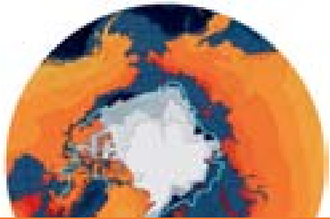

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Extended Abstracts
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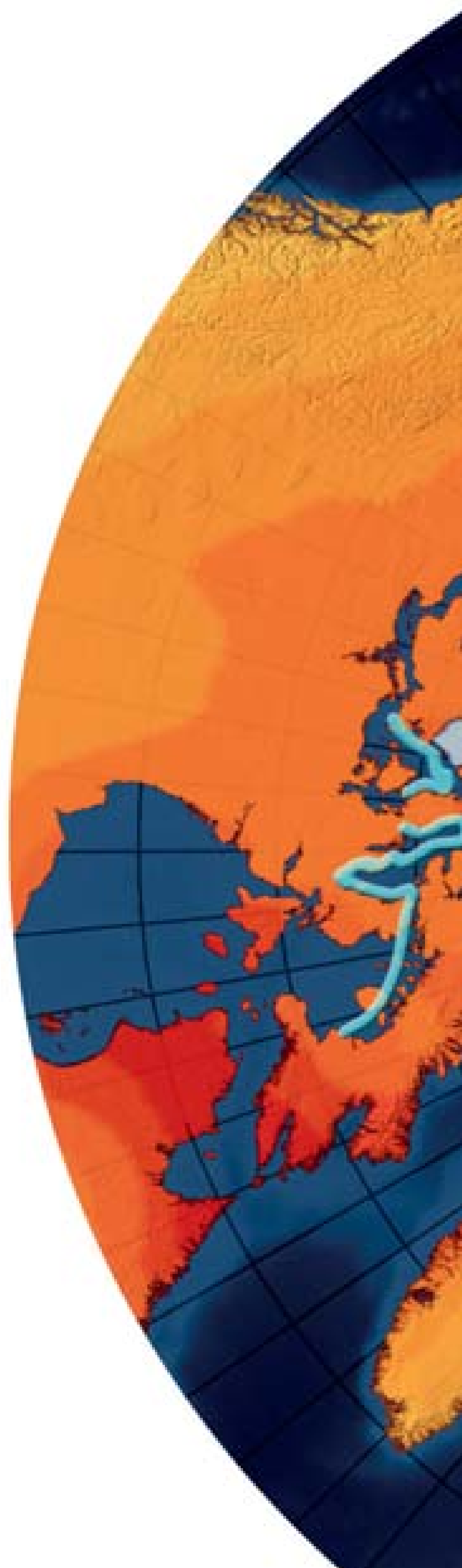


The ACIA International Scientific Symposium on Climate Change in the Arctic

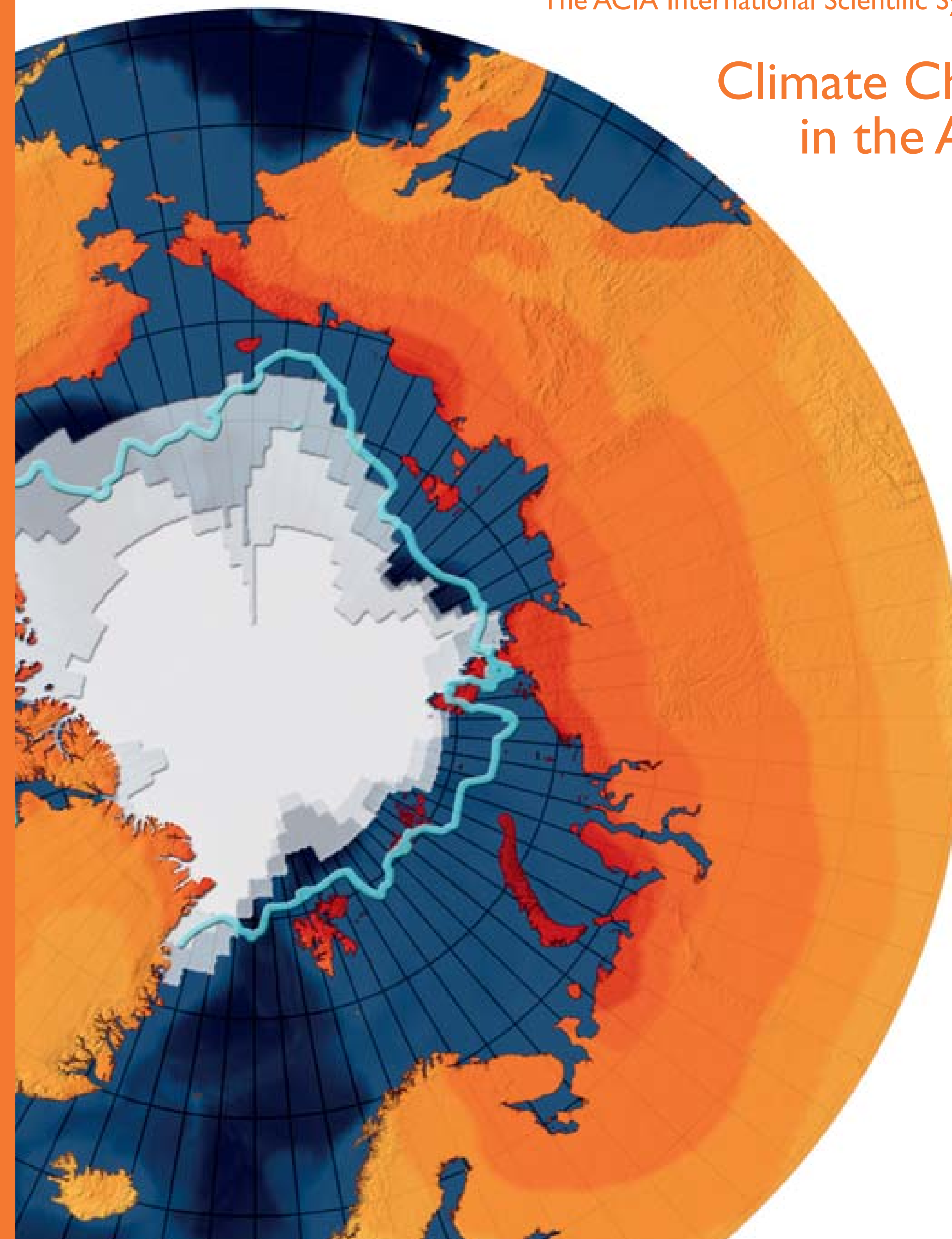
AMAP Report 2004:4

GUTENBERG 26739

Arctic Climate Impact Assessment (ACIA)
AMAP Report 2004:4

The ACIA International Scientific Symposium on

Climate Change in the Arctic



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Arctic Monitoring and Assessment Programme (AMAP)
Conservation of Arctic Flora and Fauna (CAFF)
International Arctic Science Committee (IASC)
ACIA Secretariat

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Arctic Monitoring and Assessment Programme (AMAP)
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The ACIA International Scientific Symposium

on

Climate Change in the Arctic

Extended Abstracts

Reykjavik, Iceland, 9 - 12 November 2004

Preface

This volume comprises the extended abstracts of oral and poster presentations at the *ACIA International Scientific Symposium on Climate Change in the Arctic*, Reykjavik, 9-12 November 2004, organized by the Arctic Climate Impact Assessment (ACIA). The Arctic Climate Impact Assessment is conducted under the auspices of the Arctic Council working groups: Arctic Monitoring and Assessment Programme (AMAP) and Conservation of Arctic Flora and Fauna (CAFF), in association with the International Arctic Science Committee (IASC).

Abstracts are arranged according to the symposium sessions, oral sessions first, followed by poster sessions. A list of contents follows this introduction.

The Symposium is an important part of the process by which the results and conclusions of the Arctic Climate Impact Assessment will be communicated to Arctic stakeholders and to Ministers at the Fourth Arctic Council Ministerial Meeting in Reykjavik, November 2004.

ACIA gratefully acknowledges the countries and organizations that have sponsored the Symposium and/or participated in its arrangement, and welcomes all participants to Reykjavik.

Symposium Scientific and Organizing Committee:
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Environment and Food Agency of Iceland (Helgi Jensson, Svanhvit Bragadottir)

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B4.3	Evidence and Implications of Dangerous Climate Change in the Arctic *Lynn D. Rosentrater, Mark New, Jed O. Kaplan, Josefino C. Comiso, Sheila Watt-Cloutier, Terry Fenge, Paul Crowley, and Tonje Folkestad*	Tonje Folkstad
B4.4	Heavy Metals and Persistent Organic Pollutants in Air and Precipitation in Iceland *Elin B. Jonasdottir and Johanna M. Thorlacius*	Elin B. Jonasdottir
B4.5	Global Emission Estimates for GHG within the EU EVERGREEN project (EnVisat for Environmental Regulation of GREENhouse gases) *J.M. Pacyna, S. Mano, A. Luekewille, D. Panasiuk, S. Wilson and F. Steenhuisen*	F. Steenhuisen
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B7.3	Freshwater Ecosystems and Global Change: A Brief Introduction to EURO-LIMPACS *Jón S. Ólafsson*	Jón S. Ólafsson
B7.4	Zackenberg Basic: Monitoring of Ecosystem Dynamics in High-Arctic Northeast Greenland *Morten Rasch, Birger U. Hansen, Hans Meltofte, Dorthe Petersen, Søren Rysgaard, Mikkel P. Tamstorf*	Morten Rasch

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B7.7	Arctic Change Detection in the Post-ACIA Period *Nancy N. Soreide, John Calder, James E. Overland and Florence Fetterer*	Nancy N. Soreide
B7.8	The Swedish Icebreaker Oden as a Research Platform: The Arctic Ocean Experiment 2001 *Michael Tjernström and Caroline Leck*	Michael Tjernström
B7.9	Development of the Archive of Historical Ice Charts of the Arctic Region for the XX Century and Statistical Parameters Describing Variability of Ice Conditions *V.M. Smoljanitsky*	V.M. Smoljanitsky
B7.10	The AARI Oceanographic Database and Its Use in Investigations of the Arctic Ocean *V.T. Sokolov, V.Yu Karpiy and N.V. Lebedev*	V.T.Sokolov
B7.11	Climate Change in the Arctic: Information Support of the Problem *V. Rykova*	
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B8.1	Climate Change and Health among Women of Labrador *Sandra Owens and Christopher Furgal*	Christopher Furgal
B8.2	Interactive Poster – "When the Weather is Uggianaqtuq: Inuit Observations of Environmental Change" *Shari Fox Gearheard and Inuit from the communities of Baker Lake and Clyde River, Nunavut*	Shari Fox Gearheard
B8.3	Climatic Changes Associated with Societal Changes Produce New Combination of their Direct Impacts on Health *Juhani Hassi*	Juhani Hassi
B8.4	Impacts of Climate Change on the Health of Northern Indigenous People (see Session 8 abstract) *Keith Maguire and C. Dickson*	

* Provisional

The Arctic Climate: – Past and Present (ACIA Chapter 2)

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1. Introduction

This paper will present an analysis of the Arctic climate over the past century. The emphasis will be on changes in land-surface temperatures. The paper is based on Chapter 2 of the Arctic Climate Impact Assessment (McBean, et al., 2004).

2. Methods

All Arctic countries maintain programs of synoptic observations to support their economic activity and the sustainability of communities in the Arctic. Arctic systematic *in-situ* meteorological observations started in the late 18th century in the Atlantic sector and in other sectors later. In terms of the circum-Arctic region, only for the last 50 years or so has there been adequate (but not good) coverage. The observational base for Arctic climate is quite limited with few long-term stations and a paucity of observations in general, making it difficult to distinguish with confidence between the signals of climate variability and change. For this study, the focus has been on land surface stations for the Arctic, defined arbitrarily as north of 60^{o}N. For discussions of atmospheric pressure, analyzed fields over the entire Arctic have been used.

In developing data sets for climate analysis, there are different levels of quality assurance, data infilling and homogenization adjustments of these datasets. Consequently, temperature trends using the Climatic Research Unit database (CRU)(Jones and Moberg, 2003) and the Global Historical Climatology Network database (GHCN)(updated from Peterson and Vose, 1997) have been compared. Both databases were employed in the IPCC Third Assessment Report (2001c, Section 2.2.2) to summarize the patterns of temperature change on global land areas since the late 19th century.

3. Results

The CRU time series of annual land-surface air temperature variations in the Arctic (north of 60^{o}N) from 1900-2002 is virtually identical to the GHCN (Figure 1). During that period, there is a statistically significant warming trend of 0.09 ºC decade^{-1}. This Arctic trend is more than the 0.06 ºC decade^{-1} increase averaged over the Northern Hemisphere (IPCC 2001b, p.152). In general, temperature increased from 1900 to the mid-1940s, then decreased until about the mid-1960s, and increased again thereafter. For the period, 1966-2002, the average over the region was 0.38 ºC decade^{-1}, approximately 4 times greater than the average for the century. While the changes are most pronounced in winter and spring, all seasons experienced an increase in temperature during the last several decades. The general features of the Arctic time series are similar to those of the global time series, but decadal trends and interannual variability are somewhat larger in the Arctic.

The instrumental record of land-surface air temperature is qualitatively consistent with other climate records in the Arctic (Serreze et al., 2000). For instance, the 'maritime' Arctic (as represented by coastal land stations, drifting ice stations, and Russian North Pole stations) warmed at the rate of 0.05 ºC decade^{-1} during the 20th century (Polyakov et al., 2003b). As with the land-only record, the warming was largest in winter and spring, and there were two relative maxima during the century (the late 1930s and the 1990s). For periods since 1950, there is a similar rate of warming. However, due to the scarcity of data prior to 1945, it is very difficult to say whether the Arctic as a whole was as warm in the 1930-40s as the most recent decade. In the Polyakov et al. (2003) analysis, only coastal stations were chosen and most of the stations contributing to the high values in the 1930s were in Scandinavia. Interior stations, especially those between 60^{o}N (the southern limit for this study) and 62^{o}N (the southern limit for the Polyakov et al. study), have warmed more. Arctic pack-ice extent contracted from 1918 to 1938 and then expanded between 1938 and 1968 (Zakharov 2002). The expansion after 1938 implies that the Arctic was cooling during that period.

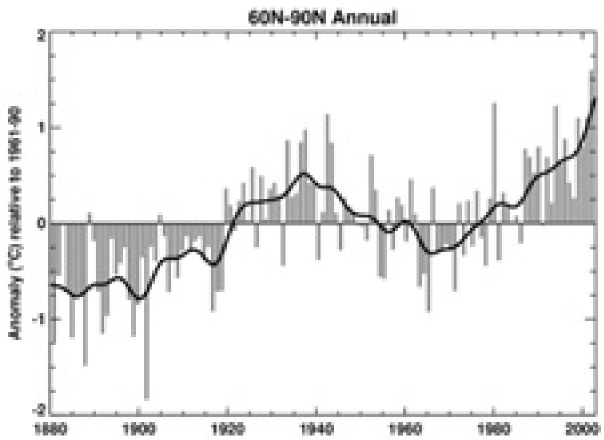

Figure 1: Annual anomalies of land-surface air temperature (^{o}C) from 60^{o}N-90^{o}N for the period 1980-2002, using the GHCN time series (updated from Peterson and Vose, 1997). Anomalies are relative to a 1961-90 base period. The smoothed curve was created using a 21-point binomial filter giving near decadal averages.

For comparison purposes, the temperature trends (in ^{o}C yr^{-1}) for the land-surface temperatures (GHCN database) were computed for the latitude bands 60N-90N and Equator-60N (Figure 2). For the 60^{o}N-90^{o}N band, the trend over any period from the present back to 120 years is positive (i.e., the Arctic is warming). For the 0-60^{o}N band, the trend is also always positive. Although the trends for both bands have been increasing over the past 60 years, the trend for 60^{o}N-90^{o}N is larger. The rate of warming in the Arctic (as defined here) exceeds that of lower latitudes. Due to natural variability and sparse data in the Arctic, the Arctic trend shows more variability and the confidence limits are wider. Over the past 40 years, the Arctic warming is about 0.4 ^{o}C decade^{-1} compared to 0.25 ^{o}C decade^{-1} for the lower latitudes.

Likewise, satellite thermal infrared data on surface temperature, which provides pan-Arctic coverage from 1981-2001, exhibited statistically significant warming trends in all areas between 60^{o}N-90^{o}N except Greenland (Comiso, 2003). The warming trends were 0.33 ºC decade^{-1} over the sea ice, 0.50 ºC decade^{-1} over Eurasia and 1.06 ºC decade^{-1} over North America. In addition, the recent reduction in sea ice thickness (Rothrock et al., 1999), the retreat of sea ice cover (Parkinson et al., 1999), and the decline in perennial ice cover (Comiso, 2002) are consistent with large-scale warming in the Arctic.

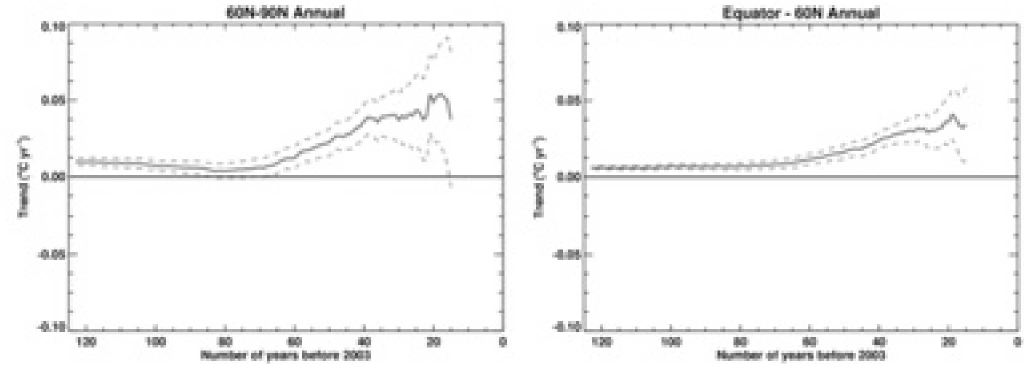

Figure 2: Temperature trends (in ºC yr^{-1}) for land-surface temperatures (GHCN database) (solid lines) and 95% significance levels (dashed lines) based on the period from present to 120 years before present. Hence, the value corresponding to 60 years before present is the average trend for the period 1944-2003.

