sakakibara 2008b, 2009). Narratives were arranged with the source and indigenous group, as well as the latitude and longitude representing a central point as noted in the report or approximated from the locations using NASA World Wind (<http://worldwind.arc.nasa.gov/>) (Figure 1). We focused on compiling narratives relating to climate change, and not on those documenting other factors at work beside climate change. Observations were characterized as to whether the reported changes were expected with warming or cooling. Further work would bring forth more narratives, extend to a larger group of participants, and involve further qualitative analysis of the narratives.

Figure 1. Locations of changes in physical and biological changes from indigenous knowledge narratives and peer-reviewed scientific studies overlaid on global HadCRUT3 temperature trends (Brohan et al. 2006). Circles represent locations of statistically significant trends in changes in either direction in systems related to temperature or to other climate change variables, and that contain data from at least 20 years between 1970 and 2004 (Rosenzweig et al. 2008). Stars represent indigenous knowledge narratives related to climate change brought forth by the panel participants.

A geographic information system (ArcView GIS) was used to overlay the locations of the narratives with temperature changes from 1970-2004 and with a database of peer-reviewed studies documenting physical and biological climate-related changes (Rosenzweig et al. 2008). Two different gridded observed temperature data sets were used: HadCRUT3 (Brohan et al. 2006) and GHCN-ERSST (Smith and Reynolds 2005).

Narratives Related to Impacts and Adaptation

The narratives collected related to impacts of and adaptations to a changing climate in North America, Europe, Asia, Oceania, Latin America, and Africa, but in this paper we focus primarily on the Northern Hemisphere high latitudes where the predominance of the indigenous narratives from the participants originated. The scale of the knowledge assembled indicates potentially dramatic and widespread impacts on indigenous populations perceived to be caused by global climate change. Attempts to generalize some of the information to specific geographic areas, however, could be subject to ecological fallacy and possibly to challenge by critics. One possibility of challenge occurs because indigenous knowledge is characterized as what knowledge holders report over relatively large areas. Other individual knowledge holders might report differently, and a survey administered to a representative sample of indigenous individuals might reveal very different observations. However, this means of gathering individual narratives and knowledge mapping from the universe of indigenous communities offers a view of the impacts of climate change experienced by local communities, as opposed to what is measured by

instruments. This method of knowledge assemblage offers the potential human voices from the larger universe of resource dependent communities as well.

Northern High Latitudes

In the northern high latitudes, particularly in North America and Asia, recent warming has resulted in physical, biological, and social changes in many communities (IPCC 2007). Changes in the northern high latitudes, found at multiple locations by multiple groups, have several shared characteristics.

1. **Polar animals are being affected negatively.** Some melting of snow and ice and enhanced variability have had a profound effect on the migration patterns of birds and mammals, with several species of fauna particularly affected. These include the bowhead whale (*Balaena mysticetus*), and reindeer (*Rangifer tarandus*) – the latter also showing signs of malnourishment (Sakakibara 2009, Shadrin 2008, Smetzer 2008).
2. **Hunters are having less success.** Some changes in animal behavior, often accompanied by signs of stress, have led to difficulties for indigenous hunters (Mustonen 2005, Sakakibara 2008a).
3. **Hazards are increasing.** Some thinning ice jeopardizes modes of transportation, and some melting permafrost destabilizes community infrastructure (Mustonen 2005, Sakakibara 2008b, Shadrin 2008).
4. **Exotic species are appearing.** Some rarely encountered or exotic species, such as willow trees (*Salix* spp.) and beavers (*Castor canadensis*), are moving into some areas of the region. Mosquitoes are increasing in abundance in some places. Some of these species changes necessitate the development of new food-gathering strategies (Mustonen 2005, Sakakibara 2008a).
5. **Fires are occurring more often.** Forest fire frequency appears to be increasing in some places, adversely affecting land mammals such as caribou (*Rangifer tarandus groenlandicus*), modifying their migratory patterns, and causing geographic and temporal changes in indigenous livelihood practices (Mustonen 2005).

