Climate Change, Sea Ice Conditions, and Effects on Marine Birds in Arctic Canada

H. Grant Gilchrist*, Anthony J. Gaston*, and Mark J. Mallory#

*National Wildlife Research Centre, Canadian Wildlife Service, 1125 Colonel By Drive, Raven Road, Carleton University, Ottawa, Ontario, Canada. K1A OH3. #Canadian Wildlife Service, Iqaluit, Nunavut, Canada.

In recent decades, climate change has been shown to be affecting many biological systems. Some strong signals of the biological effects of global climate change come from long-term studies of temperate birds, with many species showing recent trends towards earlier timing of spring migration (Bradley et al., 1999; Inouye et al., 2000), and earlier egg laying (Brown et al., 1999).

Because greenhouse-gas induced global warming is predicted to be most intense at high latitudes (Ledrew, 1993; Cattle and Crossley, 1996), high-latitude environments may be among those most strongly affected by climate change (Boyd and Madsen, 1997). Sea ice extent (i.e. the area of ocean covered by ice), a major factor in Arctic marine ecology, has decreased at a rate of about 3% per decade since the 1970’s (Parkinson et al., 1999). The extent of the retreat appears to be well beyond that expected as a result of natural variation in climate (Vinnikov et al., 1999). Earlier sea ice break-up has already caused changes in fish communities in northern Hudson Bay (Gaston et al., 2003) and deterioration in female body condition among polar bears (Ursus maritimus) in western Hudson Bay (Stirling et al., 1999). In the same area, increasing peak temperatures and consequent increased activity of mosquitoes has been shown to cause mortality in breeding thick-billed murres – a phenomenon not seen until 1997.

Most predictions of the effects of climate change on wildlife assume that temperature increases will lead to contraction of species range at low latitudes, accompanied by expansion at higher latitudes (Slaymaker and French, 1993; Boyd and Madsen 1997). However, to date, demonstrations of the potential mechanisms involved in such a transition are lacking. To investigate this problem, we examined the effects of sea ice conditions on two marine bird species in the Canadian Arctic. In the first, we examined the impacts of heavy sea ice conditions on the population demography and habitat use of the Hudson Bay Common Eider duck (Somateria mollissima sedentaria); a sea duck that winters in the pack ice and polynyas of Hudson Bay.

In the second study, we analysed data relating to the reproduction of a marine diving bird, the thick-billed murre, Uria lomvia, breeding at two Arctic colonies at the northern and southern limits of the species’ range in the Canadian Arctic. Although not all of this area is currently experiencing rapid warming, there has been substantial inter-year variation in climate in recent decades. To develop predictions about the likely impacts of climate change on murres, we made inferences from indices of their reproduction in relation to inter-year differences in temperature and ice conditions in the vicinity of the two colonies.

Methods

Hudson Bay common eider ducks - The Hudson Bay Common Eider duck, Sommateria mollissima sedentaria, winters at polynyas and leads in pack ice within Hudson Bay. The sub-population of eiders nesting on islands within the Belcher Islands archipelago of Hudson Bay was surveyed by boat in 1984 and again in 1997 to derive population trend (Robertson...
We also conducted aerial surveys of their marine habitat use during the winters of 2000-2003, and conducted detailed studies of eider foraging ecology from observation blinds placed on the sea ice in winter (Gilchrist and Robertson 2000).

**Thick-billed murres** - The thick-billed murre is a circumpolar species that breeds only in the Arctic and Subarctic, wintering in the northernmost ice-free areas and feeding almost entirely in waters at less than 8°C throughout the year. Thick-billed murres forage underwater to depths of 200 m, feeding on small fishes, squid and large zooplankton (Gaston and Hipfner, 2000). Observations of reproduction by murres have been made intermittently in Canada since 1975 at a breeding colony of about 100,000 pairs on Prince Leopold Island (see Gaston and Nettleship, 1981), and annually since 1984 at a colony of 30,000 pairs on Coats Island, both in Nunavut, Canada (Gaston et al., 1994). Coats Island (62°N, 82°W) experiences the highest July temperatures of any major (>1000 pair) Canadian thick-billed murre colony (July mean ~ 10°C), whereas Prince Leopold Island (74°N, 90°W), has the lowest summer temperatures (~ 3°C).

**Conclusions**

We found that the majority of Hudson Bay eiders winter off-shore over a shallow under-water bank; a region typically covered by moving pack ice from December to May (often >95% ice cover). In contrast to many regions of the circumpolar arctic, current climate models predict that colder temperatures and heavy ice conditions will occur in this region of Hudson Bay. When extreme cold occurs (-38°C) concomitant with calm wind conditions, this marine region freezes over. Under these conditions, we found that eiders fly to small, recurring polynyas within the Belcher islands that act as temporary refuges. However, if these conditions persist, eiders can deplete their benthic prey at polynyas; resulting in their mass starvation. The effects of this scenario on eiders were felt during the winter of 1991-1992 following the Pinatubo volcanic eruption, which lowered circumpolar temperatures. Heavy pack ice and loss of some polynyas occurred in Hudson Bay during the winter of 1992, and these conditions prevented eiders from reaching shallow feeding areas. This resulted in their mass starvation and a population decline of 85% (Robertson and Gilchrist, 1999; Gilchrist and Robertson, 2000).

In the second study, we compared the reproduction of a marine diving bird, the thick-billed murre, *Uria lomvia*, breeding at two Arctic colonies at the northern and southern limits of the species’ range in the Canadian Arctic. At Coats Island, in the low Arctic waters of northern Hudson Bay, the date of egg-laying has advanced since 1981, concomitant with a decrease in summer ice cover in surrounding waters. Lower ice cover in this region is correlated with lower chick growth rates, suggesting that reduction in summer ice extent is having negative effects on reproduction. Conversely, at Prince Leopold Island, in the High Arctic, there has been no trend in summer ice cover and no detectable change in timing of breeding. Reproduction there is less successful in years of heavy ice than in years of early ice break-up.

Given that Arctic sea ice patterns are changing, our research on marine birds collectively suggests that climate change will have a significant effect on many Arctic marine birds. However, these effects may not be consistent across regions or even within species, and thus regional studies will be required to elucidate effects.
References


Climate Change and Goose Grazing on Svalbard’s Tundra

Elisabeth Cooper1, Ingibjörg Svala Jónsdóttir1, Dominique Chaput1, Dries Kuijper2, Maarten Loonen2, Astrid Pahud1, Sofie Sjögersten3, Richard Ubels2, René van der Wal4, Sarah Woodin3, Ad Huiskes5

1The University Centre in Svalbard (UNIS), N-9171, Longyearbyen, Svalbard, Norway.
2Zoological laboratory RUG, 9750 AA Haren, The Netherlands.
3Department of Plant & Soil Science, University of Aberdeen AB24 3UU, Scotland.
4Centre for Ecology & Hydrology – Banchory, AB31 4BW, Scotland.
5NIOO-CEME, 4400 AC Yerseke, The Netherlands.

Introduction

Change in Arctic climate has direct effects on the growth and productivity of tundra vegetation and indirect effects through climate induced changes in herbivore intensity. Herbivores have huge potential to modify both species composition and biomass through selective grazing, intensity of grazing and trampling, and nutrient turnover through feces deposition. When considering future scenarios of climate impacts on Arctic tundra it is therefore important to include the knock-on effects of changes in grazing, caused by changes in climate and/or socio-economic/political decisions. Land use changes in temperate biomes can affect Arctic systems via changes in the grazing pressure caused by migratory herbivores such as geese. Migratory geese breed in Svalbard in summer and return to Western Europe for the winter, feeding on wetlands and agricultural fields. Recent changes in climate, land use and the implementation of protective measures have dramatically improved the birds’ ability to survive the winter. This has resulted in a 30-fold increase in the barnacle goose and a 4-fold increase in the pink-footed goose populations in Svalbard over the past 40 years. Increased temperatures in the Arctic as predicted by climate change models may result in earlier snow melt allowing birds to breed earlier and produce more offspring. Warmer temperatures during summer may also affect plant productivity and vegetation composition. Selective removal of plant tissue by geese may change the vegetation composition, amount and quality of plant litter produced and carbon balance of the system. Goose droppings and nitrogen fixation function as a nitrogen source thus increasing plant productivity. Arctic ecosystems are vulnerable to overgrazing, as shown by recent experience in N.E. Canada, where high numbers of snow geese caused large-scale degradation of pristine low arctic salt marshes, leading to desertification of these ecosystems. This project aims to assess the vulnerability of Svalbard tundra ecosystems to further increases in breeding goose populations caused by changes in European land use and bird protection measures, in a context of future climatic change. This paper presents the methodology used for the field experiment and results from the first field season.

Methods

The experiment was carried out in Adventdalen, 15 km east of Longyearbyen, Svalbard (78°N) in two habitats representative of those used by geese in summer; a mesic tundra vegetation with shrubs, flowering plants and grasses and a wet moss-dominated vegetation with grasses. Open top chambers (OTCs) were used as small greenhouses to increase the temperature of the air and ground. Captive wild barnacle geese were put on the 2 x 2 m experimental plots for one or five hours, to simulate ‘natural’ and ‘high’ grazing pressure. The grazing pressure was calculated from the time spent foraging during the grazing trials based
on observations of goose behaviour and compared to data from the literature of grazing pressure in a natural situation on Svalbard. The number and length of shoots of key species were recorded before and after grazing to determine the amount grazed. Moss depth was measured at eight locations in each plot after the first field season.

Results

2003 was an unusually warm summer on Svalbard; however the open top chambers increased temperatures above ground in both habitats and below ground in the mesic habitat (Table 1); temperature increases were highest in the mesic habitat. OTCs increased the size of plants of *Alopecurus borealis* but had no significant effect on *Dupontia* sp. (Figure 1).

The grazing pressure created with captive geese on experimental plots for one hour was similar to that observed in natural systems on Svalbard for both mesic and wet habitats (Table 2). The 5 hour treatment achieved a grazing pressure much higher than that observed experimentally in one hour or in natural systems on Svalbard. Foraging time was 2.6 and 3.4 times higher in the 5 hour compared to the one hour treatment for mesic and wet habitats (respectively). Geese are selective grazers- they prefer the wet habitats and start grazing *Equisetum* then *Dupontia* then switch to mosses. The proportion of shoots grazed or removed by grazing was higher in the 5 hour treatment than in the one hour treatment for *Bistorta vivipara* and *Alopecurus borealis* on the mesic habitat and *Equisetum arvense* and *Dupontia* sp. in the wet habitat (Figure 2). Trampling by the geese caused a reduction in the depth of moss in the wet habitat (Figure 3).

Conclusions

This unique field experiment has enabled a detailed study into climate-goose-vegetation interactions. In our presentation we show further tundra responses to the experimental treatments outlined here.

Acknowledgements

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References


Table 1. Mean July temperatures (°C) of ambient and warmed plots in Adventdalen, Svalbard, 2003.

<table>
<thead>
<tr>
<th></th>
<th>Ambient</th>
<th>Open Top Chamber</th>
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<td>+0.5</td>
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<tr>
<td>Below ground</td>
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<td></td>
<td></td>
</tr>
<tr>
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<tr>
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<td>5.3</td>
<td>-0.4</td>
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Table 2. Grazing pressure in experimental plots compared to observations made of natural goose populations on Svalbard.

<table>
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<tr>
<td></td>
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<tr>
<td></td>
<td>Natural</td>
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</tbody>
</table>

Figure 1. Length of live leaves (mm per plant) at the end of July 2003. n = 25.

Figure 2. Percentage of shoots present which were grazed. n = 5.

Figure 3. Moss depth after one season of treatments. n = 5.
Vulnerability of Arctic Shorebirds to Climate Variability and Change


Contact address: Hans Meltofte, National Environmental Research Institute, Department of Arctic Environment, P.O. Box 358, DK-4000 Roskilde, Denmark. E-mail mel@dmu.dk

Introduction

Shorebirds constitute the dominating avian biodiversity in the Arctic both concerning numbers of species and population densities. Opposite to most biodiversity, which decrease heavily towards high latitudes, a number of shorebird genera have most or even all species breeding in the Arctic. A total of 35 shorebird species have their main distribution within the Arctic zone, i.e. on tundra habitat, and a further c. 15 extend their distribution from south into the Arctic. Outside the breeding season, Arctic shorebirds disperse over virtually all temperate and tropical parts of the globe.

Even though a number of Arctic breeding shorebird species have a circumpolar distribution, most species are confined to certain tundra types within different parts of the Arctic. In particular, most species breed either in the relatively lush Sub- and Low Arctic tundra types or on the poorer High Arctic tundra. This means that each species is highly dependent on the distribution and extent of that particular type of tundra and hence dependent on the climatic conditions prevailing there and having shaped and maintained the habitat.

With the anticipated climate changes, which are expected to become particularly pronounced in the Arctic, extensive and dramatic changes in habitat types, snow, and weather regimes can be foreseen for most tundra areas.

The present team of authors has worked with shorebirds in virtually all parts of the Arctic for extended numbers of years, and we have included published as well as unpublished material for this review. By presenting existing knowledge on weather and climate impacts on each segment of the annual breeding cycle and not the least differences between different parts of the Arctic, we try to pinpoint the most critical segments and thereby facilitate evaluations of possible future impacts.

Conclusions

Arctic shorebirds spend most of the year on tidal coasts and other wetlands in temperate and tropical areas, but during the summer they expose themselves for a relatively few weeks to the often harsh Arctic environment to reproduce. Conditions vary extremely, both between different parts of the Arctic and temporally: from apparently favorable environments in many Sub- and Low Arctic areas to the harshness of the northernmost tundras and from year to year.

Primary production is nearly 1000 times higher in Low Arctic shrub communities than in High Arctic desert, and this is the most likely explanation for 100-fold higher shorebird breeding densities in certain Sub- and Low Arctic areas than in High Arctic desert.

Productivity (food) must be the overall governing factor in shorebird breeding density in the Arctic, but this may regionally and locally be moderated by long lasting snow cover etc. Two
possible energetic bottlenecks seem to stand out: (1) the pre-breeding, egg-laying and early incubation period all over the Arctic and (2) the chick growth period in large parts of the Arctic. Both aspects relate to the apparent precondition that it is advantageous for Arctic shorebirds to commence egg-laying as early as possible. Early egg-laying both appears to improve production of viable young and to facilitate early departure of adults.

During pre-breeding, Arctic shorebirds first have to transform their bodies from “flying machines” to “breeding machines”. Body stores accumulated during migration and remaining after arrival on the breeding grounds may facilitate such physiological changes, while at the same time, body stores may also serve as an insurance against spells of severe weather upon arrival. In both of these respects, body stores saved from their final staging areas may be of great importance. In this way, stores acquired remotely from the nesting grounds themselves may play a key role in enabling shorebirds to breed successfully in the Arctic. Finally, they have to acquire resources both for egg-laying (females) and for incubation (most often both sexes). In large parts of the New World Sub- and Low Arctic, snow is no problem in most years, while in parts of the Siberian Low Arctic and in the circumpolar High Arctic, ‘sufficient’ snow free land is the first precondition, which has to be fulfilled. This is either because the shorebirds simply need sufficient snow free land to feed on, snow free land to nest on or sufficient snow free land to space nests on to reduce predation – or all of this. Secondly, in all parts of the Arctic there has to be enough food available for egg production, i.e. ‘high’ temperatures.

In parts of both the Nearctic and the Palearctic, feeding conditions for chicks during pre-fledging were found to influence production of juveniles. The data suggest that weather variation makes it very hard for a shorebird to predict the peak of insect emergence on a within-year timescale, and that they possibly do best by breeding as early as possible so that as much as possible of the pre-fledging period falls within the period with a reasonable chance of finding sufficient food to grow.

Owing to the large differences between the regions, shorebirds are able to initiate egg-laying up to one month earlier in parts of the Nearctic as compared to parts of the Palearctic. With a final date for laying around 1 July, this implies that the “time window” for re-nesting in case of failure is much longer in the early snow free parts of the Arctic. Hence, taken together, feeding conditions during pre-breeding and egg-laying may be a strongly contributing factor in determining shorebird breeding densities and breeding performance in the Arctic. This is intensified in the High Arctic and large parts of the Siberian Low Arctic, where up to 80-90% of the tundra is snow covered during pre-breeding and egg-laying. Furthermore, particularly in the Siberian Arctic predation has a very strong impact on breeding productivity, and since lemmings are keystone species in this ecosystem, any climate effects on their abundance or population dynamics may indirectly affect shorebird populations through predation.

During recent decades, large population declines seem to have taken place in both Nearctic and Palearctic shorebird populations. Based on present knowledge of population trends (known for 52% of the 100 biogeographical populations of 37 species recognized in the Arctic), 12% are increasing, 42% are stable, and 44% are decreasing, while 2% are possibly extinct. The reasons for these declines are not known, but habitat changes and other anthropogenic disturbance in temperate and tropical staging and wintering areas are suspected to contribute. The climatic amelioration having influenced large parts of the Arctic during recent decades has not been shown to affect shorebird population sizes. On the contrary, the results presented in this review generally point to warmer spring and summer weather being beneficial to Arctic shorebirds also in the two phases of the breeding cycle, which appear to be most critical. Furthermore, warmer winters should even benefit the populations wintering
in temperate regions. In fact, warmer winters in Western Europe during recent decades have made it possible for shorebirds to winter farther north and east. But the situation is hardly that simple in the longer term.

Looking at the future, things get complicated. The relationships between shorebird breeding performance and weather/temperature observed in studies performed within the limits of variation of current climatic conditions may tell us little about effects over a longer timescale, or a larger amplitude of climate change, which may involve much more fundamental changes in the ecosystems. Neither do we know to what extent the birds are able to adapt to fast changing climatic conditions. Current Arctic climate scenarios for the future do not have a spatial or temporal resolution either for temperature, incoming radiation (cloud cover and thereby microclimate temperatures), precipitation (including duration of snow cover), or wind, nor for frequency and intensity of severe weather events, which would allow us to impute our findings into these models, but possibilities may improve in the near future. For the time being, it seems most useful to take a shortcut and look at macro-scale relationships between species and their environment. Since most Arctic shorebirds are largely confined to specific habitat zones within the Arctic, we must expect them to react to changes in the vegetation and climate occurring in these zones.

A general expansion in Subarctic shrub and boreal forest is expected with increasing temperatures, and this will reduce the breeding areas available to tundra shorebirds. However, tundra is not just tundra. In the same way as Subarctic shrub expands northwards, the different Arctic plant zones will move northwards or disappear. Here, the High Arctic shorebirds seems to be particularly at risk, since the High Arctic already now constitutes a relatively limited area “squeezed in” between the extensive Low Arctic biome and the Arctic Ocean. Furthermore, the disappearance of dense ice cover on large parts of the Arctic Ocean may cause the climate to become more maritime-dominated in the High Arctic – approaching present day Svalbard conditions, where few shorebirds breed.

That High Arctic shorebirds could be especially vulnerable to climate change may be indicated by their much more limited genetic diversity than found in Low Arctic species studied. This is thought to be related to earlier climatic perturbations, particularly during fast warming periods in the Quaternary, where these High Arctic shorebirds went through narrow population bottlenecks. One may actually ask how many High Arctic shorebird species or populations disappeared altogether in an environment where, for instance, the number of reproducing female red knots (a sandpiper species) apparently was down to a few hundred?

In addition, living conditions for shorebirds in the staging and wintering areas, together with wind systems during migration, could be highly altered by climate change and the expected resulting sea level rise. Since most Arctic shorebirds are living in intertidal areas outside the breeding season, and that conditions here are fundamental for their ability to build up body stores for the long migrations to the breeding grounds and for their first time there, climate changes affecting conditions on staging areas have the potential to alter shorebirds’ abilities to breed successfully in the Arctic dramatically. For species dependent on inland spring staging areas, the anticipated drought in many temperate and subtropical areas would have the same effect.

On top of this, anthropogenic disturbance and destruction of shorebird staging and wintering habitat continue at a high rate in many parts of the World, and have the potential to supersede effects of global climate change considerably at least in the short term.
Modeling the Response of Parasites in Arctic and Sub-arctic Ungulates to Climate Change

Susan Kutz¹, Eric Hoberg² and Lydden Polley¹

Research Group for Arctic Parasitology:
¹Western College of Veterinary Medicine, 52 Campus Drive, University of Saskatchewan, S7N 5B4, Saskatoon, Saskatchewan, Canada
²US National Parasite Collection, and Animal Parasitic Diseases Laboratory, USDA, Agricultural Research Service, 20705 Beltsville, Maryland, USA

Introduction

Wildlife in Canada’s Arctic and Sub-arctic is an important renewable resource, providing subsistence for northerners and contributing to local and regional economic stability through tourism, fur harvesting, outfitting, and commercial harvests. Sustainable wildlife populations, therefore, are not only critical for ensuring biodiversity and ecosystem integrity, but also for the maintenance of healthy, productive northern communities. Parasites, including viruses, bacteria, protozoa, arthropods and helminths (worms), can negatively impact the health of wildlife through a variety of mechanisms and, therefore, can alter the stability of those populations. Additionally, some parasites of wildlife can infect people and pose a risk to those who harvest, handle and consume wildlife. Consequently, knowledge of parasites found within wildlife and the factors affecting the survival and spread of those parasites among individuals, is essential for ensuring persistence of wildlife as well as ensuring public health in our rapidly changing world.

Climate change, particularly warming, is one such factor altering our world. It is considered to be one of the most important drivers of emerging disease in people and domestic livestock, and is anticipated to have significant impacts on parasitic disease in arctic and sub-arctic wildlife (Harvell et al., 2002; Dobson et al., 2003). Many parasites of wildlife have life stages that develop in the environment or require invertebrate intermediate hosts or vectors for transmission. However, at northern latitudes these parasites are typically constrained by the long cold winters and short, cool summers. Climate change, through warmer temperatures, earlier springs, later autumns, and milder winters is expected to relax some of these constraints and alter the survival and development of parasites in the northern environment (Kutz et al., 2004). Predicted responses of parasites include: increased over-winter survival, faster rates of development, increased rates of transmission, and a shift in geographic distribution. Movement of “southern” parasites to higher altitudes and latitudes, together with changes in host range, may also result in new parasites being introduced into northern wildlife, parasites for which they may be ill equipped to resist. These changes, together with other climate change impacts on hosts and the environment (such as changes in host condition and immune function, increases in severe weather events [e.g., rain-on-snow], and habitat changes) are predicted to result in emergence of parasite-induced disease and challenges to stability of wildlife populations. (e.g., Hoberg et al., 2003; Dobson et al., 2003; Kutz et al., 2004). However, these are predictions based on reasoning and have not been tested.

Umingmakstrongylus pallikuukensis, a protostrongylid nematode lungworm of muskoxen first discovered in 1988 near the community of Kugluktuk, on the mainland of western Nunavut, Canada (Hoberg et al., 1995), gives us an excellent opportunity to test the above predictions and better understand the potential impacts of climate change on parasite development and transmission in an arctic environment. The adult parasites are found in cysts ranging from 5-40mm in diameter in the lungs (Kutz et al., 1999) and over 250 of these cysts have been observed in adult bulls (Gunn and Wobeser, 1993). There is anecdotal evidence that the U. pallikuukensis has increased in abundance since the 1980’s and currently, where it occurs, close to 100% of adult muskoxen are infected (Kutz et al., 2004). The parasite’s life cycle is indirect, requiring a slug or snail as an intermediate host for the first-stage larvae that are shed in the muskox feces to grow to the infective stage (L3). Development of larvae within the gastropods is temperature-dependent with no detectable development occurring
below 8.5°C and development rates increasing up to approximately 24°C (Kutz et al., 2001). Based on a simple mathematical model that we constructed from a series of laboratory and field experiments, development of *U. pallikuukensis* to L3 is predicted to require two years under ‘normal’ arctic temperatures (1961-1990 average) (Kutz et al., 2002). We have since validated this model for a second northern protostrongylid, *Parelaphostrongylus odocoilei*, from Dall’s sheep (*Ovis dalli*) in the Sub-arctic (E. Jenkins, unpub. data). Herein, we apply this model to historic northern temperatures and future scenarios to gain a better understanding of the potential impacts of climate change on the transmission of *U. pallikuukensis* among muskoxen and to provide insight into climate change impacts on other northern host-parasite associations.

**Methods**

We used our model to calculate historic larval development rates of *U. pallikuukensis* based on hourly air temperatures near Kugluktuk, Nunavut, for each year from 1978-2003. We then added increments of 1°C to the mean hourly temperatures from this time period to calculate rates of larval development and to determine when L3 would first become available under climate warming scenarios. Finally, we predicted the abundance of larvae using these climate change scenarios and data for gastropod and larval survival from our previous field experiments.

**Results**

Our retrospective analysis of patterns of larval development indicated that development to L3 within a single year has probably become more common over time. For example, from 1978-1990 development of the parasite to the infective stage occurred within a single summer in only 5 of 13 years. In contrast, in the second half of this time period, (1991-2003), parasite development to L3 within a single summer was predicted for 12 of 13 years. Based on the mean hourly air temperatures from 1978-2003, larvae of *U. pallikuukensis* could not develop to L3 within a single year but would have to over-winter and resume development in the second summer. As little as a 1°C increase in temperature allowed larval development within a single summer and the first L3 would be expected by August 16; an 8°C increase would result in L3 as early as July 4th. Quantitatively, assuming a constant rate of infection of slugs throughout the summer, there was more than a six-fold increase in potential L3 available by the end of the summer under a warming scenario of 8°C vs. 1°C.

**Discussion**

Results from this simple modeling exercise provide considerable insight into potential impacts of climate warming on host parasite systems in the Arctic. Perhaps the most significant finding is the predicted switch from a predominantly two year transmission cycle (1978-1990) to a single year cycle (1990-2003 and beyond). This shift has great quantitative significance in that larvae that have to over-winter before completing development to L3 have significantly poorer survival rates than those that complete development within a single summer (Kutz et al., 2002). Together, the shift to a single year transmission cycle, faster larval development rates, and lengthened seasons for development, are anticipated to lead to an earlier and greater availability of L3, and, all else equal, increased infection levels in muskoxen. Depending on the host response, including immune function, and other environmental factors, increased infection levels could lead to emergence of parasite-induced disease, as well as more subtle effects such as decreased reproduction rates, poorer body condition, altered behaviour, and greater susceptibility to other sources of mortality such as predation and nutritional stress.

This modeling exercise has the potential for broader application to other northern host-parasite systems. Caribou, reindeer, moose, and wild sheep are all hosts for a variety of potentially pathogenic protostrongylid nematodes. Changes in climate are anticipated to impact the transmission dynamics of these parasites in much the same ways as in the muskox system we examined (e.g., see Handeland and Slettbakk, 1994). Depending on host behaviour and the life history characteristics of the parasites,
these changes may result in significant effects on the health of the hosts. The model we present herein can provide considerable insight into how transmission dynamics may change in this family of parasites when combined with parasite-specific parameters (threshold temperature and thermal constants can vary among parasite and gastropod species), and knowledge of the life history traits of the different host species. This understanding will enable us to identify vulnerabilities, including the possible establishment of parasite species that were previously excluded because of temperature constraints. Principles derived from this research also can be applied to a much broader range of parasite species, including those that are transmitted directly or by insect vectors, in arctic and sub-arctic wildlife.

In conclusion, this study represents the first step to understanding how changing temperatures may affect the survival, development, and transmission of the larval stages of northern parasites. However, climate change scenarios also indicate changes in precipitation and increases in severe weather events. Most scenarios suggest increased precipitation in the Canadian north, which in general is anticipated to improve parasite, intermediate host, and vector survival. Additionally, high levels of parasitism may compound the negative effects of severe weather events, especially those that limit access of animals to food (e.g., rain-on-snow) (e.g., see Gulland, 1992). Ultimately, it is the interaction among host factors, the environment, and the parasites that will determine the fate of the host population. Clearly, we need to continue to build empirical and conceptual models, together with experimental and observational studies, to better understand how the various aspects of climate change in the north will impact the occurrence of parasites and parasite-induced disease, and the long-term persistence of wildlife populations.

References


Mercury in the Arctic Ecosystem: Understanding Pathways of Contamination through Atmosphere and Biosphere

Noelle Eckley Selin, Daniel J. Jacob, Rokjin J. Park

Department of Earth and Planetary Sciences, Harvard University, 29 Oxford Street, Cambridge MA 02138 USA

Chapter 17 of the Arctic Climate Impact Assessment (ACIA) draws attention to problem of contaminants in the context of climate impacts, and identifies mercury as a particular substance of concern. Mercury has been identified as a priority pollutant in the Arctic, due to high levels of mercury found in the environment, and indigenous people can be particularly affected by such pollution through consumption of traditional foods (AMAP, 2002). The transport and chemistry of mercury in the global atmosphere has been a topic of increasing scientific as well as policy interest. We address selected questions about mercury’s transport and fate in the Arctic and the global atmosphere using a global three-dimensional model (GEOS-CHEM).

We have developed a global-scale simulation capability of the fate and transport of mercury in the GEOS-CHEM atmospheric chemistry and transport model. Our model has several advantages over previous attempts to simulate mercury on a global scale. First, we use a streamlined chemical mechanism, incorporating updated kinetic information and rate constants, to identify the major reactions that control mercury’s speciation in the atmosphere. In addition, we have included an improved parameterization of surface-atmosphere interactions in assessing the contributions of natural sources to the global mercury budget. Finally, using the GEOS-CHEM model, which incorporates more realistic meteorology than previous mercury models, we are able to compare model results and measurements directly, which enables us to assess episodic mercury depletion and transport events.

The GEOS-CHEM mercury model simulates three species of mercury in the atmosphere: elemental mercury (Hg0), divalent mercury (Hg(II)), and particulate mercury (HgP). Anthropogenic emissions of Hg0, Hg(II), and HgP are estimated by the GEIA emissions inventory at 1446, 774 and 204 Mg, respectively (Pacyna and Pacyna, 2002). Oceanic emissions of Hg0 are assumed to vary based on latitude (i.e. they are higher at the equator) and are scaled to 2000 Mg. Re-emission of previously deposited mercury from land as Hg0 is estimated at 1500 Mg and mapped according to the deposition patterns of current anthropogenic sources, following the methodology of Bergan et al. (1999) and Seigneur et al. (2001). A natural land source of 500 Mg Hg0 was incorporated based on the locations of mercury mines worldwide (Frank, 1999).