4. Conclusions

Based on the analysis of the climate of the 20^{th} century, it is concluded that the Arctic has *very likely* warmed up over the past century, although the warming has not been uniform. The average surface temperature for land stations north of 60^{o}N increased approximately 0.09ºC $decade^{-1}$ over the past century, more than the 0.06 ºC $decade^{-1}$ increase averaged over the Northern Hemisphere. The rate of change has increased over the past 4 decades and is higher than that for the regions $0\text{-}60^{o}$N. The paper will also examine the evidence for polar amplification, which depends on the time scale of examination.

Other analyses presented in the ACIA Chapter 2, lead to the following additional conclusions. While atmospheric pressure over the Arctic basin has *very likely* been dropping, it is *likely* that there has been an increase in total precipitation at the rate of about 1% $decade^{-1}$ over the past century. Trends in precipitation are hard to assess because it is difficult to measure with precision in the cold Arctic environment. Snow cover extent around the periphery of the Arctic has *very likely* decreased. There *very likely* have also been decreases in sea ice extent averaged over Arctic over at least the last 40 years and *very likely* a decrease multi-year ice extent in central Arctic.

Reconstruction of the Arctic climate over thousands to millions of years demonstrates that the Arctic climate can vary by large amounts. There appears to be no natural impediment to human-induced climate change being very large (and much larger in the Arctic than the change on the global scale). The variability and transitions have been rapid, from a few to several degrees over a century.

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Indigenous Perspectives on the Changing Arctic (ACIA Chapter 3)

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Chapter Summary

Indigenous peoples in the Arctic have for millennia depended on and adapted to their environment. Their knowledge of their surroundings is a vital resource for their well-being. Their knowledge is also a rich source of information for others who wish to understand the Arctic system. In the context of climate change, indigenous observations and perspectives offer great insight not only into the nature and extent of environmental change, but also into the significance of those changes for the peoples whose cultures are built on an intimate connection with the Arctic landscape.

Chapter 3 of the ACIA reviews the concept of indigenous knowledge, summarizes indigenous observations of environmental and climate change that have been documented to date, and presents a series of case studies, largely from hunting and herding societies, examining the perspectives of specific communities or peoples. The case studies are idiosyncratic, but they have in common the intent of conveying the sense of how climate change is seen, not in aggregate statistics or general trends, but in specific details for particular individuals and communities. The case studies set the stage for a discussion of resilience, or protecting options to increase the capacity of Arctic societies to deal with future change, and a review of further research needs.

The observations and case studies in the Indigenous Perspectives chapter contain some common themes. One such observation is that the weather has become more variable and thus less predictable by traditional means. Social changes, such as less time spent on the land, may influence this observation, but there are climatological implications worthy of further exploration. In terms of perceptions of the significance of climate change, there are few, if any, areas where climate change is regarded as the most pressing problem being faced. Nonetheless, most Arctic residents are aware of it, have experience with the types of changes that are being seen and are anticipated, and are concerned about what it will mean for them, their communities, and the future.

Several general conclusions drawn from the chapter are likely to be applicable to all communities affected by climate change, whether the impacts are on balance beneficial or harmful. Climate change is not an isolated phenomenon, but one that is connected to the web of activities and life surrounding Arctic peoples. Thus, it must be understood and assessed in terms of how it interacts with other phenomena and societal and environmental changes taking place. Responses to climate change will not be effective unless they reflect the particular circumstances of each place. Increasing resilience is a useful way to consider the merits of various response options, which are best developed and evaluated iteratively to promote adjustment and improvement as experience and knowledge increase. Indigenous perspectives on climate change offer an important starting point for collaborative development of effective responses.

Symposium Presentation

Chapter 3 of the ACIA, "Indigenous Perspectives on the Changing Arctic", summarizes and synthesizes available information of indigenous observations of climate change from around the circumpolar North. This presentation provides an overview of the chapter, exploring how local and individual approaches to understanding climate change help to create a more complete picture of Arctic change. Examples from chapter case studies that document indigenous observations in different Arctic regions will be presented. The presentation will also explore how indigenous observations contribute to understanding climate change through detecting changes, identifying the implications of those changes, recognizing the many interactions involving specific changes, and understanding the impacts to individuals and communities.

> *We cannot change nature, our past, and other people for that matter, but we can control our own thoughts and actions and participate in global efforts to cope with these global climate changes. That I think is the most empowering thing we can do as individuals.*
>
> George Noongwook, St. Lawrence Island Yupik, Savoonga, Alaska
> (Noongwook 2000)

Acknowledgements

Many thanks to all of the indigenous peoples around the Arctic who are working to share their observations, experiences and responses to climate change. Thanks to the contributing and consulting authors for this chapter, and to those who provided case studies. Thank you to the ACIA for supporting our work and helping to raise awareness of indigenous perspectives on climate change.

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Future Changes of Climate: Modelling and Scenarios for the Arctic Region (ACIA Chapter 4)

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Increased levels of atmospheric greenhouse gases (GHG) will have a larger effect on climate in the Arctic region than anywhere else on the globe. To estimate a possible future climate change we use physically based, global coupled atmosphere-land-ocean climate models. Given a change in GHG concentrations we can calculate the resulting changes in temperature, precipitation, seasonality etc. Future concentrations of GHG and aerosol emissions can be estimated assuming future demographic, socio-economic and technological changes. Within IPCC, a set of emission scenarios has been prepared; in this assessment we choose to use the so called A2 and B2 scenarios. These are in the middle of the range of scenarios provided by the IPCC. Climate projections, using five different global models and comparing with the present climate, show an average warming of 1.4°C in the mid-21st century for both the A2 and the B2 scenarios. Towards the end of the century, the globally averaged warming is 3.5°C and 2.5°C for the A2 and B2 scenarios, respectively. Over the Arctic region the warming is larger: for the region northward of 60°N, by mid-21st century, both scenarios give 2.5°C. By the end of the 21st century, the Arctic warming is 7°C and 5^{e}C for A2 and B2, respectively (Fig. 1). By that time, in the B2 scenario, the annual average warming of around 3ºC is projected for Scandinavia and East Greenland, about 2ºC for Iceland, and up to 5ºC for the Canadian Archipelago and Russian Arctic.

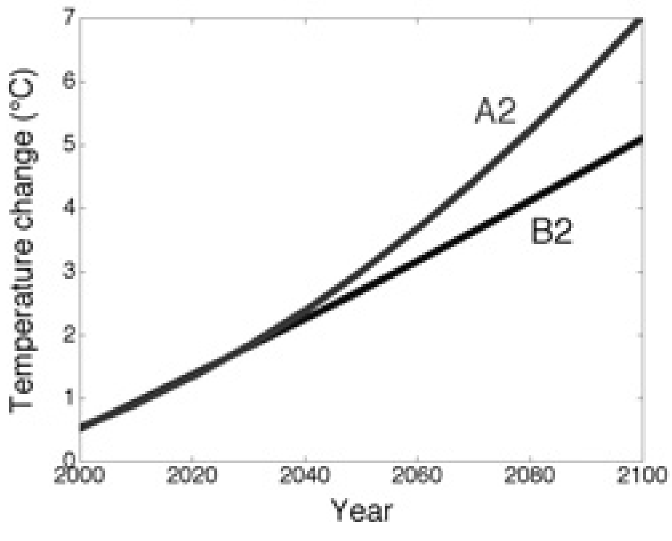

Figure 1. Model-mean A2 and B2 projections of the Arctic (60-90°N) annual mean surface air temperature changes (°C) relative to 1981-2000. A binomial approximation is applied to the original model means.

The model mean warming over the central Arctic Ocean is largest in autumn and winter (for the B2 scenario – up to 9ºC by late-21st century), when the air temperature reacts strongly to reduced ice cover and thickness. Average autumn and winter temperatures are projected to rise by 3-5ºC over most Arctic land areas. By contrast, the warming in summer remains below 1ºC. A contrast between larger warming in autumn and winter and smaller warming in summer also extends to the surrounding land areas but is less pronounced there. In summer (winter), the warming over northern Eurasia and northern North America is larger (smaller) than that over the Arctic Ocean. All of the models suggest substantially smaller warming over the northern North Atlantic sector than in the other parts of the area.

The simulated precipitation increases in the Arctic, by late 21st century from about 5-10% in the Atlantic sector (5-10%) to locally up to 35% in the high Arctic (for the B2 scenario). Like the temperature increase, the increase in precipitation is also generally largest in autumn and winter and smallest in summer.

Throughout the year, there is a slight decrease in pressure in the polar region. While many impact studies would benefit from projections of wind characteristics and storm tracks in the Arctic, the available analysis from the literature are insufficient to justify any firm conclusions on their possible changes in the 21st century.

The models also show a substantial decrease of snow and sea-ice cover over most parts of the Arctic area by the end of the 21st century.

The Arctic is a region characterized by complex and still insufficiently understood climate processes and feedbacks, contributing to the challenge, which the Arctic posres from the viewpoint of climate modelling. We have identified several weaknesses of the models in high-latitude surface process descriptions and we find this to be among most serious shortcomings in present day Arctic climate modelling. Simulation deficiencies are partly due to a coarse model resolution. Additionally, many model formulations are based on low latitude observations that do not cover the extreme climatic conditions occurring in the Arctic. A consequence is a larger spread for model results from the Arctic area (Fig.2) than for results from lower latitudes.

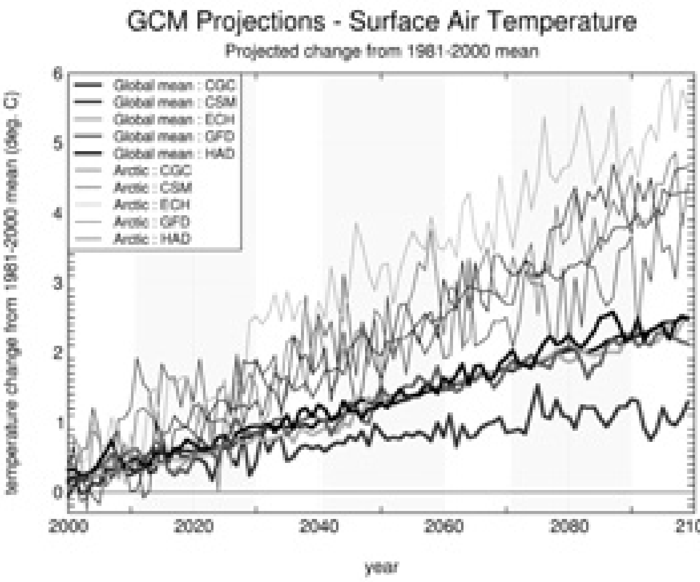

Figure 2. Global (thick lines) and Arctic (60-90°N, thin lines) change in the annual mean surface air temperature relative to the baseline period 1981-2000 (ºC) in the 5 individual ACIA B2 projections.

Local and regional climate features, such as enhanced precipitation close to steep mountains, are not well represented in global climate models due to their limited horizontal resolution. To describe local climate, we can either use statistically based empirical links between the large-scale flow and local climate or physical modelling. A local climate change can more easily be translated into impacts than a direct use of global model results. Physically based methods for local and regional climate simulation rely on high resolution models run over limited time slices. One alternative is to use a high resolution global stand-alone atmospheric model driven with ocean surface conditions simulated in a coarser resolution coupled model. Another alternative is a regional model with an increased horizontal resolution, driven at the lateral boundaries with coarser resolution global model output. All methods can be used to interpret global simulations on finer scales and capture areas with intensified precipitation, extreme wind events etc. Unfortunately, high-resolution global model results for the Arctic have not been available for this assessment. In spite of fast developments in the Arctic regional climate modelling, its current status does not allow regional models to be employed as principal tools for ACIA. Thus the main possibility for ACIA is to use coupled global models' projections either directly or in combination with statistical downscaling techniques.

A model simulation gives us one possible climate scenario. This is not a prediction of future climate, we can only calculate the climate change based on a prescribed change in atmospheric GHGs. A climate shift can be due to natural variability as well as a GHG induced change. Natural variability in the Arctic is large and could mask or amplify a change due to human activities. This effect could be larger or smaller depending on the region, the climate parameter (temperature, precipitation, snow cover etc) and the time and space scales. To assess the relative importance of natural variability versus a prescribed climate forcing an ensemble of differently formulated climate models should be used. This technique requires substantial computing resources; here we use only five different models to give an indication of simulation uncertainty versus forced changes. Ensembles containing on the order of hundred simulations would give a better estimate of climate change probability distributions. We would also have a possibility to estimate changes in the frequency of winter storms, temperature and precipitation extremes, etc.

While we believe that the level of uncertainty in climate simulations can be lowered with improved model formulations, we can never be certain that all physical processes relevant to climate change have been included in a model simulation. There can still be surprises to come in our understanding of climate change. Our present estimates are based on the best knowledge available today about climate change; as climate change science progresses there will always be new results that can change our understanding of how the Arctic climate system works.

Ozone and Ultraviolet Radiation (ACIA Chapter 5)

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Introduction

The ozone depletion observed over the Arctic during the past twenty years has reduced normally high winter and springtime ozone amounts, potentially allowing more ultraviolet (UV) radiation to reach the Earth's surface. Ozone loss over the Arctic has been of similar magnitude to that over the Antarctic (Figure 1). Observations have shown substantial late winter and early springtime column ozone reductions in the Arctic over the last two decades. These reductions have been directly tied to chemical losses occurring at low temperatures in the presence of human-produced chlorine and bromine compounds. The year-round ozone trend over the Arctic for 1979-2000 has been about -3% per decade with accumulated losses of approximately 7%. The springtime ozone trend has been about -5% per decade. Accumulated springtime total ozone losses are approximately 11%.

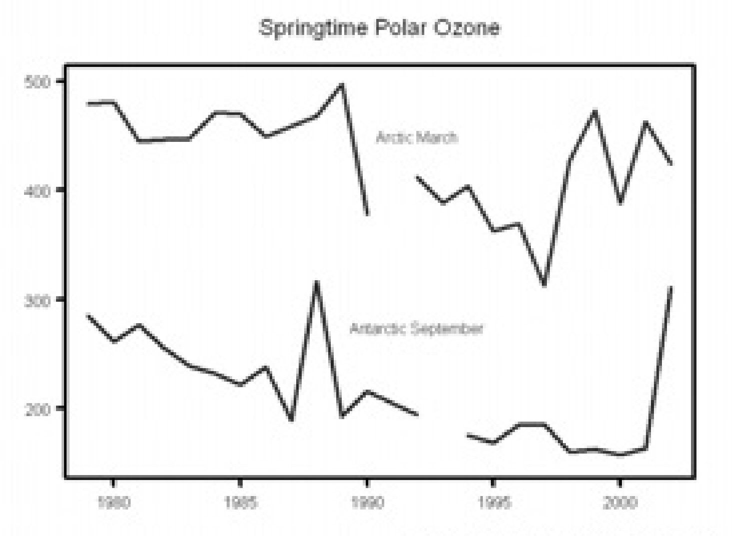

Figure 1. Springtime ozone depletion over the Antarctic and the Arctic. Substantial depletion has occurred over both poles, and depletion has been similar in magnitude, though not in percent loss, over each region.

Ozone in the stratosphere absorbs radiation at UV wavelengths and therefore directly influences the amount of UV radiation reaching the Earth's surface. Surface UV levels are also strongly affected by clouds, aerosols, altitude, solar zenith angle, and surface albedo. These different factors contribute to high variability in UV levels and make it difficult to identify clear UV changes resulting from ozone depletion. Because of the low solar elevation in the Arctic, the region is subject to an increased proportion of diffuse UV radiation, from scattering in the atmosphere as well as from reflectance off snow and ice. Reflectance off snow can increase the biologically effective irradiance by over 50%. Understanding changes in UV doses has important implications for human and ecosystem health. UV exposure has been linked to skin cancers, corneal damage, cataracts, immune suppression, and aging of the skin in humans, and can also have deleterious effects on ecosystems and on materials.

Changes in global climate are likely to result in changing snow cover and sea ice in the Arctic, affecting the UV exposure of various ecosystems. Both snow and ice cover have strong attenuating effects on UV, protecting organisms underneath. A reduction in snow and ice cover on the surface of rivers, lakes, or oceans may increase exposure of many organisms to damaging UV. Loss of snow or ice cover earlier in the season when UV radiation may be at increased levels could be stressful for both aquatic and terrestrial life.

Monitoring Arctic Ozone and UV

Ground-based and satellite instruments are used to monitor the amounts and profiles of stratospheric ozone. Currently, over 30 Dobson and Brewer instruments are operated in or near the Arctic. Some of these records date back to the 1920s. The vertical ozone distribution can also be measured using ozone sondes. The available data have been used in many analyses of ozone depletion and indicate strong downward trends in stratospheric ozone amounts, particularly during the late winter and spring. Ozone amounts also show strong latitudinal variations as well as notable longitudinal variations.

Ground-based instruments measure UV levels in all eight Arctic countries, though the amount of coverage varies with the region. Surface UV amounts can also be inferred from satellite data. Available individual measurements suggest localized increases in UV levels reaching the surface, but so far the measurement time series are not long enough to allow upward trends in UV to be detected. Reconstructed surface UV time series based on total ozone, sunshine duration, and cloud cover suggest distinct UV increases, but reconstruction methods are less certain than direct measurements because they involve assumptions about the spectral characteristics of cloud and aerosol attenuation and surface reflectivity. The increases in UV have been found to occur mainly in the springtime, during the maximum ozone depletion. This increase can result in springtime UV levels that can be higher than those measured during the summer.