Oceania, Latin America, and Africa

Some of the narratives from Oceania, Latin America, and Africa (which are limited in this collection) relate to impacts affecting health, coastal livelihoods, water resources, and food production – as well as adaptation to changes in climate regimes. The impacts of climate change on the indigenous peoples in Australia and elsewhere may bring disproportionate burdens (Green D. et al. 2009b):

For many Indigenous people, a connection with 'country' – a place of ancestry, identity, language, livelihood and community – is a key determinant of 'health'... Therefore, as ecosystems change due to biophysical impacts and extreme weather events, many traditional owners living in remote areas are likely to face increased physiological, psychological, economic and spiritual stress as it becomes more difficult to 'look after their country'.

On the north coast of Australia, Aborigines have reflected on how animal migrations and sea level rise threaten their own survival and identities (Castillo Ameyali Ramos 2009a, Castillo Ameyali Ramos 2009b). For example, saltwater intrusion threatens the Kowanyama, a coastal Aboriginal community in tropical Queensland, Australia. The delicate balance of freshwater from the rivers and ocean saltwater has in the past nurtured the lifeways of the area. However, the Kowanyama report that every year when the tide comes in it comes further and further, threatening terrestrial plant and animal life, and freshwater ecosystems (Castillo Ameyali Ramos 2009a). In the Torres Strait Islands, off the far north coast of Australia, the Saibai are adapting to higher sea levels by raising their homes on stilts, a return to traditional housing design (Green D. 2006). In Peru, changing climate regimes as a result of melting glaciers are having detrimental effect on water supplies (Rhoades et al. 2008). In South Africa, droughts have had an influence on the methods of farming of traditional teas (Archer D. W. et al. 2008a).

Spatial Correspondence of Indigenous Observations and Temperature Changes

To explore the complementarity between indigenous and scientific knowledge, we first overlaid the geographic location of the narratives onto observed temperature data. We found that the majority of narratives are from indigenous communities located in temperature cells with measured temperature increases (Figure 1).

Narratives of observed changes in the northern high latitudes coincide with instrumentally-documented changing temperature trends for the region (IPCC 2007). For several decades, surface air temperature trends in the Arctic have warmed at approximately twice the global rate (IPCC 2007). The warming is strongest over the interior parts of northern Asia and northwestern North America (ACIA 2005). Together with the Antarctic Peninsula, these are the most rapidly changing areas on the globe (Turner et al. 2007).

Narratives of warming effects that are located in cells with observed cooling may be a result of warming not being detectable at the 5x5 degree gridbox scale, or may be related to global effects of warming, such as sea level rise, rather than local warming. Indeed, the six narratives in the Torres Strait north of Australia in cooling cells are all related to sea level rise. These are six of the eight narratives located in gridcells with significant cooling. The two other narratives, in Europe, are in cells with slight cooling (0 to -0.2 degrees C) and these observed impacts – both in the direction of warming despite the slighting cooling grid cell – are related to animal migrations that could be influenced by the strong warming in adjacent gridcells.

Linking to Impact Studies

To bring indigenous and scientific knowledge into a similar geographic context, we compared the locations of indigenous knowledge narratives with peer-reviewed impact studies (IPCC 2007, Rosenzweig et al. 2008) (Figure 2). Many of these data series are over 35 years in length.

We find that peer-reviewed observations of climate change impacts and indigenous knowledge narratives located in the same cell are complementary in that both are reporting system changes consistent with warming temperatures. The presence of indigenous narratives in gridcells that may not have studies of climate change impacts shows that indigenous groups are expanding knowledge of climate change impacts to regions that may not have documented changes in the peer-reviewed scientific literature. If this and other indigenous knowledge databases were to be expanded, more narratives from Oceania, Latin America, and Africa could prove very useful to climate science, as these are regions of the world generally lacking extensive longterm scientific data records of climate change impacts. We hope that development of this complementary

framework will foster more narratives and studies from other places in the world.