Two oxidation pathways are included in the model: Hg0 can react with either OH (Sommar et al., 2001) or O3 (Hall, 1995) to form Hg(II). Hg(II) then undergoes wet and dry deposition. Wet and dry deposition are parameterized in the GEOS-CHEM model and based on the Henry’s Law constants for Hg0 and HgCl2.

The results from our initial simulation agree to a reasonable degree (+/-20% on average) with measured values of total gaseous mercury (TGM=Hg0(g) + Hg(II)(g)) in the atmosphere at several locations, and do not show any global bias (see figure 1). This level of accuracy is similar to that reported for other global mercury models (e.g. Seigneur et al., 2004). In particular, we reproduce well the global average concentrations as well as the inter-hemispheric gradient. We also show a good agreement between measured and modeled wet deposition over the United States (see figure 2). Our results suggest that reaction with OH is
an important pathway in the atmospheric mercury cycle. Our results therefore disagree with Bergan and Rodhe (2001), who report that incorporating this reaction led to levels of mercury three times lower than observations and suggested that the reported rate constant was too high. Our model, which uses a rate constant at the low end of the reported uncertainty range, results in reasonable global concentration profiles.

There is growing interest in the scientific and policy communities in linking research on contaminants and climate, particularly in the Arctic, where climate change is likely to be extremely significant (AMAP, 2003). Global climate change could have significant impacts on the transport and fate of contaminants in the atmosphere, as well as the storage of contaminants in environmental reservoirs. A future application of the GEOS-CHEM mercury simulation will be to assess the impacts of climate changes to 2050 on mercury pathways and contamination in the Arctic and around the globe.

References

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Arctic Monitoring and Assessment Programme (AMAP) (2003) AMAP, Oslo, Norway.
Figure 1. Annual Average TGM, modeled vs. measured. Measurements are presented as round circles superimposed on model results. The high end of the color scale is cut off at 2.5 ng/m$^3$ for ease of presentation.

Figure 2. Annual Total wet deposition, modeled vs. measured, for 2001. Measurements are presented as round circles superimposed on model results. Measurements are from U.S. Mercury Deposition network.
Biodiversity of Arctic Sea Ice Biota and Possible Effects of Oil Spills during Oil Transportation

Johanna Ikävalko¹ and Birte Gerdes²

¹Dept. of Biological and Environmental Sciences, Aquatic Sciences / Hydrobiology, P.O. Box 65, FIN-00014 University of Helsinki, Finland
²Alfred-Wegener-Institute for Polar and Marine Research, P.O. Box 120161, 27515 Bremerhaven, Germany

Introduction
The EU project “ARCOP” (Arctic Operational Platform, www.arcop.fi) focuses on a survey of the most economical way for oil transportation along the Northeast Passage, and the analysis of environmental risk (ERA) of such activities. Within ARCOP and its ERA subtask, a survey of the diversity of sea ice biota, i.e. invertebrate organisms living within or closely associated with sea ice in the Arctic region, was made (Ikävalko, accepted). Also, connected to the ARCOP project, an experimental study on the effects of oils spills on sea ice biota was made in Spittsbergen in April 2004.

Methods
For the survey of the diversity of the arctic sea ice biota, data was gathered from 91 different sources - earlier published literature, submitted manuscripts and the author’s own unpublished data (Ikävalko, accepted). The work is a literature survey of unicellular and invertebrate organisms that have been encountered in Arctic sea ice since the turn of the last century (Gran, 1904) until today (e.g. Ikävalko & Gradinger 1997, Werner & Arbizu 1999, von Quillefeldt et al. 2003). Only literature that was relevant to the preparation of the checklist, i.e. articles and reports with taxonomic names of adequate resolution (genera, species, subspecies, forma) was included. The author’s own unpublished data originates from an expedition to the North Pole on the Swedish icebreaker Oden in summer 2001. Identification of organisms was made from ice core samples, with a Leitz DMIL inverted microscope, 500x final magnification.

For the study of effects of oils spills during transportation by tankers, a field experiment was carried out in Spittsbrgen in April 2004. Each experimental area (dimensions 64 x 45 cm) was surrounded by a hard plastic box to avoid contamination in the water column and surrounding sea ice. Statfjord oil (150 ml), oil and Inipol (150 ml + 15 ml), and oil and fishmeal (150 ml + 15 g) was spilled onto sea ice (Figure 1). Also experiment areas with only oil (150 ml), Inipol (15 ml) or fishmeal (15 g) were included in the study. Inipol is a commercial product, an agent that accelerates the speed of bioremediation of oil (www.atofinachemicals.com). Fishmeal functioned as a fertiliser as the bioremediation of hydrocarbons is usually limited by the availability of nutrients (N and P).
Results

Organisms from the following systematic ranks have been recorded living associated with arctic sea ice: Cyanophyta, Cryptophyceae, Dinoflagellata, Chrysophyceae and Dictyochophyceae, Bacillariophyceae, Pedinellales, Xanthophyceae, Haptophyceae, Chlorophyceae, Euglenida, Pedinophyceae, Prasinophyceae, Raphidophyceae, Straminopiles, Heliozoa, Amoebae, Choanoflagellida, Foraminifera, Radiolaria, Ciliata, Hydrozoa, Ctenophora, Turbellaria, Rotatoria, Nematoda, Gastropoda, Bivalvia, Polychaeta, Ostracoda, Copepoda, Cirripedia, Mysidacea, Amphipoda, Isopoda, Euphausiacea, Decapoda, Chaetognatha, Echinodermata, Tunicata, Chordata, Mollusca, Pelecypoda, Incertae sedis. Thus, the food webs within arctic sea ice consist of photosynthesising microscopic algae, heterotrophic flagellates and larger metazoans. Both juvenile and adult stages of metazoans were found.

At the time of submission of this abstract, the analysis of the oil spill samples was not finished. The results of the experiment will be presented in the ACIA International Scientific Symposium on Climate Change in the Arctic on Wednesday, 10 November, 2004.

References


www.arcop.fi/
www.atofinachemicals.com/oilspills
Why Do Global Climate Models Project So Different Climates for the Arctic?

Gunilla Svensson and Thorsten Mauritsen

Department of Meteorology, Stockholm University, S-106 91 Stockholm, Sweden

1. Introduction

The radiation from the sun is the driving force for our climate. The sun heats the surface and the earth radiates heat back to the atmosphere and space. However, a large amount of energy is also exchanged at the surface to/from the atmosphere via turbulent heat fluxes. These energy transfers are determined and determine the structure of the Atmospheric Boundary Layer (ABL).

The ABL is the lowest part of the atmosphere that is directly influenced by the surface. The depth of this layer varies between a few meters to 1-2 km and it is the place where we live and experience the climate. It is also within the ABL the greenhouse gases are exchanged between the surface and the free troposphere. The properties of the ABL vary quite substantially and the variation in depth of the layer makes it harder to represent well in a climate model. Global climate models (GCMs) have difficulty in the proper representation of turbulent mixing processes in general – which in turn has implications for ABL clouds as well (IPCC 2001).

The Arctic ABL has special characteristics and differs significantly from its mid-latitude counterpart. The lack of diurnal cycle and the strong seasonal cycle (polar night and day) are aspects that are unique for the Polar region. In the Arctic, the ABL can be thermally stably stratified for long periods and surface inversions are a very frequent and important feature. Today’s GCMs are not well suited for these conditions since the parameters used are based on mid-latitude observations and turbulence theories for strong static stability have shortcomings. Furthermore, for these extreme conditions, there is evidence that the turbulence is not stationary, local and continuous (Mahrt, 1998), assumptions used in models. Additionally, the vertical resolution is a critical issue since the ABL may be very thin and is thus not resolved in the GCMs.

Arctic climate projections show that there will be significant changes in the sea-ice extent, temperature and precipitation (ACIA, 2004). The modeled sea-ice declines by 10-50% by 2100; the temperature and precipitation increase by about 5°C and 20%, respectively. It is very likely that nearly all land areas will warm more rapidly than the global average – particularly those at northern high latitudes in the cold season. The models also project a decrease in diurnal temperature range in many areas, with nighttime lows increasing more than daytime highs. These findings are all dependent on the GCMs boundary-layer parameterisations, especially for stably stratified situations.

2. Boundary-layer parameterizations for stably stratified conditions.

The GEWEX Atmospheric Boundary Layer Study (GABLS – GEWEX stands for the Global Energy and Water Cycle Experiment) general goal is to improve the understanding of the atmospheric ABL and its representation in regional and large-scale climate models (Holtslag, 2003). For the first inter-comparison, a simple shear-driven stable ABL case with a cooling surface was studied both with single-column models and Large Eddy Simulations (LES). Detailed discussion of the LES intercomparison can be found in Beare et al. (2004) and the sin-
gle column models results are discussed in Cuxart et al. (2004). The single-column models include models of different types: first- and higher-order closures (prognostic turbulent kinetic energy) both operational and research models. More information can be found on the GABLS homepage: www.met.wau.nl/projects/Gabls/index.html

2.a Boundary-layer wind

The most obvious result for this weakly stably stratified case is that the operational models gives a much deeper ABL than both the LES and the research models. In addition, there is a very clear difference between the operational and research models/LES concerning the angle between the surface wind and the geostrophic free tropospheric wind. For the research models, the angle is typically larger than the operational ones. Figure 1 shows the Ekman spiral for the single-column models and averaged LES results. Note the difference in the wind at the ABL top – most research models have a negative v-component while the operational ones do not.

The turning of the wind gives rise to the cross-isobaric flow that fills the synoptic scale cyclones and as a secondary effect also slows down the spinning of the cyclones (Holton, 1992). If the ABL is deeper, the integrated mass flow is usually larger which is seen in Figure 2. In theory, for an Ekman layer in steady state the wind integral is equal to the surface value of the turbulent momentflux along the geostrophic wind direction (Svensson, 2004). This is presumably tuned in the operational forecast models so that the lifetime of the cyclones is predicted correctly. However, it is well known that these ABLs are too deep and have too little wind shift compared with observations (e.g. Bosveld, 2004). Another reason for having too much mixing (that causes the too deep ABL) is to prevent the models to go to a "decoupled" mode, which in turn may lead to run-away characteristics close to the ground (Viterbo et al., 1999).

2.b Surface temperature

When applying a closure that gives too deep ABLs with too much mixing, the temperature profile is also affected. Excess mixing means less stably stratified ABL and higher temperatures. This is shown in a study where two different formulations of the so-called long-tail formulation are tested (Holtslag, 2003). The impact on the 2-m temperature is large. The monthly averaged temperature for January differs by as much as 10°C over land, with large
areas in the Arctic with differences of 1 – 4 °C. However, both formulations give excess mixing in the stable regime compared with observations (Poulus and Burns, 2003).

3. Observations

Analysis of turbulence measurements taken in stably stratified conditions is difficult since the energy levels decrease as the stability increases. A new scaling method (Mauritsen et al, 2004) is applied to observations taken in US during CASES-99 (Poulus et al, 2002) and is presented in Figure 3. The figure shows normalized fluxes of heat and momentum plotted as a function of local gradient Richardson number. With increasing stability (increasing Ri) the turbulent fluxes decreases. First, we note that there is no critical Richardson number where the turbulence dies, in contrary, there seems to be a constant level of the normalized fluxes at high stabilities. Secondly, the turbulent heat flux decreases faster than the momentum flux indicating that the processes are different. This is not properly taken into account in the parameterizations used today.

4. Conclusions

The consequences of not describing the atmospheric ABL in climate models may have a very large impact on the results; the climate is defined within the ABL. There are problems with the parameterizations available, especially for strongly stably stratified ABLs. The errors are
largest during nighttime and wintertime – the impact for the Arctic region is thus larger than for the mid-latitudes. The turbulent surface fluxes are important for the surface energy balance. New observational material indicates that transport mechanisms of heat and momentum are different for heat and momentum for strong stability. Errors in these fluxes may have a large influence when coupling with the ice/ocean. Also, the surface wind direction and strength is important for the ice structure, leads and drift.

5. References


The Sensitivity of Arctic Climate Projections to Natural Variability

Asgeir Sorteberg1, Helge Drange1,2, Tore Furevik1,3 and Nils Gunnar Kvamstø1,3

1Bjerknes Centre for Climate Research, University of Bergen, Norway
2Nansen Center for Environmental and Remote Sensing
3Geophysical Institute, University of Bergen

Introduction

Simulation of future climate change encompasses a wide range of uncertainties. Some are related to uncertainties in future external forcings like solar variability and future emission of greenhouse gases and particles, while other are related to our understanding of the climate system and uncertainties due to internal climate variability.

Scenario simulations of future climate changes due to increased levels of greenhouse gases, predict the worldwide strongest warming in the Arctic, but also the largest spread. This highlights the difficult task of simulating the Arctic climate, but also the fact that the feedbacks that enhance the sensitivity of the Arctic climate to increased greenhouse gases also enhance the natural variability. Thus, the spread in model results may both be due to real intermodel differences (parameterisations, level of sophistication, resolution), but also due to insufficient sampling of the natural internal variability of the climate system, which will add ‘noise’ to the climate signal imposed by changes in the external forcings. Here, we attempt to quantify the uncertainties related to insufficient sampling of natural variability.

Method

An ensemble (consisting of 5 members) of CMIP2 (1% increase in CO₂ per year) simulation with the coupled Bergen Climate Model (BCM) has been performed. The initial conditions have been taken from a 300-year control integration. The true state of the Atlantic Meridional Overturning Circulation (AMOC), which is a good measure of the poleward oceanic heat transport, is not exactly known and each experiment has been initialized in different phases of the AMOC to span the natural variability of the AMOC. The simulations are integrated for 80 years until doubling of CO₂ is reached. There is indications that the AMOC has a ‘memory’ of one to two decades, thus the initial state of the AMOC is assumed to directly influence the simulation during the first few decades. However, the initial state may have indirect effects on the simulations for a longer time since it might affect the initiation or enhance/reduce the strength of other feedbacks in the system.

Results

The Spread Among the Different BCM Members

It seems fair to assume that the relative effect of natural variability on the climate change results will decline with the strength of the external forcing. Thus, we expect the signal-to-noise ratio to increase with time during the integrations. Figure 1 shows the mean BCM annual temperature response and spread (maximum-minimum change) among the 5 different members of the ensemble at two different times: Year 20-40 when the external forcing is weak and year 60-80 when it is relatively strong (around doubling of CO₂).
Figure 1: Ensemble mean (a,c) BCM annual temperature change (°C) and spread (b,d) calculated as maximum-minimum change (°C) among the 5 different members of the ensemble at two different times corresponding to weak (year 20-40, upper) and strong (year 60-80, lower) external forcing.

As expected, during weak external forcing (year 20-40) the relative spread (calculated as the spread divided by the mean response) is strong, and above 60% of the ensemble mean signal in much of the Arctic area. Thus, even for annual mean changes averaged over 20 years, internal natural variability may be a significant contributor to changes we will observe during the next decades. The BCM spread the first few decades is surprisingly large and seems linked to the initial state and development of the AMOC (which is strongly related to the decadal ‘memory’ of the AMOC). The simulations having a decrease in the AMOC during the first decades, have a weaker warming than the simulations having a constant or increased AMOC. As the external forcing is increased the relative spread is reduced to around 20% of the mean response (at doubling of CO₂). A similar pattern is seen for precipitation, where the BCM ensemble relative spread in 20 year average changes was 75-125% in central Arctic during year 20-40 and dropped to 25-50% for year 60-80.

The BCM Spread versus the Multimodel Spread

As mentioned earlier, a reason for the reduction in relative spread at year 60-80 compared to year 20-40, is the strength of the external forcing. However, also the fact that the sea ice feedbacks are drastically reduced (a large fraction of the sea ice is melted by the year 60-80) makes the simulations converge.

In order to quantify how much of the multimodel spread that is related to real model differences and how much can be explained by internal natural variability, we have calculated the ratio of the standard deviation of the BCM spread versus the standard deviation of the multimodel spread for year 20-40 and year 60-80 (Figure 2). The results suggest that the spread in temperature change seen among the different models in the Barents Sea area (Figure 2a) to a large extent is related to real multimodel differences, most probably different initial seaice extent in the different models. In central Arctic the standard deviation in the one-model is 60-150% of the standard deviation of the multimodel ensemble for temperature and
approximately the same for precipitation during weak external forcing (year 20-40). Thus, one can not rule out that in areas where all the models have seaice, the spread may largely be due to insufficient sampling of internal variability. At doubling of CO₂ around 10-30% of the spread in the 20 year averaged annual temperature change may be attributed to insufficient sampling of internal variability. The same number for precipitation is 20-40%

Figure 2: The multimodel spread (a,d), BCM spread (b,e) and ratio (%) of the standard deviation of the BCM spread and the standard deviation of the multimodel spread (c,f) for annual temperature at two different times corresponding to weak (year 20-40, upper) and strong (year 60-80, lower) external forcing.

Conclusions

An ensemble of CMIP2 (1% increase in CO₂ per year) simulation, where the ocean initial conditions have been taken at different phases of the control integration’s Atlantic Meridional Overturning Circulation (AMOC) , have been performed using the coupled Bergen Climate Model (BCM). The response to increased CO₂ showed large differences among the different members. This was especially pronounced during weak CO₂ forcing and pinpoints the importance of internal natural variability on the Arctic climate system. As the CO₂ forcing strengthened and the feedbacks related to sea ice were weakened (due to less ice), the signal to noise ratio was increased.

The ratio of the BCM spread versus a multimodel spread was used as a indication of how much of the multimodel spread that might be due to insufficient sampling of internal variability and how much that may be related to real model differences. During weak forcing, the results indicate that the spread in the central Arctic in the one-model ensemble starting in different phases of the AMOC was comparable to the multimodel spread. For a strong forcing (doubling of CO₂) the one-model ensemble spread was in the order of 10-30% of the multimodel spread for annual temperature changes and 20-40% for precipitation. The large spread the BCM ensemble (especially during weak external forcing) emphasises the need for ensemble simulations. In addition it pinpoints that the divergence of multimodel ensembles from a single solution should be seen both as a manifestation of real intermodel differences, but also the fact that the model spread may partly be due to insufficient sampling of the internal climate variability.
Long-term Climate Stability in the Québec-Labrador (Canada) Region: Evidence from Paleolimnological Studies

Reinhard Pienitz1, Émilie Saulnier-Talbot1, Marie-Andrée Fallu1,2, Tamsin Laing1,3, Karin Ponader1,4, Kerrie Swadling1,5, Ian Walker6

1 Paleolimnology-Paleoecology Laboratory, Centre d'Études Nordiques (CEN), Université Laval, Québec, G1K 7P4, Canada (reinhard.pienitz@cen.ulaval.ca);
2 Dép. Chimie-biologie, Université du Québec à Trois-Rivières, Trois-Rivières, G9A 5H7, Canada;
3 Environmental Sciences Group, Royal Military College of Canada, Kingston, Ontario, K7K 7B4, Canada;
4 The Academy of Natural Sciences, Philadelphia, PA 19103, U.S.A.
5 School of Zoology, University of Tasmania, Hobart 7001, Australia
6 Dept. Biology and Earth and Environmental Sciences, Okanagan University College, 3333 University Way, Kelowna, British Columbia, V1V 1V7, Canada.

Introduction

To explore the potential response of the circumpolar region to global climate change and to place instrumental temperature records into a longer-term perspective, we analysed a suite of paleo-indicators in northern lake sediments. Specifically, we studied the fossil diatom and chironomid records preserved in the sediment cores of 20 lakes distributed throughout northern Québec and Labrador in north-eastern Canada. Our observations show that this region has experienced long-term environmental stability, and underscore the need to understand the underlying mechanisms for striking differences in climate response among different sectors of the circumpolar Arctic.

Methods

Inference models based on the present-day distribution of aquatic algae (diatoms) and insects (chironomids) in northern Québec and Labrador were developed using multivariate numerical procedures. The resulting transfer functions were applied to the fossil data to infer variations in temperature and several limnological variables (dissolved organic carbon, water colour, alkalinity) closely related to the terrestrial environment at high temporal resolution (decadal to sub-decadal). The paleolimnological reconstructions were compared to the records obtained from other proxy indicators (e.g., pollen, macrofossils, tree-rings) and meteorological data.

Results and Discussion

The results of our paleolimnological studies into the recent (ca. last 200 years) history of these northern lakes have revealed a striking discrepancy between climatic trends inferred for regions roughly located north and south of the Foxe Basin and Hudson Strait. While most freshwater ecosystems show signs of pronounced changes associated with global warming in the High Arctic (e.g., Overpeck et al. 1997; Perren et al. 2003; Mueller et al. 2003), these changes are not yet detectable in lakes and ponds of northern Québec and Labrador (e.g., Laing et al. 2002; Ponader et al. 2002; Paterson et al. 2003; Saulnier-Talbot et al. 2003; Fallu et al. 2004). This remarkable stability in the latter region at timescales of decades and hundreds of years is consistent with decadal observational (e.g., Serreze et al. 2000) and tree-ring data (D’Arrigo et al. 2003) that reveal climatic stability or even slight cooling over the western subpolar North Atlantic and adjoining land areas of eastern subarctic Canada. It also suggests that northern Québec and Labrador may experience less short-term or delayed
climate change relative to other sectors within the Canadian Arctic. The study region may be experiencing a climatic lag comparable to that at the end of the last ice-age, when deglaciation of north-western Canada preceded that of north-eastern Canada by several millennia (Dyke and Prest 1987).

The “climatic resilience” of northern Québec and Labrador is not fully understood, yet this region is strongly influenced by oceanographic factors due to its peninsular shape. Cold ocean currents from Hudson and Davis Straits encircle the peninsula and, together with cooling of the prevailing westerly winds by sea ice on Hudson Bay, may have dampened the warming trend that has been recorded in paleolimnological studies from the High Arctic. Regional variations of this trend are subtle and likely due to the proximity of most of our study sites to the coast, where cooling is particularly acute. The seasonal melt of sea ice on Hudson Bay follows a similar pattern in that the ice breaks up earlier on the western (Keewatin) side and the resulting floating ice is pushed towards northern Québec on the eastern shore of Hudson Bay, strengthening the cooling effect in this region.

Our paleolimnological data indicate that the impacts of global climate change can differ strikingly among regions. However, monitoring of permafrost temperatures now documents warming in the north-westernmost part of the Ungava Peninsula (Salluit area) since about 1995 (Allard et al., unpublished), and climate models imply that these regional differences in climate change may disappear during the coming decades (ACIA Report 2004), by which time the freshwater ecosystems of northern Québec and Labrador may be subjected to the climate impacts that are well advanced in other circumpolar regions. Thus, this sector could be the ultimate bellwether of large-scale circumpolar change because of its resistance to minor variations in the past. Its abundant freshwater ecosystems offer a unique opportunity for monitoring these changes at high temporal resolution and great detail, which is the primary focus of our ongoing research activities at Centre d'Études Nordiques.

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Figure 1. Synthesis of paleoenvironmental data for Lake K2, northern Québec (58˚44’N, 65˚56’W). After Fallu et al. 2004, in press (Palaeogeogr. Palaeoclim. Palaeoecol.).
Figure 2. Stratigraphy of the most abundant diatom taxa in four sediment cores from the Rivière George region, northern Québec (58°30’N, 65°30’W). After Laing et al. 2002 (Arct. Ant. Alp. Res. 34: 454-464)
Climate Change and Hydrology of the Large Siberian Rivers

Vitaly Kimstach¹, Lars-Otto Reiersen¹ and Vladimir Grouzinov²

¹ The Secretariat of the Arctic Monitoring and Assessment Programme, Strømsveien 96, P.O. Box 8100 Dep., N-0032, Oslo, Norway
² Polar Foundation and State Oceanographic Institute, Kropotkinsky per. 6, 119034 Moscow, Russia

The Asian part of the Arctic basin is one of the regions of the World richest with freshwater resources. Three of the 10 World largest rivers (Yenisey, Lena and Ob) are located in this region. Besides them, a number of other large rivers discharge their flows to the Arctic Ocean (Table 1). It should be noted that their drainage areas cover huge territories down to 45⁰ N, and only 30% of these basins are located within the Polar Circle.

Table 1. Characteristics of the largest Siberian rivers.

<table>
<thead>
<tr>
<th>River</th>
<th>Drainage area M km²</th>
<th>World ranking</th>
<th>Water discharge km³/a</th>
<th>World ranking</th>
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<td>Ob</td>
<td>2.990</td>
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<td>404.0</td>
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<tr>
<td>Yenisey</td>
<td>2.590</td>
<td>7</td>
<td>620.0</td>
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<tr>
<td>Lena</td>
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<tr>
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<td>Yana</td>
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<td>0.219</td>
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</table>

In general, water resources and the hydrological regime of the Siberian rivers are formed in specific physiographic conditions, explained by severe climate, frozen ground producing an impermeable screen, and by processes connected with phase transformation of water. River flows of the Siberian rivers are extremely uneven. For most of them, significant part of annual water discharge is formed during a short (up to few weeks) spring flood (Fig. 1). Many small and medium rivers freeze in winter to the bottom bed and practically do not have water discharge at that period (r.r. Khatanga, Olenyok; Yana, Indigirka, Kolyma etc.) During the flood period, which usually happens in June-July, these rivers discharge more than a half of their annual water flow. For example, average June discharge of r. Olenyok (Laptev Sea basin) is 60% of annual one.

The Project “Dialogue on climate change adaptation strategy in water management and flood preparedness at the Lena basin” has been implemented by the AMAP Secretariat and the Polar Foundation, in collaboration with the Russian and the Republic of Sakha (Yakutia) authorities and institutions in 2002-2003 as one of the basin level projects within the global Dialogue on Water and Climate. The project has shown significant increase of temperature and precipitation in the Lena basin associated with climate change.

Significant warming is documented at the Lena basin since the 1980s, and reached its maximum in the 1990s. Almost everywhere in the basin, the highest temperature increase is observed during the winter period. In summer time, it is less sound. Air temperature increase
is the most significant in the eastern part of the basin, where mean annual temperature increased 1.5-1.8°C, and winter temperature – 3.5-3.8°C. In the other parts of the basin it was 1° and 2°C correspondingly. During the last two decades of the XX Century most of the meteorological stations observed, sometimes repeatedly, absolute temperature maximums for the whole observation period. Average air temperature in May, during which snow cover melts at most of the basin, increased 1.1-1.2°C practically all over the basin, promoting intensive melting of snow cover.

Warming in the basin is accompanied by humidity growth. Total precipitation that forms spring-summer flood (October-May) increased in 1998-2001 compared to average in both, flat part of the upper Lena basin, and in the basins of its major tributaries – Aldan and Viluy for 20-40 mm, and in some cases – up to 60 mm.

Under the impact of climate change during the last two decades, general increase of annual runoff in the Lena basin is observed. At average for 1988-2000, annual runoff of Vitim, Olekma, Amga, Markha and Kampendyay is 10% higher that long-term values. This increase is mostly caused by significant increase of runoff during spring floods. However, in 1980s – 1990s winter runoff in number of basin rivers increased as well. For example, runoff of Olekma and Aldan rivers during winter low-water increased 20-25%, and of Amga river – almost 50%.

Two independent approaches were used in development of climate change forecasts:

- Based on modelling of future climate change using general atmospheric circulation models;
- Based on assessment of past climate variations.

**According to the first scenario, annual discharge of the Lena river to the Arctic Ocean by the middle of this century will increase 12% (60 km³), according to the second one – 21% (110 km³).** In case the other Siberian rivers meet the similar climate change effects, it can be expected that total increase of annual off from the Siberian part of the Arctic may be up to 400-440 km³.

Freshwater inflow into the Arctic Ocean, particularly with the large Siberian rivers, largely contributes to changes of the thermohaline circulation and the energy budget of the Arctic Ocean with far-reaching consequences and its feedback to hydrological cycle. In spite of the fact that discharge of the Arctic rivers comprises only slightly more than 2 percent of the total inflow to the Arctic Ocean (together with ocean currents), its changes, in combination with an input from thawing glaciers, may bring noticeable changes in salinity and other characteristics of the Arctic Ocean waters. It should be also noted that freshwater input to the Arctic Ocean is significantly higher than to the other oceans (AMAP 1997). Due to this, surface water salinity in the Arctic Ocean and the adjacent shelf seas is relatively low compared to other oceans. In the Arctic Ocean itself, surface water salinity varies between 30 and 33, and decreases in the area of the shelf seas to below 30. In general, the salinity is lower during summer than winter due to input of freshwater from rivers and ice melt (AMAP 1998). Close to where the large Siberian rivers enter the Kara Sea and the Siberian shelf, the salinity is below 20 throughout the year and drops to as low as 10 during the summer (USSR Ministry of Defence 1980).

Total mean annual inflow of continental waters to the Arctic Ocean is 5220 km³, 5140 km³ of which belong to the surface runoff (including 470 km³ from icebergs and glaciers), and approximately 80 km³ – to groundwater discharge. Totally. It presents 335 mm layer over all Arctic Ocean. However, distribution of this average inflow is strongly uneven. Contribution of the Siberian discharge is 800 mm, compared to 215 mm from the northern European basin. Role of the large Siberian rivers is particularly important. For example, freshwater inflow to
the Kara Sea is 1520 mm, 90% of which belongs to Yenisey, Ob and Pyasina rivers (Treshnikov 1985). It is obvious that increase of discharge of these rivers due to climate change would strongly influence the state of the Arctic Ocean.

On its turn, the Arctic Ocean plays a fundamental role in circulation of water in the oceans of the world. When warm, salty North Atlantic water reaches the cold Arctic, it becomes denser as it cools, and therefore sinks to deeper layers of the Ocean. This process of forming deep water is slow, but takes place over huge area. Every year, millions km³ of water sink to deeper layers, which move water south along the bottom of the Atlantic Ocean and further – to other parts of the World Ocean contributing to global climate formation.

Formation of massive ice jams during ice cover break-up is one of specific hydrological features of the Lena river and its tributaries. It is caused by:

- Predominant south-north river flows;
- Large amount of river channel obstacles for free ice drifting;
- Thick ice cover reaching 150 – 200 cm, whereas the other at the other large Siberian rivers (Ob, Yenisey) it is only 100 – 150 cm, and for the Russian European rivers – 70-80 cm;
- High water discharges and flow velocity (more than 1m/c) during rush spring and intensive flood wave development, promoting ice cover break-up with the rate of 100-300 km/day (in the potentially ice jammed rivers of other regions of Russia it is 50-70 km/day).