Future Arctic Ozone and UV Projections

Atmospheric sampling indicates that the Montreal Protocol and its amendments have resulted in a peak and the beginning of a decline in the amounts of some ozone depleting substances. However, climate change and other factors are likely to affect the recovery of the ozone layer. Changes in both the overall meteorology of the region and in atmospheric composition may delay or accelerate the recovery of Arctic ozone. These changes contribute to difficulties in projecting future Arctic ozone amounts. Generally, the two-dimensional (2-d) models compared in the 2002 Ozone Assessment predict local minimums in Arctic ozone in the late 1990s, followed by a slow, gradual increase. Ozone values in 2020 are significantly lower than the 1980 values for all of these 2-d models. Three-dimensional chemistry-models offer greater insight into dynamical factors affecting current and future Arctic ozone levels. Expectations from three chemistry-climate models are shown in Figure 2 and report larger ozone depletion for the Arctic during 1980-2000 than is projected by the 2-d models. The 2015 results from the 3-d models show improvement to levels above those in 1980 but still lower than the 1960 amounts. The only 3-d model to project ozone amounts beyond 2020 predicts only modest recovery in 2045.

Arctic ozone experiences high natural seasonal and interannual variability, driven primarily by the atmospheric dynamics governing the large-scale meridional transport of ozone from the tropics to high latitudes. The large natural variability complicates our ability both to interpret past changes and to predict future ozone levels. Confounding matters further, stratospheric temperatures and polar stratospheric cloud formation also affect Arctic ozone depletion. Climate changes leading to lower temperatures in the stratosphere are likely to increase the frequency and severity of ozone depletion episodes. Overall, ozone levels are expected to remain depleted for several decades and thus UV levels over the Arctic are likely to remain elevated in the coming years. The elevated levels will likely be most pronounced in the springtime when ecosystems are most sensitive to harmful UV.

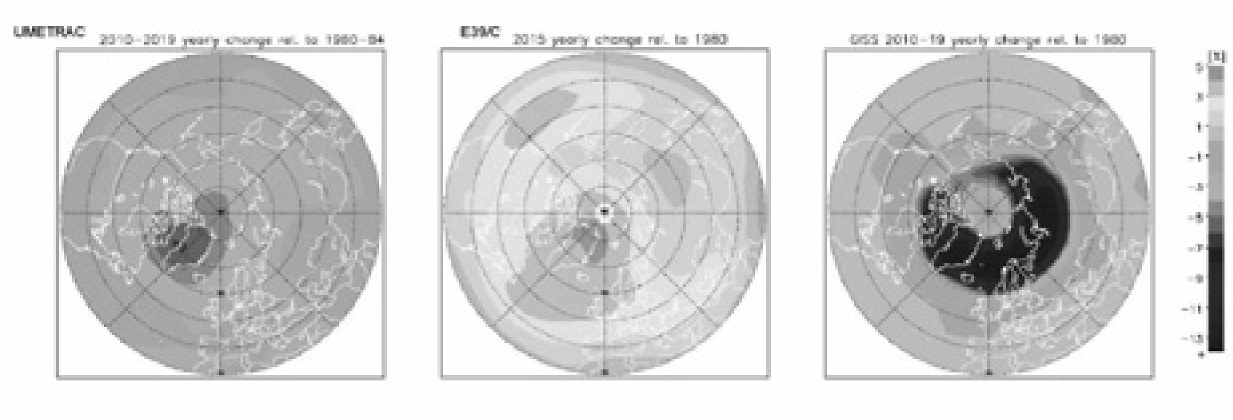

Figure 2. 3-d model projections of changes in the yearly average column ozone for the period 2010-2019 relative to the model results for 1980. (a) UMETRAC, change calculated relative to 1980-1984; (b) E39/C, projected change for 2015; (c) GISS, change relative to 1980.

Cryospheric and Hydrologic Variability (ACIA Chapter 6)

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Recent observational data present a generally consistent picture of cryospheric variations that are shaped by patterns of recent warming and variations of the atmospheric circulation. While the various cryospheric and atmospheric changes are consistent in an aggregate sense and are quite large in some cases, it is likely that low-frequency variations in the atmosphere and ocean have played at least some role in forcing the cryospheric and hydrologic trends of the past few decades. Model projections of greenhouse-driven warming indicate a continuation of the recent trends through the next century, although the rates of the projected changes vary widely among the models.

Sea ice coverage has decreased by 5-10% during the past few decades. The decrease is greater in the summer, when new period-of-record minima have been reached several times in the most recent decade. The coverage of multiyear ice has also decreased, as has the thickness of sea ice in the central Arctic. Models project a 21st-century decrease of sea ice by more than 50% in the summer season, with a corresponding lengthening by 2-4 months of the navigation season in the Northern Sea Route. Other impacts of the reduced sea ice cover will be a larger fetch for wave generation by storm systems, increased vulnerability of coastlines now protected by sea ice for at least part of the year, and an increase in the availability of oceanic moisture for the atmosphere.

Snow-covered area has diminished since the early 1970s by several percent over both North America and Eurasia, although most of the decrease occurred during a period of several years in the late 1980s. Snow cover is projected to continue to decrease, with the largest decreases projected for spring and autumn. If such changes occur, the snow season will be shortened and the growing season will lengthen. The springtime pulse of runoff is likely to occur earlier, raising the possibility of drier land areas during summer if precipitation does not increase.

Glaciers throughout much of the Northern Hemisphere have lost mass over the past several decades, as have coastal regions of the Greenland ice sheet. The cumulative loss of mass since 1960 from glaciers in the North American Arctic is nearly 500 cubic kilometers. The glacier retreat has been especially large in Alaska since the mid-1990s. During the past decade, glacier melt has resulted in an estimated sea level increase of 0.15-0.30 mm/year. The wastage of arctic glaciers and the Greenland ice sheet is projected to contribute several additional cm to global sea level rise by 2100. Superimposed on the glacial contributions to sea level change are the effects of thermal expansion and isostatic rebound, which combine to produce a spatially variable pattern of sea level rises of several tens of centimeters in some areas (the Beaufort Sea and much of the Siberian coast) and sea level decreases in other areas (e.g., Hudson Bay, Novaya Zemlya).

Permafrost temperatures over most of the subarctic land areas have increased during the past few decades by several tenths °C to as much as 2-3°C. On the basis of the warming projected to occur over the next century, permafrost could begin to thaw over 10-30% of the present permafrost area, and the outer limit of permafrost may move northward by several hundred km. A key uncertainty is the timing of permafrost degradation, defined as the failure of the active layer to completely refreeze during winter, relative to the warming of the surface air temperatures. Whether the permafrost degrades or the active layer thickens, there will be major impacts on the infrastructure, hydrology and ecosystems of the Arctic.

Earlier break-up and later-freeze-up have combined to lengthen the ice-free season of rivers and lakes by 1-3 weeks over the past century in much of the Arctic. The lengthening of the ice- free season has been greatest in the western and central portions of the northern continents. Continued trends toward earlier break-up and later freeze-up of Arctic rivers and lakes are also likely if the projected warming occurs. While these trends point to a longer navigation season, there is also the possibility that summer water levels will decrease during summer if there is a longer post-breakup period during which evapotranspiration exceeds precipitation over the arctic terrestrial watersheds.

River discharge over much of the Arctic has increased during the past several decades, and the springtime discharge pulse is occurring earlier on many rivers. The increase of discharge is consistent with an irregular increase of precipitation over northern land areas. On the basis of the model projections of precipitation and temperature, arctic river discharge may increase by an additional 5-25% by the late 21st century. This increase of discharge has potentially important implications for the Arctic Ocean freshwater budget and stratification, as well as for the export of freshwater to the North Atlantic subpolar seas.

While the changes summarized above have the potential to cause substantial impacts on arctic ecosystems, infrastructure and people, the changes may combine in ways that enhance the impacts. For example, the increase of sea level, the retreat of sea ice and the degradation of coastal permafrost can combine to accelerate the vulnerability of arctic coastal areas to erosion. Similarly, the lengthening of the snow-free season, in combination with warmer temperatures and greater evapotranspiration rates, can lead to a drying of some areas, increasing their vulnerability to disturbance (e.g., fire, insects).

Climate Change and UV-B Impacts on Arctic Tundra and Polar Desert Ecosystems (ACIA Chapter 7)

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Introduction

A general recognition that the Arctic will amplify global climate warming, that UV-B radiation may continue to increase there because of possible delays in the repair of stratospheric ozone, and that the Arctic environment and its peoples are likely to particularly susceptible to such environmental changes stimulated an international assessment of climate change impacts. The Arctic Climate Impacts Assessment (ACIA) is a four year study, culminating in publication of a major scientific report (ACIA, 2004) as well as other products (Callaghan et al., 2004). The present paper focuses on terrestrial ecosystems of the Arctic, from the treeline ecotone to the polar deserts.

The Arctic is generally recognized as a treeless wilderness with cold winters and cool summers. However, definitions of the southern boundary vary according to environmental, geographical or political biases. This assessment focuses on biota (plants, animals and microorganisms) and processes in the region beyond the northern limit of the closed forest (the taiga), but we also include processes South of this boundary that affect ecosystems in the Arctic.

Arctic ecosystems are expected to be vulnerable to the dramatic environmental changes that the Arctic is experiencing for many reasons. The Arctic is outstanding amongst the biomes of the World in the dominance of climate change amongst the major factors affecting biodiversity. Also, the Arctic biota of the present day are relatively restricted in range and population size compared with their Quaternary history. When the treeline advanced northwards during the warming of the early Holocene, a lowered sea level allowed a belt of tundra to persist around the Arctic basin whereas any future northwards migration of the treeline will further restrict the area of tundra because sea level is expected to rise. Arctic ecosystems are known to be vulnerable to current disturbances and to have long recovery times. Current and predicted environmental changes are likely to add additional stresses and decrease the potential for ecosystem recovery from natural disturbances while providing thresholds for shifts to new states, for example when disturbance opens gaps for invasion of species new to the Arctic.

Changes in Arctic ecosystems and their biota are important to the peoples of the Arctic in terms of food, fuel and culture and potentially could have global impacts because of the many linkages between the Arctic region and those regions further South. Several hundreds of millions of birds migrate to the Arctic each year and their success in the Arctic determines their roles at lower latitudes. Physical and biogeochemical processes in the Arctic affect atmospheric circulation and the climate of regions beyond the Arctic. We know that ecosystems have responded to past environmental changes in the Arctic: we know that current environmental changes are occurring. This understanding indicates that there will be future responses of Arctic ecosystems and species to expected future and ongoing changes in climate. We also know that current levels of UV-B radiation, as well as higher levels, can affect sub-Arctic plants. Arctic plants may be particularly sensitive to increases in UV-B radiation because UV-B damage is not dependent on temperature whereas enzyme-mediated repair of DNA damage could be constrained by low temperatures.

For all these reasons, we need to understand the relationships between ecosystems and the Arctic environment. Although many aspects of the Arctic environment are changing concurrently, for example climate, pollution, atmospheric nitrogen deposition, atmospheric concentrations of carbon dioxide, UV-B radiation and land use, the specific mission of this assessment is to focus on impacts of changes in climate and UV-B radiation on Arctic terrestrial ecosystems and their species and processes.

Our assessment recognizes that the effects of climate are specific to species, age/developmental stages of individuals and processes from metabolism to evolution. We therefore follow a logical hierarchy of increasing organizational biological complexity to assess impacts on species, the structure of ecosystems, the function of ecosystems, and landscape and regional processes. A basic understanding of biological processes related to climate and UV-B radiation is required before we can assess impacts of *changes* in climate and UV-B on terrestrial ecosystems. Consequently, the structure of our assessment progresses from a review of climate and UV controls on biological processes to an assessment of potential impacts of changes in climate and UV-B on processes at the species and regional levels. Some effects of climate change on ecosystems may be beneficial to people, while others maybe harmful.

The changes in climate and UV-B that we use to assess biological impacts are of two types: those already documented and those established from scenarios of UV-B and climate derived from GCMs (Global Climate Models). We assess information on interactions between climate/UV-B radiation and ecosystems based on a wide range of sources derived from experimental manipulations of ecosystems and environments in the field; laboratory experiments; monitoring and observation of biological processes in the field; conceptual modeling using past relationships between climate and biota (paleo analogs), and current relationships between climate and biota in different geographical areas (geographical analogs) to infer future relationships; and process-based mathematical modeling. Where possible, we include indigenous knowledge (limited to published sources) as an additional source of observational evidence.

We recognize that each method has uncertainties and strengths. By considering and comparing different types of information we hope to have achieved a more robust assessment. However, the only certainties of our assessment are that there are various levels of uncertainty with our predictions and that even if we try to estimate the magnitude of these, surprise responses of ecosystems and their species to changes in climate and UV-B radiation are certain to occur.

The key findings of the assessment of climate change impacts on tundra and polar desert ecosystems are listed below and the context in which they were derived is provided in detail in the assessment reports (see Key Publications section).

Key Findings

- The dominant response of current Arctic species to climate change, as in the past, is very likely to be relocation rather than adaptation. Relocation possibilities vary according to region and geographical barriers. Some changes are occurring now.
- Some groups such as mosses, lichens, some herbivores and their predators are at risk in some areas, but productivity and number of species is very likely to increase. Biodiversity

is more at risk in some sub-regions than in others: Beringia has a higher number of threatened plant and animal species than any other ACIA sub region.

- Changes in populations are triggered by trends and extreme events, particularly winter processes.
- Forest is very likely to replace a significant proportion of the tundra and this will have a great effect on the composition of species. However, there are environmental and sociological processes that will probably prevent forest from advancing in some locations.
- Displacement of tundra by forest will lead to a decrease in albedo which increases the positive feedback to the climate system. This positive feedback will generally dominate over the negative feedback of increased carbon sequestration. Forest development will also ameliorate local climate.
- Warming and drying of tundra soils in parts of Alaska have already changed the carbon status of this area from sink to source. Although other areas still maintain their sink status, the number of source areas currently exceeds the sink areas. However, geographical representation of research sites is currently small. Future warming of tundra soils would probably lead to a pulse of trace gases into the atmosphere, particularly in disturbed areas and areas that are drying. It is not known if the circum-Arctic tundra will be a carbon source or sink in the long term, but current models suggest that the tundra will become a weak sink for carbon because of the northward movement of vegetation zones that are more productive than those they displace. Uncertainties are high.
- Rapid climate change that exceeds the ability of species to relocate will very probably lead to increased incidence of fires, disease and pest outbreaks.
- Enhanced CO_2 and UV-B affect plant tissue chemistry and thereby have subtle but long-term impacts on ecosystem processes that reduce nutrient cycling with the potential to decrease productivity and increase or decrease herbivory.

Key Publications

ACIA 2004. Arctic Climate Impact Assessment: Cambridge University Press.

Callaghan, T, V., Björn, L. O., Chernov, Y, Chapin, III. F. S., Christensen, T. R., Huntley, B., Ims, R. A., Johansson, M., Jolly, D., Jonasson, S., Matveyeva, N., Panikov, N., Oechel, W. C., Shaver, G. R. Elster, J., Henttonen, H., Jonsdottir, I. S., Laine, K., Schaphoff, S., Sitch, S., Taulavuori, K., Taulavuori, E. and Zöckler, C. 2004 . Climate Change and UV-B impacts on Arctic Tundra and Polar Desert Ecosystems. *Ambio 33, Number 7, 94 pp.*

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Freshwater Ecosystems (ACIA Chapter 8)

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Introduction

Arctic freshwater ecosystems are particularly vulnerable to climate and UV change impacts. The physical, chemical and biological nature of high-latitude freshwater ecosystems is dominated by pronounced seasonality in weather, the distribution of continuous and discontinuous permafrost, and prominent snow and ice. Widely diverse aquatic biota are well adapted to, and in some instances dependent upon, these environmental variables. Slight changes in temperature and precipitation may result in drastic changes to freshwater ecosystems,. These may occur directly or indirectly through associated terrestrial impacts.

Assessing the impacts of climate change and UV on arctic freshwater ecosystems presents significant challenges. Climate interactions with freshwater systems are complex (Figure 1), as are the potential responses of these diverse systems (i.e., synergistic, cumulative, non-linear, threshold, and feedback effects are likely). Projecting climate change effects on freshwater systems is confounded by a still limited understanding of the structure and function of these systems, but also of the coupling of the climate system to key hydrological and ecological processes.

Figure 1. Interactions between climatic variables, their influence on the biophysical features of freshwater ecosystem habitat, subsequent effects on biological structure and function, and the interaction of feedbacks within and between components.

Given the limited knowledge about aquatic systems, climate change impacts were evaluated using a weight-of-evidence approach. The general hydrological and ecological features of arctic freshwater ecosystems were reviewed, as were historical changes in freshwater systems over the Holocene and recent past. Based on the findings of this historical review and of recent research, the effects of climate change on broad-scale hydro-ecology, ecosystem structure and function, fish, fisheries and aquatic wildlife were assessed. The synergistic effects of effects ultraviolet radiation and contaminants were also addressed.

Key Findings

Changes to runoff and river-ice will alter in-channel, riparian and delta habitats. The most marked impacts will be associated with less pronounced freshet, ice break-up, and flooding as latitudinal temperature gradients decline and as rainfall increases. The effects will include altered channel morphology reflecting a depressed disturbance regime and loss or alteration of riparian, pond and wetland habitats, and reduced species richness and diversity.

Changes to the composition, thickness and duration of ice will also affect freshwater lake habitat. Thermal and radiative regimes of lake waters will very likely shift as ice thins and the ice-free season extends, affecting open water and under-ice habitat. Increased under-ice productivity, rapid spring stratification, reduced circulation, and increased productivity over a lengthened open-water growing season will lead to a loss of habitat as deeper lake waters become increasingly oxygen-depleted. Furthermore, UV damage to organisms and allocation of resources for protection will increase. Changes to timing of freeze-up and melt will affect migratory behavior and reproductive success of some aquatic species.

Changing water levels will also produce important impacts on river, lake and wetland ecosystems. Specifically, rising winter water levels will increase under-ice habitat and affect species abundance and geographic range. Reduced summer water levels due to evaporation and drainage in permafrost degraded landscapes will result in loss of aquatic systems, reduced quality and quantity of aquatic habitat, and promote establishment of terrestrial species. New ponds, wetlands and drainage networks will develop in thermokarst landscapes, creating new habitat and increasing opportunities for the extension of the geographic range of aquatic species northward.