Side-by-Side

We next identified places where indigenous knowledge observations are located within 250 kilometers of peer-reviewed studies related to observed impacts. The “stars” on the map indicate the central location but do not cover the full extent of the region occupied by the indigenous groups and their narratives. For instance, the Iengra region, which is occupied by the twelve nomadic and semi-nomadic Yukaghir tribes, is a vast area covering multiple cells with significant warming (each cell being about 500x500 km) (Figure 2). These examples further demonstrate how the two knowledge systems can complement each other. In Russia, changes in the ice and water content of lakes and streams – along with detrimental impacts on reindeer herders – have coincided with climate-induced changes in season freeze and thaw depths (Frauenfeld et al. 2004). Further investigation into the relationships between these and other co-located reports could likely yield more correspondences.

Figure 2. Observed climate change impacts in Yakutsk, Russia, where indigenous knowledge narratives are located within 250 kilometers of observations from the peer-reviewed scientific literature. Latitude and longitude indicate the central location of the indigenous knowledge narrative. Legend as in Figure 1.

Indigenous knowledge narratives have also been linked with scientific datasets in smaller geographic areas (Sakakibara 2009). Several Iñupiaq indigenous knowledge narratives were presented that described the changes in sea ice and whale migrations that have been affecting hunting success. This is influencing the Iñupiaq’s spiritual and physical ties with the whale in relation to traditional music-making (Sakakibara 2009). These narratives were then linked to NASA Earth Observations Records (NASA 2007) (Figure 3). As time series of remotely sensed data become longer, further links between human and remotely sensed observations may be achieved.

Figure 3. Indigenous observations and remotely sensed data related to near-shore sea ice and whale hunting. Images of the Beaufort Sea north of Alaska and Canada’s Yukon and Northwest Territories. The

Moderate Resolution Imaging Spectroradiometer ([MODIS](#)) on NASA's [Terra](#) satellite captured these images on July 25, 2006, and July 25, 2005. NASA images courtesy Jeff Schmaltz, [MODIS Rapid Response Team](#) at NASA GSFC.

Fostering Connections

Our indigenous knowledge assemblage is still at an embryonic stage, but we find these preliminary results promising and such linkages important to understanding climate change. Collating indigenous narratives in parallel with peer-reviewed studies represents a valuable approach to deepening assessments of the impacts of climate change, as well as to sharing adaptive strategies. Indigenous knowledge, often from remote areas, is contributing to a significant expansion of global knowledge and understanding of observed responses related to warming and sea-level rise already underway.

Currently, indigenous knowledge narratives are minimally included in IPCC or other global assessments of climate change, as changes observed by local people are not documented frequently in peer-reviewed studies. Yet indigenous narratives provide a rich source of information about climate change that can contribute a great deal to science assessments that provide policy-relevant information such as the IPCC. Indigenous knowledge often provides understanding about what climate change means for livelihoods, cultures, and ways of life – beyond statistically-significant changes reported in the scientific literature. These narratives show that global climate change is already affecting integrated physical, biological, and human ecosystems, especially in the northern high latitudes.

Guidance for this process may be provided by the Convention on Biological Diversity (CBD), which is currently advancing a code of ethical conduct to respect, preserve and maintain the knowledge, innovations and practices of indigenous and local communities embodying traditional lifestyles relevant for the conservation and sustainable use of biological diversity, to promote their wider application with the approval and involvement of the holders of such knowledge, and encourage the equitable sharing of the benefits arising from the utilization of such knowledge. The IPCC could similarly provide guidance to include traditional knowledge in its assessments. Such a process of inclusion would enhance the IPCC Fifth Assessment (AR5)

process, now underway. Following and adding to the principles set forth by the CBD, this process could include:

1. The full participation of indigenous and local communities in the detection and description of climate change impacts.
2. Consideration and valuation of indigenous knowledge alongside scientific studies obtained using instrumental records.
3. A holistic approach that respects the spiritual and cultural values of the communities and allows indigenous knowledge to be brought forth in the form and format identified by the communities themselves.
4. An appreciation that indigenous knowledge can have an integrated awareness of the stewardship of land, water, and living resources, and with hopes that this knowledge can contribute to conservation and sustainable use of resources in an equitable manner.
5. Understanding that access to indigenous knowledge narratives will entail informed participation and approval from the holders of such knowledge.