Assessment of catastrophic floods formation indicates that they are caused by combination of a set of factors, possibly related to climate change. High humidity of the catchment area in autumn, high ice cover thickness, intensive snow melting and surplus precipitation during spring flood wave formation in the upper parts of the basin are general conditions in all cases (Kilmyaninov et al., 2001, Kilmyaninov 2001). Increase of water resources in the Lena basin rivers will significantly increase the risk of extremely high water levels caused by ice jam formation, which may exceed current extreme values.

References

Variations in Arctic Sea-Ice

Ignatius G. Rigor and John M. Wallace

Department of Atmospheric Science, University of Washington

Three of the past six summers have exhibited record low sea-ice extent on the Arctic Ocean, and this summer appears to be on pace to set a new record minimum. Simultaneous decreases in sea ice thickness have also been observed (Rothrock, et al. 1999). Taken together, these observations imply a precipitous decline in the total volume of sea ice on the Arctic Ocean. Is this decline due to changes in the advection of heat into the Arctic, or due to a simple change in winds and the drift of sea ice on the Arctic Ocean?

Rigor et al. 2000 showed that the increases in surface air temperature (SAT) noted over the northern hemisphere continents (e.g. Jones et al. 1999) extend out over the Arctic Ocean (Fig. 1, top row). A trend of +1°C/decade is found during winter in the eastern Arctic Ocean, but a trend of −1°C/decade is found in the western Arctic Ocean. During spring, almost the entire Arctic shows significant warming trends. In the eastern Arctic Ocean this warming is as much as 2°C/decade. The spring warming is associated with a trend toward a lengthening of the melt season in the eastern Arctic. The western Arctic, however, shows a slight shortening of the melt season. In this paper, we also showed that the winter trends in SAT are highly correlated to the Arctic Oscillation (AO, Thompson and Wallace, 1998; Fig. 1, bottom, left).

Given the increases in air temperatures, one could argue that this caused the decreases in summer sea ice extent in the Arctic. However, in Rigor et al. 2002 we showed that the increases in SAT during the spring and fall, and the decreases in summer sea ice extent are also highly correlated to the prior winter Arctic Oscillation index (Fig. 1, bottom row). We hypothesized that these delayed responses reflect the dynamical influence of the AO on the thickness of the wintertime sea-ice, i.e. the winter wind anomalies associated with the high-index AO conditions increases the advection of ice away from the Eurasian and Alaskan coasts. This advection increases the production of thin ice in the flaw leads along the coast during winter, and preconditions the sea-ice to be more prone to melt during the following spring and summer. The persistent 'footprint' of the prior winter AO conditions is reflected in the heat fluxes during the subsequent spring, in the extent of open water during the subsequent summer, and the heat liberated in the freezing of the open water during the subsequent autumn (Fig. 1, bottom). This hypothesis is supported by an increase in the advection of cold air from Siberia onto the Arctic Ocean during high AO winters.

During summer, low-index AO conditions favor southeasterly wind anomalies which increase the advection of ice away from the Alaskan coast and increase the advection of warm air onto the ocean, both of which act to decrease the amount of ice in the Beaufort and Chukchi seas. However, the impact of the summer AO on sea-ice extent appears to be preconditioned by the state of the AO during the previous winter (Rigor et al. 2002), and in recent years the correlations between the summer AO-index and summer sea-ice extent are not as strong as they were in prior years. For example, during the summers of 2002 and 2003, the summer AO was in a high-index phase, which favors above normal ice concentrations along the Alaskan coast, and yet record minima were observed during both years.

We hypothesize that the minima in Arctic sea ice extent may have been dynamically induced by changes in the surface winds (Rigor and Wallace, 2004). Based on results of a simple model that keeps track of the age of ice as it moves about on the Arctic Ocean, we argue that...
the areal coverage of thick multi-year ice decreased precipitously during 1989-1990 when the Arctic Oscillation was in an extreme “high index” state, and has remained low since that time. In this model, ice anomalies produced during summer are advected away from the Alaskan coast during low AO conditions (Fig. 2, left), however, during moderate to high AO conditions, younger, thinner ice anomalies recirculate back to the Alaskan coast more quickly, decreasing the time that new ice has to ridge and thicken before returning for another melt season (Fig. 2, right). During the 2002 and 2003 summers this anomalously younger, thinner ice was advected into Alaskan coastal waters where extensive melting was observed, even though temperatures were locally colder than normal. The age of sea-ice explains more than half of the variance in summer sea-ice extent.

Acknowledgements
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References
Figure 1. Seasonal memory of the prior winter AO. This figure shows the trends in surface air temperature and sea-ice extent from 1979 – 1998 (top), and the regression of these fields on the prior winter Arctic Oscillation index (bottom). Note the remarkable similarity between the trend and regression maps. Decreasing trends in SAT and increasing trends in SIC are shown as gray dashed lines. The zero contours for SAT are shown as thick isolines. The summer maps also show the winter trends in sea-ice motion and the regression of these fields on the winter Arctic Oscillation index. Trends units are °C/decade and %/decade, regressions units are the same per standard deviation of the AO index. Adapted from Rigor et al. 2002.

Figure 2. These maps show the changes in the age (thickness) of sea ice from the 1980’s (left) to the present. Open water (OW) is shown as dark blue, and the oldest ice is shown as white. The drift of buoys that reported for at least 8 months of the year are also shown. The larger area of younger, thinner ice (right) is less likely to survive the summer melt enhancing the decreases in summer sea ice extent observed during the last few years. Adapted from Rigor and Wallace (2004).
Polynya Variability in Arctic Shelf Areas as Inferred from Passive Microwave Imagery and Numerical Modeling

S. Kern and I. Harms
Center of Marine and Atmospheric Science, Institute of Oceanography
Bundesstrasse 53, 20146 Hamburg, Germany

Abstract
We compared the ice coverage of the Kara Sea obtained a) with a hydrodynamic coupled ice-ocean model (10km resolution) and b) from SSM/I data (5-10km resolution) using the Polynya Signature Simulation Method (PSSM). Model results show a high year-to-year variability in the number of ice-free months for the late 90s. Both, model and PSSM permit to identify even small-scale polynyas and agree within 10km in terms of the open water area associated with ice-cover openings east of Novaya Semlya. Regarding the ice-compactness gradient agreement between model and PSSM is also convincing - at least for fresh openings.

Introduction
In polar regions open water and thin ice areas can develop in a consolidated sea-ice cover under either suitable wind conditions (latent heat polynya) or a sufficient sensible heat supply (sensible heat polynya) (Smith et al., 1990). In Arctic shelf areas such as, e.g., the Kara Sea, polynyas are very common. Arctic sea-ice is shrinking in extent (Johannessen et al., 2004) and thickness (Rothrock et al., 2003). What does this process mean for the characteristics of polynyas? A change in polynyas’ characteristics can have a lot of substantial implications for the climate system (see Morales-Maqueda et al., 2004). In this paper we examine the dynamics of polynyas in the Kara Sea by means of numerical modeling and spaceborne passive microwave imagery.

Methods
Remote Sensing: Data of the spaceborne passive microwave radiometer Special Sensor Microwave/Imager (SSM/I) is used with the Polynya Signature Simulation Method (PSSM) (Markus and Burns, 1995) to estimate open water and thin ice areas of a polynya. The SSM/I is mounted on the polar orbiting DMSP spacecraft (4 are currently in orbit, i.e., excellent spatial and temporal coverage of the polar regions), and is equipped with 7 channels operating at frequencies of 19, (22), 37, and 85GHz with horizontal & vertical polarization (just vertical polarization). SSM/I data are interpolated into a polarstereographic grid using the Backus-Gilbert-Interpolation technique (resolution: 5km at 85GHz, 12.5km otherwise). The PSSM combines the finer spatial resolution at 85GHz with the lower weather influence at 37GHz in an iterative approach to obtain maps of polynya extent and associated open water/thin-ice area at 5km resolution. A threshold-based classification of 85GHz data is used to get maps with 2 (3) surface types: thin and thick sea ice (+ open water). These are prescribed to a simulation of 37GHz data. Correlation and RMS error between measured and simulated 37GHz data are calculated. Optimization of the thresholds iteratively yields maximum correlation and minimum RMS error, i.e., best classification. Areas of open water, thin and thick ice are taken from the map with the best classification (see Hunewinkel et al., 1998, for details).
Numerical Modeling: A hydrodynamic 3-d coupled ice-ocean model is applied to the Kara Sea (horizontal grid resolution: 9.4km). The model is based on the coding of the Hamburg Shelf Ocean Model HAMSOM, previously applied to the Kara Sea by Harms et al. (2003). HAMSOM is a level-type model based on non-linear primitive equations of motion, invoking the hydrostatic approximation. The circulation model is coupled to a thermodynamic and dynamic sea ice model, which calculates space and time dependent variations of ice thickness and ice compactness.

The Kara Sea studies are forced with realistic atmospheric winds and heat fluxes (NCEP data base for the years 1996 – 2001), daily mean river runoff from Ob (incl. tributaries Taz and Pur), Yenisei and Pyasina (Regional, Hydrometeorological Data Network for the pan-Arctic Region, http://www.r-arcticnet.sr.unh.edu/abstract.html) and M2-tides. For the open boundaries, data from the large scale AWI/NAOSIM coupled ice-ocean general circulation model for the Arctic and sub-Arctic domain is used (Karcher et al., 2003).

Results

The Kara Sea model shows a considerable inter-annual variability in ice extent and ice volume for years 1996-2001. Unusual atmospheric conditions during the late 90’s reduced the ice export to the Arctic Ocean and the Laptev Sea. As a result, the ice volume in the Kara Sea increased mainly because of a more close and compact ice cover. This is clearly visible when looking at the ice-free periods and areas which decreased significantly in 1998/1999 (Fig.1).

Fig. 1: Number of ice-free months in the Kara Sea as obtained with the Kara Sea model.

Model results also point to the east coast of Novaya Semlya as an important area for frequently occurring polynyas. As an example, a series of daily ice cover patterns for Feb 2001 is shown (Fig. 2, top). The figures show that although in the central parts of the Kara Sea the ice coverage is higher than 90%, a coastal strip of more than 50km has an ice coverage (ice compactness) below 50% for almost 10 days. The model shows even 20-30km open leads for at least two days. This agrees with the PSSM (Fig. 2, bottom) revealing thin ice/open water area of comparable size along the east coast of Novaya Semlya (e.g. Feb. 4).
Note the agreement between the change in modeled ice compactness from Feb. 4 to 7 and in PSSM thin ice/open water area as well as the agreement between the shift of areas with low ice compactness and of thin ice/open water areas from Feb. 4 to 10 into the southwestern Kara Sea. These changes in ice coverage are by far less obvious in Comiso-Bootstrap ice-concentration maps (not shown).

Fig. 2: Modeled ice compactness (top, legend in leftmost image) and PSSM thin ice/open water area (bottom, white: first-year ice, gray: thin ice, black: open water) for Feb. 1, 4, 7, and 10, 2001.

**Fig. 3** gives an example about how the thin ice/open water area in the Kara Sea may change during winter/spring from year to year. Relatively large thin ice/open water areas as seen in the beginning of 2001 are caused by a northeastward shift of the ice edge in the Barents Sea. The rightmost image of **Fig. 3** reveals that Comiso-Bootstrap ice concentrations average about 50% for quite substantial open water areas and about 80% for thin ice areas.

Fig. 3: Time-series of thin ice area (top left) and open water area (bottom left) as obtained with the PSSM for the Kara Sea for Jan.-May 2001, 2003, and 2004 (going from left to right). Missing areas are set to below zero. Image on top right shows a comparison between PSSM thin ice/open water areas and the mean Comiso-Bootstrap ice concentration of PSSM-classes first-year ice, thin ice, and open water for Feb. 1-16, 2001.

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On the Recent Time History and Forcing of the Inflow of Atlantic Water to the Arctic Mediterranean

Jan Even Ø. Nilsen, Hjálmar Hátún, Anne Britt Sando, Ingo Bethke, Olivier Laurantin, Yongqi Gao, Helge Drange, Tore Furevik

1 Nansen Environmental and Remote Sensing Center, Thormøhlensgt. 47, Bergen, Norway
2 Faroese Fisheries Laboratory, Tórshavn, Faroe Islands
3 Geophysical Institute, University of Bergen, Norway
4 Bjerknes Centre for Climate Research, Bergen, Norway
5 Nansen-Zhu Research Centre, Beijing, China

Introduction

The amounts of heat and salt carried northward by Atlantic Water (AW) across the Greenland–Scotland Ridge (GSR) are substantial, and both quantities are of importance for the regional climate, water mass and ice distribution of the Nordic Seas and Arctic Ocean, and possibly for the deep mixing and water mass modifications and transformations taking place in the region.

Large anomalies in the properties of the inflowing AW to the Arctic Mediterranean have been observed over the last few decades (Hansen and Østerhus, 2000; Turrell et al., 2003). However, with regards to volume transports, measurement based estimates are scarce prior to the ‘90s. While the time series from current measurements and hydrography available for the latest decade show almost negligible interannual transport variations through the passages (Orvik and Skagseth, 2003; Hansen et al., 2003), model studies show interdecadal and interannual variations of 1-2 Sv (Nilsen et. al., 2003; Zhang et al., 2004). In the study by Nilsen et al. (2003) the transport variability was strongly linked to an atmospheric pattern resembling the North Atlantic Oscillation (NAO), via anomalous Ekman transports and barotropic adjustment processes.

Model results also suggest that there is a tight link between the inflow in the Faroe Shetland Channel (FSC) and the outflow through the Denmark Strait (DS) (Nilsen et al., 2003). The atmospheric pattern found to be the main driving force for the transport variations consists of variability in both east Greenland northerlies and north Atlantic westerlies. Together with the strong barotropic component and topographic control of the Nordic Seas’ ocean circulation, this kind of synchronous atmospheric variability can explain the strong DS-FSC correlation found (R=0.74).

The main inflow branches to the Nordic Seas go over the Iceland Faroe Ridge (IFR) and through the FSC, and their volume transports have been found to have a negative correlation (Mork and Blindheim, 2000; Nilsen et al., 2003). It has been indicated that this out of phase relationship is connected to the changing position of the NAO’s northern center of action.

Hansen et al. (2001) found indirect evidence of a reduction in overflow through the FBC of 0.5 Sv over the last 50 years, implying that the Atlantic inflow has been reduced to a similar degree. The model results from Nilsen et al. (2003) show a similar reduction in the inflow and points to the inflow over the IFR as the reduced branch.

In this study, we will quantify variations of key quantities of the inflow based on available observations and observation-based time series, and assess to which degree state-of-the-art OGCMs are able to reproduce the observed anomalies. Furthermore, a series of model sensitivity experiments will be presented that addresses the relative role of wind and
buoyancy forcing of the anomalies. Finally, assessments of possible changes in the 21st century climate system of the Nordic and Barents Seas will be given.

Methods and Results

The model system used in this study is a synoptic forced, global version of the Miami Isopycnic Coordinate Ocean Model (MICOM, Bleck et al., 1992). Dynamic-thermodynamic sea ice modules are included. The model has 24 model layers with potential density ranging from 23.54 to 28.10. The configuration uses stretched grids with focus in the North Atlantic-Arctic region (Bentsen et al., 1999), with 80 km grid spacing in the Nordic Seas, as well as a 20 km model for this area nested within the global. The atmospheric forcing was by daily fields from the NCEP/NCAR reanalysis from 1948 to present (Kalnay et al., 1996). Hydrographic data from a section through the Faroe Current north of the Faroes (Hansen et al., 2003) are used to study the IFR inflow in the period 1987-2001. There is a clear seasonality in the hydrography of this section, and both the temperature and the salinity have maxima around August-October (Figure 2). The interannual variability in this period consists of a temperature and salinity minimum around 1994, a maxima around 1998-1999, and since 2002 both salinity and temperature have risen to the highest values on record (Figure 3).

Hydrography from sections in the FSC have been merged to produce a century long time series (Turrell et al., 1993). The resulting AW inflow temperature series is shown together with our simulated temperatures in Figure 4. The overall mean values are 9.29°C and 9.73°C, respectively, and the model is seen to match the data points more often than not. Fitting a cosine to the observed and simulated time series gives the same seasonal amplitudes (1.32°C), and the seasonality is thus simulated in a correct way. Time series from the Rockall Trough, one pathway by which AW reaches the FSC, are similar to the IFR inflow, also showing a warming and salinification of the inflow in the latter half of the ‘90s (Figure 5).

The mean simulated volume transports through the gaps compare fairly well with the measurement based estimates (Table 1), and for the time of available measurement based transports, the model reproduces the mean, the annual cycle, as well as variability down to weekly timescales (Figure 6).

The relative role of surface wind stress for the variability of water exchanges between the North Atlantic and the Nordic Seas in the second half of the 20th century is investigated using model integrations with zero, half, normal and double wind stress forcing. The model shows increasing northward flows through the FSC and across the IFR, and southward flow through the DS, with stronger wind forcing (Figure 7). The results from the zero and double wind stress experiments differ in northward Atlantic flow through the FSC and IFR by ~2 Sv through each gap, and in southward DS flow with as much as 3.8 Sv (not shown). Furthermore, for the normal and double wind stress simulations, the inflow over the IFR is found to have a negative trend over the 50 years, while the FSC inflow show an increased inflow.

The dominant influence of the atmospheric variability pattern found in Nilsen et al. (2003) on the oceanic transports are further substantiated, as the magnitude of the SLP regression patterns are found to be dominant in all simulations with wind stress, dependent on the magnitude of the applied wind stress, and non-existent in the zero wind stress simulations.

The atmospheric variability pattern of SLP variability showing strongest influence on the transport variability in the IFR differs from the corresponding regression pattern for the FSC.
(Figure 8a,b). The former does not contain variability in the east Greenland northerlies and has more meridional wind variability in the north Atlantic. In fact, the IFR-pattern is similar to the to the NAO-pattern prior to the ‘70s while the FSC-pattern is similar to the post ‘70s NAO (Figure 8c,d). Combined with the knowledge that the NAO has increased into a more positive phase over the last decades, this might explain the simulated trends in the two gaps.

Conclusions

Comparisons from the Rockall Trough, the IFR and the Svinøy Section show that the simulated long-term hydrographic conditions and the volume transports of northward flowing AW are, indeed, realistic.

Model experiments using different strength wind stress forcing show increased Atlantic inflow and increased variability with increased wind stress magnitudes. The model also indicates that normal wind forcing is responsible for 3 Sv of the modeled 9.5 Sv total Atlantic inflow to the Nordic Seas. Furthermore, the normal and double wind stress introduce trends in the FSC (positive) and IFR (negative), which may be related to the strengthened the NAO and westward shift of its northern center of action, over the last 50 years.

This NAO shift and increase represents a strengthening of the cyclonic atmospheric circulation over the North Atlantic. With a continued strengthening, we may expect a stronger inflow of AW to the Nordic Seas. Based on the model results and observational data, the increase will likely occur through the FSC, while there may actually be a reduced inflow over the IFR (see also Mork and Blindheim, 2000; Nilsen et al., 2003). Such a shift in the inflow path might result in increased Atlantic inflow to the Barents Sea (see Figure 1), and a warmer and thicker Atlantic layer in the Arctic. Less AW to the western branch of the NwAC, might lead to less AW to the Greenland Gyre, reducing its contribution to the DW formation. Furthermore, the strengthened cyclonic circulation over the Nordic Seas leads to more Polar Water export through the Fram Strait, inhibiting DW formation, freshening the oceans, and ultimately leading to fresher overflows to the Atlantic Ocean.

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Table 1: Simulated (80 km configuration) and observation-based mean northward (N) and southward (S) volume transports in Sv (10^6 m^3 s^-1) over the GSR. The model transports are mean values for the periods of available observations, typically from the 1990s.
Figure 1: The northern North Atlantic and the Nordic Seas. Isobaths are drawn for every 500 m. Schematic upper layer currents are based on literature. See text for abbreviations. Circled M shows the position of Ocean Weather Station M and thin line indicates the Svinøy Section. From Furevik and Nilsen 2004).

Figure 2: Simulated (dotted line) and observed (points) section maximum of temperature (a) and salinity (b) in the Faroe North Section.

Figure 3: De-seasoned observed (full line) and simulated (dotted line) temperature (a) and salinity (b) in the core of the Faroe Current.
Figure 4: Temperature series of the FSC inflow 1948-2002, calculated as spatial averages over the grey frame in the inlay (Hátún et al., 2004).

Figure 5: De-seasoned anomalies of temperature (a) and salinity (b) horizontally averaged over the uppermost 800 m in the Ellett Section in the Rockall Trough (Holliday et al., 2000; points on dashed lines) and the simulated time series processed in a similar way (Hátún et al., 2004; full lines).

Figure 6: Simulated inflow through the FSC (thick grey line) compared with seven days low pass filtered transport estimates for the eastern branch of the NWAC, from current meter measurements and hydrography at the Svinøy Section (thin black line; Orvik and Skagseth, 2003).
Figure 7: Temporal variation of the 3-years low-pass filtered simulated inflow through the IFR (a) and FSC (b) for normal (full line), zero (dashed), half (dash-dotted), and double (dotted) wind stress.

Figure 8: Upper panels: Regression maps showing the NCAR/NCEP winter (December–March) mean SLP regressed on standardized simulated inflow through IFR (a) and FSC (b). Isolines are drawn at 0.5 mb intervals. Correlations in the centers of action reach 0.6 (northern) and 0.5 (southern) and are highly significant. Lower panels (from Furevik and Nilsen 2004): The leading mode of variability of the winter-mean SLP for the periods 1948–1975 (c) and 1976–2003 (d). The principal components are calculated from the NCEP/NCAR reanalysis data for the Atlantic sector (90±W–30±E, 20±N–80±N). Solid lines are positive, dashed lines negative.
References


Sensitivity to Climate Change in the Canadian High Arctic: Ellesmere Island Lakes, Fiords and Ice Shelf Ecosystems

Warwick F. Vincent, Patrick Van Hove, Derek R. Mueller
Centre d'Études Nordiques, Laval University, Québec G1K 7P4, Canada
(warwick.vincent@bio.ulaval.ca)

Martin O. Jeffries
Geophysical Institute, University of Alaska Fairbanks, Fairbanks, AK 99775-7320, U.S.A.

Introduction
The northern coast of Ellesmere Island in the Canadian High Arctic (latitude 83°N, longitude 75°W; Quttinirpaaq National Park) contains a diverse range of lakes in which persistent ice plays a major role in their ecosystem structure and dynamics (Fig. 1). Five meromictic (never completely mixed) lakes occur in this area and are the result of isostatic uplift trapping basins of seawater that were subsequently overlain by low conductivity meltwater. The lakes are protected from wind-induced mixing by thick ice cover through most or all of the year. As a result they are highly stratified with remarkable temperature regimes and strong vertical gradients in biogeochemical properties. A 440 sq. km expanse of ice (Ward Hunt Ice Shelf, the largest Arctic ice shelf; Jeffries, 2002) extends off the coast of Ellesmere Island and has acted as a dam for inflowing meltwater to the surface of a deep fiord (Disraeli Fiord). The resultant ‘epishelf lake’ (freshwater overlying saltwater connected to the sea) contained a complex microbial food web supporting higher trophic levels including zooplankton and fish (Van Hove et al., 2001). The ice shelf itself is covered by numerous elongate (up to 15 km long) meltwater lakes. These are the habitats for a complex microbial flora and are providing insights into the survival of life during major periods of freeze-up in the deep evolutionary past (Vincent et al., 2004). All of these unique ecosystems are currently undergoing rapid change, disruption and in some cases complete habitat loss, associated with climate warming in the region.

Methods
Synthetic aperture radar images were obtained from the satellite RADARSAT for the end of each melt season from 1998 onwards, and were spatially and radiometrically corrected. The satellite instrument was operated in standard beam mode 5 (12.5 m resolution) or fine beam mode 1 (6.5 m resolution). The images were provided through the Canadian Centre for Remote Sensing (1998, 1999, Sept 27 2003) or through the Alaska Satellite Facility (all other dates). The temperature and conductivity profiles for the lakes and fiords were logged at 1 second intervals using a Brancker XR-420 Conductivity-Temperature-Depth instrument (CTD) that was slowly lowered through drilled holes or natural openings in the ice. Further limnological protocols used in our studies are described in Van Hove et al. (2001). Meteorological data were obtained from the Environment Canada meteorological stations at Alert and Eureka, and from a Campbell automated climate station that we installed in the study region.
Results and Discussion

The RADARSAT time series showed that large sections of the Ward Hunt Ice Shelf broke away in 2001-2003, and that the lakes and fiords of the region experienced unusual open water conditions in 2000 and 2003 (Fig. 1). A large central fissure developed in the ice shelf in 2000-02, cleaving it in two, with many secondary fissures radiating out from the central crack.

Fig. 1. Fine Beam RADARSAT-1 image of the northern end of Quttinirpaaq National Park, Nunavut, Canada (September 27, 2003). The main crack in the Ward Hunt Ice Shelf is traced in black, the southern edge of the ice shelf is traced in white. We noted further widening of this crack during our fieldwork in the region in August 2004. The dotted line marks the shoreline of Disraeli Fiord which continues for 20 km off the image. Note the recent ice break-up in Disraeli Ford and in Lake A (black= recent open water). From Vincent et al. (2003) with permission from the Canadian Polar Commission; the RADARSAT data are © Canadian Space Agency/Agence spatiale canadienne 2003, received by the Canada Centre for Remote Sensing and processed and distributed by RADARSAT International. See: http://www.polarcom.gc.ca/english/pdf/meri_04_spring_en.pdf and http://earthobservatory.nasa.gov/Study/wardhunt/

CTD profiling in Disraeli Fiord in 2002 showed that this break-up had been accompanied by the complete loss of the epishelf lake structure (Mueller et al., 2003), and subsequent profiling in 2003 and 2004 showed that there was no return to earlier conditions. CTD profiles over the period 2000-2004 also showed significant changes in the surface structure of the meromictic lakes of the region (Van Hove et al., unpublished data). Climate data indicate an overall
warming trend over the 35 year period of lake observations, and record melt conditions over the last 5 years.

These observations of widespread habitat disruption in the Northern Ellesmere region underscore the importance of threshold effects in the cryosphere, and the extreme sensitivity of ice-dependent High Arctic ecosystems to climate forcing. The Ward Hunt region is the northern end-member in our current research on latitudinal trends in Arctic climate change, through the new programs ArcticNet and Northern Regional Impacts and Sensitivity to Climate Change. Further information about these programs is given at http://www.geog.ubc.ca/~ghenry/N-RiSCC/home.htm and http://www.articnet.ulaval.ca.

Fig. 2. The latitudinal gradient (53-83N) currently under study in ArcticNet/Northern RiSCC. SILA (‘climate’ in Inuktitut) is a network of climate stations operated by Centre d'Études Nordiques, Université Laval, including the Ward Hunt Ice Shelf region (northernmost star).

References


Multivariate Statistical Analysis of Icelandic River Flow Series and Variability in Atmospheric Circulation

Jóna Finndís Jónsdóttir¹,², Cintia B. Uvo² and Árni Snorrason¹

¹NEA Hydrological Service, Grensásvegur 9, IS-108 Reykjavík, Iceland, jfj@os.is
²Department of Water Resources Engineering, Lund University, Box 118, SE-221 00 Lund, Sweden

Abstract

The variability of the atmospheric circulation strongly affects precipitation and runoff in Iceland. The island is situated in the center of the North Atlantic Ocean in the path of the low-pressure frontal systems that transport moisture and thermal energy northward.

A multivariate statistical analysis is performed on discharge data for several rivers in Iceland. The characteristics of these rivers are largely different since some of them are mainly glacier fed and other mainly groundwater fed. The modes of variability are identified by a principal component analysis and the physical explanation of the modes is searched for by canonical correlation with precipitation, temperature, sea level pressure (SLP) and other climatic and oceanographic variables.

The annual discharge in the western part of the country appears to be well correlated with the strength of westerly winds over the North Atlantic Ocean during the winter, while in the eastern part of the country precipitation and discharge is associated with northerly and easterly winds.

The discharge in the spring is largely affected by the temperature the preceding winter, if the winter is cold, more snow accumulates over the winter and the discharge in the spring is higher.

Introduction

According to WMO (2003), an analysis of proxy data indicates that in the Northern Hemisphere, the late 20th century temperatures are unique in the history of at least the last 1000 years. Natural long term and interannual variability of climate is, however, large and may mask climate change of anthropogenic origin. Statistical analysis of historical records of climate and hydrology, focusing on variability and the causes of the oscillations is, therefore, an important step towards better understanding of future climate and hydrological conditions.

The interannual variability in runoff is high in most of the Icelandic rivers. The variability in atmospheric circulation causes to a large extent the variability in runoff (Snorrason 1990, 1999). An investigation of how the atmospheric circulation affects the streamflow should reveal which processes control the interannual variability of streamflow. It is of importance to reveal which are the most prominent factors that can be used to predict hydrological conditions in Iceland as they can be used for both statistically based seasonal forecasts as well as physically based models.

Seasonal snow cover, glaciers and groundwater play a large role in the hydrology of Iceland. The largest contribution to Icelandic runoff is by rivers fed directly by rain and snowmelt. However, glacial contribution to annual runoff is estimated to be approximately 20% of the total runoff and another 20% of the runoff is estimated to be groundwater. The different geophysical characteristics of watersheds in Iceland give an extra basis for variability. Groundwater storage masks some of the climate variability and glaciers create their own variability of runoff through changes in mass balance, forced by climatic variations (Jóhannesson and Snorrason 1991).
The most prominent pattern of variability of atmospheric conditions in the North Atlantic region is the North Atlantic Oscillation (NAO). The NAO is a mode of variability described by the difference of SLP between the Icelandic Low and the Azores high-pressure systems. In the wintertime this difference is larger and the westerly winds are stronger over the North Atlantic Ocean. A large difference is associated with a positive NAO index. Positive NAO index winters are typified by more intense and frequent storms in the vicinity of Iceland and the Norwegian Sea and more precipitation than normal falls from Iceland through Scandinavia (Hurrell et al., 2003). However, different patterns of sea level pressure control the variability of precipitation in different parts of the country. When the winds are southerly, the northeastern part of the country is rather dry, while when the winds are northerly the southern part of the country is fairly dry (Jónsson 1990).

Methods, Result and Discussion

An empirical orthogonal function (EOF) analysis (Lorentz 1956) was applied to datasets of discharge, precipitation, temperature and sea level pressure in order to find stations and areas that vary together. Then a canonical correlation analysis (CCA) (Barnett and Preisendorfer 1987) was used to find coupled patterns in the datasets, i.e., to see which of the different analyzed parameters vary together. Some of the results have already been presented by Jónsdóttir et al., 2004.