Freshwater habitat and ecosystem productivity will be affected by reductions in permafrost and shifts in vegetation. Productivity will rise and UV exposure decline with increased nutrient, sediment and carbon loading from permafrost-degraded and increasingly vegetated catchments. Enhanced loading of suspended solids may, however, be detrimental to productivity through light-limitation, destruction of aerobic habitat in bottom sediments, and infilling of fish spawning beds.

Degrading permafrost and alteration of vegetation in lake, river and wetland catchments will also affect biogeochemical inputs to and processing within freshwater ecosystems, and the production and consumption of carbon-based gases that may positively feedback to climate change. Biogeochemical cycling will increase as temperatures rise and nutrient- and carbon-enriched runoff from degrading permafrost increases, altering the generation and consumption of trace gases. Though carbon loss from wetlands will likely increase as temperatures rise and soils dry, enhanced vegetation growth will increase carbon sequestration.

The above changes to the physical and biogeochemical nature of arctic freshwater systems will have direct and indirect affects on biodiversity. The magnitude, extent and distribution of these effects will vary with system type and location. This will result in extinctions or loss of certain species, genetic adaptations, alteration of species' ranges and distributions, and increased invasions by southern species. Extension of the geographic range of southern species northward will increase competition for resources and result in increased mortality of northern species due to the introduction of new diseases and parasites. Over time, these effects will likely result in the extirpation of northern species along the southern margins of their geographic ranges.

Changes to the biodiversity and abundance of fishes are of particular relevance to the human population of the Arctic. Likely changes include alteration of species composition with northward migration of southern species, contraction of geographic range of arctic species, and shifts in the balance between migratory (sea-run) and non-migratory (freshwater) forms of many fish species as inland and nearshore waters change. Species that are wholly northern are most vulnerable to change. As fish species and ranges change, fisheries will have to adapt to ensure sustainable populations of northern fishes; the most northerly will potentially be devastated by complete loss of some species. New opportunities for fisheries may, however, occur.

These effects of climate change will be further compounded by cumulative, synergistic and overarching interactions. Decoupling of environmental cues will probably have significant impacts on population processes and the projected rate and magnitude of climate change will outstrip the capacity of many arctic biota, particularly those that are longer-lived (e.g., fish), to adapt or acclimate. Furthermore, climate interactions with contaminants will exacerbate the detrimental effects of climate change, e.g., increased toxic contaminant loadings from melted permafrost and perennial snow and ice, to aquatic systems.

Marine Systems: The Impact of Climate Change (ACIA Chapter 9)

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Approximately 2/3 of the Arctic Region in the ACIA context is comprised of ocean. The Marine Arctic includes the Arctic Ocean and its adjacent shelf seas, as well as the Nordic Seas, the Labrador Sea and the Bering Sea. From a climate change perspective these areas are very important since processes occurring in the Arctic affect the rate of deep-water formation in the convective regions of the North Atlantic, thereby influencing the ocean circulation across the globe. In addition, global climate modeling studies consistently show the Arctic to be one of the most sensitive regions to climate change.

Not surprisingly, many Arctic life forms, including humans, are directly or indirectly dependent on productivity from the sea. Several physical factors make Arctic marine systems unique from other oceanic regions including: a very high proportion of continental shelves and shallow water; a dramatic seasonality and overall low level of sunlight; extremely low water temperatures; presence of extensive permanent and seasonal ice-cover; and a strong influence from freshwater, coming from rivers and ice melt. Some of these factors represent harsh conditions for many types of marine life. Arctic fauna is young, geologically speaking. Recent glaciations resulted in major losses of biodiversity, and recolonisation has been slow because of the extreme environmental conditions and overall low productivity of the Arctic system. This results in Arctic ecosystems, in a global sense, being “simple”. They are composed largely of specialists that have been able to adapt to the extreme conditions and overall species diversity is low. The high seasonal pulse of summer production in the Arctic, during the period of 24 hours light is particularly pronounced near the ice edge and in shallow seas such as the Barents and Bering Sea. This production attracts seasonal migrants that travel long distances to take advantage of Arctic summers and return to the south to overwinter.

Some of the main conclusions are:

- Large uncertainties in the response of the arctic climate system to climate change arise through poorly quantified feedbacks and thresholds associated with the albedo, the THC, and the uptake of greenhouse gases by the ocean. Since climate models differ in their projections of future change in the pressure fields and hence their associated winds, much uncertainty remains in terms of potential changes in stratification, mixing, and ocean circulation.
- The arctic THC is a critical component of the Atlantic THC. The latest assessment by the Intergovernmental Panel on Climate Change (IPCC) considers a reduction in the Atlantic THC likely, while a complete shutdown is considered unlikely but not impossible. If the arctic THC is reduced, it will affect the global THC and thus the long-term development of the global climate system . Reduction in the global THC may also result in a lower oceanic heat flux to the Arctic. If the THC is reduced, local regions of the Arctic are likely to undergo cooling rather than warming, and the location of ocean fronts may change. The five ACIA-designated models cannot assess the likelihood of these occurrences.
- Most of the present ice-covered arctic areas are very likely to experience reductions in sea-ice extent and thickness, especially in summer. Equally important there will very likely be earlier sea-ice melt and later freeze-up. This is likely to lead to an opening of

navigation routes through the Northwest and Northeast passages for greater periods of the year and thus to increased exploration for reserves of oil and gas, and minerals.

- Decreased sea-ice cover will reduce the overall albedo of the region, which is very likely to result in a positive feedback for global warming.
- Upper water column temperatures are very likely to increase, especially in areas with reduced sea-ice cover.
- The amount of carbon that can be sequestered in the Arctic Ocean will likely increase significantly under scenarios of decreased sea-ice cover, through surface uptake and increased biological production.
- Greenhouse gases (CO_2 and CH_4) stored in permafrost may be released from marine sediments to the atmosphere subsequent to warming, thus initiating a strong positive feedback.
- In areas of reduced sea-ice cover, primary production is very likely to increase, which in turn is likely to increase zooplankton and possibly fish production. Increased cloud cover is likely to have the opposite effect on primary production in areas that are currently ice-free.
- The area occupied by benthic communities of Atlantic and Pacific origin will very likely increase, while areas occupied by colder water species will very likely decrease. Arctic species with a narrow range of temperature preferences, especially long-lived species with late reproduction, are very likely to be the first to disappear. A northward retreat for the arctic benthic fauna may be delayed for the benthic brooders (the reproductive strategy for many dominant polar species), while species producing pelagic larvae, will likely be the first to colonize new areas in the Arctic.
- A reduction in sea-ice extent is very likely to decrease the natural habitat for polar bears, ringed seals, and other ice-dependent species, which is very likely to lead to reductions in the survival of these species. However, increased areas and periods of open water are likely to be favorable for some whale species and the distribution of these species is very likely to move northward.
- Some species of seabird such as little auk and ivory gull are very likely to be negatively affected by the changes predicted to occur within the arctic communities upon which they depend under climate warming, while it is possible that other species will prosper in a warmer Arctic, as long as the populations of small fish and large zooplankton are abundant.
- Increased water temperatures are very likely to lead to a northward shift in the distribution of many species of fish and to changes in the timing of their migration, and to a possible extension of their feeding areas, and to increased growth rates. Increased water temperatures are also likely to lead to the introduction of new species to the Arctic but are unlikely to lead to the extinction of any of the present arctic fish species. Changes in the timing of biological processes will likely affect the overlap of spawning for predators and their prey (match/mismatch).
- Stratification in the upper water column is likely to increase the extent of the present ice-free areas of the Arctic, assuming no marked increase in wind strength.
- Present assessments indicate that UV-B radiation generally represents only a minor source of direct mortality (or decreased productivity) for populations, particularly in DOC-protected coastal zones. However, for those species whose early life stages occur near the

surface, it is possible that under some circumstances – a cloudless sky, thin ozone layer, lack of wind, calm seas, low nutrient loading – the contribution of UV-B radiation to the productivity and/or mortality of a population could be far more significant. Thus, it is likely that UV-B radiation can have negative impacts (direct and/or indirect effects) on marine organisms and populations. However, UV-B radiation is only one of many environmental factors responsible for the mortality typically observed in these organisms.

Many aspects of the interaction between the atmosphere and the ocean, and between climate and the marine ecosystem, require a better understanding before the high levels of uncertainty associated with the predicted responses to climate change can be reduced. This can only be achieved through monitoring and research, some areas requiring long-term effort. For some processes, the ocean responds more or less passively to atmospheric change, while for others, changes in the ocean themselves drive atmospheric change. The ocean clearly has a very important role in climate change and variability. Large, long-lived arctic species are generally conservative in their life-history strategies, so changes, even dramatic changes, in juvenile survival may not be detected for long periods. Zooplankton, on the other hand, can respond within a year, while microorganisms generally exhibit large and rapid (within days or weeks) variations in population size, which can make it difficult to detect long-term trends in abundance. Long data series are thus essential for monitoring climate-induced change in arctic populations.

Although the ACIA-designated models all project that global climate change will occur, they are highly variable in their projections. This illustrates the great uncertainty underlying attempts to predict the impact of climate change on ecosystems. The models do not agree in terms of changes projected to wind fields, upon which ocean circulation and mixing processes depend. Thus, conclusions drawn in this chapter regarding future changes to marine systems are to a large extent based on extrapolations from the response of the ocean to past changes in atmospheric circulation. This is also the case for predictions regarding the effects of climate change on marine ecosystems. The present assessment has been able to provide some qualitative answers to questions raised regarding climate change, but has rarely been able to account for non-linear effects or multi-species interactions. Consequentially, reliable quantitative information on the response of the marine ecosystem to climate change is lacking.

Some important gaps in our knowledge are listed below. These require urgent attention in order to make significant progress toward predicting and understanding the impacts of climate change on the marine environment.

- Thermohaline circulation (THC)
- Ocean currents and transport pathways
- Vertical stratification
- Location and intensity of ocean fronts
- Release of greenhouse gases and sequestration of carbon
- Species sensitivity to climate changeatch/mismatch between predators and prey
- Indirect and non-linear effects on biological processes
- Competition when/if new species are introduced into the ecosystem
- Long-term UV-B exposure studies

Principles of Conserving the Arctic's Biodiversity (ACIA Chapter 10)

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Introduction

Biodiversity is fundamental to the livelihoods of Arctic people. The species used range from mammals, fish and birds to berries and trees. However, each of these species also depends both upon a range of other species within the Arctic ecosystems and upon the ecological processes that occur in those ecosystems. The Convention on Biological Diversity defines 'biological diversity' (often shortened to 'biodiversity') as meaning "the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems" This definition clearly implies that biodiversity, and both its conservation and utilisation, must be viewed at three levels - the gene, the species and the ecosystem (or habitat). A changing climate can affect all three of these levels of biodiversity, especially by changing the major ecosystem processes of photosynthesis and decomposition.

Conserving Biodiversity

There are many competing pressures on the ability of an individual, group, organisation or nation to conserve the biodiversity of the Arctic, of which six will be highlighted. First, no species which is native in the Arctic should be allowed to become extinct. Second, genetic variation within these species needs to be conserved because this ensures the greatest chance of the species' adaptation to a changing environment. Third, the ecosystems in which these species occur need to be conserved, because each species is an integral part of a food web (and hence with other species dependent upon it). Fourth, human populations are themselves an integral part of the Arctic's biodiversity and food webs. Fifth, non-native species and external human pressures will present challenges to the Arctic's genes, species and ecosystems, and hence risk assessments are a vital factor in managing such new pressures. Finally, protected areas are not a universal panacea for the conservation of the Arctic's biodiversity, but should be viewed as land and water managed for the primacy of nature in a broader geographical area where other land- and water-uses have primacy.

Predicted Influences of Climate Change

(1) *There will be changes in the geographical ranges of species and habitats.* In a warming environment it might generally be assumed that ranges will move northwards and locally they will move uphill. There will, however, be large differences in the distance moved, depending upon a species' ability to move. New combinations of species that have moved at different speeds might give rise to novel communities. In the sea, the retreat of sea ice northwards will result in the ice-edge species moving northwards. On land, there will be a squeeze, as for the spruce *Picea abies* that is constrained in its northward migration by the barrier of the Arctic Ocean.

(2) *There will be changes in the extent of many habitats.* We know that the response of each of the present-day Arctic habitats is likely to be individualistic, and that it will depend upon the dynamics of the populations and communities, as well as on a host of species interactions such as competition, predation, parasitism, hyperparasitism and mutualism. There is some evidence that changes might be relatively fast, especially in the marine environment. To understand what might occur in the Arctic in the future, the habitats occurring in the sub-Arctic and Boreal zones today offer the best guidance.

(3) *There will be changes in the abundance of Arctic species.* These changes will be complex, depending upon the rate of movement of the species, the amount of habitat available for them, and upon the species' own physiology and biochemistry. For example, experiments have shown that birch (*Betula pendula*) trees grown in elevated CO_2 atmospheres can produce more that half as much more biomass than trees grown in ambient CO_2 atmospheres, and that their roots are associated with a different set of species of mycorrhizal fungi. Sea surface temperatures are also known to have large effects upon the breeding success of seabirds, such as the common guillemot or muree (*Uria aalge*).

(4) *There will be changes in genetic diversity.* It has recently been said that landscape genetics promises to facilitate our understanding of how geographical and environmental features structure genetic variation at both the population and individual levels. Given the fact that there is relatively little knowledge about the genetical variation of most Arctic species, we have to make the assumption that geographical and environmental factors have structured the genetic variation that we have today. This has been verified for the common eider duck (*Somateria mollissima*), in which five major groups have been identified. Because many species in the Arctic are at the edge of their range, where gene flow may be more restricted than in the centre of a species' range, speciation may be occurring and hence the conservation of the gene pool is even more important.

(5) *There will be a change in the behaviour of migratory species.* To avoid the cold of the Arctic winter, species need to adopt a strategy of cold avoidance. Some migrate to warmer environments (e.g. from tundra to forest), whereas others exploit the food resources of the Arctic during the summer breeding season (e.g. many birds such as waders and geese). As the Arctic's biodiversity changes, there will be effects on migratory species. In some instances the breeding habitat might be further from the wintering habitat, necessitating expenditure of more energy. Often birds have 'stopping-off' points in boreal or temperate latitudes between the two ends of the migration route; these could also be affected. It is unknown how the migration routes might change, but such changes could be important for people dependent upon migratory species for their food.

(6) *Some non-native species are likely to become problematic.* To date the Arctic has escaped the major problems that invasive species have caused elsewhere on the planet. Terrestrial environments will be prone to invasions from the south, and there is already some evidence of the movement of insects that can defoliate large areas of sub-Arctic forests. Freshwater environments are susceptible to invasion by fish, often escaping from fish farming cages, and the parasites that are associated with them. Marine environments are prone to the introduction of species in ballast water; with the prospect of the Arctic Ocean being accessible to shipping for more of the year, the probability of accidental introductions of invasive species becomes greater. The risks to the Arctic's biodiversity could be huge and hence extreme precaution is needed when contemplating the introduction of non-native species to the Arctic.

(7) *Protected areas will need to be managed in different ways.* It has been suggested that there are three approaches to managing protected areas under the scenarios of climate change. There are currently about 400 protected areas with extents of greater than 10 km^2 in the Arctic, and

consideration will need to be given to their management. Static management involves the 'business-as-usual' scenario, conserving the current species and communities within the present boundaries, using the existing goals. Passive management would accept the ecological response to climate change, and allow evolutionary processes to take place unhindered. Adaptive management would maximise the capacity of species and communities to adapt to climate change through active management so as to slow the pace of change or to facilitate change to a new climate-adapted state. There could also be schemes of hybrid management whereby two or more of these approaches could be adopted on any one protected area.

Actions Required

What should be done now before the anticipated changes occur? First, it is important to document the current state of the Arctic's biodiversity. We know that the Arctic has about 1735 species of vascular plants, 600 bryophytes, 2000 lichens, 2500 fungi, 75 marine and terrestrial mammals, 240 birds, 3300 insects, 300 spiders, 5 earthworms, and so on. Local inventories of biodiversity have generally not been carried out, though the inventory for Svalbard is a striking exception, recording both native and non-native species in both terrestrial and marine environments. Such work requires trained ecologists, trained taxonomists, circum-Arctic knowledge, and a focus on all three levels (genes, species and ecosystems) of biodiversity.

Second, the changes that take place in the Arctic's biodiversity need to be identified. Ecological succession is a process whereby communities of plants and animals naturally change over time. Management of the Arctic's biodiversity, in the sea, in fresh water, or on land, must work with ecological succession and not against it. In many sciences, modeling has been developed so that predictions can be made. However, where biodiversity is concerned, models have not yet become particularly sophisticated so that there are few predictions. Considerably more effort needs to be invested in developing predictive models that can explore changes in biodiversity under the various scenarios of climate change.

Third, changes in the Arctic's biodiversity need to be recorded and the data shared. In a situation where so much uncertainty surrounds the conservation of biodiversity, knowledge of what has changed, where it has changed, and how quickly it has changed, becomes critically important. Monitoring biodiversity, especially on a circum-Arctic basis, must be a goal, and a circum-Arctic monitoring network needs to be fully implemented so as to determine how the state of biodiversity is changing, what the drivers of change are, and how other species and people respond. It is obvious that only a few aspects of the Arctic's biodiversity can actually be monitored, and hence it becomes important to devise a series of indicators that can be widely monitored. Such indicators should be made publicly available in formats that can inform public opinion, educators, model-builders, decision-makers and policy-makers.

Finally, new approaches to managing the Arctic's biodiversity need to be explored. Best practice guidelines should become available on a circumpolar basis. The Circumpolar Protected Area Network (CPAN) needs to be completed and reviewed so as to ensure that it does actually cover the full range of the Arctic's present biodiversity. An assessment needs to be made for each protected area of the likely effects of climate change, and in the light of this assessment the methods of management for the future and any revisions to the area's boundary determined. However, biodiversity is not confined to protected areas, and hence an ethos of biodiversity conservation needs to be incorporated into all aspects of policy development and all aspects of managing the Arctic's seas, land and fresh waters. This poses questions of resources and priorities, but it is essential that the Arctic's ecosystems continue to exist and function in a way that such services as photosynthesis, decomposition, and purification of pollutants, continue in a sustained manner.