We believe that it is crucial to foster the linkages between knowledge systems. For example, in remote areas that do not have temperature records, indigenous knowledge narratives may be able to serve as proxy data. On the other hand, point data and/or remote sensing measurements may aid in explaining local phenomena that may be difficult to observe through tactile or visual means (e.g., ocean current strength and direction changes, atmospheric oscillations, ocean temperature, air temperature, wind strength/direction, and long-term trends). Our hope is that the relationship between the two knowledge systems can indeed become complementary, with wide benefits to many groups. In the examples shown here, temperature and sea-ice records provide links to the global climate system, which is unequivocally changing. The narratives resonate with human voices that speak with deep understanding and concern for our changing planet.

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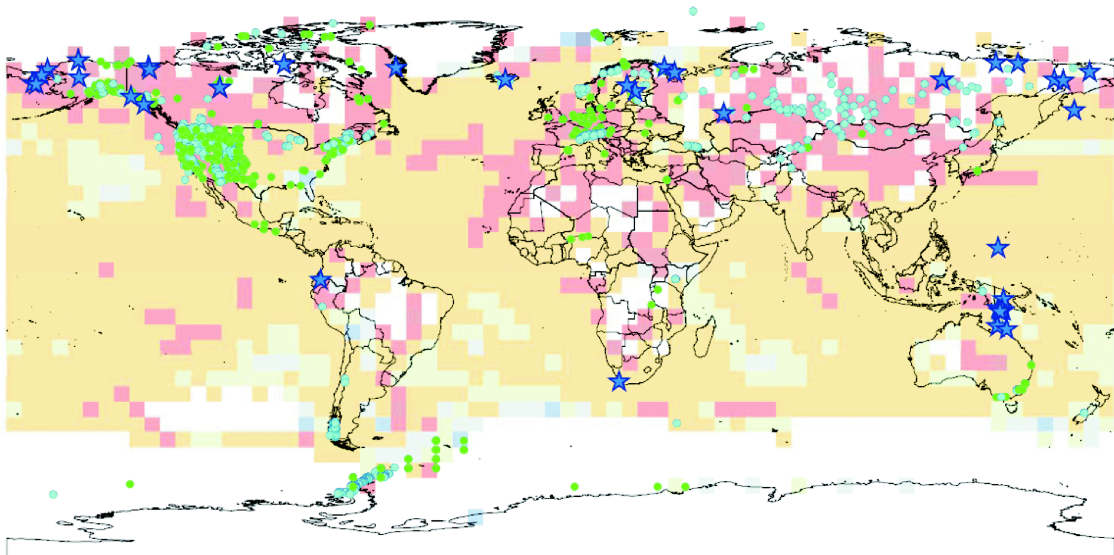
Authorship: C.A., U.K., T.M., N.O., C.S., V.S., and J.W. provided indigenous knowledge narratives and expert advice ; C.R., P.N., and M.V. assembled the studies and narratives. N.B., L.J., and B.W. organized the conference that brought the knowledge-holders together. C.R., P.N., M.V., N.B., L.J., B.W., T.M., and U.K., wrote the paper.