The CCA between discharge and SLP shows that the annual discharge in the western part of the country is well correlated to the strength of westerly winds over the Atlantic Ocean, especially during the winter (DJF). The discharge in the whole western part of the country is correlated to the winter NAO-index; when the NAO-index is positive the discharge in the western part of the country is higher than normal. Northerly winds during the winter and spring indicate low discharge in the western part of the country. The effects of southerly winds reach the glacial watersheds in the East, probably not because of increased precipitation in that area but rather because of enhanced melting of the glaciers during warm summers and autumns.

The distribution of precipitation between seasons, and temperature evolution throughout the year, determines how much of the precipitation falls as snow. It, therefore, determines whether a large fraction of the runoff will be snowmelt floods in the spring or whether autumn or winter floods will be larger. The summer and fall temperature affects how much glacial meltwater will be in the glacial rivers during the summer; the higher the temperature, the more meltwater. The CCA analysis of precipitation and temperature with discharge shows some of these relationships quite clearly; the winter precipitation (Dec-Feb) has large effects on the spring (Apr-Jun) discharge in the North since the winter precipitation gets stored as snow until the spring, while in the South the spring precipitation has larger effect on the spring discharge.

Conclusions

The EOF analysis and the CCA have been successful in identifying the major characteristics of climatic variability in and around Iceland. A good correlation of precipitation and temperature with discharge explains which processes are important in the hydrology of different watersheds. A high correlation appears between the discharge of many of the rivers and the fields of mean SLP. The results of this analysis are promising and after a further
analysis, a development of successful seasonal forecasts should be possible for many of the Icelandic watersheds.

Future analysis will then focus on how the variability of atmospheric circulation is represented in climate scenarios of the future, addressing questions such as whether we can expect the same modes of atmospheric variability to control the variability in future runoff or if other physical processes become more important.

Acknowledgements

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References


Empirically Based Modelling of Variability and Trends in Local Snow Conditions

Inger Hanssen-Bauer

Norwegian Meteorological Institute, P.O. Box 43, Blindern, NO-0313 Oslo, Norway

1. Introduction
Local snow conditions largely affect terrestrial biota in the Arctic. Global climate models have too coarse spatial resolution to give useful information for impact studies concerning projected changes in snow cover and snow depth. Even in regional models, valleys and mountains are not resolved sufficiently to allow for realistic estimation of local snow conditions, especially in rough terrain. Realistic snow scenarios can be achieved by adjusting daily precipitation and temperature scenarios from regional models to local conditions, and then feed these into a water balance model. This is, however, resource demanding. In the present study a simple empirical model is suggested for calculating the local monthly averaged snow depth, based upon monthly mean temperature and precipitation. Running such a model will be very simple, and further, monthly climate data are more easily available from international databases than daily data are. The model is developed and tested on data from climate stations in different parts of Norway (section 2). Preliminary results, and a tentative scenario for changes in snow conditions produced by the model, are presented in section 3.

2. Methods
The idea behind the model is that the change in average snow-depth from month m-1 to month m (ΔSDm) basically depends on temperature conditions (represented by the average monthly temperature Tm) and precipitation (represented by the monthly precipitation sum Rm), while the average snow-depth of the previous month (SDm-1) is the upper limit for melting. An estimate for the change in monthly mean snow-depth may thus be expressed as:

\[ ΔSD_m = \max \{f(T_m, R_m), -SD_{m-1}\} \] (1).

It is suggested that the function \( f \) may be written on the form:

\[ f(T_m, R_m) = a R_m + b T_m R_m + cT_m \] (2).

The coefficients a-c will obviously depend on temperature, as both precipitation phase and melting conditions depend on temperature. Two threshold temperatures (TT1 and TT2) are thus suggested. When \( T_m \) is below TT1 all precipitation is supposed to be solid, and no melting is supposed to occur. When \( T_m \) is above TT2 all precipitation is supposed to be liquid. Thus:

\[ f(T_m, R_m) = \begin{cases} 
  a_1 R_m + b_1 T_m R_m & \text{when } T_m < TT1 \\
  a_2 R_m + b_2 T_m R_m + c_2 T_m & \text{when } TT1 \leq T_m < TT2 \\
  c_3 T_m & \text{when } T_m \geq TT2 
\end{cases} \] (3).

Preliminary threshold temperatures were chosen after inspection of data from a number of Norwegian climate stations. The sensitivity of this choice has not yet been analysed in detail. The model was adjusted to different Norwegian localities by multiple regression analysis of observed data from the period 1961-1990. Preliminary results indicate that the optimal values of the coefficients a and b vary (by a factor of 2) dependent on terrain and distance from...
coast, while the optimum value of c is similar for all stations. Figure 1 shows how the model fits the observations at three climate stations in different parts of Norway.

3. Preliminary results and conclusions
The model has so far been tested at 16 climate stations. Observed and modelled annual mean snow-depth at two stations is given in Figure 2. The long-term trends are well reproduced by the model.

It is also possible to deduce a rough measure for the length of the snow season by counting the number of months with average snow-depth above a threshold (e.g. 1cm). Preliminary results indicate that though the model systematically underestimates the length somewhat (because the last snow – in the model – tends to disappear too fast in the spring) the trend is reproduced reasonably well. An example is given in Figure 3.

Empirical downscaling has been applied to produce local monthly climate scenarios for Norway based on several global models (Benestad, 2002; Hanssen-Bauer et al., 2003). In the present study, downscaled temperature and precipitation scenarios based on the Max-Planck Institute climate model (run with the IS92a emission scenario) were applied as input in the snow-depth model. An example of a scenario for local snow-depth is given in Figure 4.

Conclusively, preliminary results indicate that reasonably good local estimates of mean monthly snow-depth can be achieved by the present model from monthly mean temperature and precipitation. The adaptation and adjustment of the model is not yet completed. The connection between model coefficients and topographical variables will be studied further, and so will the sensitivity of the results for the choice of threshold temperatures. When the model is optimised, it will be possible to produce – in a simple way – ensembles of local snow scenarios based upon temperature and precipitation scenarios downscaled from different climate models.

References

Figure 1. Model fit at 3 stations in different parts of Norway. Left: Karasjok in Northern Norway; Middle: Røros in Mid-Norway; Right: Kjevik in Southern Norway. R² between observed and modelled snow-depth is given in each plot.
Figure 2. Observed and modelled annual mean snow-depth in Tromsø, Northern Norway (upper panel) and Kjevik, Southern Norway (lower panel). Linear trends are shown.

Figure 3. Observed and modelled number of months with average snow-depth >1cm at Kjevik, Southern Norway. Linear trends are shown.

Figure 4. A scenario for annual mean snow-depth at Kjevik, Southern Norway.
Variations in Climatic Constraints on Living Conditions in the Nordic Arctic, 1900-2050

Eirik J. Førland and Inger Hanssen-Bauer

Norwegian Meteorological Institute, P.O.Box 43, Blindern, N0313 Oslo, Norway

1. Introduction

Dealing with the harsh climate is of paramount importance for the living conditions in the Arctic. Important changes in the Arctic climate have occurred during the 20th century. The rate of temperature change for land stations north of 60°N has increased over the past 4 decades and is higher than that for the regions 0-60°N (McBean et al., 2004). The current coupled atmosphere-ocean general circulation models (AOGCMs) predict a greater warming for the Arctic than for the rest of the globe (Räisänen, 2001).

Moritz et al. (2002) state that the warming during the latest decades was correlated with changes in many other Arctic climate and environmental variables, such as precipitation, sea-ice extent, snow cover, permafrost temperature and vegetation distribution. The past and future climate changes thus imply considerable impacts on people and ecosystems in the Arctic and may also have global impacts through a variety of climate feedback mechanisms.

In the present study (Førland et al., 2004) past and future temperature variations are applied to discuss variations in climatic indices of importance for the living conditions in the Arctic, i.e. indices illustrating variations in vegetation conditions (growing season) and energy consumption (heating season). Based on observations during 1900-2002 and empirically downscaled scenarios for 2021-2050, length and degree-day sums for these indices are studied. The analyses do mostly involve stations in the Nordic high Arctic, but for comparison reasons climatic series from capitals in the Nordic countries are also included.

2. Methods

Estimates of the length and degree-day-sum of growing and heating seasons are usually based on daily mean temperatures. For the Nordic region, very few digitised long-term series of daily temperatures are available. On the other hand, 30-years normal values are available for a large number of sites for the periods 1901-30, 1931-60 and 1961-90. In the present study, daily mean temperatures were interpolated from the mean monthly temperatures by fitting a spline curve through the twelve monthly mean temperatures. The technique provides a simple, fast and robust method that can be applied everywhere where only mean monthly temperatures are available. To illustrate the current conditions, mean values for two recent time periods (1976-2000 and 1990-2002) were also included.

The temperature scenarios were based on empirical downscaling from the ECHAM4/OPYC3 AOGCM with the transient GSDIO integration. This integration includes greenhouse gases, tropospheric ozone, and direct as well as indirect sulphur aerosol forcing. The concentrations of greenhouse gases are specified according to the IPCC IS92a scenario. Compared to IPCCs new set of emission scenarios (SRES), the projected increase in the global mean temperature up to 2050 for the IS92a scenario is similar to SRES B1, and lower than for the other SRES scenarios. The empirical downscaling was based on an approach utilising common EOFs as described in Benestad (2001, 2002), using multiple regression for calibrating the empirical models. The predictor consisted of gridded 2-meter temperature fields from the NCEP
reanalysis and the ECHAM4/OPYC3 GSDIO results. The predictors for deriving the local climatic series were taken from three domains: Greenland: Domain I (90°W-30°W, 52°N-80°N); Fennoscandia and Iceland: Domain II (40°W-40°E, 52°N-80°N); Svalbard (Bjørnøya and Svalbard Airport): Domain III (35°W-40°E, 67°N-85°N). It is important to keep in mind the fact that one climate scenario represents one plausible description of a future climate, and should not be interpreted as a 'forecast'.

The air temperature is found to be a limiting factor for growth potential, thus the growing season is rather short at high latitudes. Different species respond differently to air temperature, some are sensitive to lower temperatures while others are more resistant to cold climate. It should however be emphasized that plant growth also depends on additional factors, both climatological (precipitation, snow cover, radiation) as well as soil, moisture, exposure, etc. Different definitions of the thermal growing season exist. The number of days with daily mean air temperatures (2m) above a given threshold temperature is often used. Carter (1998) argues that the season for active plant development and growth in the Nordic countries should be defined as the period during which the mean daily air temperatures remain above 5°C. The thermal growing season is in this study defined as the period of the year when the smoothed daily mean temperature ($T_i$) is above 5°C, while the growing-degree-days (GDD) are the accumulated degree sum above the threshold temperature $T = 5°C$

The heating season is the period of the year when buildings need to be heated. The sums of heating degree-days closely correlate to energy consumption for heating, and have numerous other practical implications. The amount of energy for heating of buildings is also depending on other climatological factors (wind speed, radiation), as well as factors related to demographic changes, living standards, and building instructions (e.g. volume of heated buildings, preferred indoor temperatures, thermal insulation, etc.). The heating season is in Norway (Skaugen and Tveito, 2002) defined as the period of the year when the smoothed daily mean temperature is below a threshold $T = 10°C$, while heating degree-days (HDD) are the sum of the difference between a base temperature $T_{base}=17°C$ and the daily mean temperature $T_i$.

Table 1 gives a survey of the main results for the present normal period (1961-90) and the projected changes in temperature, growing season and heating season up to 2021-2050 for selected sites in the Nordic region.

3. Conclusions

- The normal period 1901-30 was colder than the present normal period (1961-90) at all stations except two continental stations in northern Fennoscandia. The length of the growing season was shorter, and the heating and freezing seasons were longer at a majority of the locations studied. The high heating-degree-day sums indicate a larger need for energy to heat buildings during 1901-30 than for present conditions.

- During 1931-60 the mean annual temperature was higher than the present normal values at all stations in the Nordic Arctic. The growing season was 2-3 weeks longer at some locations, and the length of the heating and freezing seasons were lower than during 1961-90.

- The recent decades (1976-2000 and 1990-2002) have been warmer than the 1961-90 normals in most parts of the region. An important exception is western Greenland, where all stations have experienced lower temperatures than during 1961-90 and where the
1931-60 values are substantially higher than the present level. In the rest of the region, the thermal growing conditions have improved, and the need for heating is reduced.

- The tentative scenarios for 2021-2050 indicate substantially higher temperatures than observed in the 20th century. The projected growing season is 3-4 weeks longer than present in large parts of the region. Similarly the projected energy consumption for heating buildings is substantially reduced compared to the present conditions. One exception is the eastern Greenlandic station Tasilaq, where the projected temperature for 2021-2050 is still lower than experienced during 1931-60.

Table 1. Mean values (1961-90) of annual temperature (T, °C), length (days) of growing (LG) and heating (LH) seasons, sum of growing (GDD) and heating (HDD) degree-days, and differences (Δ) between projected values for 2021-2050 and observed values 1961-90.

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Acknowledgement

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References


Climate, Water and Renewable Energy in the Nordic Countries

Árni Snorrason¹ and Jóna Finndís Jónsdóttir¹,²

¹NEA Hydrological Service, Grensásvegur 9, IS-108 Reykjavik, Iceland, ifj@os.is
²Department of Water Resources Engineering, Lund University, Box 118, SE-221 00 Lund, Sweden

Introduction

Climate and Energy (CE, www.os.is/ce) is a new Nordic research project (2003-2006) with funding from the Nordic Energy Research (NEFP, www.nefp.info) and the Nordic energy sector. The main objective of the project is to make a comprehensive assessment of the impact of climate change on renewable energy resources in the Nordic area including hydropower, wind power, bio-fuels and solar energy. (Snorrason and Jónsdóttir, 2004). This study will include the evaluation of power production and its sensitivity and vulnerability to climate change on both temporal and spatial scales and the assessment of the impacts of extremes including floods, droughts, storms, seasonal pattern and variability. The projected climate changes will influence both the energy requirements and the possibilities of energy production. Furthermore, extreme weather events could impact the planning, design and operation of the energy system (Snorrason et al., 2000).

Project Organization

The project organization is based on a matrix structure (Fig. 1).

For each of the four renewable energy sources the following issues must be addressed: Production potential in various climate scenarios (long term, seasonal and regional), and sensitivity to extreme events.
**Climate scenarios**

Within CE, the Climate Group (CG) prepares input data for impact modeling by the CE renewables groups, in the form of regional climate scenarios. The basic data set refers to a small set of plausible projections from the 30-year-period of 1961-1990 to the period of 2071-2100 on a resolution of approximately 50 km. This basic data set is based on recent Nordic regional climate projections from the Rossby Centre of SMHI (Räisänen et al., 2004), DMI (Kiilsholm et al., 2003) and met.no (Haugen and Ødegaard, 2003) that have been prepared by using the respective regional climate models and will be made available to CE. In addition to differences due to different regional climate models, RCMs, differences between these climate projections arise from the choice of emission scenario; both the A2 and the B2 IPCC SRES scenario have been used; and which global climate model the large-scale boundary conditions are imported from (HadAM3H, and ECHAM4/OPYC3). Two sets of additional simulations are planned: Reanalysis simulations, using the ERA-40 as the large-scale boundary conditions, and transient climate projections from about 1950 to 2050.

**Hydropower**

Snow and glacier studies are important for the assessment of the long-term variability of climate in the Nordic countries. Furthermore, the effect of climate change on snow cover and glacier mass balance is important in connection with changes in average river runoff and seasonality and thus on production of hydropower in the near future (Jóhannesson 1997). The results from mass balance and dynamic ice flow models on the future shape of the glaciers will be used for water resources scenarios. In addition, an analysis of the impact of climate change on the snow and ice cover of lakes and rivers is relevant since they may have large impacts on the operation of the hydropower industry.

Hydrological models serve primarily the role of a link between climate scenarios and water power production simulations as well as in estimating the magnitude and risk of floods and drought. Two main topic areas of research are on one hand an analysis of the hydrological processes and their relationship to changes in climate. On the other hand the integration and coupling of climate and hydrological models.

Comprehensive hydrological climate change maps that shows climate change impacts on the most important hydrological components and on water resources in the Nordic region will be provided for the 30-year-periods 1961-1990 and 2071-2100. The work will also include sensitivity analysis of a design flood to changes in design precipitation, temperature and model parameters. Statistical and model based methods of design flood assessment will be compared and evaluated.

**Statistical Analysis**

Statistical analysis of long time series of hydrological and meteorological time series and other long time series reflecting the renewable energy sources is a key area of research. The work will focus on studies of trends in both annual and seasonal values, and the magnitude and timing of extremes. Furthermore, an analysis of which processes relate the variability of the atmospheric circulation to the variability of the Nordic rivers will be performed (Jónsdóttir et al., 2004, Snorrason et al., 2003). It will thereby reveal the options of predicting the hydrological conditions in the region based on indices, e.g., NAO, and information from the general prevalent circulation patterns.
Preliminary Result

In a paper by Hisdal et al. (2004) a study of streamflow in the Nordic countries reveals that the streamflow has already changed. Even though the period analyzed and the region studied influences the trend seen in the data, the conclusion is that the spring and winter streamflow has increased and the snow melts earlier than before.

A study of climate change impacts on runoff in Sweden (Andréasson et al., 2004) shows that annual runoff volumes will, according to the scenarios, decrease in southeastern Sweden, especially summer runoff. However, annual runoff volumes in northern Sweden will increase, especially in the mountains. The estimated 100-year flood decreased in large parts of the country, but increased in the Southwest and along the Norwegian border. Trends in runoff records in Sweden for the period 1991-2002 do not contradict with the scenario results.

A paper by Veijalainen and Vehviläinen (2004) discusses the effects of climate change on design floods in Finland. In northern Finland, the design floods remain spring floods, they stay unchanged or decrease since increase in design precipitation is partly compensated by decrease in snow accumulation. In central and southern Finland, however, the design floods in 2070-2099 are expected to occur during summer or fall (or winter) and these may intensify, some considerably.

Acknowledgements

The CE project is funded by the Nordic Energy Research and the Nordic energy sector. Information on the project can be found at the websites: http://www.os.is/ce

References


Changing Marine Access in the Arctic Ocean - A Strategic View for the 21st Century

Lawson W. Brigham

U.S. Arctic Research Commission, 420 L Street, Suite 315, Anchorage, Alaska 99501 USA

Marine Access Changes

Marine access in the Arctic Ocean changed in unprecedented ways during the second half of the 20th century. The Arctic Climate Impact Assessment (ACIA) has documented substantial observational evidence that the sea ice cover is undergoing profound changes including: a steady decrease in extent with larger areas of open water during summer; decreasing coverage of multi-year sea ice in the Central Arctic Ocean; and, thinning of sea ice throughout the Arctic Ocean. These changes have implications for a host of marine uses such as shipping, offshore development, fishing, indigenous hunting, tourism, and scientific exploration. In addition to these well-documented environmental changes, icebreaker access to nearly all regions of the Arctic Ocean has been attained by the end of the 20th century. During 1977-2004, 52 transits have been made to the Geographic North Pole by the icebreakers of Russia (42), Sweden (4), Germany (2), USA (2), Canada (1), and Norway (1) [remarkably, eight successful transits by surface ships to the North Pole were conducted during the summer of 2004]. Thirteen of the voyages were in support of scientific research and the remaining 39 were devoted to tourist voyages to the North Pole and across the Arctic Ocean. Only one voyage of the 52 was not conducted in summer and that was the nuclear icebreaker Sibir's (Russia) celebrated voyage which supported scientific operations 8 May to 10 June 1987 (reaching the North Pole 25 May 1987). During the decade of the 1990's, five historic trans-Arctic voyages were accomplished: a transit across the Central Arctic Ocean by the nuclear icebreaker Sovetskiy Soyuz (Russia) with tourists in August 1991; transits by the Louis S. St Laurent (Canada) and the Polar Sea (USA) during July and August 1994 from Bering Strait to the North Pole and to Svalbard - the first scientific transect of the Arctic Ocean conducted by surface ship; and, two crossings by the nuclear icebreaker Yamal (Russia) with tourists in 1996. During the late summer of 2004, a small 'armada' consisting of the nuclear icebreaker Sovetskiy Soyuz, the icebreaker Oden (Sweden) and the icebreaking ship Vidar Viking (Norway), out-fitted for drilling, conducted a unique scientific drilling voyage in the remotest reaches of the Arctic Ocean. A review of these pioneering voyages provides substantial confirmation that marine access in summer throughout the Arctic Ocean has been achieved by highly capable icebreaking ships.

ACIA Model Sea Ice Simulations

Within ACIA, projected changes in Arctic sea ice coverage were evaluated in the context of potential improvements in marine access. The evaluation is based on monthly fields of sea ice from simulations by five different global climate models (GCMs), each forced by the conservative, Intergovernmental Panel on Climate Change (IPCC) B2 scenario of increasing greenhouse gas concentrations. While continued greenhouse warming reduces sea ice coverage in the five model simulations, especially during summer and in all the coastal Arctic seas, there is a considerable range among the retreats projected. One model projects an ice-free Arctic Ocean in summer by mid-century. Overall, the seasonality of the retreats projected by the models (largest in summer) is consistent with trends in the observed sea ice coverage.
during the past five decades. The suite of plausible, alternative futures of Arctic sea ice during the ACIA time periods (2010-2030, 2040-2060, and 2070-2090) represents a first-order, strategic guide to future marine access in the Arctic Ocean.

**ACIA Regional Assessments**

The work of ACIA also included first-order attempts at regional assessments for the Northwest Passage (NWP) in the Canadian Arctic and the Northern Sea Route (NSR) along the northern Eurasian coast. Two serious constraints limited an adequate ACIA assessment of the NWP: the GCMs could not resolve the complex geography of the Canadian Archipelago; and, the observed sea ice trends analyzed by the Canadian Ice Service, although negative for sea ice extent since the late 1960's (in both the eastern and western regions of the NWP), indicated a very high inter-annual variability of coverage. Sea ice simulations conducted for the NSR (analyzing the region from Kara Gate in the west to Bering Strait) were more successful and these indicated decreasing sea ice coverage and plausible increases in the length of the NSR navigation season throughout the 21st century. Many of the simulations show retreating ice conditions along the NSR, but with ice consistently present at the northern tip of Severnaya Zemlya; such model results imply, for example, a potential reliance on a transit route through Vilkitskii Strait between the Kara and Laptev seas, rather than a more northerly route in the open Arctic Ocean.

**Arctic Sea Ice Atlas of the Future**

The sea ice analyses conducted during ACIA have provided the foundation for an initial attempt at construction of an 'Arctic sea ice atlas of the future.' Climatological sea ice atlases of the Arctic Ocean and regional seas have been developed by several Arctic nations during the 20th century. Unlike these earlier atlases based on the observed record, this new atlas will be based primarily on GCM projections of Arctic sea ice conditions for the remainder of the 21st century. Illustrated will be the 5-model median Arctic sea ice simulations for the ACIA time slices, and simulations for single models over a complete annual cycle. Although some uncertainty remains in the projections, the intent of the atlas will be to provide a strategic, long-range view of plausible futures of sea ice and potential marine access throughout the Arctic Ocean. The atlas will be designed as a strategic planning tool and potentially can be a vehicle to provoke wide-ranging discussions about the future of the Arctic Ocean.
Arctic Sea Ice Atlas of the Future:
ACIA Projections (January - June)
Have Recent Biological Changes in Newfoundland Capelin (*Mallotus villosus*) occurred because of Physical Changes in the Arctic?

J. E. Carscadden, B. S. Nakashima and F. K. Mowbray

Dept of Fisheries and Oceans, St. John’s, Newfoundland, Canada

Capelin (*Mallotus villosus*) is a small, pelagic, cold-water, schooling species, circumpolar in distribution and occurring in arctic and sub-arctic seas worldwide. Major stocks can be found in the Bering Sea, Barents Sea, near Iceland and in waters off Newfoundland and Labrador in eastern Canada. In the Newfoundland-Labrador area, capelin exhibit a more southerly distribution compared to other stocks worldwide, because of the presence of the southward-flowing, cold Labrador Current, which draws most of its water from the Arctic. Capelin are highly migratory and they are important in transferring energy from their northern feeding areas to more southerly spawning areas where they are an important forage species. In recent decades, capelin has become an important commercial species, with large industrial fisheries in the Barents Sea and near Iceland. A smaller commercial fishery exists in the waters off Newfoundland and Labrador.

Commercial exploitation of capelin in the eastern Newfoundland-Labrador area has been relatively light and this exploitation has probably not had an impact on stocks in this area. However, since the early 1990s, capelin have exhibited measurable changes in several biological characteristics. Given the light exploitation rate and the fact that the ocean environment has been highly variable, it is likely that these biological changes have been determined by environmental variations.

The purpose of this paper is twofold, first, to review the trends both in the major oceanographic features of the eastern Newfoundland and Labrador region and in the biological characters of capelin, and second, to present the hypothesis that the changes in capelin biology in this region may be resulting from physical changes that have been occurring in the Arctic.

During the 1990s, the physical environment exhibited some of the most extreme variations since routine measurements began about 50 years ago. Temperature anomalies were above normal during the 1950s and 1960s, declining after that to reach near-record lows in the early 1970s. Temperature anomalies were above normal during the late 1970s and early 1980s. The 1980s saw a decline in temperatures, reaching a record low in the upper water column in 1991. On a decadal scale the 1950s and 1960s were the warmest decades in the series while the 1990s represent the third consecutive decade with below normal temperatures, even though the water temperatures in the latter half of the 1990s were above normal.

The salinity time-series is dominated by three low salinity periods, namely, the early 1970s, the early to mid 1980s and most of the 1990s and early 2000s. The persistent lower than normal salinities during this later period represents the longest time period of below normal salinities. The combination of below normal temperatures and salinities which characterized the 1970s, 1980s and early 1990s was associated with positive North Atlantic Oscillation index anomalies, below normal winter air temperatures, heavy ice conditions and larger than normal volumes of less than 0°C water on the Newfoundland shelf.

During the latter half of the 1990s and up to 2002, water temperatures have been above normal. During the 1990s and up to and including 2001, salinities were below normal. The unusual persistence of warmer, combined with fresher, water (rather than warmer combined
with saltier water) during the latter half of the 1990s and into the 2000s has not been explained. The reduced surface salinities have been identified as a cause of increased stratification which in turn can reduce vertical mixing and transport of nutrients to the surface, and thereby reduce productivity. In 2002, salinities increased to the highest level during the last decade.

The assessment of capelin abundance has been problematic since the early 1990s, making the status of the stock highly uncertain. Offshore estimates of abundance of juvenile capelin, normally used to forecast the abundance of mature capelin arriving inshore to spawn, declined precipitously in the early 1990s and have remained low ever since. Inshore abundance indices never displayed the decline that would have been predicted from the offshore indicators. This discrepancy has never been reconciled. Estimates of yearclass abundance for the 1990s using a mathematical model did not differ significantly from those estimated for earlier periods. However, the statistical uncertainties for the later estimates were large, there have been concerns as to whether some of the indices used in the model were reliable indicators of abundance, and the results from the model disagree with the opinions of inshore capelin fishermen, who believed that capelin stocks declined during the 1990s.

Mature capelin have been smaller and this became most apparent beginning in 1991. This has occurred because of a combination of an increased proportion of younger fish in the mature stock as well as smaller mean length at age of the mature fish.

Historically, the spawning of capelin at Newfoundland beaches during June and July was a well-known and highly predictable event. Beginning in 1991, spawning was later and this delayed spawning of up to six weeks has continued. In an earlier study, 80% of the variation in spawning time was significantly and negatively related to mean fish size and sea temperatures that capelin experienced during gonadal maturation. Capelin spawning on Newfoundland beaches has continued to be delayed in spite of the fact that sea temperatures have returned to normal. However, mean lengths of capelin have continued to be small throughout this period. During the 1990s, there was an increase in spawning in deeper waters adjacent to spawning beaches. Comparative studies of survival of eggs and larvae on beaches and at the demersal spawning sites indicate that survival of eggs and larvae has been lower at the demersal sites.

During the early 1990s, capelin exhibited large-scale changes in distribution within and outside their normal range, changes that were initially associated with colder water temperatures. Within the normal distribution area, capelin essentially disappeared from the area adjacent to the Labrador coast, to occupy an area to the south on the northern Grand Banks. Outside their normal distribution area, capelin occurred on the Flemish Cap and eastern Scotian Shelf. They appeared in those areas during the 1990s and occasionally earlier in the time-series only during cold periods. They were not found there during every cold period, suggesting that cold sea temperatures were a necessary but not a sufficient condition for capelin to occur outside their normal range. Capelin normally exhibit extensive vertical migrations, typically moving up and dispersing in the water column at night and descending and aggregating at greater depths during the day. This pattern changed during the 1990s when capelin remained deeper in the water column and exhibited reduced vertical migration. These changes in vertical migration patterns initially were coincident with the cold period during the early 1990s but they have persisted throughout the 1990s when water temperatures warmed.

Condition factors (a commonly calculated expression to describe well-being of fish) of maturing Newfoundland capelin were higher during the 1980s than during the 1990s and up to 2001.
It is not known what physical feature(s) influenced the changes in capelin biology or the dramatic reduction in the offshore estimates of abundance. These changes occurred at about the time that the sea temperatures were the lowest ever recorded. However, water temperatures have ameliorated and capelin characteristics have not reverted to the historical patterns. The zooplankton record for the area is weak but the sparse records indicate a large-scale change in the zooplankton community. This observation and the continuing presence of lower salinity water and its link with overall productivity would suggest productivity at lower trophic levels has significantly changed.

On a broader scale, we hypothesize that large changes in the physical oceanography in the Arctic may be having an effect on the oceanography and the biological productivity off the Newfoundland coast, directly as a result of the Arctic water that flows south in the Labrador Current. The physical changes in the Arctic are profound and are consistent with the predictions of changes that would occur as a result of global climate change. There have been attempts in the past to statistically link Arctic outflow and productivity off the Newfoundland coast, with mixed success. The recent dramatic changes both in the Arctic and off Newfoundland may provide adequate contrast to establish significant correlations.