Management and Conservation of Wildlife in a Changing Arctic (ACIA Chapter 11)

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Climate changes in the Arctic in the past have had major influences on the ebb and flow in availability of wildlife to indigenous peoples and thus have influenced the distribution of peoples in the Arctic and the development of their cultures. As northern cultures have developed, their relationships to wildlife also were influenced beyond strictly subsistence dependency through trade or other economic relationships, both internal to their own cultures and with other cultures. Trade in animal parts, especially skins and ivory of marine mammals; the semi-domestication of reindeer; and trapping and sale of fur-bearing animals go far back in time. Over the last two to three centuries cash income has sometimes become important from selling meat and hides and as well as through home industries producing saleable craft items from animal parts. Wildlife in the Arctic is valued by many who live outside of the Arctic for its attraction for viewing and photographing (especially whales, sea birds, polar bears, and caribou), for incorporation in art depicting the arctic environment, and for associated tourism. Sport and trophy hunting of wildlife bring many to the Arctic with associated economic benefits to local residents through services they provide. Others value the Arctic through virtual recognition of and fascination for the role of wildlife species in the dynamics of arctic ecosystems, many of whom may never visit the Arctic but learn about arctic wildlife through the printed and visual media. Responsibility for management and conservation of wildlife in the Arctic clearly falls heavily on the residents of the Arctic, but also on the global community that shares in the use of arctic resources and the appreciation for wildlife and other values of the arctic environment. A sense of global stewardship toward the Arctic is critical for the future of Arctic wildlife and its peoples.

Throughout most of the Arctic, natural ecosystems are still functionally intact (Chapters 6-8) and threats to wildlife typical for elsewhere in the world – extensive habitat loss through agriculture, industry, and urbanization – are absent or are localized. Similarly, introduced and invading alien species are scarce. However, change in the Arctic is accelerating. Contaminants from the industrialized world to the south have reached arctic food chains, threatening the health and reproduction of some marine mammals and birds and the humans who include them in their diets. Energy and mineral extraction developments in the Arctic, although localized and widely scattered, nevertheless contribute to the pollution and contamination of the waters, atmosphere, and lands of the Arctic and result in local loss of wildlife through habitat destruction, excessive hunting, and other cumulative impacts. Protection of critical wildlife habitats in the Arctic is becoming increasingly recognized as essential for both the conservation of arctic wildlife and its sustainable harvest by residents of the Arctic as pressures from outside of the Arctic for exploitation of its resources increase.

Management of wildlife and its conservation, as practiced in most of the Arctic, is conceptually different than at lower latitudes where management efforts often focus on manipulation of habitats to benefit wildlife. Residents of the Arctic have in the past often seen little apparent justification for conventional wildlife management and have resisted additional systems for wildlife management and conservation imposed from outside of the Arctic, particularly when these systems rely heavily on new and strange technologies and are based on unfamiliar tenets.

Increased emphasis by those living outside of the Arctic on conservation of the flora and fauna of the Arctic has focused on maintaining the Arctic's biodiversity, valuing all its ecosystem components and relationships. This has understandably appeared hypocritical to many arctic indigenous peoples dependent on sustainable harvest of arctic wildlife and in view of their past resistance to over exploitation of marine mammals and birds for oil and skins to serve interests outside of the Arctic. Thus, some indigenous peoples have questioned the justification for wildlife management in the Arctic as a discrete aspect of ecosystem or land use management. In other areas, systems of co-management have developed, giving local residents a greater role in the practice of wildlife management if not in determining the premises on which it is based.

Throughout much of the Arctic, harvesting of wildlife for food and furs through hunting and trapping has, nevertheless, been the most conspicuous influence that residents of the Arctic have had on arctic wildlife in recent decades. It was the overexploitation of wildlife during the period of arctic exploration and whaling in the 18^{th} and 19^{th} centuries that led to the extinction of the Steller's sea cow in the Bering Sea and the great auk in the North Atlantic, and drastic stock reductions and local extirpation of several other terrestrial and marine mammals and birds. In many regions of the Eurasian Arctic, the adoption of reindeer herding by indigenous hunting cultures led to the extirpation or marked reduction of wild reindeer (caribou) and drastic reductions of wolves, lynx, wolverines, and other potential predators of reindeer. In recent decades heavy grazing pressure by semi-domestic reindeer has altered plant communities in parts of the Fennoscandian and Russian Arctic. This has in some areas been exacerbated by encroachment of timber harvest, agriculture, hydroelectric development, and oil and gas exploration within traditional grazing areas. Large-scale extraction of nonrenewable resources has accelerated in the Arctic during the latter half of the past century with impacts on some wildlife species and their habitats, especially in Alaska from oil production, in Canada from mining for diamonds and other minerals, and in Russia primarily from extraction of nickel, apatite, phosphates, oil, and natural gas.

Among the factors that influence arctic wildlife, harvest of wildlife through hunting and trapping is potentially the most manageable, at least at the local level. Indigenous peoples throughout much of the North are asserting their views and rights in wildlife management, in part through increased political autonomy over their homelands. However, people still feel largely powerless to control influences on wildlife and wildlife habitats brought about through climate change, or large-scale resource extraction in both the marine and terrestrial environments, changes largely resulting from the effects of humans living outside of the Arctic.

Along with the increasing political autonomy of indigenous peoples of the Arctic in recent decades, these arctic residents are starting to influence when, where, and how industrial activity may take place in the Arctic. Part of this process has been the consolidation of the efforts of indigenous peoples across national boundaries to achieve a greater voice in management of wildlife and other resources through international groups such as the Inuit Circumpolar Conference (ICC) and the Indigenous Peoples Secretariat (IPS) of the Arctic Council. The stage appears to be set for indigenous peoples of the Arctic to become major participants in the management and conservation of arctic wildlife. The legal institutions, however, encompassing treaty and land rights and other governmental agreements vary regionally and nationally throughout the Arctic posing differing opportunities and constraints on how structures for wildlife management and conservation can be developed.

Conservation of wildlife in the Arctic requires sound management and protection of wildlife habitats at the local, regional, and national levels if the productivity of those wildlife populations that arctic peoples are dependent upon is to be sustained. Wildlife populations and their movements in both the marine and terrestrial environments transcend local, regional, and national boundaries, thus successful management and conservation of arctic wildlife must also transcend political boundaries through international agreements and treaties. Many of the pressures on arctic wildlife originate outside of the Arctic, such as contaminants in marine wildlife, habitat alteration through petroleum and mining developments, and climate changes resulting from increases in greenhouse gases. It seems clear that responsibility for maintaining the biodiversity that characterizes the Arctic, the quality of its natural environment, and the productivity of its wildlife populations must be exercised through global stewardship.

Effective wildlife management and associated conservation in a changing Arctic requires:

- Inclusion of arctic residents in the monitoring, inventory, and regulation of harvest and conservation of wildlife.
- Inventory of wildlife populations and their habitats for assessing changes in distribution, movements, and population trajectories that may be the consequence of climate change or other human-induced changes in the natural environment.
- Restructuring of wildlife management systems in the Russian North that remain unchanged since the Soviet era.
- Development of regional land and water use plans that enable layout of proposed human activities on the land, such as roads, communities, other structures, and their cumulative effects to avoid conflicts with critical habitats of wildlife, their movement corridors, and patterns of human use of the wildlife.
- Areas designated to protect critical wildlife habitat units may at times need to be altered through expansion, relocation, or removal of protection in response to major changes in wildlife distribution and habitat use brought about through climate-induced or other changes in the land and marine environments.
- The international or bi-national nature of many species of marine wildlife requires international efforts in the development of marine area use and agreements to assure protection of critical habitats for marine wildlife.
- Understanding that marine ecosystems are more difficult to study and less well known than terrestrial ecosystems and require more complex and costly research efforts if arctic wildlife in the marine environment is to be effectively conserved and managed.

Hunting, Herding, Fishing and Gathering: Indigenous Peoples and Renewable Resource Use in the Arctic (ACIA Chapter 12)

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This paper summarises some of the key findings of Chapter 12 of the Arctic Climate Impact Assessment, which deals with terrestrial and marine resource use by indigenous peoples. Indigenous peoples throughout the Arctic maintain a strong connection to the environment through hunting, herding, fishing and gathering renewable resources. These practices provide the basis for food production and have endured over thousands of years, with cultural adaptations and the ability to utilize resources often associated with or affected by seasonal variation and changing ecological conditions.

Climatic variability and weather events often greatly affect the abundance and availability of animals and thus the abilities and opportunities to harvest and process animals for food, clothing and other uses. Many species are only available seasonally and in localized areas and indigenous cultures have developed the capacity and flexibility to harvest a diversity of animal and plant species. They have, in many cases, also shown resilience in the face of severe social, cultural and economic change, particularly in the last one hundred years.

The longstanding dependence of contemporary indigenous societies on hunting, herding, fishing and gathering continues for several critically important reasons. One main reason is the economic and dietary importance of being able to access customary, local foods. Many of these local foods – fish, and meat from sea mammals or caribou and birds, for instance, as well as berries and edible plants – are nutritionally superior to the foodstuffs which are presently imported (and which are often expensive to buy). Another reason is the cultural and social importance of hunting, herding and gathering animals, fish and plants, as well as processing, distributing, consuming and celebrating them.

These activities remain important for maintaining social relationships and cultural identity in indigenous societies. They define a sense of family and community and reinforce and celebrate the relationships between indigenous peoples and the animals and environment upon which they depend. Hunting, herding, fishing and gathering activities are based on continuing social relationships between people, animals and the environment. As such, they link people inextricably to their histories, their contemporary cultural settings, and provide a way forward for thinking about sustainable livelihoods in the future.

Arctic communities have experienced, and are experiencing, stress from a number of different forces that threaten to restrict harvesting activities and sever these relationships. The Arctic regions are tightly tied politically, economically and socially to the national mainstream and are inextricably linked to the global economy. Rapid social, economic and demographic change, resource development, trade barriers and animal-rights campaigns have all had their impacts on hunting, herding, fishing and gathering activities.

For many Arctic residents, consuming food from animals is fundamentally important for personal and cultural well-being. Indigenous peoples have reported their loss of vitality, decline in health and personal well-being when they are unable to eat traditional/country foods. These problems do not only emerge when climate change denies people access to traditional/country foods, but are very much linked to problems associated with the undermining of local modes of production. The erosion of a person's position as a provider of welfare to family and community also has serious ramifications.

The conservation of Arctic wildlife and ecosystems depends in part on maintaining the strength of the relationship between indigenous peoples, animals and the environment, and securing the rights of indigenous peoples to continue customary harvesting activities. As the ACIA shows, these activities and relationships appear to be threatened by severe climate change. The potential impacts of climate change on harvesting wildlife resources are of fundamental concern for the social and economic well-being, the health and cultural survival of indigenous peoples throughout the Arctic, who live within institutional, legal, economic and political situations that are often quite different from non-indigenous residents. Furthermore, indigenous peoples rely on different forms of social organisation for their livelihoods and well-being. Many of these concerns about climate change arise from what indigenous peoples are already experiencing in some areas, where climate change is an immediate and pressing problem, rather than something that may happen, or may or may not have an impact in the future.

The aims of Chapter 12 are:

- to discuss the contemporary economic, social and cultural importance of harvesting renewable resources for indigenous peoples;
- to provide an assessment of how climate change has affected, and is affecting, harvesting activities in the past and in the present;
- through a selection of detailed case studies based on extensive research with indigenous communities in several Arctic settings, to discuss some of the past, present and potential impacts of climate change on specific activities and livelihoods.

The case studies in Chapter 12 (from Alaska, Yukon, Northwest Territories, Nunavut, and the Russian North) have been selected to provide a sense of what impacts climate change is having in the present, or could have in the near future on the livelihoods of indigenous people, and is illustrative of the common challenges faced by indigenous peoples in a changing Arctic.

Part of the purpose of Chapter 12, although not its primary aim, is also to assess what adaptations have enabled communities to succeed in the past and what extent these options remain open to them. There is little data published on this area, but based on what is available the chapter shows that while indigenous peoples have often generally adapted well to past climate change, the scale and nature of current and predicted climate change brings an altogether different sense of uncertainty for indigenous peoples, presenting different kinds of risks and threats to their livelihoods.

Chapter 12 illustrates the complexity of problems faced by indigenous peoples today and underscores the reality that climate change is but one of several, often intersecting problems affecting their livelihoods. The chapter emphasises the urgency for further extensive, regionally-focused research on the impacts of climate change on hunting, herding, fishing and gathering activities, research that will not only contribute to a greater understanding of climate impacts, but will place these impacts within a broader context of rapid, social and economic change.

Fisheries (ACIA Chapter 13)

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Introduction

This chapter deals largely with the effects of climate change on commercial fisheries and the impacts of these on society as a whole (see Chapters 9, 10 and 11 on implications for indigenous peoples). Arctic fisheries of selected species are described in the following regions: the Northeast Atlantic consisting of the Barents and the Norwegian Seas; the waters around Iceland and Greenland; the waters off northeastern Canada; and the Bering Sea. The species discussed are: first, those few species, which are circumpolar (capelin, Greenland halibut, northern shrimp and polar cod); and, second, those additional species, which are of commercial importance in specific regions. These species include stocks of Atlantic cod, haddock, Alaska pollock, Pacific cod, snow crab and a number of others. Because marine mammals play an important role in northern marine ecosystems and can be commercially important, they are also considered in this chapter.

Methods

In order to identify the possible effects of climate change on fish stocks and the fisheries based on them in the Arctic, selected case studies from the 20th Century involving both the effects of cooling and warming of the marine environment have been used. However, there are several possible caveats that one must be aware of when attempting to interpret such case studies. The most important of these are:

1) Commercial fisheries in Arctic regions are based on a number of species belonging to ecosystem complexes. The dynamics of these ecosystems are not well understood in many cases. This imparts a significant degree of uncertainty to evaluating future response of individual species and stocks to climate change.
2) It has historically proven difficult in many cases to identify the relative importance of fishing and the environment on changes in fish populations and biology and current fish populations are different in abundance and biology from those in the past due to anthropogenic effects (exploitation rates).

As a result it is uncertain whether current fish populations will respond to climate changes as they may have in the past.

Once the fish population changes have been evaluated, an attempt was made to relate those changes to economic and other changes in society. That introduces a third set of methodological challenges, as social change is driven by a number of factors, of which environmental change is but one.

Conclusions

On balance it appears likely that a moderate warming (up to 3˚C) will improve conditions for some of the most important commercial fish stocks, as well as for aquaculture, in Arctic regions (see Chapter 8). This will likely take place through more primary production due to less ice coverage and more extensive habitat areas for sub-Arctic species like cod and herring. There is also some chance that global warming will induce an ecosystem regime shift in some areas with a different species composition. Changing environmental conditions are also likely to be deleterious for some species and beneficial for others. Therefore, relative population sizes, rates of fish growth and geographical distribution of fish stocks are likely to be altered. Adjustments will then have to be made in the Arctic commercial fisheries. Unless there is a dramatic climatic change over a very short time period, these adjustments are likely to be relatively minor and will probably not entail major economic and social costs.

In this chapter the possible effect of global warming on four major ecosystems, i.e, the Northeast Atlantic (Barents and Norwegian Seas), the central North Atlantic (Iceland/Greenland), Northeast Canada (Newfoundand/Labrador) and the North Pacific (Bering Sea) is considered. There are substantial differences between these regions in that the Barents and Norwegian Seas and Icelandic waters are of a sub-Arctic/temperate type, while Arctic influence is much greater in Greenland waters, off NE-Canada and in the Bering Sea. It follows, therefore, that climate warming need not affect all of these areas in the same or similar manner. Furthermore, the length of useful time series on historical environmental variability and associated changes of hydrobiological conditions, fish abundance and migrations vary greatly from one region to another. And, finally, there are differences in species interactions and variable fishing pressure, which have to be considered.

Due to heavy fishing and stock depletions, the Barents Sea, Icelandic waters and probably also the Bering Sea could, through more efficient management, yield larger catches of many fish stocks. For that to happen research must be increased, and cautious management strategies must continue to be implemented and complied with. A moderate warming could enhance the processes of rebuilding stocks and, furthermore, generally result in higher sustainable yields of most stocks, i.e. through enlarged distribution areas and increased availability of food in general. On the other hand, warming could also cause fish stocks to change their migratory ranges and area of distribution. As history has demonstrated, this could trigger conflict among nations over distribution of fishing opportunities and require tough negotiations to arrive at viable solutions as regards international regimes fisheries management.

Greenland and NE-Canadian waters are very different cases. These are much more Arctic in nature and e.g. Greenlandic waters appear not to be able to support more temperate species like cod and herring except during warm periods. For Greenland, there are examples from the 20^{th} Century that demonstrate this point. No cod in the first two and a half decades, a large local self-sustaining cod stock from about 1930 and until the late 1960s, apparently initiated by larval and 0-group drift from Iceland. With a climatic status quo nothing much can be expected to change at Greenland. On the other hand, a 'moderate warming' like that of the 1920s, resulting in warm conditions which lasted until the late 1960s, could bring about some dramatic changes in species composition, a scenario where cod would play the most important role by far and double the value of exported goods. The NE-Canadian case is an extreme example of a situation where a stock of Atlantic cod, (the so-called northern cod), which had sustained a large fishery for at least two centuries, is suddenly gone. Opinion differs with regard to how this could have happened, where some believe that inhospitable environment is the main cause while others hold the view that the stock appears to have simply been fished out. In this case it is worth noting that the Newfoundland-Labrador ecosystem is open, i.e. there are no temperature barriers, to the south and west. In earlier times of climatic adversities the northern cod could therefore have backed out and then repopulated its earlier distribution areas when conditions improved again. In the present situation, however, the northern cod is so depleted that, due to its slow growth rate, it will very likely take decades to rebuild – even under the conditions of a warming climate.

The economic and social impacts of altered environmental conditions and their effects on fish stocks depend crucially on the ability of the relevant social structures, not the least the fisheries management system, to generate the necessary adaptations to the changes. It is unlikely that the impact of global warming in the 21st Century, as signaled by the 'moderate' scenarios used here, will have long-term economic or social impacts on a national scale. A possible exception is the large boost to the national economy of Greenland should a large local cod stock and fishery, like that of the mid 20th Century, recur.