References cited

- ACIA. 2005. *Arctic Climate Impact Assessment, Scientific Report*. Cambridge, U.K. Report no.
- Albert TF. 2001. The influence of Harry Brower, Sr., an Iñupiaq Eskimo hunter, on the bowhead whale research program conducted at the UIC-NARL Facility by the North Slope Borough. Pages 265-278 in Norton D, ed. *Fifty more years below zero: Tributes and meditations for the Naval Arctic Research Laboratory's first half century at Barrow, Alaska*. Fairbanks, University of Alaska Press.
- Allen CJ. 1998. *The hold life has: Coca and cultural identity in an Andean community*. Washington: Smithsonian Institution Press.
- Archer DW, Halvorson AD, Reule CA. 2008a. Economics of irrigated continuous corn under conventional-till and no-till in northern Colorado. *Agronomy Journal* 100: 1166-1172.
- Archer ERM, Oettle NM, Louw R, Tadross MA. 2008b. "Farming on the edge" in arid western South Africa: climate change and agriculture in marginal environments. *Geography* 93.
- Berkes F. 1993. Traditional ecological knowledge in perspective. Pages 1-9 in Inglis JT, ed. *Traditional Ecological Knowledge: Concepts and Cases* Ottawa: Canadian Museum of Nature and the International Development Research Centre.
- . 1999 *Sacred ecology: Traditional ecological knowledge and resource management*. Philadelphia, PA: Taylor & Francis.
- Brewster K. 2004. *The whales, they give themselves: Conversations with Harry Brower Sr.* . Fairbanks: University of Alaska Press.
- Brohan P, Kennedy JJ, Harris I, Tett SFB, Jones PD. 2006. Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. *Journal of Geophysical Research-Atmospheres* 111.
- Castillo AR. 2009a. Walking on country with spirits www.ourworld.unu.edu/en.
- . 2009b. Sea level rise in Kowanyama www.ourworld.unu.edu/en.
- Celi L. 1978. Watchers of the Pleides: Ethnoastronomy among native cultivators in northeastern North America. *Ethnohistory* 25: 301-317.
- Clement D. 1995. *La Zoologie des Montagnais*. Paris Editions Peeters
- Diffenbaugh NS, Giorgi F, Raymond L, Bi XQ. 2007. Indicators of 21st century socioclimatic exposure. *Proceedings of the National Academy of Sciences of the United States of America* 104: 20195-20198.
- ELOKA. 2010. Exchange for Local Observations and Knowledge of the Arctic, <http://eloka-arctic.org/>.
- Fathy H. 1986. *Natural energy and vernacular architecture*. Chicago: University of Chicago Press. .
- Feld S. 1982. *Sound and sentiment: Birds, weeping, poetics and song in Kaluli expression*. Philadelphia, PA: University of Pennsylvania Press.
- Fox S. 2004. *When the Weather is Uggianaqtuq: Inuit Observations of Environmental Change*. Boulder: University of Colorado.
- Frauenfeld OW, Zhang T, Barry RG, Gilichinsky D. 2004. Interdecadal changes in seasonal freeze and thaw depths in Russia. *Journal of Geophysical Research* 109.