There are several pieces of ancillary evidence that suggest that such a hypothesis is worth exploring. In the eastern Canadian Arctic itself, capelin may be increasing in abundance and/or moving into the area. Evidence of this can be found in the observations that capelin have appeared more prominently in the diets of thick-billed murres in both Lancaster Sound and Hudson Bay with a coincident decline in the occurrence of their usual prey, arctic cod (*Boreogadus saida*). Many major changes in Arctic waters occurred during the late 1980s, only a few years before the extreme events in the physical oceanography during the 1990s and the first signs of the significant biological changes in capelin off Newfoundland. In the Gulf of St Lawrence, an ecosystem adjacent to the eastern Newfoundland ecosystem and also a recipient of water from the Arctic via an offshoot of the Labrador Current, capelin also exhibited a change in distribution from north to south and reduced mean lengths during the 1990s. Also in the Gulf of St Lawrence, a diatom native to the North Pacific appeared in 2001 and researchers surmised that the mode of transport was advection through the Arctic. In addition, an arctic amphipod increased in abundance in the Gulf of St Lawrence by about five times between 2000 and 2001.
Climate Change and Arctic Fisheries: Assessing the Economic and Social Impact in Iceland

Ragnar Arnason, Sveinn Agnarsson

Climate changes in the 21st Century are expected to significantly increase ocean temperatures and modify other oceanographic conditions in the North Atlantic. These changes will undoubtedly affect the size, yield and distribution of commercial fish stocks in the area. Fisheries biological predictions suggest that these impacts on the commercially most important fish stocks in the Icelandic-Greenland ecosystem may well be quite substantial. However, there is great uncertainty regarding the timing, size and even the direction of the impact.

Iceland, as the other nations and national regions across the Arctic and sub-Arctic Atlantic, is heavily dependent on fisheries. It is therefore of considerable social importance to obtain as reliable estimates as possible of the potential impact of alterations in fish stock availability due to global warming on the Icelandic economy. Since the extent of global warming, its impact on fish stocks and the economic and social implications are all uncertain these estimates are most usefully presented as stochastic distributions. Estimates of this kind are not only relevant for Iceland. Due to the similarities of the fish-based economies across the Arctic and sub-Arctic Atlantic, it seems likely that such estimates will also throw light on the likely outcomes in the other countries.

This paper attempts to provide such estimates for the Icelandic economy. The approach is one of stochastic simulations. This involves essentially three steps. The first step is to estimate the role of the fisheries sector in the Icelandic economy. This is done with the help of modern econometric techniques based on standard economic growth theory and historical data. The basic relationship estimated is the so-called error correction model explaining economic growth in Iceland. More precisely, this relationship may be written as

\[ \Delta y_t = \beta_0 + \sum_{i=0}^{k} \beta_i \Delta f_{t-i} + \sum_{i=0}^{k} \delta_i \Delta k_{t-i} + \sum_{i=0}^{k} \gamma_i \Delta l_{t-i} + \lambda \mu_{t-1} + \varepsilon_t, \]

where \( \Delta y_t, \Delta f_t, \Delta k_t, \) and \( \Delta l_t \) represent percentage changes in the gross domestic product (GDP), the production of marine products, the physical capital stock and labour, respectively. \( \mu_{t-1} \) is the error correction term lagged one period. The \( \beta_s, \delta_s, \gamma_s \) and \( \lambda \) are parameters to be estimated and \( \varepsilon \) represents a white noise error term. The error-correction term is in many respects central to this equation. It represents deviations from the long-term relationship between the GDP, fish production, capital and labour. If there are no changes in fish production, capital and labour, the error correction term will gradually converge to zero and the GDP revert to the long term relationship defined by

\[ y_t = \alpha_0 \cdot f_t^{\alpha_1} \cdot k_t^{\alpha_2} \cdot l_t^{\alpha_3}, \]

where \( \alpha_i \) represents the long term percentage response of GDP (elasticity) with respect to a percentage change in fish production. It was found that this relationship appeared statistically sound with the estimate of \( \alpha_1 \) equaling 0.31. With an estimate of \( \alpha_1 \) it is obviously possible to predict the impact of changes in fish production on the GDP.
The second step is to obtain predictions of the impact of global warming on fish stocks and, even more importantly, a confidence interval for that prediction. Natural scientists believe that on the whole global warming of the magnitude predicted will increase the availability of commercial valuable fish around Iceland. However, this prediction is subject to considerable uncertainty. This uncertainty stems from two sources. First there is uncertainty about extent timing and regional impact of global warming itself. Second, there is a possibly great uncertainty about the impact of this on fish stocks. The habitat impacts of any particular global warming are by no means clear and the ecosystem response to any particular habitat change is similarly murky. Thus, it is thought quite possible that global warming, instead of being beneficial to commercial fisheries, will actually hurt them. Another, nontrivial, source of uncertainty is the estimation error in the estimated equation linking fish production with GDP.

The third step is to carry out Monte Carlo simulations on the basis of the above model and the associated uncertainties. For that purpose we use the estimated equation GDP- growth equation with the following stochastic addition:

\[ \Delta f_t = \hat{\Delta f}_t \cdot \Delta t + \sigma(f_t, t) \cdot \Delta z, \]

where \( \hat{\Delta f}_t \) is the predicted change in fish production, \( \sigma(f_t, t) \) is a measure of the uncertainty of that prediction and \( \Delta z \) is a normally distributed white noise increment. This specification means that the expected change in fish production at each time has the probability distribution

\[ \Delta f_t \sim N(\hat{f}_t, \sigma(f_t, t)^2) \]

The result of the Monte Carlo simulations consists of a set of dynamic paths for GDP over time with some expected value and distribution in each future year. On this basis it is possible to calculate confidence intervals for the most likely path of GDP over time.

Preliminary results indicate that the fisheries impact of global warming on the Icelandic GDP are more likely to be positive rather than negative and unlikely to be substantial compared to historically experienced growth rates and fluctuations. The uncertainty of that prediction, however, is large.

Wider social implications such as habitation, unemployment, political instability etc. are assumed to be highly correlated with the GDP impact with the qualification that any change in fish production is likely to impact the various regions in Iceland differently.
Scenarios of Social Response to Climate Change Impacts on Two Subsistence Resources in Interior Alaska: An Analysis of Resilience and Vulnerability

Chanda Meek, Alison Meadow, Anna Godduhn and Sherri Wall

University of Alaska Fairbanks, Regional Resilience and Adaptation PhD Fellows, UAF PO Box 751121, Fairbanks, AK 99775
ftclm@uaf.edu, fflamm1@uaf.edu, ftarg@uaf.edu, fsslw3@uaf.edu

The sustainability of Alaska’s subsistence system – the harvesting of wild foods for sustenance – is a function of community health, the available food base, and the condition of subsistence resource habitat. Despite its relatively pristine condition, Alaska is still affected by global phenomena such as air pollution and climate change. The influence of global climate change is expected to be significant in Alaska.

Movement, adaptation, and change characterized life in pre-contact Interior Alaska. Accordingly, Alaska Natives thrived in the harsh climate through the development of cultural traditions and technological advances that enhanced survival. Since the arrival of Russians, Europeans and Americans in Alaska, the rate of change to subsistence systems in Interior Alaska has been rapid and drastic. Despite these changes, the Athabaskan people of the region continue to be active participants in regional ecological and economic dynamics.

In order to evaluate the sustainability and resilience of the subsistence system in Interior Alaska, our study builds scenarios of depleted stocks of moose and salmon – key subsistence resources in the region based on harvest data – for three communities of varying size, dependence upon subsistence foods, and economic structure. Drawing upon key informant interviews with resource managers, biologists and community experts, we then utilize these scenarios to predict community responses, vulnerabilities and resilience to change. For small and medium-sized communities, we predict significant financial hardship for families in their replacement of subsistence protein with store-bought foods. Culturally, lower availability of key foods will require significant adaptation. Diversity in the economy of larger communities adds to their resilience and access to technology needed for more precise hunting trips further afield.
Vulnerability Assessment: The Role of Indigenous and Local Communities and Place-Based Assessments in Contributing to a Sustainable Arctic Future

David N. Roddick
Prepared for Arctic Athabaskan Council
11 Nisutlin Drive, Whitehorse, Yukon Territory Y1A 3S4

The United States National Research Council (NSC) in *Our Common Journey: A transition Toward Sustainability* has argued that the major threats and opportunities of the transition from the world today to a sustainable future are to be found not only in the assessment of multiple and cumulative interactions between environment and human systems, but in the place-based assessment of these impacts (National Research Council: 1999). By place-based assessments the NSC means specific regions with distinctive social and ecological attributes in which the critical threats to sustainability emerge. It is in this context, the NSC argues, that through applied analytic and policy work progress in the integrative understanding and management of these threats and opportunities will occur. The Arctic Climate Impact Assessment (ACIA) has demonstrated the value of comprehensive regional, integrative assessments to our understanding of the underlying issues associated with climate change impacts (ACIA: 2004). ACIA has given rise to the further need to undertake more focused, place-based assessments of the current vulnerabilities and cumulative impacts of climate change on Arctic human societies with a specific focus on institutional arrangements (McCarthy and Martello: ACIA 2004).

Between 1993-2004, the emergence of new forms of indigenous self-government in the Yukon Territory, Canada, has provided a blueprint for effecting the transition to a sustainable future which the NSC’s *Common Journey* envisions. This paper reviews the history of the land claims settlement process, together with the complex legal and rights-based institutional framework that has arisen as a consequence and the resulting gradual movement toward integrating disparate government and academic research activities into a single, inter-related framework (Canada: 1993). What the NSC has described as sustainability science has emerged in the Yukon Territory in its earliest, nascent stages as a consequence of the adoption of an evolving, rights-based constitutional framework for Yukon Territory that gives priority to the integration of the principle of sustainable development and indigenous traditional knowledge, practices and innovations within resource management decision-making frameworks (Council for Yukon Indians: 1993; MacDonald and Roddick: 2003).

This paper concludes that if the sustainability science project described by the National Research Council is to emerge at all, at least in regard to assessing the impacts of climate change in the Yukon Territory, it will likely make its first appearance as a result of the slow, patient development of regional, place-based initiatives, such as those now arising in the context of the Yukon land claims settlement implementation, rather than as the result of an over-arching, transnational process based on broadly conceived objectives implemented between nation states at the international level. It is here, within the context of placed-based local and regional assessments, conducted in cooperation with local and indigenous communities, that sustainability science as envisioned by the National Research Council, is most likely to assist political decision-makers take their first, hesitant steps toward achieving a sustainable future.
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Indigenous Perspectives on Environmental Change in the Canadian Arctic: Community-based Vulnerability Assessment

Barry Smit, Johanna Wandel and James Ford

Department of Geography, University of Guelph, Guelph, Ontario, Canada, N1G 2W1
Contact author: bsmit@uoguelph.ca (519) 824-4120 x53279

Vulnerability assessment has often been based on scenario-driven climate impact studies. This approach begins with a prediction of future climate scenarios, which is then used to predict impacts on bio-physical and socio-economic systems. “Adaptation” in these assessments is what is expected to happen or what might be possible in light of predicted and expected impacts. “Vulnerability” is viewed as a net, or residual, impact after adaptation has been accounted for. This type of research serves many purposes, but it is limited in its contribution to actual adaptive management decision-making, particularly because it tends not to be connected to the experience of affected people.

Indigenous knowledge, including Inuit Qaujimajatuqangit (IQ), has been recognized as a rich source of information for the documentation of environmental changes, their implications, and management. Indigenous knowledge can indicate changes in conditions and how the change are understood by those affected. Indigenous knowledge incorporates insights often not captured by southern scientists’ research, and perceptions from the communities themselves may be different from scientific observation from elsewhere. Day-to-day decisions are made in light of perception and observed knowledge, and indigenous knowledge is important in assessing vulnerability in the Canadian Arctic. Its inclusion is an essential component if vulnerability and adaptation initiatives are to be relevant to and reflective of the people of the Arctic.

Vulnerability assessment has often been based on scenario-driven climate impact studies. This approach begins with a prediction of future climate scenarios, which is then used to predict impacts on bio-physical and socio-economic systems. “Adaptation” in these assessments is what is expected to happen or what might be possible in light of predicted and expected impacts. “Vulnerability” is viewed as a net, or residual, impact after adaptation has been accounted for. This type of research serves many purposes, but it is limited in its contribution to actual adaptive management decision-making, particularly because it tends not to be connected to the experience of affected people.

Indigenous knowledge, including Inuit Qaujimajatuqangit (IQ), has been recognized as a rich source of information for the documentation of environmental changes, their implications, and management. Indigenous knowledge can indicate changes in conditions and how the change are understood by those affected. Indigenous knowledge incorporates insights often not captured by southern scientists’ research, and perceptions from the communities themselves may be different from scientific observation from elsewhere. Day-to-day decisions are made in light of perception and observed knowledge, and indigenous knowledge is important in assessing vulnerability in the Canadian Arctic. Its inclusion is an essential component if vulnerability and adaptation initiatives are to be relevant to and reflective of the people of the Arctic.

This paper reviews an approach to research vulnerability of Inuit communities in the Canadian Arctic that explicitly incorporates IQ. This approach is applied in a case study for the community of Arctic Bay, Nunavut. It presents a “bottom up” research model, which begins by documenting vulnerabilities in Arctic Bay, using IQ and other sources, in order to first get a comprehensive knowledge of the conditions that are relevant to community members. This includes an identification of conditions important to the people and a description of how they manage them or adapt to them. It provides an assessment of the community’s ability to cope with current and anticipated perturbations (its adaptive capacity). This provides a basis to predict vulnerability in light of predicted changes in conditions important to community members.

The Hamlet of Arctic Bay is located 73º02’ north on Baffin Island, on the north shore of Adams Sound on Admiralty Inlet. More than 90% of its population of approximately 700 is Inuit. Similar to other communities in Nunavut, more than half of the population of Arctic Bay is under age 25. Since the closure of nearby Nanisivik Mine in September 2002, formal employment opportunities in Arctic Bay are limited. A substantial portion of Arctic Bay residents is engaged in traditional hunting activities and spend extended periods of time traveling on sea ice, water, and the tundra.

The research undertaken in Arctic Bay sought to identify environmental conditions relevant to community members (including but not limited to active hunters), and in-depth interviews were conducted with 60 community members during June and July of 2004. Researcher legitimacy was established with a pre-research visit (March 2004) which allowed some
preliminary publicity (at town meetings and on local radio) and the identification of and collaboration with local facilitators. During the main research visit, these facilitators became research partners who advised researchers on the wording of questions and local customs, identified representatives of various social groups (hunters, elders, youth, women, full-time workers, etc.), arranged some interviews, and acted as translators as needed.

Research interviews using the vulnerability approach focused on the life histories and management strategies of Inuit. Interviews sought to document what livelihood strategies community members employed and what conditions had in the past, were currently, or would potentially challenge these strategies. Often, Inuit would explain how they go about various activities (e.g. hunting narwhal) and what environmental conditions influence these. This approach yielded a wealth of observations on already observed environmental changes, their impacts, and management of these impacts. Most actual and potential concerns were focused on travel on sea ice: the ice was reported to be thinner and less predictable than it has been in the past, making travel more dangerous. This risk was compounded by changes in hunting behaviour, since dogs are now rarely used and hunters travel much further with snowmobiles. Furthermore, externally imposed changes in harvesting practices led to a greater dependence on floe edge hunting, exposing hunters to greater dangers including the risk of being stranded. Southerly winds potentially compounded this, as an ice floe would travel toward Lancaster Sound away from land-fast ice. The community, however, has a tremendous capacity to manage these risks using traditional knowledge of ice, technology (GPS, VHF radio) and a community-based search and rescue committee. Environmental conditions posed challenges to members of Arctic Bay, but the community has in the past and is currently managing these challenges in a variety of innovative and effective ways.

Employing the vulnerability perspective highlighted that people do not make decisions to one stress independent of other stresses. For example, Arctic Bay’s lack of formal employment opportunities coupled with a youthful population with little vocational training influenced management of environmental conditions. If a hunter cannot afford a snowmobile, he has few opportunities to join the narwhal hunt and consequently even fewer opportunities to take part in informal employment. Similarly, the introduction of cable television has begun to erode elders’ authority and thus some traditional skills which are a vital part of safe travel on ice are not passed on as effectively as in the past. Thus, it is vital to view management of environmental issues in the context of people’s lives and livelihoods.

The community members of Arctic Bay are managing environmental conditions in conjunction with opportunities provided and challenges posed by the transition of a traditional Inuit lifestyle into a southern, wage-based economy. Research which employs a “bottom-up”, vulnerability perspective using local partners allows a synthesis of community dynamics and stresses which incorporate local and indigenous knowledge. Assessments of community adaptive capacity and the formulation of relevant policy must consider these dynamics and stresses if they are to be relevant and effective.

The paper addresses the recognized need to incorporate indigenous knowledge into scientific assessments in a meaningful way. It provides a research model for assessing vulnerability of communities that is widely applicable, engages local peoples, is relevant to community members, fits with existing management processes, and is pertinent now as well as in the future.
Physical, Biological and Human Coupling in a Traditional Ecological Knowledge-based Climate Change Model - Theory, Formalism and Interpretation

Raphaela Stimmelmayr

Alaska Native Technology and Development Group, Fairbanks, Alaska 99709; rafstimmel@yahoo.com

Traditional Ecological Knowledge (TEK) on the environment is a 'phenomenal' science, in the sense that the variables of the science range over macroscopic parameters [i.e. temperature, ocean currents, tides, wind, snow, ice etc]. Macroscopic parameters and observations of the environment represent maximized information content. Ontological beliefs are the foundation for the underlying mechanisms [i.e. microphysics] of these parameters. These ontological beliefs are not speculative in their nature and knowledge of these ontological beliefs is crucial to remember and understand the environment and its changes. TEK practitioners continually examine Umwelt (Uexküll, J. 1982) for its basic functions, such as food, shelter, enemy, or an object that is used for orientation (sensu landmark) and the acknowledged all-encompassing presence of “Spirit” [i.e. Inua] within the Umwelt. Thus TEK Umwelt models are by nature centered and built on locally based physical, biological and human coupling.

Arctic change is altering and redefining known cultural Umwelt functions for people, animals, and plants. The temporal characteristics of Arctic change events as experienced by TEK practitioners are described in relational concepts, i.e. earlier, simultaneous, and later (sensu B-times). [i.e. spring break up, freezing, bird arrival etc.]. There is a clear understanding that environment is changing and that permanence is a fragile concept. Arctic change presents itself as physical change such as a) change between states (solid or liquid or gas) to another without a change in chemical composition [i.e. permafrost melting; glacier melting/emergence; disappearance of permanent snow patches, open water], and b) a change in physical properties (i.e. texture, shape, size, color, odor, volume, mass, weight, and density) [i.e. sea-ice extent, ice thickness; snowfall, sea and water level, sky color, thinner polar bears; thinner caribou, funny smelling meat etc.]. These physical properties are sensory dependent attributes and are expressed and described according to cultural tools of measurement (Stimmelmayr 2003c). Emergence of new entities also belongs to the expression of local Arctic change [i.e. new insects, plants, fish etc].

Traditional narratives [i.e. folklore, myths, legends, stories,] figure prominently in the generational and seasonal transfer of TEK. Oral tradition has specific storytelling language and techniques that are followed and maintained by storytellers. The frame work of stories focus on providing spatial and temporal contextual relationships on how things happened and on the knowledge of important environmental pairings, structured around progressive (linear and non-linear) linguistic recitation and description of events that culminate in the phenomenon (creation of it). Sequential narrative events become in retrospect when the phenomenon is delivered the explanadas. Stories contain all the relevant causal and nomological information to the outcome of interest [sensu Umwelt functions] and are as such “ideal explanatory text” (Railton 1981). The purely and precise descriptive character [sensu without interpretation, condensing, and abstract thought] exemplified by the narrative script of traditional stories allows for the continued personal “making sense of the events and experience” and reinterpretation of content within the current context [sensu hermeneutic principle] without altering the original narration. Oral tradition and their stories thus function
as an important cultural vehicle by which TEK is epistemically accessible for the individual and the community. Personal and communal experience, place name knowledge, and oral tradition confluent to continually recreate and evolve TEK.

References:
Never-ending Perfect Circle of Seasons – SnowChange, Indigenous Knowledge and Education for a Post-Colonial Arctic

Elina Helander¹ and Tero M. Mustonen² - SnowChange Project, Finland

¹University of Lapland / Arctic Centre, PO Box 122, FIN-96101 Finland
²SnowChange Project, c/o Rauhaniementie 28 a2, FIN-33180 Tampere, Finland

Introduction

Winner of the prestigious Worldwide Fund for Nature 2002 ‘Panda Prize’ for best national ecological project, SnowChange was started in late 2000 to document and work with local and Indigenous communities of the Northern regions. In 2001, a partnership was established with the Arctic Climate Impact Assessment to provide case studies from Finland and Russia to the Chapter 3 of ACIA: Indigenous perspectives.

Aim of this project was to document and work with local communities and Indigenous peoples to present their findings of climate and ecological change in a way that would offer a viewpoint that empowers the local people of the changing Arctic. As well, a strong educational element was included to introduce students of the mainstream societies of Russia, Finland, Iceland, Canada and Alaska to the values, ethics, lifestyles and knowledge of the Indigenous societies of the North. Students worked with reindeer herders, fishermen and hunters in the circumpolar regions to collect the Indigenous observations of change. The results were released in a groundbreaking publication Snowscapes, Dreamscapes in Helsinki, Finland in June 2004. This presentation for the Reykjavik meeting will focus on the Sámi findings and observations of changing climate and weather.

Methods, Findings and Locations of the Project

Sápmi, home to the Indigenous people of the European North (known as Sámi) extends across the northern part of Norway, Sweden, Finland and the Russian Kola Peninsula. The Sámi are concerned about ecological and climatic changes. Issues such as Indigenous rights, co-management and self-governance also manifest in different ways in the four countries in which the Sámi live. SnowChange has organised various interviews and community visits in Sámi with Elders, reindeer herders, and fishermen over the past four years with the purpose of documenting experiences of indigenous people related to change. The communities that have taken part include Jokkmokk region in Sweden, Purnumukka and Kaldoaivi in Finland, Nesseby / Unjarga in Norway and Lovozero area in Murmansk, Russia. In addition to the Sámi documentation, SnowChange has worked with Indigenous and local communities to document their observations of change in Alaska, Canada, Iceland, the Faeroe Islands, Finland, Siberia, Nepal, Samoa, Bolivia and Ghana.

The issue of traditional knowledge came up frequently in the Sámi discussions. In an interview in March 2002, in Sirma, (Norway), Nillas Somby asserted that traditional knowledge was invaluable because it was “knowledge about everything. Of food and material and storytelling, symbols.”

Recounting earlier times, Somby spoke about an old man whom his family used to visit. This old man could predict the weather by reading signs present in nature. He had an explanation for everything. Somby emphasized that this kind of information was created over thousands of years. “Now all of a sudden, one generation is wasting it away by just turning on the radio..."
and listening to the weather forecast,” he said. “Our generation hasn’t been educated the right way. In practical things like weather forecasting, medicine and also lots of spiritual ceremonies,” he added. He felt that young people were less in touch with traditional skills and knowledge and that this was partly a result of their schooling.

Stefan Mikaelsson, a vice-president of the Sámi Council in Sweden, is a reindeer herder. Because of the Sámi dependence on renewable natural resources, the Sámi Council is particularly concerned about the effects of climate change and/or climate variability. Mikaelsson himself has noticed the changes in the weather from one year to another.

He felt that the local flora and fauna would probably be affected by the rise in temperatures. Such changes would most probably not be advantageous for reindeer herding. Another potential hazard could be the spread of new diseases that are not found at higher latitudes today. Globally scientists have predicted further spread of Dengue Fever, Malaria and other diseases northwards because of warmer temperatures and animal migrations that changes in weather might trigger. In Sámi land there is a fear of new diseases that might be introduced by arrival insects, such as the deer ked, [lat. Lipoptena cervii] that is now quite common in southern border areas of the Sámi. These diseases might affect the reindeer for example.

“Uncertainty makes the situation more worrisome. What happens to reindeer, other animals, plants and trees when they are exposed to new bacteria, virus and parasites? I am not sure the scientists can tell us exactly what will happen,” Mikaelsson said. He is also worried about the possibility of trees that are not grown locally being introduced in this region. On the other hand, the unlimited economic forestry poses a more imminent threat to delicate ecosystems in the reindeer herding territories.

Pentti Nikodemus, another Sámi reindeer herder (a resident of Purnumukka, Finland) also expressed his concerns about the sudden variation in climatic conditions and their effects. The Purnumukka region had been experiencing late and heavy snowfall. He described sudden, extremely cold weather, close to -50 °C in the region in the previous winter, which prevented the use of motor transportation in reindeer herding. Pentti said that this was a good occasion to use the reindeer as a means of transportation. Ice rain in autumn does not allow a proper freezing of the ground and the reindeer are unable to penetrate an ice layer formed by this new type of rain in trying to locate lichen for food. This causes both reindeer deaths and increased dependency on additional feeding by humans.

Elina Helander, a Sámi from Ochejohka [Utsjoki] region of Sámi, Finland, said that people have been noticing evidence of changing climate. “Many claim that the weather has become warmer, especially the fall and early winter. During the recent years, the ground has not frozen properly in the fall, and there has been little rain in September,” she reported. She added that many herders and subsistence hunters claim that there are no winds anymore. That was an important concern. “Winds have some positive effects. For instance, wind gathers the snow to certain spots. In other spots, there is little snow and it is then easy for the reindeer to dig through where the amount of snow is small. The wind can also make the snow soft, but on the other hand, the extremely strong wind (known as guoldu in Sámi) makes the snow hard,” she said.

The Sámi, like many other Circumpolar peoples, combine different economic activities over the year, such as berry picking, reindeer herding, fishing, hunting, trapping and handicraft. “The Sámi”, said Helander, “have an ecological knowledge of their own, rooted in the traditional way of life.” This knowledge goes beyond observation and documentation because it is a precondition for survival.” “Indeed”, she added, “Sámi traditional knowledge also contains evidence of long-term experience in adaptation.” Traditional knowledge of the Sámi, like other Indigenous and local cultures, is built on generations of close relationship and
observation of nature. Weather lore has been partly based on long-term trends and close observations of seasonal changes. In the past 20 years the traditional calendar has been off-balance because of these sudden and unexpected changes in weather, including wind. Helander mentioned in the community visits that in the olden times a change within 24 hours from – 25 Celsius to + 4 Celsius would be seen as catastrophic. Today, such unpredictable, sudden variations are quite common each winter. Traditional knowledge is challenged by the human-induced climate change and variation caused by unlimited misuse of fossil fuels.

Residents of Murmansk Kola Sámi in the Russian Federation too, expressed concern over weather-related changes in the community interviews. For example, Larisa Avdejeva stated that similar sudden periods of above-zero temperatures followed by a quick freeze overnight make it difficult for the reindeer to reach the lichens upon which they feed just like in the western parts of Sámi. Local reindeer herders have observed the arrival of new species of insects, plants and birds, which in the past were common only in the more southern parts of Russia. People also noted that because of the late freeze-up, the arrival of ice layer to lakes and rivers, movement on the tundra is becoming more difficult. Unfortunately, the communities’ problems are compounded by the lack of resources and the state of Russian society. “This year, I think snow will melt later, but last year it melted very early. But there wasn’t any snow last year. Not a trace of the snow remained because there was no snow cover”, said Arkady Khodzinsky, a reindeer herder with the Tundra reindeer farm, brigade number 9, in an interview in April 2002. “The ice cover is necessary”, he continued. “This year it exists, that is why the snow will stay longer this year. It will stay till the end of June, in my opinion.” Later melting of the snow allows for extended travel on the land.

Conclusions

Overall the Sámi and other local participants have a clear message of the changes taking place; in the past 20 years there has been a significant new phase in the weather and natural cycles. The Sámi have traditional knowledge building on generations of people living in close relationship with the sub-arctic ecosystem. This knowledge is best expressed in the Sámi language. Despite colonization attempts by missionaries, boarding schools and the Nordic states, the Sámi culture and people survive and are regaining the control of their own destiny once again. They have survived the very worst that Europeans could think and they are ready to win new victories. SnowChange community interviews are being digitalized and archived into DVDs for future generations, while new documentation goes on.

Acknowledgements

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References

On the Effect of Sea Ice on Icelanders' Lives from 1850 to the Present Day: Combining Historical Analysis and Remote Sensing through Geographical Information Systems

Ingibjörg Jónsdóttir

Department of Geology and Geography, Faculty of Science, University of Iceland, 101 Reykjavik, Iceland
<ij@hi.is>

Introduction

This paper studies how the presence of sea ice has affected people's lives in Iceland from AD 1850 to the present day. The goal is to examine in what way people can be affected, and whether there are any differences through time and in different regions of Iceland. Furthermore, possible impacts of sea ice in the future are considered.

Miscellaneous data sources are used to establish the history of sea-ice impacts. These include farmers' diaries, various reports, questionnaires (figure 1), autobiographies, newspapers and interviews with captains. A Geographical Information System (GIS) is used to build a databank where the various impacts are categorised and registered according to geographical location and time. At the same time, the GIS is used to store information on the sea-ice extent each month during this period. The GIS allows the data to be viewed geographically and according to different attributes. It is thus possible to search the database for certain "appearances" of impacts, such as polar bear sightings or loss of fishing gear, view the results geographically and to study the connection of such events to the amount of sea ice. A few examples will be demonstrated.

Figure 1. The Icelandic Literature Society sent a questionnaire with 70 questions on people and nature to all priests and sheriffs in Iceland. The questions on sea ice were: "Does sea ice come? And what have people noticed about its behaviour, nature and impacts?" Only 8 of 194 reports are missing and the answers are very useful when studying past sea-ice impacts and people's conception on sea-ice and its impacts.
The different types of sources allow comparison of what people mention on the impacts in their diaries and when ask directly about the impacts. There is a considerable difference in the answers where people tend to forget tedious extra work that the ice caused when answering questionnaires.

The project also considers people's reaction to the sea ice; how they tried to predict its arrival, adapt to the different environment that it shaped or mitigate the negative impacts. The role of satellite images and daily sea-ice charts in coping with the sea ice nowadays is contemplated.

By studying the past, including both severe and mild periods and identifying the "essence" of sea-ice impacts, possible future impacts could be predicted. As the sea-ice conditions, the Icelandic society and the available technology have changed dramatically during this period it is believed to be useful to isolate the "appearance" of impacts and then attempt to project them into future. Both scenarios are considered, with less or more ice, even though predictions suggest the former. Under such circumstances the ice can still be a hazard as navigation in the Polar Regions is likely to increase (International Ice Charting Working Group). GIS has proven to be a valuable tool for impact studies and for understanding the connection between different factors of sea-ice impacts and sea-ice extent.