Certain regions in the Arctic, i.e. those heavily dependent on fisheries or marine mammals and birds in direct competition with a fishery may, however, be radically affected. Local communities in the north are however exposed to a number of forces of change. Economic marginalization, depopulation, globalization-related factors and public policies in the different countries, are most likely going to have a stronger impact on the future development of northern communities than a moderate climate change, at least in the foreseeable future.

An evaluation of what could happen should climate warming proceed beyond what here is defined as moderate (plus 1°-3°C), is not attempted. This is beyond the existing range of available data and would therefore be of limited value. In general terms, however, it is likely that at least some of the ecosystems would experience reductions in the present-day commercial stocks which, on the other hand, might be replaced partially or in full by species from warmer waters.

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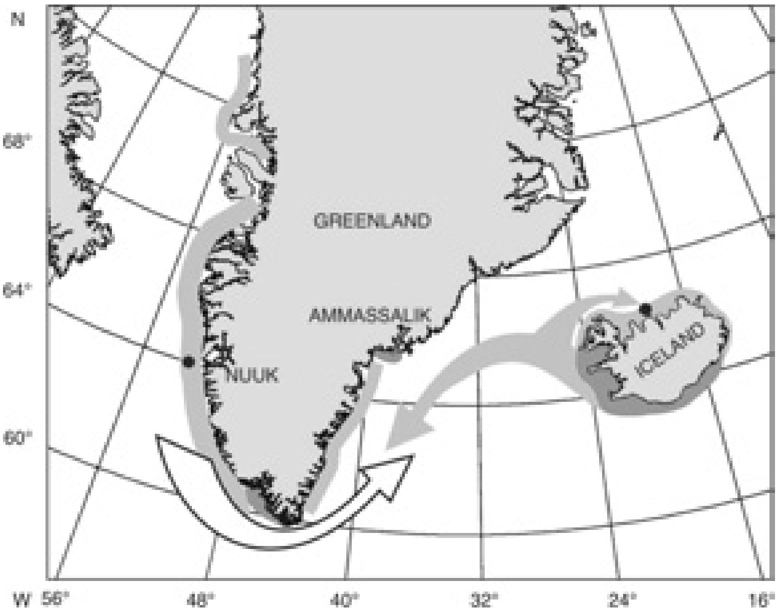

Figure 1. The arrows show the drift of cod larvae and 0-group to Greenland and return spawning migrations during the warm period 1920-1965). The light grey shaded area at Greenland shows the maximum extent of cod distribution during the latter half of the warm period 1920-1965. Before 1920 only a few cod had been found near Cape Farewell and Ammassalik (dark grey shade). Adapted from Vilhjalmsson 1997

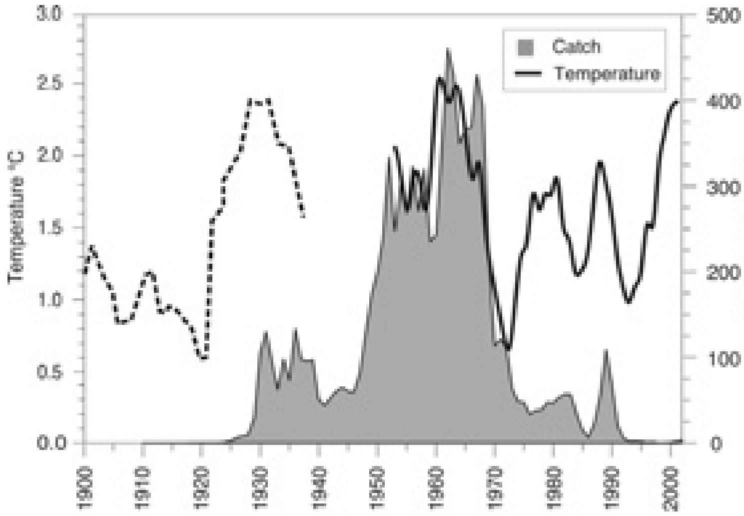

Figure 2. Temperature variations west of Nuuk (black dot in Fig. 1) and the cod catch from W-Greenland waters 1900-2002. Overfishing greatly accelerated the rapid decline of this stock in the late 1960s and the early 1970s. Adapted from Buch et al. 1994 with later data added.

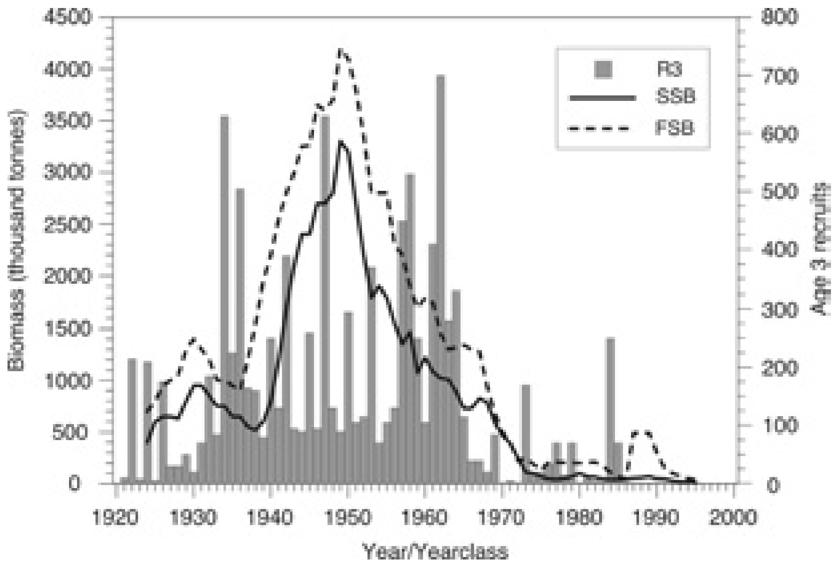

Figure 3. Fishable and spawning stock biomass and recruitment to the W-Greenland cod stock 1920-2000. This cod stock produced very large year classes from the mid-1930s until the mid-1960s. After that, almost all recruitment to the W-Greenland cod is the result of larval drift from Iceland in 1973 and 1984. Adapted from Buch et al. 1994 with later data added.

Boreal Forest and Agricultural Responses to Climate Warming (ACIA Chapter 14)

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Introduction

The boreal region covers about 17% of the earth's land surface area. The boreal forest affects Earth's climate through carbon uptake and release and albedo. Boreal forests influence global levels of atmospheric carbon dioxide and other greenhouse gasses by taking up CO2 in growth, and storing carbon in live and dead plant matter and releasing carbon through decomposition of dead organic matter, live plant and animal respiration, and combustion during fire. Humans influence carbon uptake and storage by rearrangement of forest age classes, timber harvest, suppression of wildfires, selection of tree species, fertilisation, and thinning regimes. Residents of the boreal region depend on the products and resources of the forest for traditional ways of life that have become impractical to follow elsewhere on earth. Agriculture has existed in the ACIA region for well over a millennium, and today consists of a mixture of commercial agriculture on several thousand farms and widespread subsistence agriculture.

Methods

The ACIA analysis included a review and synthesis of primary scientific and resource management literature. Primary data sets included the record of key climate variables at 14 sites broadly distributed across the boreal region and chosen to represent major population, trade, or transportation centers. The analysis examined output of 5 GCM model scenarios for the grid cells containing the 14 sites for mean monthly temperature, total monthly precipitation, and Growing Degree Days (GDD). Tree-ring data sets from northern trees provide a direct record of the relationship between past climate and above-ground forest growth and projections of future growth.

Conclusions

In the period between 9000 and 7000 B.P. trees occurred in at least small groups in what is now treeless tundra nearly all the way to the Arctic coastline across the Russian north. Mean July temperature along the Russia Arctic coastline was 2.5 to 7.0^{0}C higher than currently. Past forest advance during suggests similar treeline change is likely in scenarios that produce similar levels of warming, and that ecosystems present today have the capacity to respond and adjust to such climate fluctuations. At 6000 BP (the Postglacial thermal maximum) northern treeline on the Taymir Peninsula, which is currently the farthest north in the world, was at least 150 km further north than at present. In northeast Canada the black spruce forest limit of Quebec has remained stable during the last 2000-3000 yr BP, but in recent decades milder winters have permitted low stems to emerge into the upright form. In the Polar Ural Mountains, larch reproduction is associated with warm weather, and newly established trees have measurably expanded forest cover during the 20th century, although there is a time lag between warming and upslope treeline movement. At about 6000 BP, ring growth of larch trees on the Taymir Peninsula of Russia surpassed the average of the last two millennia by 1.5 to 1.6 times. Tree growth and warm season temperature irregularly decreased in northernmost Eurasia and North America from the Postglacial thermal maximum through the end of the 20th century. Long-term tree-ring chronologies record a Medieval Warm Period about one thousand years ago, a colder Little Ice Age ending about 150 years ago, and various types of climate change involving warming more recently. Recent decades are the warmest in at least a millennium. Temperature and tree growth records generally change at the same time and in the same direction across much of the Arctic and Subarctic, although opposite temperature and tree growth trends occur in specific subregions.

All the scenarios produce warming within the boreal region greater than reconstructions of climate for nearly the last 1000 years. Climate warming in the last several decades is already associated with both improved and decreased current (not projected) boreal tree growth, depending on species, site type, and region. Some tree growth declines are large in magnitude and have been detected at different points across a wide area (although the total extent of declines has not been delineated) as the result of temperature-induced drought stress. Other tree growth declines are not currently explained. Reduced growth by high temperatures is common in treeline white spruce of western North America, suggesting less potential for treeline movement under a warming climate than previously believed. Boreal forest tree growth is increasing in some locations, generally where moisture and nutrients are not limiting such as boreal regions of Europe and eastern North America. The 5 GCM scenarios produce climates that apparently would not allow the growth of commercially valuable white spruce types and widespread black spruce types in Alaska and probably western boreal Canada, based on empirically calibrated measurements. The upper range of scenario conditions represent climates that may have crossed ecological thresholds, and it is possible that novel ecosystems could result as happened during major periods of global climate change in the past. If additional moisture were available, trees on many of the driest sites would not be as stressed as current temperature relationships indicate.

Large-scale forest fires and outbreaks of tree-killing insects are naturally characteristic of the boreal forest, are triggered by warm weather, and promote many important ecological processes. Boreal forests are a major storehouse of carbon in trees and soils, containing approximately 20% of the world's reactive soil carbon, an amount similar to that held in the atmosphere. On a global basis, atmospheric carbon equal to 15-30% of annual emissions from fossil fuels and industrial activities is taken up annually and stored in the terrestrial carbon sink. During the years 1981-1999, it is estimated that the three major factors affecting the terrestrial carbon sink were biomass carbon gains in the Eurasian boreal region and North American temperate forests, and losses in areas of the western North American boreal forest. Recent patterns of boreal forest disturbance are consistent with a climate warming influence expressed as 1) a greater frequency of fire or insect outbreaks, 2) more extensive areas of tree mortality, and 3) more intense disturbance resulting in higher average levels of tree death or severity of burning.

Carbon uptake and release at the stand level in boreal forests is strongly influenced by the interaction of nitrogen, water, and temperature influences, acting together, on forest litter quality and decomposition. Warmer forest soil temperatures that occur following the death of a forest canopy by disturbance increase the rate of organic litter breakdown, and thus the release of elements for new plant growth (carbon uptake). The most likely mechanism for significant short-term change in boreal carbon cycling as a result of climate change is the control of species composition caused by disturbance regimes. Successional outcomes from disturbance have different effects on carbon cycling especially because of the higher level and availability of nutrient elements (and thus decomposition) in organic litter from broadleaf trees compared to conifers. Net global land use/land cover change, especially aggregate increases or decreases in the area of forest land, may be the most important factor influencing the terrestrial sink of carbon.

Different crops species, and even varieties of the same species can exhibit substantial variability in UV-B sensitivity. In susceptible plants, UV-B causes gross disruption of photosynthesis, and may also inhibit plant cell division. Damage by UV-B is likely to accumulate over the years in trees. Evergreens receive a uniquely high UV dose in the late winter, early spring, and at the beginning of the short growing season because they retain vulnerable leaf structures during this period of maximum seasonal UV-B exposure which is amplified by reflectance from snow cover. UV-B radiation plays an important role in the formation of secondary chemicals in birch trees at higher latitudes. Secondary plant chemicals released by willows exposed to UV-B might stimulate the herbivore resistance of birch. A lower level of animal browsing on birches because of this chemical change induced by UV-B could possibly improve the performance of birch over its woody plant competitors.

The five GCM scenarios all produce rising temperatures that would very likely enable crop production to advance northward throughout the century, with some crops now suitable only for the warmer parts of the boreal region becoming suitable as far north as the Arctic Circle. Average annual yield of farms would likely increase at the lower levels of warming due to climate suitability for higher yielding crop varieties and lower probabilities of low temperatures limiting growth. However, in warmest areas, increased heat units during the growing season may cause a slight decrease in yields since warmer temperatures can speed crop development and thereby reduce the amount of time organic matter (dry measure) is accumulated. Under scenario conditions, water deficits are very likely to increase or appear in most of the boreal region, the main exceptions being portions of eastern Canada, Iceland, and western Scandinavia, which experience the strongest maritime influence on their climates. In the later scenario period, unless irrigation is practiced, water stress would very likely negatively impact crop yields. Water limitation may become more important than temperature limitations for many crops in much of the region. Overall negative effects would not likely be stronger than positive effects on agriculture. Lack of infrastructure is likely to remain a major limiting factor for commercial agricultural development in the boreal region in the near future, and climate warming that thawed permafrost would affect land transportation routes. Shipping across the Arctic Ocean could fundamentally change the costs of shipping cargoes that affect agriculture. If climate warming is associated with migration of people northward, the larger resident population base is likely to stimulate the agricultural sector, ultimately expanding and improving infrastructure which would improve economic potential of agriculture. Even under scenario levels of climate warming, government policies regarding agriculture and trade will still have a very large, and perhaps decisive, influence on the occurrence and rate of agricultural development in the north.

Climate Change and Health in the Circumpolar North: Findings from the Arctic Climate Impact Assessment (ACIA Chapter 15)

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The nature of predicted climate related changes and variability, and characteristics of Arctic populations means that impacts of climate change on the health of Arctic residents will vary considerably depending on such factors as age, gender, socioeconomic status, lifestyle, culture, geographic location, and capacity of local health infrastructure and systems to adapt. It is more likely that populations living in close relationship with the land, in remote communities and those that already face a variety of health related challenges will be most vulnerable to climate changes in the future. Health status in many Arctic regions has changed significantly in the past decades related to a variety of factors and climate, weather and environment has had, and will likely continue to have a significant role in health in these regions in the future.

In the assessment of health impacts of climate change in the North conducted for the Arctic Climate Impact Assessment a number of *direct* and *indirect* impact mechanisms were identified and described. In this sense "direct impacts" refers to *those health consequences resulting from direct interactions with aspects of the environment that have changed or are changing with local climate* (i.e. resulting from direct interactions with physical characteristics of the environment: air, water, ice, land; e.g. exposure to thermal extremes). "Indirect impacts" refer to those health consequences resulting from indirect interactions mediated via human behaviors and components of the environment that have changed or are changing with local climate.

Direct health impacts may result via changes in the incidence of extreme events (avalanches, storms, floods, rockslides) which have the potential to increase the numbers of deaths and injuries each year. Direct impacts of winter warming in some regions may include a reduction in cold-induced injuries such as frostbite and hypothermia and a reduction in cold stress. As death rates are higher in winter than summer months, milder winters in some regions could reduce the number of deaths. Direct negative impacts of warming could include increased heat stress in summer months and accidents associated with unpredictable ice and weather conditions.

Indirect impacts from climate change in circumpolar communities may include increased mental and social stress related to changes in the environment and lifestyle and potential changes in bacterial and viral proliferation, vector borne disease outbreaks, as well as changes in the access to quality drinking water sources. Additionally, some regions may experience a change in the rates of illnesses resulting from impacts to sanitation infrastructure from melting permafrost and increased storm surges. Impacts to individuals' food security through changes in animal distribution and accessibility has the potential to have significant impacts on health as shifts from a more traditional diet to a more "western" diet are know to be associated with increase risks of cancers, diabetes, and cardiovascular disease.

Increased exposure to UV among Arctic residents has the potential to impact immune system's response to disease, influence skin cancer development and non-Hodgkins lymphoma as well as the development of cataracts. However, as the current rates of many of these ailments are low in small Arctic communities it is difficult to detect, let alone, predict any trends in their incidence in the future. Currently, the presence of environmental contaminants threaten the safety of traditional food systems, which in many cases are the central fabric of communities. Potential influence of shifts in temperature can affect transport to, distribution within and the chemical behaviour of environmental contaminants and therefore human exposure to these substances in northern regions.

It is critical to understand that these potential, and in some cases, currently observed changes are taking place in a context of social, economic, and physical change and evolution throughout the North. They therefore represent yet another source of stress on societies and cultures as they impact the relationship between people and their environment which is a defining element of many northern cultures. Through potential increases in factors influencing acculturative stress and mental health, climate related changes may further stress communities and individual psychosocial health.

Communities must be prepared to understand, document, and monitor changes in their area in order to adapt to shifts in their local environment now and in the future. The basis of this understanding is the ability to collect, organize and understand information indicative of the changes taking place and their potential impacts. To this end, a series of community indicators are proposed in the ACIA Health Chapter to support this development of capacity within northern regions and communities.

Climate Change and Arctic Infrastructure (ACIA Chapter 16)

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Introduction

This chapter discusses the potential impacts of climate change on Arctic infrastructure. Infrastructure is defined as facilities with permanent foundations or the essential elements of a community. It includes schools; hospitals; various types of buildings and structures; and facilities such as roads, railways, airports, harbors, power stations, and power, water, and sewage lines. Infrastructure forms the basis for regional and national economic growth.

Particular concerns are associated with permafrost warming and degradation, coastal erosion, the stability and maintenance of transportation routes, and industrial development.