- Freeman MMR, ed. 1984. Contemporary Inuit exploitation of the sea-ice environment Ottawa:: Canadian Arctic Resources Committee.
- Green D. 2006. How Might Climate Change Affect Island Culture in the Torres Strait Australia Commonwealth Scientific and Industrial Research Organisation Report no.
- Green D, King U, Morrison J. 2009a. Disproportionate burdens: the multidimensional impacts of climate change on the health of Indigenous Australians. *Medical Journal of Australia* 190: 4-5.
- . 2009b. Disproportionate burdens: the multidimensional impacts of climate change on the health of Indigenous Australians. *Medical Journal of Australia* 190: 4-5.
- Groenfelt D. 1991. Building on tradition: Indigenous irrigation knowledge and sustainable development in Asia. *Agriculture and Human Values* 8: 114-120.
- Huntington HP. 1992. Wildlife management and subsistence hunting in Alaska. Seattle: University of Washington Press.
- Ingold T. 2000. The perception of the environment: Essays in livelihood, dwelling and skill. London: Routledge.
- IPCC, ed. 2001. Climate Change 2001: Impacts, Adaptation, and Vulnerability: Contribution of Working Group II to the Third Assessment Report to the International Panel on Climate Change Cambridge: Cambridge University Press.
- . 2007. Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability Working Group II Contribution of the Intergovernmental Panel on Climate Change Fourth Assessment Report. Report no.
- Kassam K-A, The Wainwright Traditional Council. 2000. Passing on the knowledge: Mapping human ecology in Wainwright, Alaska. Calgary, Canada: Arctic Institute of North America.
- Mabry JB, ed. 1996. Canals and communities: Small-scale irrigation systems Tucson: University of Arizona Press
- Menzies CR, Butler C. 2006. Introduction: Understanding Ecological Knowledge in Menzies CR, ed. Traditional Ecological Knowledge and Natural Resource Management Lincoln and London University of Nebraska Press
- Mustonen T, ed. 2005. Stories of the Raven - Snowchange 2005 Conference Report Anchorage Alaska Snowchange Cooperative
- NASA. 2007. Ice in the Beaufort Sea. <http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=17067>.
- National Assessment Synthesis Team Members. 2001. Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change. Washington, DC: US Global Change Research Program.
- Nebhan GP. 1987. The desert smells like rain: A naturalist in O'odham community Tucson: University of Arizona Press.
- Nelson RK. 1980. Shadow of the hunter: Stories of Eskimo life. Chicago: University of Chicago Oxfam American. November 2007. Papua New Guinea: "The Islands Are Shrinking" Oxfam America
- Reij CS, I., and Toulmin, C. 1996. Sustaining the soil: Indigenous soil and water conservation in Africa London: Earthscan.
- Rhoades RE, Rios XZ, Ochoa JA. 2008. Mama Cotacachi: History, Local Perceptions, and Social Impacts of Climate Change and Glacier Retreat in the Ecuadorian Andes Berkeley University of California

- Rosenzweig C, Karoly D, Vicarelli M, Neofotis P, Wu QG, Casassa G, Menzel A, Root TL, Estrella N, Seguin B, Tryjanowski P, Liu CZ, Rawlins S, Imeson A. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature* 453: 353-357.
- Sakakibara C. 2008a. Iñupiat narratives. Personal communication.
- . 2008b. "Our Home is Drowning": Inupiat Storytelling and Climate Change in Point Hope, Alaska. *The Geographical Review* 98: 456-475.
- . 2009. 'No Whale, No Music': Inupiaq drumming and global warming *Polar Record* 45: 1-15.
- . 2010. *Kiavallakkikput Ağviq* (Into the Whaling Cycle): *Cetaceousness* and Global Warming among the Iñupiat of Arctic Alaska. *Annals of the Association of American Geographers* (2010 Special Fifth Issue) on the theme of Climate Change.
- Schultes RE. 1989. Reasons for ethnobotanical conservation in Johannes RR, ed. *Traditional Ecological Knowledge: A Collection of Essays*. Gland, Switzerland: International Conservation Union (IUCN).
- . 1995. 1995. Portland, OR: Timber Press.
- Shadrin V. 2008. Climate Change and Indigenous Peoples of Yakutia. *Snowchange: Ecological Traditions of Indigenous Peoples of Yakutia*.
- Simpson L. 2004. The Colonial Context for the Indigenous Experience of Climate Change in Mustonen T, Helander E, eds. *Snowscapes, Dreamscapes*. , Tampere Polytechnic
- Smetzer M. 2008. Polar bear killed near village in Interior Alaska. *Fairbanks Daily News Miner*
- Smith TM, Reynolds RW. 2005. A global merged land and sea surface temperature reconstruction based on historical observations (1880–1997). *Journal of Climate* 18: 2021-2036.
- Turner J, Overland JE, Walsh JE. 2007. An Arctic and Antarctic perspective on recent climate change. *Int. J. Climatology* 27: 277-293.
- UNDRIP. 2008. United Nations Declaration on the Rights of Indigenous Peoples
- Warren DM. 1995. Comments on article by Arun Agrawal *Indigenous knowledge and development monitor* 4: 13.
- Watt-Cloutier S. 2006. Presentation at the Inuit Circumpolar Conference 10 July. Barrow, AK.
- WCED. 1987. *World Commission on Environment and Development Our common future*. Oxford Oxford University Press.