This project could be a model for other climate impact studies, where research on past conditions and impacts, as well as adaptation and mitigations methods, are used to predict future influence and reactions. As there is evidence for extensive climatic changes in the future, the way this will influence people and society is of great importance.
ArcticNet: A Newly Funded Network of Centres of Excellence of Canada to Conduct the Integrated Natural/ Human Health/Social Study of the Changing Coastal Canadian Arctic

Louis Fortier and Martin Fortier*

ArcticNet, Room 4081, Pavillon Alexandre-Vachon, Université Laval, Québec, QC, Canada, G1K 7P4
*No kinship

Introduction
Decision makers and the scientific community recognize that climate warming and globalisation are threatening northern societies and the traditional way of life of Arctic peoples. Understanding how and to what extent northern individuals, societies, and economies will be impacted is as crucial as monitoring and modeling the on-going transformation of the Arctic environment. Down-scaling observations, models and predictions from the hemispheric to the regional, to the community and the individual requires better collaboration between arctic specialists in the natural, human health and social sciences. It is also imperative to engage Inuit organizations, northern communities and individuals in the research process and to build scientific capacity in the North. Therefore, evolving national and international efforts such as the US SEARCH (the Study of Environmental ARctic Change) and the international ISAC (the International Study of Arctic Change) are looking for ways to build bridges across science sectors and to involve northerners and their expertise.

In Canada, the Network of Centres of Excellence (NCE) program is particularly well suited for the cross-sector integration of specialists in fields of strategic importance to the country. In 2002, Canadian Arctic specialists obtained a major grant from the NCE program to fund ArcticNet: the integrated natural/human health/social study of the changing coastal Canadian Arctic. ArcticNet brings together scientists and managers in the natural, human health and social sciences, and their partners in Inuit organizations, northern communities, federal and provincial agencies and the private sector to study the impacts of climate change in the coastal Canadian Arctic. Over 90 Canadian ArcticNet researchers from 22 universities and 4 federal departments collaborate with research teams in the USA, Japan, Denmark, Norway, Spain, Sweden, Poland, the United Kingdom, Greenland, Russia and France.

Objectives
The central objective of the Network is to contribute to the development and dissemination of knowledge needed to formulate impact assessments, national policies and priorities, decision making, and adaptation strategies to help Canadians face the environmental and socio-economic impacts and opportunities of climate change and globalization in the Arctic. A primary goal of the Network is to involve Inuit Organizations, communities, universities, research institutes, industry as well as government and international agencies as equal partners in the scientific process through the exchange of knowledge, training, resources and technology.
Methodology

Starting in summer 2004, ArcticNet will conduct Integrated Regional Impact Studies on Arctic ecosystems and societies in the coastal marine Canadian High Arctic, in the terrestrial coastal ecosystems of the Eastern Canadian Arctic, and in Hudson Bay. In addition to work conducted in and around northern communities, ArcticNet field operations will benefit from the new Canadian research icebreaker CCGS Amundsen. The Amundsen provides access to the coastal Arctic to Canadian specialists and their international collaborators in diverse research domains including oceanography, terrestrial ecology, geology, and epidemiology. This integrated research offers a unique multi-disciplinary cross-sector training environment for the next generation of specialists, from north and south, needed to ensure the stewardship of a new Canadian Arctic.

At the time when evidences of the Arctic meltdown anticipated by GCMs are beginning to accumulate, decadal and multi-decadal time series of observations are desperately needed (1) to separate natural variability from actual changes and (2) to assess the rate at which the scenarios predicted by climate models are unfolding. ArcticNet is developing some of the arctic observatories that will provide the long-term time series of environmental observations needed to monitor arctic change. Time series of key climatic, oceanographic, ecological, health and socio-economic indices are initiated in the Beaufort Sea, the North Water polynya and Hudson Bay. ArcticNet researchers are also participating in the NABOS Laptev Sea Observatory.

Overall, the scientific program of ArcticNet encompasses 24 studies of environmental changes tailored to provide epidemiologists, sociologists and economists with the baseline information needed to anticipate the impacts of an Arctic meltdown on Northern societies, governments and industries. The Integrated Regional Impact Study approach will produce the regional models needed to downscale environmental information and predictions to the level of
communities and local infrastructures, in order to better answer the requirements of decision and policy makers.

Conclusion
Funded until 2011 with the potential for renewed funding until 2018, ArcticNet provides the international community of Arctic specialists with a kernel around which international collaborations can be developed to study the impacts of Arctic warming on northern societies. This presentation is an invitation to consolidate existing international collaborations within ArcticNet and to further new ones.

Acknowledgements
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Introduction
The Arctic Climate Impact Assessment (ACIA) has described the extent of recent changes in
the Arctic and their impacts and has projected a future state of the Arctic that may present
both difficult challenges and useful opportunities. As ACIA makes clear, a number of follow-on
activities are needed to verify the ACIA’s future projections and to provide the information
needed by society to deal successfully with whatever future unfolds. Consistent with
NOAA’s mission to “understand climate variability and change to enhance society’s ability to
plan and respond”, NOAA has initiated several activities that respond directly to ACIA
recommendations. These activities also support the science goals of the Study of
Environmental Arctic Change (SEARCH), a U.S. science program designed to detect and
understand environmental change in the Arctic and its impacts on humans and the
environment. NOAA is one of several U.S. federal agencies participating in implementation
of SEARCH and the NOAA role emphasizes environmental observations and data analysis.
Our contributions to ACIA follow-on activities will continue this emphasis. Current activities
include:

- Establishing long-term Arctic cloud, radiation and aerosol observatories to improve
detection of environmental change in the lower and upper atmosphere
- Initiation of a long-term program to document and attribute changes in sea ice
thickness through direct measurements and modeling
- Undertaking projects to derive added value from existing data
- Conducting a pilot study of physical-biological interactions in the Bering and Chukchi
Seas

Description of On-going Activities

A. Arctic cloud, radiation and aerosol observatories

Long-term, high-quality atmospheric observations are needed to provide a record of change at
key locations, to calibrate and validate satellite observations, and to aid in predicting global
climate change and mid-latitude weather. Because the focus is on monitoring long-term
trends related to the Arctic Oscillation, northeast Canada and the central Arctic coast of
Russia have been chosen as desirable sites as they exhibit different responses to AO
variability. Instruments that measure key properties of clouds, atmospheric radiation and
aerosols have been selected to provide informative atmospheric data products that are also
direct comparables to the already existing NOAA and Department of Energy Observatory measurements in Barrow, Alaska. These atmospheric observations have been deemed critical to assess changes in atmospheric composition and structure and in radiation balance during what are expected to be several decades of rapid environmental change in the Arctic.

NOAA is closely collaborating with Meteorological Services Canada (MSC) and the Canadian Network for the Detection of Atmospheric Change (CANDAC) program (University of Toronto) to establish an observatory at Eureka Canada. In addition, linkages are being built with both NASA and the Canadian Space Agency (CSA) to coordinate surface measurements with cloud/radiation/aerosol satellite programs. The Observatory in Eureka is expected to be operational by fall of 2005.

**B. Sea ice thickness**

Monitoring changes in the volume of the sea ice cover in the Arctic Ocean is crucial for developing our understanding of climate change processes and their impacts. Satellites do a good job of measuring sea ice extent, but cannot as yet provide useful measures of sea ice thickness. NOAA has begun deployment of a network of ice-tethered ice mass balance (IMB) buoys complemented by a few sea-floor moorings with ice profiling sonar (IPS). Together these technologies can provide data on ice thickness in areas of persistent and intermittent ice cover and allow an Arctic-wide estimate of temporal changes in sea ice volume. The IMB buoys report in real-time via System Argos, while the IPS moorings record data internally. Deployments are done via partnerships with other programs, such as Canadian, Russian and Swedish icebreaker cruises. To the extent feasible, the International Arctic Buoy Program will employ IMB systems to increase the scientific value of the program. Integrated analysis of data from the IMB and IPS systems with satellite data and, hopefully, long-duration icebreaker-based observations should allow reliable estimates of surface energy budgets and changes in sea ice mass throughout the Arctic.

**C. Retrospective data analysis**

Four different activities have been initiated, two of which are of a continuing nature.

1. Retrospective Analysis of Arctic Clouds and Radiation from Surface and Satellite Measurements – This short term activity will compare data from a variety of sources, with an emphasis on data from the Barrow region, to determine relationships and biases and provide a context for analysis of data to be generated by the Arctic atmospheric observatories.

2. Correction of Systematic Errors in TOVS Radiances – The TOVS sensors have been in use since 1978, but have never been calibrated to provide reliable data from the Arctic.

3. Arctic System Reanalysis – The goal is to create a high resolution coupled air-ice-ocean climate model that can assimilate observations and provide a harmonious view of the climate of the Arctic. Once operational, it should improve seasonal to interannual prediction and provide a continuing climate-quality depiction of the Arctic for climate change detection.

4. Arctic Climate Change Detection – This activity uses current and retrospective observations to understand and anticipate changes in the Arctic. A protocol for Arctic Change Detection will be developed that incorporates physical and biological variables from terrestrial and marine environments. A key feature of this activity is the provision of scientific information in forms understandable to non-specialists.
D. Physical-biological interactions in the Bering and Chukchi Seas

The expected warming, loss of seasonal ice cover, and possible changes in ocean circulation will have profound effect on the ecosystems in this region. Because other human influences (commercial fishing, land-based sources of pollution) are minimal in this region, the impact of climate change should be more confidently detected. NOAA will begin a long-term effort to detect ecosystem indicators of climate change in this region that will provide a model for change in other marine ecosystems. The first efforts were undertaken in summer 2004 during a joint Russian-US cruise that mapped the region’s physical, chemical and biological parameters to set the stage for future instrument installation and monitoring operations that will gather data on ecosystem change over the longer term. A line of biophysical moorings in the Northern Bering Sea-Bering Strait-Chukchi Sea region will provide detection of the expected rapid pace of change due to warming of this area of the Arctic and the basis for assessing ecological change. Ship-based CTD, chlorophyll and nutrient collections will be made at each mooring site for calibration of the appropriate sensors.

Look to the Future

These activities are part of a larger vision for climate observations in the Arctic. Long-term ocean observations in the Arctic basins will be needed and may be best done on an international basis. Also, observations of the terrestrial surface (permafrost extent, snow and vegetation cover, soil moisture, streamflow) are essential for understanding climate change in the Arctic. Existing observations of carbon dioxide and methane in the Arctic atmosphere may be adequate, but there is little information of air/sea and air/land flux of these key elements of the carbon cycle. Given the large quantities of carbon stored in the Arctic, sustained observations for detecting significant change in fluxes should be initiated. Physical-biological observations in the Chukchi Region would benefit from similar observations in other Arctic regions. We would be interested in collaboration with other organizations interested in this type of observation.

Conclusions

NOAA has initiated a multi-faceted program of environmental observation and data analysis to help understand and predict climate variability and change in the Arctic. We expect to have all these activities developed in time to contribute to the International Polar Year (March 2007 – March 2009). And we expect to continue these activities for as long as they are scientifically valid. However funds are very tight and any unanticipated costs may result in a given activity being reduced in scope or even terminated. For this reason we are very open to partnerships with others; in fact international collaboration is already a vital part of many of these activities.

Given the intended long-term nature of these activities, we expect to interact closely with the proposed International Study of Arctic Change and to integrate our activities with other Arctic Council responses to the ACIA.
Assessing Climate Change Vulnerabilities in the Barents Region through Integrated Regional Impact Studies

Manfred A. Lange\textsuperscript{1}, and the BALANCE Consortium\textsuperscript{2}

\textsuperscript{1}Manfred Lange, Westfälische Wilhelms-Universität Münster, Institute For Geophysics And Center For Environmental Research, Corrensstr. 24, D-48149 Münster, Germany, Email: Langema@Uni-Muenster.De  
\textsuperscript{2}The BALANCE Consortium consists of the following partner institutions (in alphabetical order): Institute of Marine Research, Department of Marine Environment, PO-Box 1870, N-5817 Bergen, Norway; Max-Planck-Institute of Meteorology, Bundesstrasse 55, D-20146 Hamburg, Germany; Natural Environment Research Council, Centre for Ecology and Hydrology, Maclean Building, Wallingford, OX10 8BB, United Kingdom; Royal Swedish Academy of Sciences, Abisko Scientific Research Station, SE-98107 Abisko, Sweden; SINTEF Fisheries and Aquaculture,N-7034 Trondheim, Norway; Umeå University, Department of Social and Economic Geography, S-90187 Umeå, Sweden; UNEP-World Conservation Monitoring Centre, 219 Huntingdon Road, Cambridge, CB3 ODJ, United Kingdom; University of Cambridge, Scott Polar Research Institute, Lensfield Road, Cambridge, CB2 IER, United Kingdom; University of Kuopio, Department of Social Sciences, Harjuulantie 1, FIN-70211 Kuopio, Finland; University of Lapland, Department of Social Studies, PO-Box 122, FIN-96101 Rovaniemi, Finland; University of Münster, Institute for Geoinformatics, Robert-Koch-Strasse 26-28, D-48149 Münster, Germany; University of Münster, Institute for Geophysics, Corrensstr. 24, D-48149 Münster, Germany; University of Tromsø, Norwegian College of Fishery Science, Department of Economics and Management, N-9037 Tromsø, Norway; University of Turku, Department of Biology, Section of Ecology, FIN-20014 Turku, Finland; University of Utrecht, Faculty of Geographical Sciences, Department of Physical Geography, 115 Heidelbergaan 2, NL-3508 TC Utrecht, The Netherlands

Background/Introduction

Despite remaining differences between present Global Climate Model (GCM) projections of future climate change, there is increasing coherence among the model results with regard to a significantly enhanced greenhouse-induced warming for most of the circumpolar North as compared to the rest of the globe (\textit{Holland and Bitz}, 2003; \textit{Räisänen}, 2001). This is consistent with currently available observations on the development of northern-hemisphere meteorological parameters and major (physical) impacts of climate change for the present and the recent past (\textit{Chapman and Walsh}, 1993; \textit{Johannessen et al.}, 2004). However, changing climate conditions not only influences physical factors (e.g., sea ice thicknesses and sea ice extent), but also affects terrestrial-, freshwater- and marine ecosystems (for reviews and summaries see, e.g., \textit{Callaghan et al.}, 1999; \textit{Lange et al.}, 1999; \textit{Lange and BASIS consortium}, 2003; \textit{Sakshaug}, 1995). This may lead to declining productivities and to changes in northern-ecosystem services and may strongly affect natural-resource-based economies and subsistence lifestyles in the circumpolar North. However, in order to address the vulnerability of northern communities to

![Figure 1: Major components of the European North and some of their interrelationships](image_url)
climate change, there is a need to consider the sensitivity and adaptability of natural and societal components/sectors to climate change holistically (for a definition of terms, see Nakicenovic et al., 2000). This involves an integrated assessment of the complex interrelationships and feedbacks between these components (Figure 1) as they respond to changes in climate. In so doing, it becomes increasingly clear that a regional to sub-regional scope is superior to hemispherical or global scales usually applied. This is due, among other reasons, to the need to account for the spatial scales at which main characteristics of the components considered vary and to the desire to provide guidance and policy advice on scales that are appropriate for decision makers and stakeholders. To satisfy the requirements of an integrated assessment at regional scales, Integrated Regional Impact Studies (IRISs) have been developed and successfully applied over the recent past (for summaries, see, e.g., Lange, 2000a,b; Yarnal, 1998).

Methods and Approach

The EU-funded BALANCE project (Global Change Vulnerabilities in the Barents Region: Linking Arctic Natural Resources, Climate Change and Economies; EVK2-2002-00169; for more details, see: http://balance-eu.info) aims at assessing the vulnerabilities of the Barents Sea system (BSS) to climate change based on a common modelling framework for major environmental and societal components and on the quantification of linkages between these components through an integrated assessment model (BALANCE-IAM). Objectives of BALANCE include: specification of environmental and societal vulnerability indicators; estimates of present environmental and societal vulnerabilities, partly based on an assessment of presently observable shifts in terrestrial biodiversity; the refinement/adjustment/development of impact models for specific components of the BSS; the assessment of the nature and strength of links between components of this system and their quantification through an integrated assessment model; the implementation of a regional climate model for the study region; the assessment of climate change impacts for 2020 and 2050 (and possibly 2080), i.e., the time slices used by the Arctic Climate Impact Assessment (ACIA); estimates of future environmental and societal vulnerabilities to climate change of the BSS; the implementation of a stakeholder-scientists collaborative and an assessment of perceptions and views of local residents on climate change. The basic approach adopted in BALANCE builds on the IPCC-methodology for integrated assessments (see, e.g., Parry and Carter, 1998). However, in addition, we emphasize an involvement of stakeholders in all phases of the project. The BALANCE-IAM consists of a number of individual sub-models that describe specific components of the BSS. The sub-models are

![Figure 2: Basic components of the BALANCE-IAM and modelling strategy](image-url)
operated sequentially along distinct impact chains that enable an assessment of climate change impacts for the terrestrial and marine components and sectors considered (Figure 2). The spatial resolution of the control- and the climate change runs are 1/2° and 1/6°. The climate change run of the model is driven by results from a dedicated regional climate model (RCM) that is based on GCM results obtained by employing the A2-SRES scenario (Nakicenovic et al., 2000). We will utilize the results of the first round of the impact model as boundary conditions for a second run of the RCM to explore possible feedbacks between climate impacts and subsequent climate development.

Results

First results are primarily comprised by a refinement and revision of individual component models and the RCM to be used in BALANCE. First control runs of the RCM driven by ECWMF-reanalysis data have been carried out. The results have been utilized to assess the present response of the considered components of the BSS as a means of verifying the reliability of the component models. We are currently providing results of first climate change RCM runs to the impact modellers in order to obtain impacts of climate change for marine and terrestrial components and sectors.

Conclusions

Anthropogenically driven climate changes are expected to be significantly enhanced in the circumpolar North relative to the rest of the world. This suggests that the impacts of climate change will be particularly severe for northern ecosystems and natural-resource-dependant economic sectors. In order to assess the vulnerability of the BSS to climate change, the EU-funded BALANCE project is being carried out by a consortium of 15 partners. The central objective lies in assessing the vulnerabilities of the Barents Sea system (BSS) to climate change based on a common modelling framework for major environmental and societal components and on the quantification of linkages between these components through an integrated assessment model (BALANCE-IAM). The basic methodology follows the IPCC-approach but emphasizes stakeholder involvement in all phases of the project. The BALANCE-IAM consists of a number of individual component models that are run sequentially along two major impact chains in order to assess the impacts of and the vulnerabilities to climate change for terrestrial and marine components and sectors of the BSS.

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References


Contemporary hydrometeorological monitoring is a complex multi-parameter analytical system. However exactly because huge amount of analytical data the official climatology cannot answer definitely: does the logical increase of climate destabilization take place today? It may be met the opinion about fortuity of the climatic parameters fluctuation and absence of any reason for anxiety. In this situation the indigenous people observation for the natural ecosystem conditions and changes could be as quite significant integral indicator of the climate changes.

These indigenous ecological observations are accounted as the part of the traditional ecological knowledge (TEK). It can be as significant supplement of the official environmental monitoring system. Generalization and systematization of the indigenous people’s ecological observation in the previous investigations (Riedlinger, 2000; Gordon et al., 2001; Krupnik, Jolly, 2002) allow us to talk about essential changes of the climate balance and natural ecosystems as well have occurred during last 10 – 15 years. Analogous investigations of the Kola Saami’s TEK were conducted among reindeer-breeders in Lovozero – central Saami settlement of Kola Peninsula. Main results of this investigation have shown the significant changes in the Kola Peninsula tundra’s climate took place during last 10 years. Changes of the tundra ecosystem mentioned by Saami peoples, point to this. Change of the lakes and rivers freeze-up terms, decrease of the ice cover, reins and thunderstorms during winter, wind power increase, disappear of the blood-sucker insects in tundra during last 2-3 years, appearance new southern species of insects and plants were observed. Saami said the traditional signs for the weather prediction don’t work any more.

Temperature measurements data of the Murmansk region’s official environmental monitoring system for the last 30 years were investigated. Statistical analysis of these data has shown the total average temperature logically grow up on the background of the temperature’s changes amplitude and frequency increase. This tendency has become more intensive during last 5 - 10 years.

Results of the Saami TEK investigation and official hydrometeorological monitoring data comparison allow us account the indigenous environmental observations as adequate and valuable part of monitoring.
Observational Evidence on Changes in the Thermohaline Coupling between the Arctic Mediterranean and the World Ocean

Bogi Hansen¹, Svein Østerhus², William R. Turrell³

¹Faroese Fisheries Laboratory, Box 3051, FO-110 Torshavn, Faroe Islands
²Bjerknes Centre for Climate Research, Bergen, Norway
³Marine Laboratory, Aberdeen, Scotland

Introduction

In the present-day climate system, there is a strong thermohaline coupling between the World Ocean and the Arctic Mediterranean (Arctic Ocean and Nordic Seas). This coupling contributes a significant part of the deep waters of the World Ocean and it keeps parts of the Arctic many degrees warmer than they would otherwise have been (Vellinga & Wood, 2002). Sea surface warming and increased freshwater fluxes due to anthropogenic global change have the potential to affect this system; but climate models have not yet reached a level of confidence that can allow them to provide unambiguous predictions of the future behaviour of the system. Here, we address the question, to what extent observations give any clear evidence for or against changes having already occurred.

The thermohaline coupling

The Arctic Mediterranean is linked to the rest of the World Ocean by three flow systems. In the upper layers, there is an inflow of warm and saline Atlantic waters to the Arctic Mediterranean (Fig. 1). The compensating export of water occurs partly as a low-salinity surface outflow, but mainly as a deep overflow of waters that have been made cold and dense in the Arctic Mediterranean by thermohaline ventilation (Fig. 1). The overflow currents pass the Greenland-Scotland Ridge, separating the Arctic Mediterranean from the North Atlantic,
as high-velocity flows, driven by the pressure head, set up by thermohaline ventilation (Fig. 2). As they pass the Ridge and meet the much warmer Atlantic waters, intensive entrainment of ambient waters reduces the density excess, but increases the volume flux of the overflow waters, so that they contribute the major part of the production of North Atlantic Deep Water (NADW) according to present estimates (Dickson and Brown, 1994; Hansen and Østerhus, 2000).

The overflow from the Arctic Mediterranean, driven by thermohaline ventilation, is thus an important contributor to the deep waters of the World Ocean, but its importance for the Arctic is no less. A continuous deep overflow requires a compensating net inflow in the upper layers of the same magnitude (Fig. 2). In the present day ocean, the East Greenland Current and the flows through the Bering Strait and the Canadian Archipelago provide a net outflow of low-salinity water from the Arctic Mediterranean, but the volume flux of this “surface outflow” is considerably less that the volume flux of the overflow (Fig. 1). Most of the Atlantic inflow to the Arctic Mediterranean can therefore be seen as a compensatory inflow to the overflow.

Predictions of future climate change include pronounced warming of the Arctic as well as a strengthened hydrological cycle and there are concerns that the North Atlantic thermohaline circulation (THC) may weaken. The concept of a weakened THC is supported by some numerical climate models, but not by all. Increased salinity of the compensating flow may balance the salinity decrease from the increased freshwater supply and maintain ventilation. Climate models, so far, do not provide a unique answer describing the future development of the THC (IPCC, 2001).

Observational evidence?

As argued, early evidence for changes should primarily be sought for in the ventilation and overflow. Indeed, some such changes have been reported. Since around 1960 large parts of the open sea areas north of the Greenland-Scotland Ridge have freshened and so have the overflows (Dickson et al., 2002). More direct evidence for a reduction of the North Atlantic THC has been gained from monitoring both the overflows and the compensating northward flow by hydrographic as well as direct current measurements (Arctic / Subarctic Ocean Fluxes

Figure 2. A schematic section across the Greenland-Scotland Ridge. Temperatures in °C and volume transports in Sv are approximate values.
For the Denmark Strait overflow, no persistent long-term trends in volume transport have been reported, but the Faroe Bank Channel overflow was found to have decreased by about 20% from 1950 to 2000 (Hansen et al., 2001). Recent observations indicate a reversal of this trend.

At the same time as the Arctic freshened, low-latitude Atlantic waters became more saline in the upper layer (Curry et al., 2003) and this is also reflected in the compensating flow. Long-term observations in both of the main branches of compensating flow across the Greenland-Scotland Ridge have shown increasing salinity since the mid 1970s with a record-high in 2003 (Fig. 3).

In summary, we find evidence of freshening of the Nordic Seas and a possible reduction of the strength of the overflow, both of which will tend to weaken the North Atlantic THC. On the other hand, the compensating northward flow is getting more saline, which may maintain ventilation and counterbalance the THC decrease. So, the jury is still out. This emphasizes the need for more refined climate models and long-term observational systems that are capable of identifying potential changes in our climate system.

![Salinity Anomalies](Image)

Figure 3. Anomalies of salinity of the North Atlantic Water over the shelf on the Scottish side of the Faroe-Shetland Channel (full line) and in the Faroe Current due north of the Faroes.

**References**


Assessing Vulnerabilities: A New Strategy for the Arctic


1 Centre for Human Rights, Faculty of Law, University of Oslo, Norway; 2 Nordic Sámi Institute, Kautokeino, Norway; 3 Harvard University, Cambridge, MA USA; 4 Fossbakken, Norway; 5 CICERO, University of Oslo, Norway; 6 Norwegian Meteorological Institute, Oslo, Norway; 7 NAMMCO, Tromsø, Norway; 8 Norwegian School of Veterinary Medicine, Tromsø, Norway; s.d.mathiesen@veths.no; 9 NINA, Lillehammer, Norway; 10 Sámi High School, Kautokeino, Norway; 11 Hvasser, Tønsberg, Norway; 12 Centre for Research in the Elderly, University of Tromsø, Norway; 13 Centre for Sámi Studies, University of Tromsø, Norway; 14 Association of World Reindeer Herders, Tromsø, Norway.

Vulnerability analysis is a procedure through which the potential impacts of environmental and societal change on human-environment systems may be examined in relation to systems' resilience, i.e. the ability of systems, or parts of them, to cope with and adapt to change. 'Vulnerability', therefore, is an expression of the extent to which adverse impacts can be ameliorated through adaptation and coping: a highly vulnerable system is one with only a poor ability to cope and vice versa.

A generalised interdisciplinary, conceptual, analytical and methodological approach has been developed for assessing vulnerability coupled human-environment systems in the Arctic. This approach, published in the Arctic Climate Impact Assessment, includes three key features. It (i) focuses on the interaction of multiple factors that operate across multiple spatial scales ranging from local to global, (ii) requires the active participation of indigenous people and other residents of the Arctic and (iii) emphasises that the objective of vulnerability assessment is to enhance local coping and adaptive capacity through the development of local competence based on multidisciplinary understanding.

The Arctic is highly heterogeneous in terms both of the biophysical and the cultural environment. Consequently, a generalised approach for vulnerability assessment is only useful if it is flexible and capable of being modified to suit the characteristics of specific cases. Moreover, it must also be perceived as relevant and valuable by the local peoples in whose societies it is to be applied.

Sámi nomadic reindeer herding in northern Norway was selected as a model system in which to test the generalised approach. The purpose was to determine whether it could be used to develop conceptual bases for interdisciplinary and intercultural research that could address questions such as: Which societal and/or natural perturbations pose the greatest risks and opportunities? How do human-environment systems adapt to and cope with such perturbations? What determines the capacity of communities to adapt and how can this be quantified? How, and to what extent, can adaptive capacity diminish potential adverse impacts?

The experience and perspectives of local people are essential in such a process. The study, therefore, was developed in close collaboration with Sámi reindeer herders who remained an integral part of the work from its inception to the preparation and presentation of the final report. The process of modifying the general model generated considerable interest and engagement among the herders. The resulting conceptual framework incorporated two principal elements: (i) the influences of climate variability and climate change on reindeer and the herders' responses to the effects of these and (ii) the extent to which the actions of a range
of local and national institutions and governance have constrained, and also provided opportunities for, herders' ability to cope with environmental and societal change. In this way the research successfully included the perspectives of natural science, social science and herders' understanding in a co-production of knowledge.

For reindeer herding the challenge of climate change is related to the prediction that the mean annual temperature over northern Fennoscandia is likely to increase by as much as 0.3 to 0.5 °C per decade during the next 20-30 years. Precipitation over the region may increase by 1 to 4 % per decade. The projected rise in temperature in Finnmark is greater than in the south of Norway, greater inland than at the coast and greater in winter than in summer and, consequently, Finnmark is identified as a region of special interest and Sámi reindeer herding as a potentially vulnerable sector. An increase of temperature and precipitation can potentially affect snow conditions and, hence, foraging conditions for reindeer in several ways. Increased temperature in autumn may lead to a later start of the period with snow cover. Increased temperature combined with more frequent precipitation may increase the frequency of snow falling on unfrozen ground. Increased precipitation in winter may contribute to increased snow depth over the high ground where reindeer graze. The melting period in spring will probably start earlier but the last date of melting may be significantly delayed as the initial snow cover will probably be deeper. The physical structure of the snowpack may also be affected by the projected changes. In particular, the frequency of rain on snow and of periods of melting during winter that result in the formation of ice or crust-layers may increase.

A conceptual model was developed to explore the vulnerability of reindeer herding to change in its immediate environment. The model consisted of three parts selected by the herders themselves. Climate change: a basic assumption was that large-scale climate changes influence local climate which, in turn, affects foraging conditions for reindeer, the productivity of herds and ultimately, herders' income and livelihood. Adaptation: a second assumption was that the potential impact of climate variation and change on the productivity of herds can be ameliorated by tactical and strategic changes in herding practice. Herders' responses (feedback) represent coping at both individual and institutional (siida) levels. The conceptual model proposed that responses may be triggered at two levels. Ultimately, the herders respond to climate-induced changes in the performance of their animals. However, they also respond directly to the kinds of weather conditions that are important for successful herding. The conceptual model made no assumptions about the extent or effectiveness of herders' ability to cope or about the magnitude of the influence of climate change on the system. Constraints and opportunities: Sámi reindeer herding takes place in a complex institutional setting heavily influenced by government policy, regulations and customary and legal rights. Herders' ability to cope with and adapt to climate induced changes in the performance of reindeer can be limited by a variety of extrinsic factors. 'Constraints' include loss of pasture through 'encroachment', predation and governmental regulation of the size and structure of herds, production limits, market- and price-controls on reindeer meat. 'Opportunities' include integration of traditional knowledge in State management of reindeer, improvement in local economy by adding value to reindeer products and changes in customary and siida legal rights.