Climate change is likely to have significant impacts on existing Arctic infrastructure and on all future development in the region. In most cases, engineering solutions are available to address climate change impacts, making the issue more of an economic than a technological one. It is possible that the uncertainty associated with projections of future climate change will increase the cost of new projects in the Arctic.

There are increased concerns related to the impact of projected climate change on Arctic infrastructure, particularly how future climate change may:

- increase the environmental stresses structures are exposed to, particularly in comparison to design specifications, and cause increased risk and damage to infrastructure and threat to human lives;
- affect natural hazards and the impacts of extreme events; and
- affect development scenarios for exploitation of natural resources in the Arctic.

Various aspects of changing climate on Arctic infrastructure are discussed in this presentation. Adaptation, mitigation and monitoring techniques that are necessary to minimize the potentially serious detrimental impacts are discussed.

Permafrost

Projected climate change is possible to be a factor in engineering projects if its effects go beyond those anticipated in the existing conservative approach. Therefore, engineering design should take into account projected climate change where appropriate and where the potential effects represent an important component of the geothermal design.

Permafrost engineers must address the problem of preserving infrastructure under projected future climate conditions. One solution is to construct new buildings as existing ones are damaged and abandoned. It is possible that this method will be inadequate, since the required rate of new structures rises exponentially using the climate projections presented in this assessment. In areas of warm, discontinuous permafrost, it is very difficult to find economic solutions to address the impacts of climate change on foundations or structures. These areas, together with the coastal zone, present the greatest challenges in a changing climate.

The sensitivity of permafrost soil strength to projected climate change can be mapped using a simple strength sensitivity index, such as the one proposed in this section. A risk-based procedure for analyzing structures based on their sensitivity to the potential consequences of climate change is a reasonable approach to incorporating climate change concerns into the design process.

Coastal Zone

The Arctic has approximately 200000 km of coastline, most of which is uninhabited. However, coastal development is critical to the economy and social well-being of nearly all Arctic residents.

Arctic coastal dynamics are often affected directly or indirectly by the presence of permafrost. Permafrost coasts are especially vulnerable to erosive processes as ice beneath the seabed and shoreline melts from contact with warmer air and water. Thaw subsidence at the shore allows additional wave energy to reach unconsolidated erodible materials. Low-lying, ice-rich Arctic permafrost coasts are the most vulnerable to thaw subsidence and subsequent wave-induced erosion.

Coastal communities are sensitive to climate change. Engineering solutions are available for shore protection (flood barriers, dikes, breakwaters, erosion control) but may not be able to reduce erosion rates sufficiently to save specific settlements. Moreover, while these protective measures may address one problem, they may create another by altering the dynamics of erosion and deposition processes. The combined problems of increased wave action, sea level rise, and thermal erosion have no simple engineering solutions, face the greatest challenge from a warming climate.

Thinner, less extensive sea ice is very likely to improve navigation conditions along most northern shipping routes, such as Canada’s Northwest Passage and Russia’s Northern Sea Route. However, decreasing sea-ice extent and thickness is very likely to affect traditional winter travel and hunting where sea ice has been used for these purposes.

With increased marine access to Arctic coastal seas, national and regional governments are likely to be called upon for increased services such as icebreaking assistance, improved sea-ice charts and forecasting, enhanced emergency response capabilities for sea-ice conditions, and greatly improved oil-ice cleanup capabilities. The sea ice, although thinning and decreasing in extent, will possibly become more mobile and dynamic in many coastal regions where land-fast ice was previously the norm. Competing marine users in newly open or partially ice-covered areas in the Arctic are likely to require increased enforcement presence and regulatory oversight.

Based on the scenarios presented in this chapter, a longer navigation season along the Arctic coast is very likely and trans-Arctic (polar) shipping is possible within the next 100 years.

Natural Hazards

Projected increases in temperature, precipitation, and storm magnitude and frequency are very likely to increase the frequency of avalanches and landslides. In some areas, the probability of severe impacts on settlements, roads, and railways from these events is very likely to increase.

Structures located on sites prone to slope failure are very likely to be more exposed to slide activity as groundwater amounts and pore water pressures increase.

An increasing probability of slides coupled with increasing traffic and population concentrations is very likely to require expensive mitigation measures to maintain a defined risk level. The best way to address these problems is to incorporate the potential for increasing risk in the planning process for new settlements and communication lines.

Engineering Design and Climate Change

In continuous permafrost, projected climate change is not likely to pose an immediate threat to the infrastructure. This assumption is only valid if the correct permafrost engineering design procedures have been followed; the infrastructure has not already been subjected to one of the factors mentioned at the beginning of this section or strains exceeding design values; and the infrastructure is not located on ice-rich terrain or along coastlines susceptible to erosion. Maintenance costs are likely to increase compared to the present, but it is possible to gradually adjust Arctic infrastructure to a warmer climate.

Projected climate change is very likely to have a serious effect on existing infrastructure located in areas of discontinuous permafrost. Permafrost in these areas is already at temperatures close to thawing, and further temperature increases are very likely to have extremely serious impacts on infrastructure. However, considerable engineering experience with discontinuous permafrost has been accumulated over the past century. Human interaction (such as pollution issues, fires, removing vegetation) and engineering construction very often lead to extensive thawing of both continuous and discontinuous permafrost. Techniques to address warming and thawing are already commonly used in North America and Scandinavia.

If the projections and trends presented in this assessment are borne out over the next five to ten years, this is very likely to have a serious impact on the future design of engineering structures in permafrost areas. However, engineering design should still be based on actual meteorological observations and a risk-based method.

The most important engineering considerations related to projected climate change include:

- risk-based methods should be used to evaluate projects in terms of potential climate change impacts;
- design air thawing and freezing indices should be updated annually to account for observed climate variations and change; and
- mitigation techniques such as artificial cooling of foundation soils should be considered as situations require.

Natural Resources

Climate impacts on oil and gas development have been minor so far, but are likely to result in both financial costs and benefits in the future. For example, offshore oil exploration and production is likely to benefit from less extensive and thinner sea ice because of cost reductions in the construction of platforms that have to withstand ice forces. Conversely, ice roads, now used widely for access to offshore activities and facilities, are likely to be useable for shorter periods and less safe than at present. The thawing of permafrost, on which buildings, pipelines, airfields, and coastal installations supporting oil development are located, is very likely to adversely affect these structures and the cost of maintaining them.

The coal and mineral extraction industries in the Arctic are important parts of national economies, and the actual extraction process is not likely to be affected much by climate change. However, climate change will possibly affect the transportation of coal and minerals in both a positive and negative sense. Mines that export their products using marine transport are likely to experience savings due to reduced sea ice and a longer shipping season. Conversely, mining facilities with roads on permafrost are likely to experience higher maintenance costs as the permafrost thaws.

Any expansion of oil and gas activities and mining is likely to require expansion of air, marine, and land transportation systems. The benefits of a longer shipping season in all Arctic areas, with the possibility of easy transit through the Northern Sea Route and Northwest Passage for at least part of the year, are likely to be significant. Other benefits are likely to include deeper drafts in harbors and channels as sea level rises, a reduced need for ice strengthening of ship hulls and offshore oil and gas platforms, and a reduced need for icebreaker support. Conversely, coping with greater wave heights, and possible flooding and erosion threats to coastal facilities, is likely to result in increased costs.

Climate Change in the Context of Multiple Stressors and Resilience (ACIA Chapter 17)

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Climate change occurs amidst myriad social and environmental transformations, some of which interact with climate change and help to determine its ultimate effects. The vulnerability of a human-environment system in the face of climate change, for example, depends upon multiple stresses on the system, the ways in which they interact with climate change, and the ability of the system to respond. Conceptual frameworks and analytical methodologies to examine these complex dynamics are now available. This chapter uses one such approach, namely vulnerability analysis, to carry out an initial phase of assessment for three case studies. Two of the case studies provide a cursory overview of multiple stresses, vulnerability and resilience for Sachs Harbour, NWT, Canada and coastal Greenland. The third case study provides a more in-depth analysis for Sámi reindeer herding in Finnmark, Norway. The case studies focus on multiple and interacting stresses acting on human-environment systems and the capacities of such systems to respond effectively. The stresses examined are climate change and concentrations of metallic and organic pollutants in the environment. Factors affecting vulnerability and resilience include coping and adaptive strategies, many of which reflect Arctic residents' cultural evolution through generations of experience in a highly variable environment. Largely in recognition of this latter point, this chapter focuses upon the livelihoods and well-being of indigenous peoples. It illustrates the importance of understanding stressor interactions; the need for methodologies that facilitate their characterization and analysis; and, most crucially, the need for vulnerability assessments to include the knowledge and viewpoints of local people and other decision-makers in the analyses.

Full assessments for communities in Sachs Harbour and coastal Greenland, require in-depth investigations into what the people living in these areas view as key concerns and how these residents perceive interrelations among, for example, natural resources and resource use, climate change, pollution, regulations, markets, and transnational political campaigns. This information will contribute to analysis and understanding of adaptation and coping, historically, presently, and in the future. For the Finnmark case next steps should include attaining a more complete understanding of interrelations among reindeer herding, climate change, and governance and how reindeer herders might respond to consequences arising from changes in these factors. This particular case highlights a number of other areas for future and/or continued investigation. These include analysis of the prospect that governmental management authorities or herders might respond to certain environmental and social changes in ways that could either enhance or degrade the reindeer herding habitat, and a more in-depth inquiry into extreme events and their implications for sustainable reindeer herding.

A comprehensive picture of the vulnerability and resilience of Arctic human–environment systems in relation climate change and other changes will benefit from further development of case studies, longer periods of longitudinal analysis, and more comprehensive research with interdisciplinary teams. Such assessments must include local peoples as full participants. Case studies should be selected to provide information across a wide array of human-environment systems and conditions so as to enable comparative work across sites. This will lead to improved understanding of resilience and vulnerability throughout the rapidly changing Arctic.

A Brief Summary and Synthesis of the Arctic Climate Impact Assessment (ACIA) (ACIA Chapter 18)

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Introduction

Chapter 18 of the Arctic Climate Impact Assessment (ACIA) provides a brief summary of the main conclusions of the 17 ACIA chapters. The chapter has three main parts. In the first part the conclusions are discussed chapter by chapter. Observed climate trends (Chapters 2 and 3, the latter on indigenous observations) are summarized. Projections of climate change over the 21st century, based on emission scenarios and computer model simulations (Chapter 4), are described, as are the observed and expected changes in stratospheric ozone and in UV radiation (Chapter 5).

Climate Change

Briefly, the observed temperature changes in the Arctic over the five-decade period from 1954-2003 range from a 2-3˚C warming in Alaska and Siberia to a cooling of up to 1˚C in southern Greenland. Winter temperatures are up to 4-5˚C warmer in Siberia and in the western Canadian Arctic. Composite five-model projections of annual temperatures show a fairly uniform warming of 2-4˚C throughout the Arctic by the end of the century, with a slightly higher warming of up to 5˚C in the East Siberian Sea. Summer temperatures are 1-2˚C warmer over land, with little change in the central Arctic Ocean, where sea ice melts each summer, keeping the ocean temperature close to 0˚C. Winter temperatures show the greatest warming of about 5˚C over land, and up to 8-9˚C in the central Arctic Ocean, where the feedback due to reduced sea ice is largest.

Arctic-Wide Impacts

The chapter summarizes Arctic-wide consequences of climate change, by examining the impacts on the environment (Chapters 6 on the cryosphere, Chapter 7 on terrestrial ecosystems, Chapter 8 on freshwater ecosystems, Chapter 9 on the marine system, and Chapter 10 on nature conservation). Impacts on people's lives are described in Chapter 11 on conservation and management, Chapter 12 on hunting and fishing, and Chapter 17 on multiple stress impacts. Impacts on economic sectors are described in Chapter 13 on fisheries, Chapter 14 on forestry and agriculture, Chapter 15 on human health, and Chapter 16 on infrastructure. These impacts cut across the entire Arctic and are generally not dependent on resolving regional details. For example, the timing, intensity, and magnitude of the melting of snow and ice under a warmer climate will have widespread implications for the entire Arctic and the global environment, even if these changes vary regionally.

Projected major large-scale environmental changes in the Arctic are illustrated in Fig. 1, which shows the existing and projected boundaries of sea ice, permafrost, and the tree line. The likely changes associated with these shifts are numerous and dramatic, as described in the chapters of the ACIA. For example, the map indicates that the tree line will reach the Arctic Ocean, as projected for most of Asia and western North America by the end of the century. This implies that there will be a near total loss of the tundra vegetation in these areas, with very important consequences for many types of wildlife. The consequences of permafrost thawing and sea ice reductions, as shown in Figure 1, have equally dramatic consequences.

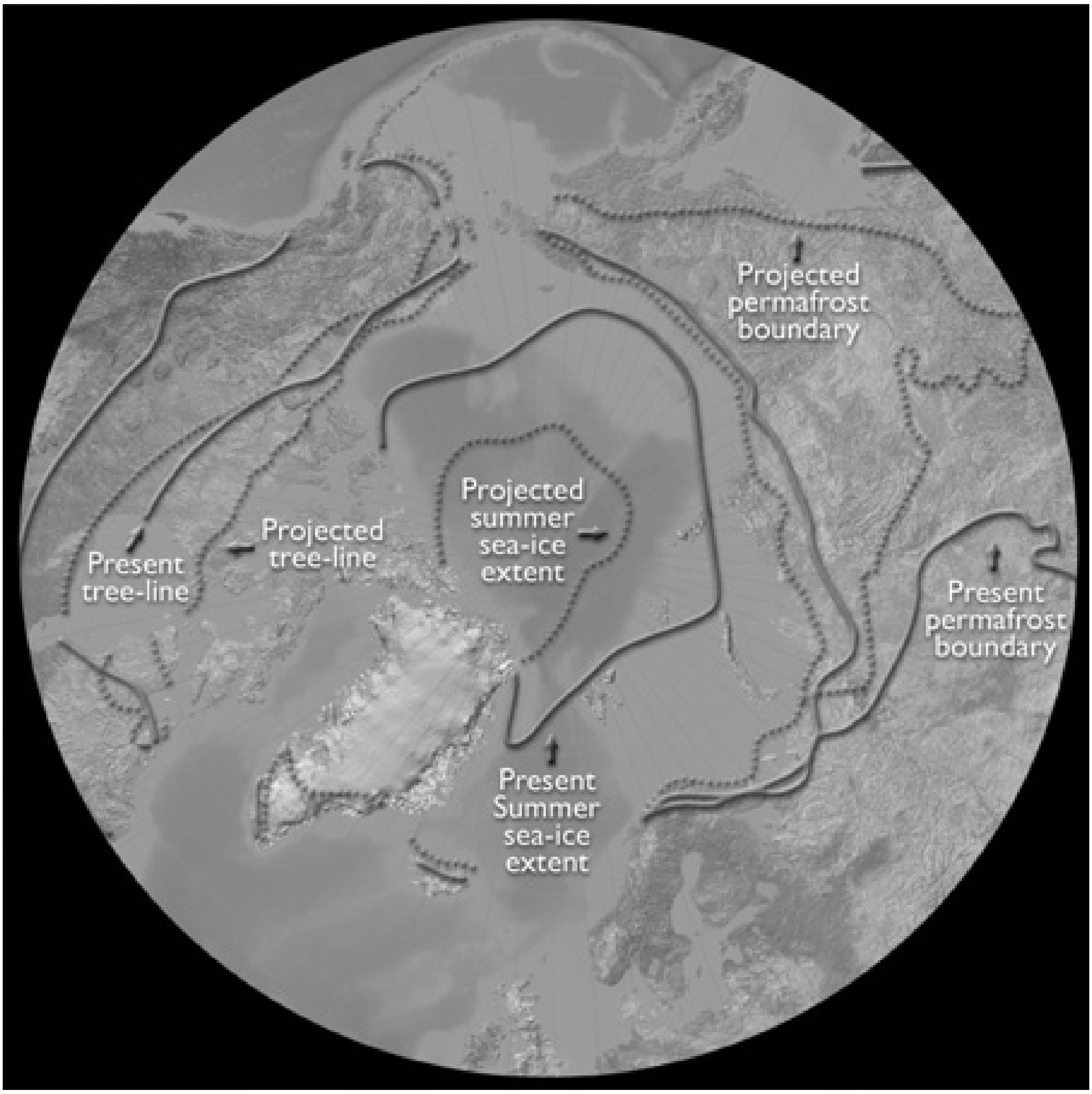

Figure 1. Map of the Arctic, showing present and projected boundaries of summer sea ice, permafrost, and the tree line. The projected changes will occur over different time periods. Changes in summer sea ice extent will occur by the end of the century, as projected by the five-model composite used by the ACIA. The projected changes in the tree line by the end of the century are from the Hadley model. The change in the permafrost boundary assumes that the present areas of discontinuous permafrost will be free of any permafrost in the future; this is likely to occur beyond the 21st century but it is not certain how long it will take.

Regional Impacts

The second part of the chapter is a synthesis of impacts on a local and regional basis, providing details on four different regions (or sub-regions) of the Arctic. This regional emphasis is necessary because the Arctic covers a large area and hence experiences significant regional variations in the changes in climate that will lead to different impacts and responses. Different regions also have different social, economic, and political systems, which will each be influenced in its own way, causing vulnerability and impacts to differ to a large extent on the basis of geopolitical and cultural boundaries. The four different regions in the Arctic for which results are presented are:

1. East Greenland, North Atlantic, northern Scandinavia, northwestern Russia
2. Siberia
3. Chukotka, Bering Sea, Alaska, western Canadian Arctic
4. Central and eastern Canadian Arctic, Labrador Sea, Davis Strait, West Greenland.

The rationale for selecting these four broad regions includes climatic, social, and other factors.

The third and final part of the chapter deals with broad crosscutting issues that are important in the Arctic. These are discussed in several chapters of the assessment, although usually in the context of the main topic of the chapters, and include the carbon cycle, biodiversity, and extreme and abrupt climate change.

Global Implications

Changes in climate and UV radiation in the Arctic will not only have far-reaching consequences for the arctic environment and its people, but also have to be viewed in a broader context since they will affect the rest of the world, including the global climate. These connections include arctic sources of change affecting the globe, e. g. feedback processes affecting the global climate, sea level rise resulting from melting of arctic glaciers and ice sheets, and arctic-triggered changes in the global thermohaline circulation of the ocean.