Indigenous knowledge database:

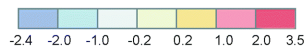
★ Physical, biological, and social changes

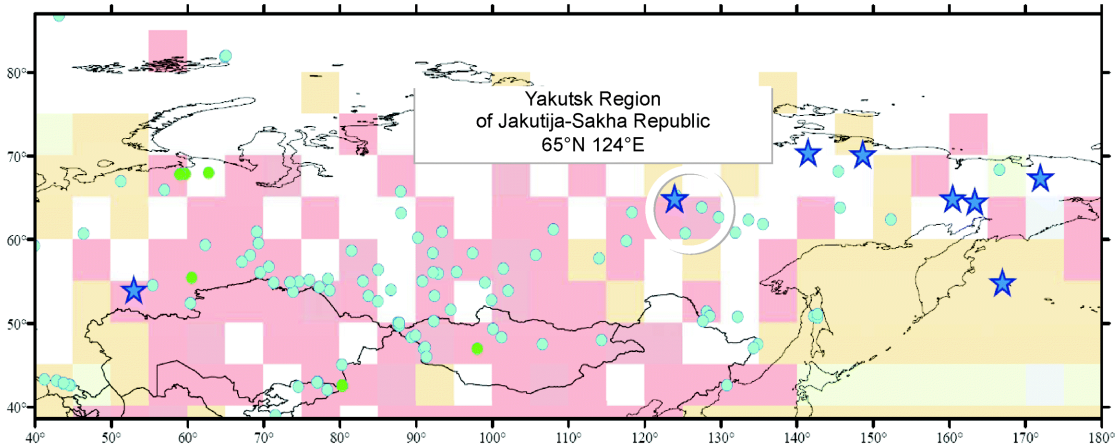
Rosenzweig et al. (2008) database:

○ Physical systems (cryosphere, hydrology, coastal processes)

○ Biological systems (marine, freshwater, and terrestrial)

Temperature change °C
1970-2004





Vyacheslav Shadrin,
Head of the Council of Yukaghir Elders
in Mustonen, T., Ed. Stories of the Raven.
Snowchange. Conference Report 2005

Frauenfeld et al. 2004

"Lakes are sinking as the permafrost melts, which means many fishing lakes have been lost. People have to go further, which is hard as the price of fuel goes up. Reindeer herders select routes based on weather forecasts so mistakes have detrimental effects."

Mean monthly soil temperature data for 1930-1990 indicate that, as temperatures have been rising, the active layer of permafrost has been deepening and the freezing depth has become more shallow.



July 26, 2005



July 25, 2006

Iñupiaq narratives	NASA Earth Observatory 2007
<p>Many Iñupiaq interviewees emphasized that the ice condition was out of the ordinary in both 2005 and 2006... An elderly captain stated that the 2006 spring season harvest in the North Slope Borough was the lowest in the past 35 years (Sakakibara C. 2009).</p> <p>"[t]hose poor whales out there in the ocean that we depend on. Are they going to come back to us? Are they going to really show up next year, like our ancestors always expected them for 20,000 years? We are heartily concerned."</p> <p>-Earl Kingik, Iñupiaq tribesman</p>	<p>Record melting during 2005 allowed old, thick ice from the north to drift into the Beaufort Sea. Some of this ice from the increased melting was pushed by wind toward the shore in 2006.</p> <p>Though there was more ice in the Beaufort Sea at the end of July 2006 than there had been in previous years, the Arctic as a whole continued to melt at an ever-quickenning pace. By June 2006, sea ice in the Arctic covered 1.2 million fewer square kilometers than the long-term average measured between 1979 and 2000. This put sea ice concentrations (the percentage of ice that covers a predefined area) at a record low for June, breaking the record set in June 2005, during which sea ice extent was down 0.8 million square kilometers from the average</p>