The study adopted a novel methodological approach. The integration of different ways of knowing, called the 'co-production of knowledge' is not widely exploited in ecological and other scientific research because aboriginal knowledge often does not conveniently lend itself to reductionist analysis and hypothesis testing. Recognising that the ability to adapt to change, which reindeer herding has demonstrated repeatedly, is based on knowledge embodied in the language, the institutions of herding, the study adopted an approach in which
the knowledge and the actions of individual herders, herders' experience and understanding were documented, analysed and combined with data in social and natural sciences. In this way several of the analyses in the study could be based on a combining of herders' knowledge with information in both social and natural sciences.

Saami understanding is based on generations' of experience accumulated and conserved in herders' specialised vocabulary and in herding practice at both individual and institutional levels. This aspect was summarised by one herder as follows:

*Herders' store of knowledge, upon which they draw when tackling variation in climate and pasture conditions, must be documented and analysed. In particular, we must focus on pastoralists' risk-analysis in regard to changes in the weather and pasture conditions that affect the normal annual cycle of husbandry and on their way of evaluating alternative responses and adaptive strategies.*

*Reindeer Sámi have to be able to read nature and predict situations that can disturb the welfare and reproduction of their herds. Sámi reindeer pastoralism has developed in response to precisely these kinds of challenge and can, therefore, be analysed as an institutionalised expert system for coping with the vagaries of weather and grazing conditions. A provisional report on the contents of this expert system must cover at least three aspects: (i) its rich and precise language which represents a meta-language for speakers of Sámi outside reindeer husbandry, (ii) reindeer Sámies collective memory which spans dramatic events, episodes, experiences and myths and (iii) the specialised capabilities developed over time and transferred from generation to generation. The combined knowledge these aspects represent has enabled the Sámi to monopolise reindeer husbandry in Fennoscandia and to maintain this monopoly over time under hugely shifting conditions.*

Documentation of these skills and competence is an ethical imperative. Moreover, a significant proportion of the information required in an analysis of this kind is not amenable to field study at less than exorbitant cost. Methods for the integration of traditional data with scientific data, however, are poorly developed. A major challenge for the future, therefore, is to refine existing methodology for (i) exploring the significance and the scope of the internal validity of traditional knowledge and (ii) articulating it in forms that permit its comparison and integration with scientific knowledge and *vice versa.*

The study demonstrated how the generalized conceptual approach for the assessment of the vulnerability of human-environment systems in the Arctic was flexible, inclusive and could easily be modified to suit the requirements of a specific case. A key feature of the study was that it was created in close collaboration with local people (the reindeer herders) who shaped it and ensured that it addressed their reality and a local understanding of the problem. The study also emphasised that the ownership of the problem ultimately rests with local people.
Long-term Observations of Cloudiness, Radiation and Aerosols with Permanent Atmospheric Observatories

Taneil Uttal\textsuperscript{1}, Shelby Frisch\textsuperscript{2}, Xuanji Wang\textsuperscript{3} and Jeffrey Key\textsuperscript{4}

\textsuperscript{1}NOAA Environmental Technology Laboratory, 325 Broadway, Boulder, CO 80305, USA
\textsuperscript{2}Cooperative Institute for Research in the Environmental Sciences, 325 Broadway, Boulder, CO 80305, USA
\textsuperscript{3}Cooperative Institute for Meteorological Satellite Studies, 1225 W. Dayton St, Madison, WI, 53706, USA
\textsuperscript{4}NOAA National Environmental Satellite Data and Information Service, 1225 W. Dayton St, Madison, WI, 53706, USA

Introduction

The goal of the U.S. interagency SEARCH (Studies of Environmental Arctic Change) program is to understand the complex web of atmospheric, oceanic, terrestrial, biological, and social changes that are occurring in the Arctic and to apply that understanding to guide societal response. This abstract describes one component of the NOAA (National Oceanic and Atmospheric Administration) SEARCH program that is focused on establishing long-term Atmospheric Observatories to measure clouds, radiation and aerosols in 2 new major Arctic regions. In addition to the programmatic description, a brief example is presented of how long-term surface and satellite measurements can be used in conjunction to develop techniques for untangling climate change issues.

At present, the only continuous measurements of Arctic surface radiation, clouds, aerosols and chemistry sufficient for detailed evaluation of interactive climate change processes in the lower atmosphere (0-15 km) are made in Barrow, Alaska. The Barrow facilities include the National Weather Service (with records from the 1920s), the National Oceanic and Atmospheric Administration (NOAA) Baseline Observatory (in operation since 1972), and the Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) North Slope of Alaska (NSA) site (in operation since 1998). It is the intention of the Atmospheric Observatory Element of the NOAA/SEARCH program to mirror the Barrow atmospheric measurements, first in northeastern Canada, and at some latter date in central Siberia.

The Canadian and Siberian regions have been selected based on the principal hypothesis of the SEARCH program that Arctic climate change is related to the Arctic Oscillation (AO). There have been observations of large scale spatial co-variability between several climate variables (e.g. surface temperatures, hydrological balances, cloud cover, winds) with the primary modes of the Arctic Oscillation. Analyses suggest that one of the most significant AO-related trends over the last 50 years has been warming in Eastern Siberia and cooling in the northeastern Canada, western Greenland region. The Barrow region also has significant trends, but these are not as clearly related to the Arctic Oscillation.

In the existing and proposed Observatories, detailed measurements of clouds are necessary because a number of studies indicate that clouds have a major influence on the surface radiation budget (Intrieri et al, 2002). This in turn will impact surface temperatures, ice ablation/melt rates, and the onset of the annual snow melt season. Therefore, some of the ideal components for Atmospheric Observatories include cloud radar (35 GHz), cloud lidar, and IR/MW radiometers from which detailed cloud properties can be deduced. To determine effects, comprehensive measurements of upward and downward broadband radiation and albedo are (Barrow) and will (Canada/Russia) be made that allow calculations of radiation budgets at the surface. Finally, aerosol measurements both at the surface (e.g. nephelometers...
and condensation particle counters) and through the depth of the atmosphere (lidar) will potentially allow separation of anthropogenic from natural forcing.

Method

Since a number of the instruments proposed for the NOAA/SEARCH Atmospheric Observatories in Canada and Russia have been operated in Barrow, Alaska for several years, it is possible to begin preliminary assessments of the utility of the unique, long-term observations. Since well validated, long-term satellite measurements are the only possibility for comprehensive spatial coverage and long-term variability studies (Wang and Key, 2003), we concentrate on a satellite validation example. A comparison is made between detailed surface measurements of clouds (from 35 GHz cloud radar measurements available in Barrow since 1998) and cloud properties as deduced by the AVHRR (Advanced High Resolution Radiometer) sensor that has operated on NOAA satellites since 1976. The AVHRR Polar Path APP-X is a polar specific cloud product that has been developed to account specifically for Arctic/Antarctic conditions. In particular, comparisons are made with cloud fraction since proper detection of cloud presence is a necessary precursor to derivation of cloud properties. Comparisons are also made to cloud optical depth since a number of studies indicate that it is the cloud characteristic that has the most control on cloud-surface radiation feedbacks (Zuidema et al, 2004).

In the past, conventional surface-satellite comparisons have concentrated on case studies; in this study, given the availability of longer term measurements we compare monthly statistics of cloud fraction and cloud optical depth for the year 2000 which was characterized with a particularly continuous set of cloud radar measurements.

Results

In long-term monitoring studies absolute values and trends are both important issues to be considered. In figure 1, the monthly statistics of cloud fraction (left) and cloud optical depth (right) are presented. The data from the various AVHRR overpasses has been interpolated to 0400 and 1400 LST which corresponds to about 17.5 GMT on the previous calendar day and 0400 GMT respectively. For cloud fraction, there is relatively good agreement between the radar and satellite data sets and the difference in monthly means varies from 0 to 14% between the radar and the 0400 LST data set, and from 5 to 24% between the radar and the 1400 LST data set. Cloud optical depths show significantly less agreement in both absolute values and trends. Monthly means vary by 0.5 to 12 between the radar and the 0400 LST data set, and 0.4 to 15.3 between the radar and the 1400 LST data set. The annual trend of larger optical depths in the warmer months when there is an increased prevalence of liquid water in the Arctic clouds is not observed by the satellite as the APPX tends to over estimate optical depths in the winter and under-estimate optical depths in the summer.

Discussion

Satellites have significant cloud detection problems due to underlying snow/ice surfaces, low sun angles, polar night and surface inversions that often result in surface temperatures that
Figure 1 Caption: Monthly mean statistics of cloud fraction (left) and cloud optical depth (right) for the 35 GHz cloud radar (top), the AVHRR Satellite 0400 (middle) and 1400 (bottom). The stars on the box and whisker plots indicate monthly means.

are warmer than cloud top measurements. There are a number of spatial and temporal averaging techniques which need to be further investigated. For instance, if actual APP-X values from actual overpass times (as opposed to interpolated times) are compared to 2 hour radar averages centered around the overpass time, a significantly better agreement may be achieved. The long term goal of this work will be 1) to identify consistent biases in satellite data that can be corrected and 2) to identify months/conditions under which the satellite performs best, so that those time periods can be used for inter-annual long-term comparisons. This type of approach will also be possible for evaluating satellite detection of aerosols in the Arctic.

The long-term observational goals of having intensive atmospheric observatories in the Arctic in three distinct climate regimes (Alaska, NE Canada and Siberia) will provide a comprehensive network of key surface observations that can integrated into Arctic-wide satellite observations.

References


Putting the Human Face on Climate Change through Community Workshops: Inuit Knowledge, Partnerships, and Research

Chris Furgal\textsuperscript{1}, Scot Nickels\textsuperscript{2}, Mark Buell\textsuperscript{3}
and communities of the regions of Labrador, Nunavik, Nunavut and the Inuvialuit Settlement Region

1. Nasivvik Centre for Inuit Health and Changing Environments, Public Health Research Unit, CHUQ-CHUL, Université Laval, Québec City, PQ, Canada; Christopher.Furgal@crchul.ulaval.ca
2. Environment Department, Inuit Tapiriit Kanatami, Ottawa, ON Canada; nickels@itk.ca
3. Ajunnginiq Centre, National Aboriginal Health Organization, Ottawa, ON Canada; mbuie@naho.ca

Introduction

There is a growing concern among Inuit in Canada about the impacts on environment, health and culture from various forms of global change such as those related to the climate changes already being observed in many regions today. To date, the focus on this subject has been primarily oriented on understanding the biophysical changes and their impacts in the environment while little attention has been given to the potential impacts on communities and the health of individuals in the North. Furthermore, very little work has been done on the very important topic of identifying and discussing how communities are currently adapting or may adapt in the future and their needs with regards to supporting this process.

In response to interest by Inuit communities and organizations in Canada, a project and series of community workshops investigating climate change, its potential impacts at the community level and strategies for adaptation was initiated. Workshops involving residents of more than 12 Inuit communities in the four Inuit regions have been convened to help residents document observations, understandings and effects of climate related changes in their local area and to identify existing or develop new strategies to cope and adapt with the related impacts, where required and when possible.

The intent of these workshops was to collect and make available community perspectives on environmental change for local, regional, national and international processes on climate change and to bring a "human face" to the issue of climate change in the Arctic. As a result of these workshops and the participation of community residents, observations based on rich and valuable local Inuit knowledge have been documented in a series of community and regional reports and have been used to develop a national Inuit community perspectives report.

Methods

The workshop facilitators from Inuit Tapiriit Kanatami (ITK), Laval University (CHUL Research Centre) and the International Institute for Sustainable Development (IISD) conducted training sessions with regional staff prior to workshops so that regional representatives were engaged in leading the process as much as possible and to facilitate the transfer of the process to the regional organization during the conduct of the series of workshops in a particular region. The workshops made use of a range of participatory exercises, utilized and tested during a similar IISD climate change study in Sachs Harbour in
1999-2000, which drew on participatory planning and analysis techniques which included Participatory Rural Appraisal (PRA)\(^1\) and Objectives Oriented Project Planning (ZOPP)\(^2\).

The workshops followed a process separated into a series of discussions and documentation exercises on each of the following: goals and expectations of the workshop, observations of environmental change in the local area, impacts of these changes, current changes taking place in the community in reaction to these changes and their impacts, identification of potential strategies that could be used to adapt to changes and minimize negative impacts in the future, identification of organizations and individuals that should be made aware of these community concerns, actions at the community, regional, national and international levels on climate change and impacts in the Arctic.

**Results**

Throughout 2002-2004, workshops were carried out in four Inuit regions of the Canadian North with more than a dozen communities. Each workshop brought together individuals from throughout the community including youth, men, women and Elders. This resulted in participation from hunters, mothers, school students, local organizational staff, and elected officials, among others.

Findings from the workshops show that some changes and impacts are consistently reported across all regions. Others varied between regions or were unique to only one location, with some being unique to a specific group in one community. Some basic findings include:

- All communities in the four regions reported that weather has become more unpredictable. Because of temperature and other changes seen in all communities and subsequent lack of consistency in weather patterns, Elders’ confidence in their ability to consistently provide accurate weather predictions has decreased across the Canadian North.
- Unpredictable weather patterns have also meant that travel has become more dangerous throughout the Canadian North. Different impacts from this include changes to regular travel times, economic and dietary impacts related to lack of access to regular hunting grounds, and many people getting stranded on the land due to quickly changing poor weather conditions.
- Communities in all regions have seen earlier spring break-up and later fall freeze-up of sea ice reported to be related to warmer temperatures during the spring and fall seasons. Ice has also become thinner across all regions in the North.

In many cases, communities have already started to cope and adapt to changes occurring in their local area. Community workshops identified communities where hunting and fishing patterns have been altered, significant investments in shoreline protection programs have taken place, where water consumption habits have changed, and in many cases, where further work to help identify the nature of impacts and develop appropriate adaptation strategies are needed.

\(^1\) Robert Chambers of the University of Sussex pioneered the PRA approach over twenty years ago. He has written extensively on its use in promoting local input into project planning and implementation. See for example Chambers, R. 1997 Whose Reality Counts? Putting the First Last. Intermediate Technology Publications, London.

\(^2\) The ZOPP technique was developed by the German development agency GTZ. ZOPP is an acronym for Ziel Orientierte Project Planning (see ZOPP: An Introduction to the Method. 1987 Deutsche Gesellschaft Fr Technische Zusammenarbeit (GTZ) GmbH, Frankfurt, Germany)
Discussion & Recommendations

This process has provided the impetus for further work in these communities and regions related to some specific climate impacts and the need for the development of local monitoring programs and community adaptation strategies. Additionally, the process is intended to help bring a "human face" to the issue of climate change in the circumpolar Arctic regions, and to enhance North – North communication on the issues of climate and environmental change.

Throughout the workshops, a number of recommendations and requests for more resources and increased communication and information dissemination were made. The individual community workshop reports show what individuals in the different communities feel is required to develop further adaptation measures and to minimize negative impacts. Some common recommendations and current or potential adaptation measures discussed in the workshop include:

- The need for more communication, both between and within communities, in the face of unpredictable weather patterns.
- Better weather forecasts provided locally as a way to aid in avoiding difficulties with weather prediction and travel.
- The need to more effectively manage community freezer programs, or implement programs where they do not exist, to allow for the increasing challenges faced in getting traditional / country foods at certain times of the year as a result of a changing environment.

In addition to examining the issue of environmental change at the national level, there is a need to conduct work from both the perspective of the region and community, as not all changes affect each area in the same way. As well, the findings of these workshops show that the needs and processes for action are in some instances unique to each community and region. The workshops and their findings represent an important initial stage in the development of regional and local understanding and the development of processes to address the concerns and questions raised by participants. They set the stage for more in-depth research to be conducted on these issues. The community, regional and national reports were prepared upon request of the participants in anticipation that Inuit observations, knowledge, as well as the needs, issues and concerns raised therein, would be taken into account by decision-makers at the local, regional, national, and international levels. As climate assessments and global models predict that the polar regions will be first and most affected by climate change, it will be important to continue investigating and learning with communities about the nature and extent of local impacts, particularly in these sensitive Arctic ecosystems where people live in such a close relationship with their environment.
Inuit and Iñupiat hunters in the North American Arctic rely on sea ice for travel and hunting for much of the year. Their use of the ice requires detailed knowledge of ice conditions for both safety and success in hunting, their main livelihood. However, the sea ice environment is changing in the Arctic. As a result, Inuit and Iñupiat communities are making changes to their day-to-day and long-term livelihood strategies and dealing with traditional knowledge and skills that are, at times, no longer applicable. At the same time, scientists struggle to understand the interactions of the forces influencing sea ice changes and variations of changes at multiple scales. How are Inuit in the eastern Canadian Arctic experiencing sea ice changes and how does this compare to the experiences of Iñupiat in Arctic Alaska? What do scientists know about sea ice changes in these two areas? How can Inuit, Iñupiat and scientists inform each other and benefit from collaboration on this topic of mutual concern?

A two-year pilot project initiated in 2004 is exploring these questions. Using a collaborative, comparative approach centred on a community exchange between Barrow, Alaska and Clyde River, Nunavut, the project brings together local and scientific experts on the western and eastern North American Arctic sea ice. Travelling and exploring the sea ice together is an important component of the research approach as the ‘hands-on’ experience makes the ice the common link for these diverse scholars and users of sea ice. Supported by a variety of methods such as interviews, group discussions and remote sensing observations, the project brings together multi-scale and interdisciplinary observations and knowledge of sea ice, how it is used, and how it is changing.

Preliminary results from the community exchange clearly point out that understanding sea ice, from physical processes, to change and variability, to interactions with humans, is “not that simple”, as one Inuit participant put it. There are complexities and nuances to knowing and observing ice and adapting to its changes that we are just beginning to understand. Both local and scientific understandings add to this complexity. By bringing these ways of knowing together we challenge each other to expand what and how we know about the Arctic environment. By bringing together sea ice users from different local environments, we also help distinguish the differences and similarities in how and why sea ice is important to communities and how their experiences of environmental change, and responses to change, cannot be generalized across the Arctic.

Focusing on the community exchange experience, findings on sea ice changes and impacts in both east and west regions of the North American Arctic will be presented, as well as a discussion on the benefits and challenges to the collaborative, comparative approach taken in the project.
Climate Change Impacts and Athabaskan Peoples: the Denendeh Environmental Working Group, an Update on Activities

C.D. James Paci


Climate Change is a threat to Athabaskan sovereignty. From Alaska (U.S.A.) to Denendeh (NWT, Canada) Athabaskan cultures and languages are tied to land and sustainable use of forests, waters, and air. Such renewable resources as caribou, moose, and many types of fish contribute to living a good life, this includes trade among neighbouring Indigenous Nations and between our communities and families. In the rush of modernity, Athabaskans have continued to practice traditions in concert with mixed wage economic activities (jobs based on non-renewable resource development and services). Traditional sustenance activities could be described as small-scale, regional and local, renewable resource development. Climate change will destabilize land-based activities in the north because of our ecology. Permafrost is vulnerable to thawing, and so on, and changes to our ecologies will limit the possibility for cultural continuity. A warming trend will significantly threaten traditional food systems. When cultures and languages are based on activities on the land, both practices and vocabulary will be affected and potentially lost.

This is an update on the work of one of the signatories to the Arctic Athabaskan Council, the Dene Nation. We have yet to caucus all Athabaskans and have not yet gathered the observations and knowledge of all Dene on climate change, and would reject broad generalizations from our work. Traditional knowledge respects differences among people. There are several layers of analysis that can be taken but a common feature is the very specific relation to traditional territories. Our talk summarizes the work we have done at the domestic national level for a regional assessment, specifically the Arctic Climate Impact Assessment (ACIA). We discuss the last of three workshops of the Denendeh Environmental Working Group, a workshop on water and climate change held in Wekweti, Denendeh.

In striking the Denendeh Environmental Working Group (DEWG), Dene Nation realized there was a need to caucus and consult membership on the state of climate and changes in Denendeh. We were driven by a need to cooperate with government policies and to bring scientists perspectives to Dene, to find the bridges in understanding and to note differences. Furthermore, we were driven by the need to find a vehicle to gather representatives of each of the Dene regions. This research method is an alternative to a mathematical model, measuring temperatures, or researchers going out to each person, interviewing them. Each method has its value. The DEWG became a respectful way to ensure traditional practice, Dene values to gather people to share and learn together, and meet a specific knowledge gap. The goal was not only the participation in scholarly production of documents, which is valuable and can contribute to mass communication and dissemination of knowledge, but also to respect traditional practices. In gathering traditional knowledge together with science it became apparent that Dene view climate change differently from what some governments and scientists were saying about the rate, types and direction of change for Denendeh. The value in documenting traditional knowledge, in the framework of assessments like the ACIA, is to improve the state of knowledge (not to replace science, but to be heard along with science).

The DEWG has described relationships and land use that can be hindered (even to the point of being severed) by different types of change. For example moving to driving trucks and travel
by airplane changes peoples connectedness. A number of pressures drive the choices people make. In using technology there can be a number of effects, for example the separation between land and people and the release of CO2. To what extent these effects and change alters culture is a discussion among many people. There is a concern we begin to understand counter-measures to ensure cultural continuity. At this time the alternatives to replace traditional systems, for example grocery stores replacing traditional food systems, would have devastating impacts, including contributing to the net global contribution of greenhouse gases. In the assessment literature we talk about vulnerability. There is a movement to better understand the adaptive capacities and sensitivity of vulnerable communities. As a northern Indigenous Peoples, Dene share concerns about impacts that are specific to the boreal forest and taiga ecosystems, which characterizes their traditional territories. Water is key to changes in Denendeh. The concern over water quality, flips in ecosystems, in particular wetlands becoming choked with willows, hazards on ice and away from town increasing, permafrost less reliable in places, water tables changing, all life irreparably changed from climatic uncertainty, have lead Dene to think about what they will need to do in the next generation or two to adjust to changes that are caused by global processes. The produced unpredictability of climate change has led us to search for predictive climate change models that demonstrate Indigenous views.

The Denendeh Environmental Working Group (DEWG)\(^1\) is featured as a case study in the Indigenous Perspectives (Huntington et al, 2004). The Working Group was developed under four essential pressures. First, Dene Elders have been pointing out changes in Denendeh, which could not be considered normal or regular climatic conditions that had started in the 1960s. Second, Indigenous institutions were in place to build research capacity and methods to focus Elders' concerns regarding these changes. Third, some funding became available at the national level to carryout systemic work. Finally, there was international (United Nations) and regional (Arctic Council) interest to assess and document Indigenous knowledge of climate change; the causes for change, impacts and adaptations.

Indigenous observations include physical, cultural and spiritual changes. Dene Elders have been pointing out unusual environmental phenomenon for a number of years. When meeting to discuss various issues we would hear about water quality and other changes; new and unusual species of insects and birds, larger animals such as buffalo moving into areas once abundant with caribou. Animal behaviours were changing, with some animals, such as bears, acting differently then they once had. Fish were showing parasites and the consistency of flesh and organs were changed. Hazards were increasing in frequency and travel in winter was more dangerous. Both localized impacts and regional changes were no longer following typical patterns. The cause for change was not always assigned specific causes, ecologically a single cause is not always more important than cumulative effects. The overall trend of unpredictability was blamed on "development."

Dene Nation's experience working on long-range contaminants (AMAP 1997, 1998, 2002, 2003; Jensen et al. 1997, CACAR 2 2003) was enough to warn us that change was most probably a result of development outside of Denendeh, that there were global sources causing local effects. Dene Nation's Lands and Environment division, has a history of participatory action research with its members on important environmental research issues.\(^3\) DEWG was a natural development and discursive site in which to form a coherent and unifying document of the views on changes in Denendeh.\(^4\) Elders speak of changes occurring as a result of increased uncertainty in climate, unlike climate change science predictions of average warming trend. This point demonstrates the different worldviews, with elders speaking about what is happening, about they know will happen. Scientists, on the other-hand project with sophisticated models what they believe will happen using mathematical logorhythms and
assumptions. Ecosystems function in life differently then models. Each perspective has its own power and together will increase what we know.\(^5\)

**Conclusions**

It is irresponsible for us to ignore the findings from traditional knowledge and science. What is needed is to gather all knowledge to improve what is known from both traditional knowledge and science so that government policy (programs) could be crafted to counteract the negative impacts climate change is causing. The DEWG enabled Dene to gather, to share with scientists and policy makers. The inclusion of Dene youth\(^6\) is the latest innovation. The Wekweti (Snare Lakes) workshop (March 27-29 2004) brought delegates together to meet and discuss specifically the relationship of water and climate change as understood by Dene Elders, youth and technical staff. We could not have gathered without the financial support of the Northern Ecosystem Initiative, Environment Canada. When Environment Canada reformed the Northern Ecosystem Initiative (NEI) to engage Indigenous Peoples in climate change research, it became the main funding source for Dene Nation to operationalize the DEWG.\(^7\) In reforming the NEI, Managers at Environment Canada sought an engagement with Indigenous Peoples to improve the program's performance and relevance to northern communities. One of several research focuses for NEI included climate change. The NEI climate change partner issue table became the funding source for Dene Nation in operationalizing the DEWG.

For 2005 Dene Nation has not sought funding from Environment Canada. There are outstanding specific themes related to climate change that require documentation. The form this documentation will take; however, has to be in keeping with the wishes of the participants and the DEWG is transforming itself to be more sensitive of Dene views and perspectives on sharing knowledge. The next gathering together of regions and spending time together will be on the land, supporting traditional cultural practices. Our challenge is to find funding that will support this approach, one that exceeds the parameters and controls set by most agencies. We have chosen not to apply for future funding from the NEI because Dene want to have greater control over the way knowledge is being gathered.

To date we have documented Dene perceptions of climate change and institutional responses to these views. There are many next steps. What is our capacity to act on these views? Domestic national programs are essential to bringing "citizen views", in particular marginalized voices such as Indigenous Peoples, to international processes such as the ACIA. There are several drivers for the national climate change discussion, in Canada, including international perspectives. In turn what is going on in the domestic arena is having an impact on international efforts. We have summarized the final DEWG results, our conceptual methodology for gathering Indigenous observations and knowledge of climate change, and the problems associated with funding this work. A regional detailed assessment and the capacity to implement the adaptive observations of Dene are obvious next steps.
Endnotes:

1 DEWG composition continues to evolve into an effective mechanism by bringing together all five regions of Denendeh: one regional technical staff member working on environment and lands issues from each tribal council; one elder selected by tradition to represent the interests of each region; and support staff from the Dene National Office, Lands and Environment division. Youth now participate as well.


3 The division has worked on the Northern Contaminants Program which is the national northern science program bringing to the international arena contaminants research in the Arctic Monitoring Assessment Programme.

4 Dene Nation had previously established the Denendeh Environment Committee to oversee their direction and work on important land and environment issues in Denendeh. The suitability of participatory action research complimented pre-existing institutional realities. The DEWG is a mechanism whereby Dene come together to workshop issues on ecosystem health related to climate change. DEWG formed in response to the need to document ecosystem adaptations. The research method evolved to gather and document traditional knowledge as it fit with Dene traditions with regional representation, for example mirroring the Dene National Assembly. Methodologically the workshop gathers regional impressions of climate change themes, with Dene developing a greater appreciation for climate change impacts and adaptations for each region by hearing from one another. Dene knowledge is evolving and each region has specific concerns as well as common issues. The iterative process is constructing a matrix to understand climate change as the Dene tell their understanding into being. These perspectives contribute to the overall circumpolar understanding of climate change impacts and adaptations. Dene concerns and responses to climate change are being systematically documented through the DEWG; however, this work is still in its infancy and conclusions on impacts and adaptations should be tempered, until a critical mass of information is gathered. Just what constitutes “critical mass” will be an important consideration for the Dene.

5 Research considerations, ethics and such, will not be topics of this presentation but are fundamentally important and require greater consideration by all sides. The up coming ICARP 2 will be an opportunity to explore some of these issues and the discussion is occurring at other forums (for example see Northern Research Forum, Yellowknife 2004).

6 A natural progression because youth will be the next generation of participants, knowledge holders, and researchers.

7 Environment Canada is the federal government department responsible for environment issues, including negotiations on the Kyoto Protocol, was renewing their Northern Ecosystem Initiative (NEI) in 2000.
Vulnerability and Adaptive Capacity in Forestry, Fishing and Reindeer-Herding Systems in Northern Europe

E. Carina H. Keskitalo

Department of Social Studies, University of Lapland, P O Box 122, 961 01 Rovaniemi, Finland
Tel +358-16-3412 901. Fax +358-16-3412 600. Email Carina.Keskitalo@ulapland.fi.

Introduction: aims and methodology

Human-induced climate change is likely to present new and largely unpredictable challenges to societies. Climate change is of particular concern at the local and regional levels, since vulnerability as well as the capacity to adapt to change are location-specific and many decisions regarding climate-induced risks are made at these levels. These considerations make it necessary to survey stakeholders’ understandings of their situation and perceived problems. Assessments should also consider other ongoing changes, such as globalisation, that may impact the communities and their vulnerabilities at large (O’Brien and Leichenko, 2000).

This paper presents an assessment of vulnerability and adaptive capacity comprising a combination of literature surveys, some 60 interviews with stakeholders, and a number of stakeholder meetings. The aim has been to develop an accurate, triangulated understanding of vulnerability in selected localities. The study centres on stakeholders in the reindeer herding, forestry and fishing sectors in three case areas: the Piteå, Kemijoki and Tana River basins, located in the northern part of Sweden, Finland and Norway, respectively. Conducted as part of the Balance project, which includes a focus on river basins, the present study concentrates on selected communities within river basin areas, with inclusion of certain additional localities for region-level interviews (see Figure 1).

Figure 1. Map of northern Norway, Sweden and Finland with the study locations indicated.

Stakeholders are seen as the main actors that are impacted by change in the sectors and areas studied. These include sawmill owners; pulp and paper factories; large- and small-scale forestry
Case study areas: the socio-economic structure of forestry, reindeer herding and fishing

The Piteå, Kemijoki, and Tana river basins are sparsely populated areas. For instance, the Piteå basin has a population of just under 60,000 (2.5 persons per square kilometre), most of whom live in the main towns and the main municipalities of the Tana river valley in northern Norway have a population of only some 7000 (Petterson, 2002; Baerenholdt, 1996; Burgess, 1996). The economies are mainly service-oriented where employment is concerned but have relatively thin structures that rely on a few large and often export-oriented businesses. In the Finnish and Swedish areas, these are located in the forestry sector; in fact, even after the heavy rationalisation of recent decades the study areas contain some of the largest forestry units in the respective countries. Piteå, a port, has large-scale production units of the international Swedish-based company SCA and the state forestry company Sveaskog. The Finnish city of Kemi (pop. 24,000 people), also a port, and the smaller inland town of Kemijärväri are sites of large pulp mills and sawmills belonging to two major international companies, Stora Enso and Metsäliitto (Riissanen and Härkönen, 2000). In recent decades, these large-scale production units have outcompeted many of the smaller sawmills that previously operated in the areas, resulting in increased pressure on the remaining ones.

The prominence of forest use for wood production places a strain on the relation between forestry and small-scale, predominantly family-based reindeer herding units. These operate across the entire area, organised into reindeer-herding villages or districts, but are dwarfed both economically and in terms of employment by forestry. For instance, reindeer herding has lost important old-growth forest grazing areas to forestry, with herders today forced to feed reindeer at relatively high costs when the weather makes grazing in other areas impossible. Like other occupations in the study areas, reindeer herding has faced considerable economic pressures in recent years; for instance it has had to make meat production more efficient, this being the principal source of income in the sector. This has largely been accomplished through technological adaptations and, unlike some twenty years ago, herders today often manage their animals using trailers, snowmobiles and even helicopters, which raises costs but also makes their work more effective.

Given these circumstances, the possibility of increased land rights for the Saami - and thereby of reindeer-herding interests - through prospective ratification of the ILO Convention No. 169 in Sweden and Finland (as it has been in Norway) has been hotly debated even in some local communities. In forestry, small-scale units in particular feel pressure from the intense competition between actors and the limited land available for forestry production. This scarcity of land is the result of, among other things, extensive felling in previous decades and recently expanded conservation efforts prompted by international forest certification norms and the
creation of nature reserves though the Natura 2000 programme. Some are of the opinion that a ratification of the ILO Convention may make forestry less viable. At the same time, however, there is often overlap between interests in forestry and reindeer herding: reindeer herding uses roads constructed by forestry and herders often work in forestry during the summer to gain extra income. Moreover, ethnic Swedes in the reindeer herding areas may own reindeer as long as the animals are managed by Saami. While reindeer herding is an ethnically Saami occupation in Sweden, in Finland it is an occupation of both ethnic Finns and Saami (predominantly ethnic Finns in the case study area).

In the Tana River region, such conflicts between forestry and reindeer herding are negligible due to the very limited forestry in area. Forest use is instead dominated by reindeer husbandry, which is a prominent livelihood as the area is home to a large proportion of Norway’s Saami, who are the segment of the population entitled to practice reindeer herding. Fishing is the primary industry of greatest relative importance in the area; for instance, the county of Finnmark, in which the study area lies, accounts for 10% of the value of Norway’s fish production (Gjøsaeter 1995). Resource conflict is visible here, too, but within a single sector: fishing has been increasingly rationalised and put under economic pressure. This has made the fleet of small boats in Finnmark continuously less able to compete for fishing resources and markets with larger southern Norwegian and Russian trawlers.

Given these developments, the problem of economic viability in the context of limited resources is mentioned by most of the interviewees as a main problem. They consider adaptation to be limited by the lack of economic and other resources, such as lobbying power or input into government legislation or support policies. Climate change will thus impact an area already facing a pattern of vulnerabilities and strained occupations. The impacts will manifest themselves in varying ways in the different sectors.

**Perceived impacts of climate change on forestry**

In forestry, a main impact of climate change would be an increase in the forest growth rate. This is considered beneficial by the actors and could possibly result in substantial economic benefits over time. Yet, it could also increase the labour required for silvicultural measures and the incidence of disease and vermin. An additional impact may be erosion of the competitive advantage which northern forests presently enjoy as producers of slow-growing, high-quality wood.

To some of the actors who have worked in forestry for 20 to 30 years, climatic changes are already perceivable in the difference between present conditions and those that prevailed when they started working. For instance, Easter is usually seen as the time when thawing starts affecting roads and prevents access to logging site by heavy machinery, suspending work in certain areas until the roads have dried. In recent years, this condition has changed, so that, for instance, ”last year it started thawing long before Easter and there were never any cold nights [during which transports could be made], so there was panic in certain places”¹ (translation from the Swedish). The impacts on accessibility from fluctuations around the freezing point are also more broadly seen as affecting forestry: if the temperature rises above freezing during a felling operation, the roads have to be gravelled at large costs. If the winter season were to shorten as a result of climate change, this would also impact access, which is best when the frozen ground makes transportation possible on sensitive locations or areas lacking forest roads. However, in

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¹ "i fjol så började det ju tina långt före påsk och det var aldrig några kalla nätter [så att man kunde köra ut virket] så det var ju panik på vissa ställen" (Robert Grimm, Arvidsjaur common forest [allmänningskog], Arvidsjaur).
contrast to those working in the forests, forestry administrators have a relatively low awareness of and largely do not plan for climate change, their main environmental focus being certification and their primary interest being market opportunities for the sector.

Perceived impacts of climate change on reindeer herding

For reindeer herding, the greatest impacts would result from mild winters during which layers of ice form due to thawing or rain, covering lichen and making it inaccessible to grazing reindeer. Such situations have occurred increasingly in recent last years, prompting comments such as “I really can’t remember when I started that we had a thaw in the middle of winter; I felt that we had a more stable climate” (translation from the Swedish). Cycles of freezing and thawing may at times force reindeer herders to feed reindeer at relatively high cost, as the old forests and, with them, opportunities for reindeer to graze on arboreal lichen disappear. “All the old forests have been cut so that additional food cannot be obtained there … It is a total threat, as is also this climate change, so we don’t know what kind of years to expect.” (translation from the Finnish). Reindeer herders are thus very aware of changes over time and potential risks.

At the same time, however, shorter winters, little snow, early spring and relatively warm and dry summers with less of an insect plague, have allowed reindeer in Norway and Finland to start grazing on summer lands early and provided large and undisturbed summer grazing. This in turn yields benefits to herding in the form of high slaughter weights and the possibility of either increasing herd sizes or culling rates. Different impacts were seen in Sweden, where these summers were perceived by actors as having been too warm, resulting in reindeer tiring and becoming dehydrated from the heat and moving towards mountain areas with snow patches as water resources in springs dry up.

Perceived impacts of climate change on fisheries

In the Tana Fjord district, a warmer climate was perceived by actors as the occurrence of rain in winter and warmer sea temperatures, meaning that the heads of the fjords do not freeze. Variations in the fish stocks were mentioned, but there was no certainty as to the causes of variations or especially the connection to climate change.

The largest variation was noted in the case of the salmon fishery, where the salmon stock was perceived as following climate changes and the abundance of salmon in a given year was seen as reflecting the climate conditions during spawning. The salmon fishers on the Tana River in particular considered the effects of climate change on the salmon catch, noting, for example, the importance of different seasonal water levels in the river, water and air temperature and precipitation: “The water level is important. When the salmon spawn, it should be low, so that they do not spawn in areas that dry up in wintertime.” (translation from the Norwegian). The most important changes perceived by the actors were invasions of king crabs and seals, which were not seen as linked to the climate. On the whole, the impact of climatic changes on fisheries was not seen as following any particular trend.

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2 “Jag minns då aldrig till att när jag började att vi hade såna här töväder mitt i vintern det kan jag inte minnas jag upplever att vi hade ett lite stabilare klimat” (Leif Anders Blind, reindeer herder, Arvidsjaure).


4 “Vannstanden i elva er viktig. Når laksen gjyter skal den vare lav, for at laksen ikke skal gjyte på områder som blir tørre på vinteren.” (Geir Hansen, salmon fisher, Rustefjelben).
Conclusion: Possibilities for adaptation?

The strong element of socio-economic change, especially with the concomitant demands for increased profitability and rationalisation in all of the sectors, illustrates that the impact of climate change needs to be understood at least in terms of the local and regional situations and capacities for adaptation. One can see for example that some earlier adaptions to internationalisation through increased forestry outtake have limited the present scope of both forestry and reindeer herding for adaptation: there are now few of the old-forest lands where reindeer could earlier feed on arboreal lichen during difficult grazing conditions and a lack of areas for forestry to expand into. Those livelihoods with the most limited resources, such as reindeer herding or small-scale forestry or fishing, are hit the hardest by negative changes of any kind, as they do not have savings to subsist on during bad winters or fishery failures. Many mention the risk of ultimately having to stop their activities. Thus, even if adaptation is considered possible it does not have to happen too quickly or become too expensive, “at a certain point you see that the sector cannot adapt further but now we don’t know where that limit runs or if we are close to it”.

Current methods for managing limited resources include both mandatory and voluntary coordination and education efforts directed towards reindeer herding and forestry. They also include adaptation and processes towards adaptation in the national policy and legislative frameworks, where actors lobby on several levels to improve their rights, for instance, in relation to implementation of norms such those embodied in the ILO Convention, Natura 2000 and forest certification. The scope of action and adaptation for a specific actor, a single sector, or local community is thus to some extent determined by these frameworks as well as by competition also more broadly on the local, regional and national levels. This pertains for instance to actors in the economically significant car testing and tourism branches, mining, oil and gas development, and others. Local and regional impacts and adaptation to climate change must thus draw on broad understandings of the socio-economic and political baseline in communities, and the complex framework within which adaptation is to take place.

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5 "I ett visst läge så ser man att näringen inte kan anpassa sig eller nu vet vi ju inte var den gränsen går om vi är nära den". (Leif Anders Blind, reindeer herder, Arvidsjaur).
Harnessing Technologies for Sustainable Reindeer Husbandry in the Arctic

Nancy G. Maynard¹, Boris Yurchak², Johan Mathis Turi³, and Svein Mathiesen⁴

To accelerate the development of sustainable reindeer husbandry under the lead of indigenous reindeer herders it is critical to empower reindeer herders with the best available technologies and to promote a new kind of science where traditional knowledge is fully integrated into the scientific management of the natural environment in the Arctic. This is particularly true given the dramatic environmental, climatic, economic, social and industrial changes, which have taken place across the Arctic in recent years, all of which have had serious impacts on the reindeer herding communities of the North. The Anar Declaration, adopted by the 2nd World Reindeer Herders’ Congress (WRHC), in Inari, Finland, June 2001 drew guidelines for the development of a sustainable reindeer husbandry based on reindeer peoples’ values and goals. The declaration calls for the reindeer herding peoples to be given the possibilities to develop and influence the management of the reindeer industry and its natural environment because of their knowledge and traditional practices.

At the same time, Arctic scientists from many institutions and governments are carrying out increasingly highly technical reindeer related research activities. It is important that the technologies and results of these activities be more commonly co-produced with the reindeer herder community and/or made more readily available to the reindeer peoples for comparison with traditional knowledge for improved herd management and for decreasing their vulnerabilities to the dramatic environmental, climatic and sociological changes taking place in the Arctic. This paper describes very preliminary results from “Reindeer Mapper”, a project in which reindeer herders and scientists are joining together utilizing technologies to create a system for collecting and sharing knowledge in the Russian Arctic. “Reindeer Mapper” is creating an information management and knowledge sharing system, which will help make technologies more readily available to the herder community for observing, data collection and analysis, monitoring, sharing, communications, and dissemination of information – to be integrated with traditional, local knowledge. The paper describes some of the technologies which comprise the system including an intranet system to enable the team members to work together and share information electronically, remote sensing data for monitoring environmental parameters important to reindeer husbandry (e.g. SAR, Landsat), acquisition of ground-based measurements, and the GIS-based information management and knowledge sharing system.

During the early months of the Reindeer Mapper project’s first year, team members selected some pilot sites for initial activities and began work on several main project tasks. Technologies tested during the first months of the project described in this presentation include the Reindeer Mapper Project Communications system, SAR studies for...
characterization of land use/cover parameters useful for reindeer husbandry, and field applications for the Reindeer Mapper education program.

The Reindeer Mapper Intranet System is a pilot system designed to address one of the high priority needs of indigenous reindeer herders - to develop advanced communications systems for enabling the collection and sharing of traditional as well as technical knowledge useful to reindeer husbandry, using state-of-the-art information technologies. The pilot version of the Reindeer Mapper Intranet was set up through a modern NASA Process Based Mission Assurance (PBMA) system to enable Reindeer Mapper team members to work together electronically. The system enables team members to collaborate and communicate with each other on reindeer issues through a private email system, topical discussion groups, comment or feedback on shared materials, preparation of joint articles and presentations for meetings. The system also allows for team members to share content (e.g. organize, store, share data, images, documents, literature articles, bibliographies, files, lists, notes). Team members may also connect real-time through instant messenger and chat sessions as well as share/manage schedules (calendars, set up field visits, meetings). The system also helps manage the member details such as member lists and addresses/contact information. The system is exchanging information in several different languages such as Russian, English, and indigenous languages such as Evenk.

SAR (Synthetic Aperture Radar) studies are being carried out to define the usefulness of SAR information for some of the key parameters which characterize reindeer pasture quality, such as vegetation distribution, snow cover parameters, and pasture damages due to fires. Studies of seasonal changes of SAR backscatter from certain land features in two locations (Anadyr River area and Vaegi settlement area) in Chukotka, Russia, are being conducted for the four seasons for the period between the years 2000 and 2004. Preliminary results provide information on seasonal changes in data from tussock and mountain tundra and from a set of Anadyr River area lakes.

The third collaborative application of technologies for sustainable reindeer husbandry during the first year in the Reindeer Mapper project has been an education project, which involved a special summer camp for children of reindeer herders in Yakutia. The Reindeer Mapper team contributed remote sensing information, educational materials, a computer and camera, which were then combined with traditional knowledge from the reindeer herders (learning the native Evenk language in a traditional nomadic setting, acquiring basic reindeer skills, and improved understanding of nature). The nomadic camp in Yakutia has been teaching traditional ways of reindeer husbandry and language and culture for reindeer herder children since 2002. The use of NASA technologies and materials provides indigenous reindeer children with an opportunity to meet a major goal of the youth of the World Reindeer Congress of 2001 to combine reindeer herding with modern education. In addition, it allows the indigenous reindeer herder children to reconnect to their tradition ways of life and work of their ancestors, while at the same time learning a global context for sustainable reindeer husbandry through modern technologies.
Local and Traditional Knowledge in Assessing Climate Changes impacts on Sustainable Development: Russian and Circumpolar Perspectives

Tatiana K. Vlassova

Russian Academy of Sciences, Institute of Geography, NorthSet programme, 119333 Moscow, Leninsky prospect, 61/1, apartment 46, Russia (e-mail: marianna@orc.ru)

Introduction

The ACIA project implementation has demonstrated the great significance of the traditional ecological knowledge and revealed vast abilities of the indigenous peoples of the Circumpolar North including numerically small Indigenous Peoples of the Russian North, Siberia and the Far East (IPRN) not only to observe climate changes but to assess its significant impacts on the sustainable development of their traditional activities and lifestyle (ACIA, 2004). In order to understand the global picture of climate change impacts on sustainable development, there is the need to develop common approaches and methods to carry out such assessments by broader groups of arctic residents, including all stakeholders permanently living in the Arctic.

Approach

The suggested approach is based on critical analysis of the previous experience gained during the involvement in the implementation of several projects, the aim of which was to gather and analyze the traditional ecological knowledge (Sulyandziga et al., 2001; Bogoyavlensky, 2002; Vlassova, 2001, 2002, 2003). The special data base “Environment Assessment Network for the Northern Russia, Siberia and the Far East” has been constructed within the NorthSet programme, Institute of Geography RAN which makes it possible to carry out this work (Vlassova, 2004). The basic principle which we follow is that in order to elaborate mitigation and adaptation strategies to climate change, climate change issues should be addressed for the arctic (including indigenous) residents observations and assessment in a broader context of socio-economic problems and sustainable development plans elaboration. Sustainable development plans elaboration, starting from the local community and administrative level foresees the identification and solution of key problems leading to vulnerabilities in the whole human-nature system. If the system is oriented to sustainability, it should properly react, respond to both natural disturbances (climate changes impacts, etc.) and human driving forces, as well as consequences of their interaction. In this respect, arctic residents’ assessments are valuable in identifying key problems (and indicators) leading to vulnerability and arising under the influence of four kinds of forces acting within the nature-social system: climate/ecological changes impacts; human activities impacts; cumulative consequences of both human and climate/ecological changes impacts; drivers in human decision realm.

Results based on previous investigations

The approach of assessing key problems acting in the human-nature system and influencing its vulnerability within four kinds of forces (and their interactions) is illustrated by the data, based on traditional ecological knowledge, gathered during structured, unstructured interviewing and interactive educational workshop with the IPRN (2001-2003).

1. The assessment of climate, ecological changes impacts tells us that at average climate and ecological changes impacts takes the forth place in IPRN pool of concern after economic,
social and problems concerning “good governance”. Nevertheless, in some settlements (for example in Lovozero), the significance of ecology improvement for Saami people is even greater than the importance of housing conditions improvement, although housing conditions are rather poor in this settlement. In spite of the fact that there are some regional geographical peculiarities of observed ecological changes, most answers in interviewed settlements situated in the taiga-tundra and boreal forest biomes are ranked in the following order: animals and plants decrease and disappearance of some species; climate changes; water quality decrease; forest and shrub area decrease. Arctic resident’s assessments of whether climate is becoming more or less suitable and what are main indicators that bring to discomfort are very valuable. The Saami and Evenk people complain that climate is getting more variable and unpredictable and this makes risks to reindeer herding; summers are becoming colder and shorter, but people want them to be warmer in order to have greater yields of vegetables; winter climate is getting wetter and warmer, although people want it to be less wet (wet winters are bad for both human health and wild animals survival). IPRN assessments provided us also with the information on natural (ecological) disasters as they are registered and perceived by the indigenous peoples. Rather new types of perceived natural disasters, such as drying up of surface water reservoirs or so called event as “acid rains” are becoming common to the IPRN in several localities and need scientific interpretation.

2. The assessment of human activities impacts can concentrate the attention of local plans developers on those problems that are most essential for the IPRN traditional activities and well-being. The IPRN rank these problems in the following order: poaching; forest fires; industrial logging; clearing of forests for firewood; water pollution by industrial wastes and discharges. The comparison of the first and this second kinds of forces tells us that many events happening within nature (disappearance or invasion of species) are not only due to natural processes, but are tightly connected with social, economic and management factors. This could be illustrated by such human impact as poaching, leading to decrease of valuable species vital for traditional food and culture as well as biodiversity as a whole.

3. The assessment of commutative negative consequences of both human and climate/ecological changes impacts. In many cases climate/ecological changes impacts and human change impacts lead to the same negative commutative consequences frequently aggravating each other. They are ranked by the IPRN assessments in such an order: less fish; absence of the harvest of wild plants; lack of the harvest of cultivated crops; reindeer pastures degradation, pasture’s areas shrink, reindeer herd decreases.

4. The identification and assessment of forces in human decision realm which are increasingly becoming the cardinal reason for climate change and socio-environmental degradation. Among these forces the IPRN mention: improper policy and management; disobey of laws; the lack of public awareness; weak public participation in decision-making; poor ecological education and public control; inappropriate local administration control (especially of poaching, and industrial companies activities), etc. It is very helpful using local peoples’ knowledge and assessments to identify those stakeholders and institutions which are inflicting the greatest harm to the environment. The IPRN consider poachers and after them the natural resource extraction companies and the forest managers to present the greatest threats. Also it is possible to gather the arctic residents’ assessments of the role of the different stakeholders in the protection of the environment: people in the settlement, environmental protection agencies; public organisations, the local administration, the indigenous community regional authorities; the federal government; international organisations. Although the IPRN of each settlement have unique views on this question, in many cases they believe, not trusting especially to local administrations, that only they themselves could improve the socio-environmental situation in their settlements. Among
essential measures to improve the environmental situation they mention the need to improve the level of environmental education and public awareness and tighten enforcement of environmental laws. The interviewing can also tell us about conflict situations arising between different groups of arctic residents. The highest frequency for the IPRN are conflicts with local administration (95% of all conflicts in interviewed settlements), regional authorities (53%), local private companies (51%) or national private companies (20%). There are rare conflicts on nature resources use with the federal government (7%) (Report 2003). It may seem strange but the new kind of conflict appears between the IPRN and the wildlife conservation institutions.

**Perspectives and recommendations**

The assessments of the IPRN are very valuable for the identification of key problems and indicators of vulnerability on the vast territory of the Russian Arctic, as these peoples are leading their traditional way of life approximately on 60% of this territory (Haruchi, 2001). Nevertheless IPRN constitute only 2% of all northern residents of Russia and 4% of the Russian Arctic, and it is very important to collect assessments from other arctic residents (also larger groups of indigenous peoples, and other stakeholders living permanently in the Arctic) and to include their values and assessments into local plans of sustainable development. Taking into account the global character of climate change issues and its impacts on sustainability, organisation of a comprehensive Circum-arctic residents’ monitoring network of socio-environment assessment and education for sustainable development is recommended. The proposed approach to gathering local and traditional knowledge and assessments of climate change issues can be discussed as one of ways towards the construction of the metadata base for such an international arctic residents’ network.

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Impacts of Climate Change on the Health of Northern Indigenous People

Keith Maguire and C. Dickson

Arctic Athabaskan Council - keith@cyfn.net

Climate change impacts in the north will result in profound changes to the northern environment and impact the health of northern people. Since the 1960s significant warming trends have been recorded in much of the Arctic. Northern indigenous people have already observed major changes to boreal ecosystems and tundra environments. Projections indicate that these trends will continue to increase creating significant impacts on the environment and people of the Arctic.

The Arctic Athabaskan Council is an international indigenous treaty organization built on a cooperative undertaking between the Council of Yukon First Nations, Dene Nation, Kaska Tribal Council, and fifteen Alaskan Tribal Governments. Athabaskan people continue to have a strong cultural and spiritual connection to their environment including significant dietary intake of traditional foods. Similarly many goods and medicines are gathered from the environment to support Athabaskan traditional lifestyles and cultures. The impacts of climate change are already altering the traditional lifestyle of Athabaskan people.

The regional impacts on northern boreal and tundra ecosystems are projected to change snow-pack levels, permafrost distributions, and plant and animal diversification through a general warming trend. Similarly foreign species of plants and animals are migrating to the warmer environments to compete with existing species. These impacts will adversely affect the animals Athabaskan people rely on for their food such as moose, caribou and other small mammals. The changes to climate are altering the distribution and migratory patterns of moose and caribou making it difficult to predict the timing and location to hunt. Aquatic ecosystem characteristics such as nutrient levels, temperature, turbidity, will affect fish species and fish habitat, which Athabaskan people also rely on as a food source. New species of fish and the migratory patterns of in particular anadromous fish species will disrupt the traditional use of fish.

Climate Change will also change northern contaminant transport mechanisms potentially creating significant risks contamination from certain types of metals and organochlorides. Tailing ponds, remnants of past and present mining activities, are in danger of contaminating northern river basins due to permafrost slumping.

Through the Northern Contaminants Program, significant studies were completed on the nutritional value of traditional food dietary intake. The report titled “Yukon First Nations assessment of Dietary Benefit/Risk” (Receveur, et. al, 1998) concludes that traditional foods bring better diet quality as well as economic benefits. Many of those surveyed stated that they would not have sufficient resources to purchase food if traditional food wasn’t available. Also traditional food is part of the spiritual connection of indigenous people with the land.

Northern indigenous communities are now faced with a challenge to adapt to an already rapidly changing environment. Changes in traditional foods and contaminants will negatively impact the nutritional diets the sociocultural values and health of Athabaskan people. It is vital that northern indigenous communities develop strategies with the support of other regional and national governments to build resiliency to this threat.
Coordinated Studies of the Russian Arctic During the International Polar Year 2007/2008

A.V. Klepikov\(^1\), A. I. Danilov\(^1\), V. G. Dmitriev\(^1\) and M. Yu. Moskalevsky\(^2\)

\(^1\) Arctic and Antarctic Research Institute, 38, Bering street, St. Petersburg, 199397 Russia, e-mail: klep@aari.nw.ru

\(^2\) Institute of Geography, Russian Academy of Science, 29, Staromonetny lane, Moscow, 109017 Russia, e-mail: moskalevsky@mail.ru

Polar regions have always been special for those dealing with the ocean and atmosphere environment. The extreme temperatures, presence of the permafrost, glaciers and sea-ice, the strong seasonal fluctuations in radiation and feeble vegetation all make for a unique environment. Observations in the past have shown, and global climate models have projected that the polar regions will undergo relatively more rapid and greater changes than other regions of the world. It has also been recognized that the polar regions play a major role themselves in the global ocean and atmospheric processes and contribute to global climate in a significant way.

The Russian Arctic plays a key role in the formation of the environmental conditions of the entire Arctic not only due to its large area, but primarily to a significant continental runoff, development of the processes of ocean/atmosphere interaction, vast sea ice volumes, large area of permafrost and also presence of glaciers. It is noted that in addition to natural changes, the environment of the Arctic regions experience anthropogenic impacts. Pollutants transferred to high latitudes through the atmosphere, river and sea waters influence the ecosystems and Man in the end. This can affect the population of the Arctic, whose way of life is closely connected with their specific environmental circumstances. The changes expected in the Russian Arctic due to global warming will have a noticeable impact on the environment, human life and economic activities in these areas.

It is necessary to note an exclusive importance of the Arctic for Russia in the 21st century. The political changes in the late 20th century moved the center of the country to the area of intersection of the Polar Circle and the Yenisey river. New Russia is a sub-Arctic state. Enormous natural resources of the Arctic region enhance its significance even more. An extensive sea boundary and a vast offshore zone with substantial supplies of hydrocarbon raw materials determine the acuteness and specifics of the problems of polar water areas of Russia.

The aforementioned circumstances determine the need for systematic studies of the Arctic. Monitoring of the anthropogenic and non-anthropogenic environmental impacts and assessment of the impact of the results of human activity on the nature of polar regions is an urgent objective of Arctic investigation of the 21st century. Therefore, the state interests of Russia in holding the International Polar Year 2007/2008 (IPY 2007/08) are determined in general by the strategic directions of sustainable development of the Russian Arctic, problems of ecology and rational nature use, social problems of the indigenous peoples of the Far North and scientific objectives of Russian research in the Arctic.

The Russian studies of the Arctic are carried out by the research institutes of Roshydromet, Russian Academy of Science, Ministry of Natural Resources, Russian Polar Foundation and other ministries and agencies. The main source of data on polar regions is a state system of routine observations. It is based on a network of land-based hydrometeorological stations in the Arctic which includes 48 stations. The synoptic observations are carried out at all stations.
including upper-air observations at 6 stations, with data of 23 stations reported in real-time to GTS of WMO. At all stations, environmental pollution monitoring is conducted. In addition, Roshydromet organizes on a systematic basis the scientific expeditions in the Arctic to study physical oceanography and the sea ice in the Central Arctic Ocean and in the shelf seas, to investigate the state of marine environment pollution, and to obtain new data necessary for decision-making, including the development of transport systems, exploration of mineral resources of the continental shelf and marine environment protection. In spring of 2003 after a long interruption, the Russian research drifting station “North Pole-32” was landed on the ice and its operation was organized. In September of 2004 ice drifting station “North Pole-33” was launched.

Scientific basis of Russia’s participation in the IPY 2007/08 is federal targeted programs within the framework of which the Arctic and Antarctic studies are carried out. These are federal targeted program “World Ocean”, federal targeted program “Ecology and Natural Resources of Russia” and federal scientific program “Studies and Development in the Priority Directions of Science and Technology”.

The main aims of the studies of this coordinated program of the Roshydromet and Russian Academy of Science are to determine the current and assess the future climate changes, environmental state and consequences of these changes for the social-economic complex of polar regions. To achieve this goal the national program of IPY 2007/2008 should include:

- study of current and assessment of future climate changes in polar regions;
- development of the scientific basis for forecasting the processes in the atmosphere, ionosphere, hydrosphere, cryosphere and the ocean in polar regions;
- determination of anthropogenic and natural environmental state changes and their influence on the ecosystems of polar regions;
- ensuring the development and availability of the technical infrastructure needed for research in the Arctic, Antarctic and Southern Ocean;
- assessment of the social and economic consequences of the environmental state changes in polar regions primarily influencing the life activity of indigenous peoples of the Arctic.

The program covers the following areas of research in the polar regions: atmosphere; ocean, sea ice cover, climatic changes, operational hydrometeorology, environmental state, system of observations and data assimilation.

Practical activities in the framework of Russian program of IPY 2007/2008 should include:

- upgrade and development of atmosphere, ocean and ice parameters monitoring system using existing ground-based observation system in the Arctic and space and automated facilities;
- development and update of climate and environmental monitoring systems of polar regions;
- conduct of integrated high-latitude expeditions in the Arctic and improvement of the Russian Arctic expedition efforts.

During the IPY 2007/2008 in Russian Arctic it is expected to:

- obtain synoptic assessment of large-scale polar processes impacting the polar and global climate with the use of drifting stations, air and ship expeditions, satellite systems, drifting and fixed buoys, etc. Program of seasonal meteorological,
glaciological, oceanographic, biological research on the polar stations, seasonal field bases and research vessels of Roshydromet, Russian Academy of Science and the Ministry of Natural Resources will be extended;

- perform research of meso- and small-scale polar processes, climate change impacted and participating in feedback creation in the polar zone of climate system (albedo, atmospheric inversion, deep convection in the mid-ocean and on the continental shoulder, glacier fluctuation, etc.);

- perform a complex of geophysical observations on the Earth’s polar caps processes, impacting climate and environment, including observations on short-term variations and long-term trends of solar activity, impacting polar regions geophysical and atmospheric processes and on electromagnetic pollution of the ionosphere and its consequences;

- assess current status of land polar cryosphere components (glacier and permafrost) and support extension of these studies to obtain paleoclimate data;

- support accomplishment of international projects and programs of climate and environmental research carried out by international organizations with Russia involved;

- assess state of polar ecosystems in changing climate and anthropogenic impacts conditions and develop recommendations for environmental activities;

- upgrade and develop existing systems of atmosphere, ionosphere, ocean and cryosphere monitoring and forecasting technologies; and

- develop recommendations for socio-economic development of the Arctic region.

The results of the IPY 2007/2008 will serve as a basis for developing recommendations for governmental bodies and interested organizations operating in the Arctic and the Antarctic. Program of Russian studies in the Arctic during the IPY 2007/08 will be implemented in a close cooperation with the international projects of IPY 2007/08. The program is considered as the input to the ACIA follow-up.