The Arctic is also important to the global economy. There are large oil and gas and mineral reserves in many parts of the Arctic, and arctic fisheries are among the most productive in the world, providing food for millions. Future openings of arctic shipping routes are likely to have benefits for the global economy and other North-South connections of consequence include the migratory birds, fish and mammals that are important conservation species in the South. The Arctic plays a unique role in the global context and climate change in the region has consequences that extent well beyond the Arctic.

The Changing Arctic Climate: Historical Observations and Recent Explanations

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Recent warming in the Arctic has similar magnitude as several historical events, but has greater geographic extent. Changes in atmospheric circulation play the crucial role.

Temperature anomalies in the last 15 years are unique in the Arctic instrumental record (1880—2003). Historically, there were regional/decadal warm events during winter and spring in the 1930s to 1950s, but meteorological analysis shows that these surface air temperature(SAT) anomalies are the result of intrinsic variability in regional flow patterns, as contrasted with the Arctic-wide Arctic Oscillation (AO) influence of the 1990s. Long-term changes in SAT from 59 weather stations north of 64°N are most evident in spring, with cool temperatures before 1920 and Arctic-wide warm temperatures in the 1990s. The recent decades are unique in having the greatest longitudinal extent of SAT anomalies and in their associated weather patterns.

Figure 1 shows the time evolution of surface air temperature anomalies for the 59 weather stations (x-axis) and over time (y-axis) for December—January and April. Figure 2 shows polar projection maps of surface air temperature and sea level pressures for particular years and seasons. Only the spring in the 1990s has Arctic-wide warm anomalies and an Arctic-wide influence from low sea level pressure.

These changes are primarily driven by changes in atmospheric circulation, and thus are subject to north/south gradients in hemispheric radiative forcing. Atmospheric circulation is sensitive to changes in radiative forcing in the sub-tropics from volcanic aerosols, insolation cycles and CO2 increase. Temperature advection in the trough-ridge structure of the AO in the North Atlantic establishes wintertime temperature anomalies in the adjacent regions, while the zonal/annular character of the AO in the remainder of the Arctic must break down in spring to promote meridional temperature advection.

Figure 3 shows the global temperature anomalies in the winter following the eruption of Mt. Pinatubo (Robock 2003). Note the warm anomalies over northern Eurasia; north/south differences in radiative forcing favor the positive phase of the North Atlantic Oscillation, which then results in wintertime warming. Figure 4 shows a conceptual model of what factors influence changes in Arctic atmospheric circulation. The circulation itself is very chaotic involving feedbacks between storms and the mean flow field (polar vortex). However, the statistics of the polar vortex can be influenced by subtropical processes and by feedbacks within the Arctic.

Change is likely to be irreversible over the next decades, as the Arctic has locked in 20% changes in tundra and sea ice reduction, northward shifts in ocean temperature, and ozone chemistry. While many of the results noted in the ACIA report can be traced to shifts in atmospheric circulation, their cumulative effect over the last two decades has produced changes in surface conditions felt by the atmosphere, such as albedo, surface temperature, and moisture and heat fluxes; the long-term trends in many Arctic variables support the concept that current conditions are moderating the former year-to-year range of Arctic weather, and thus provide persistence to current trends. Figure 5 shows the Arctic Oscillation index. Note the return to near normal values after 1996. A paradox is that the broad changes for the Arctic noted by ACIA are continuing, while atmospheric circulation indices have returned to near normal. Please consult the online version of the extended abstract for color versions of the figures. More complete information is found in Overland et al. (2004a) and Overland et al. (2004b).

We appreciate the support of the NOAA Arctic Research Office

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Figure 1

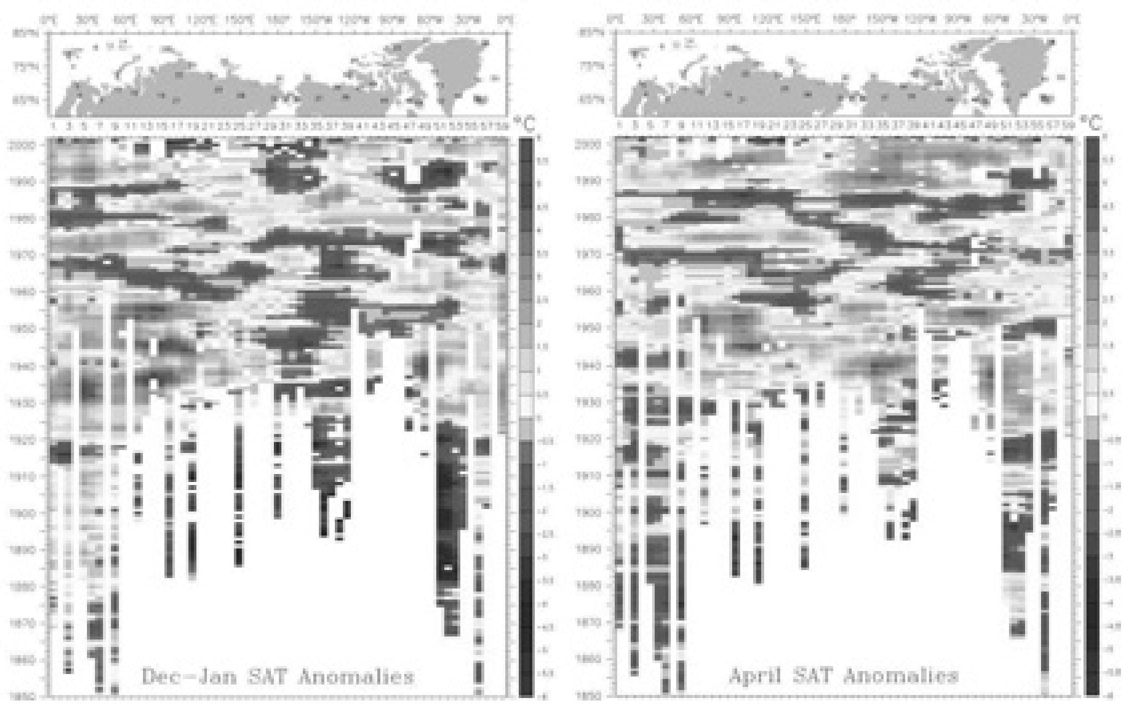


Figure 2

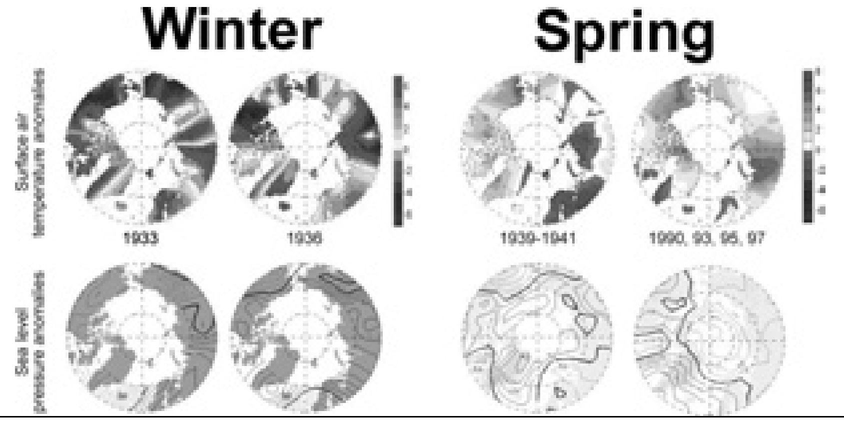


Figure 3

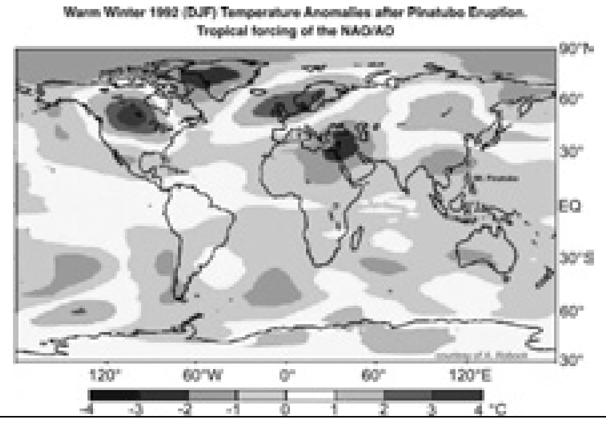


Figure 4

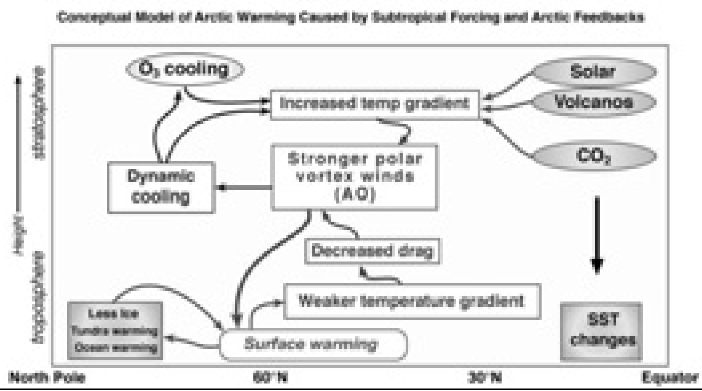
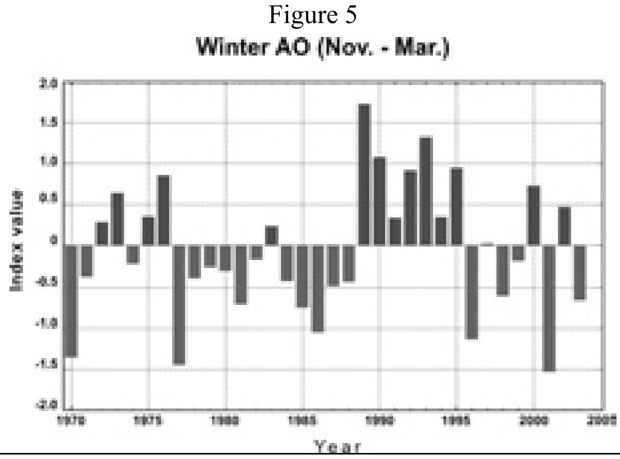


Figure 5



Spatial and Temporal Mapping of Temperature Variability in Iceland since the 1870's

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Abstract

Using data from the archives of the Icelandic Meteorology Office (IMO) timeseries of monthly mean temperature anomalies (from 1961 to 1990 climatology) have been constructed for several stations. This procedure has been applied to 10 weather stations with records starting in the late 1890's. In one case discontinuous records extend as far back as the early 1820s. Furthermore, these anomalies have also been calculated for more than 80 stations that were in continuous operation between 1961 and 2000. Using this data gridded maps of monthly anomalies were constructed. These maps provide a convenient way to examine changes in temperature in Iceland in the last century. Calculating differences of pentad means, linear trends and the EOFs of these maps shows the dominant patterns of temperature change and calculating the areal average of the temperature anomaly yields a temperature anomaly timeseries. Using series of maps thus obtained, we examine the spatial and temporal characteristics of temperature change in the Icelandic records.

Introduction

When the Icelandic Meteorological Office (IMO) was founded in 1920 it inherited an observation network that had been maintained by the Danish Meteorological Institute since its inception in 1872. The number of stations in this network varied, but was usually between 15 and 20. The IMO network was expanded in the next decades, and during the 30 year period from 1961 to 1990, more than 80 manned weather stations were simultaneously in operation (see Figure 1). Of these stations, a few have been in continuous operation since the late 19th century (solid circles in Figure 1), but several more stations from the 1920s onwards (triangles in Figure 1).

For each station, monthly anomalies from 1961 – 1990 climatology were calculated. The monthly station anomalies were then interpolated to a grid using the Kriging interpolation method [1]. This work was done separately for the period 1961 to 2000 using the dense network of stations, and also starting in 1898 using a network of 10 stations. The dense network provides a good estimation of the areally averaged temperature changes in the last 40 years of the 20th century, and the 10 station network can be used to calculate areally averaged changes in the mean temperature throughout the 20th century. The two timeseries compare favorably in the period of overlap (see Figure 2).

Results

Figure 2 shows timeseries of areally average temperature anomalies calculated using 1961 – 1990 as a reference period. The figure shows the timeseries from Stykkisholmur, which has reconstructed data from 1823 to 1845 and continuous measurements thereafter [2,3]; from 1898 onwards the figure shows the areal average of a 10 station network, and from 1960 an average of 85 stations.

First, there is an amazing agreement between the data from Stykkisholmur and the areally averaged curves. This shows that for annual averages, one station can be a good indicator of temperature changes for a larger region (the dimensions of Iceland are roughly 300 by 500 km), however, one should note that the annual curves average out seasonal and spatial variability. Second, the extremes in the early part of the record from Stykkisholmur are suspicious (especially the warming observed in 1828 which may be an artifact of the way the thermometer is known to have been mounted).

In examining the figure, one is immediately struck by the scale of the warming during the 1920s and 30s. The lowest annual temperatures from 1925 to 1945 are similar to temperatures that were previously the warmest observed. There is a cool period in the late 1960s which coincides with the years of the Great Salinity Anomaly (GSA), when sea ice was prevalent during late winter along the north coast, and there is another cold period in the late 1970's with 1979 being the coldest year of the 20th century. Incidentally, this winter was the last period with heavy ice conditions during the 20th century. There is a warming trend during the last 20 years of the record.

The spatial characteristics of this recent warming trend are shown in Figure 3. It shows the annual mean temperature from 1996 to 2000 minus the average from 1976 to 1980. The figure clearly shows that in the last decades of the 20th century, all of the country warmed, but the warming was greatest in the north-eastern part. Similar spatial pattern was seen for seasonal averages. Generally speaking, the predominant winds in Iceland are either south-westerlies or north-easterlies. A pattern such as that seen in Figure 3 is consistent with either an enhanced frequency of SW winds which would warm the country as a whole, but preferentially warm the NE due to Föhn effects, or the pattern could be due to a reduced frequency of NE winds, but these tend to cool the northern coast. The two mechanisms do obviously not exclude each other, but in general this pattern resembles the one eigenmode for the temperature field in Iceland, which is a SW-NE dipole. The map in figure 3 is produced using all the stations shown in Figure 1, but a similar map is obtained from the 10 station network (filled circles in Figure 1).

The spatial pattern of warming during the early part of the 20th century is shown in Figure 4. The warming is clearly greater during this period than for the period shown in Figure 3. In both cases, however, all of the country warms, but the warming is enhanced in the NE part of the country. However, the warming in Figure 4 is greater along most of the northern coast, whereas the results in Figure 3 show enhanced warming predominantly on the NE coast. Examining the period 1916 to 1940 in through differences of pentad means revealed that between 1916-20 and 1921-25 the warming was predominantly along the north coast, and only later acquired a SW-NE character.

Discussion

Timeseries of temperature change in Iceland since the 19th century show a period of rapid warming following the 1920s. Similar warming is observed in global averages, but in Iceland the temperature change was greater and was more abrupt. From the 1950s temperatures in Iceland had a downward trend with a minimum reached during the GSA years in the late 1960s and again in 1979. Since the 1980's, Iceland has experienced considerable warming, although temperatures at the end of the 20th century had not reached values comparable to those observed in the 1930s.

Comparison of the spatial pattern of the warming in the 1920s and 1930s with temperature changes in the last 20 years, shows systematic differences. Recent warming has spatial characteristics that resemble the first eigenmode of the temperature field in Iceland (i.e., a SW-NE dipole), whereas the rapid warming in the early part of the 20th century is more complex. During the first part of the rapid warming it is greater along the north shore than along the south shore (has an N-S character to it) and only later acquires an SW- NE character. The N-S pattern may be due to the climatic influences of sea ice. During the GSA years when winter sea ice was prevalent along the north coast, the cooling on the north coast far exceeded that further south. In 1918, exceptional amounts of sea ice occurred along the Icelandic coast, and the early phase of the warming that followed is likely to reflect a shift from sea-ice conditions to more normal conditions. The air temperature in Iceland is greatly influenced by advection of warmer air from the south [4,5]. Proximate causes for differences in warming patterns can thus further be linked to differences in the large scale circulation patterns.

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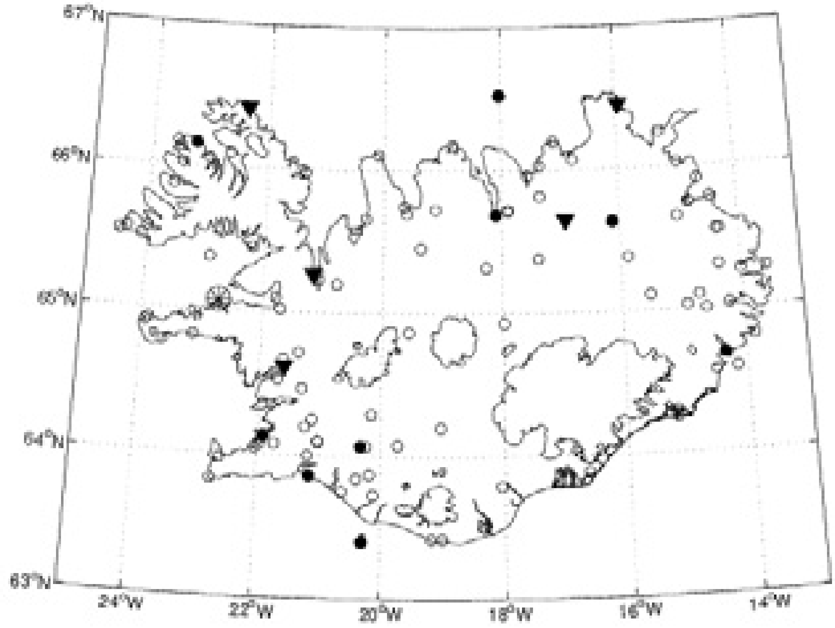

Figure 1. Station network. All stations on the figure were in operation between 1961 and 1990. The stations marked with a filled circle where operational throughout the entire 20th century. The station at Stykkisholmur, marked with an asterix has data since 1823.

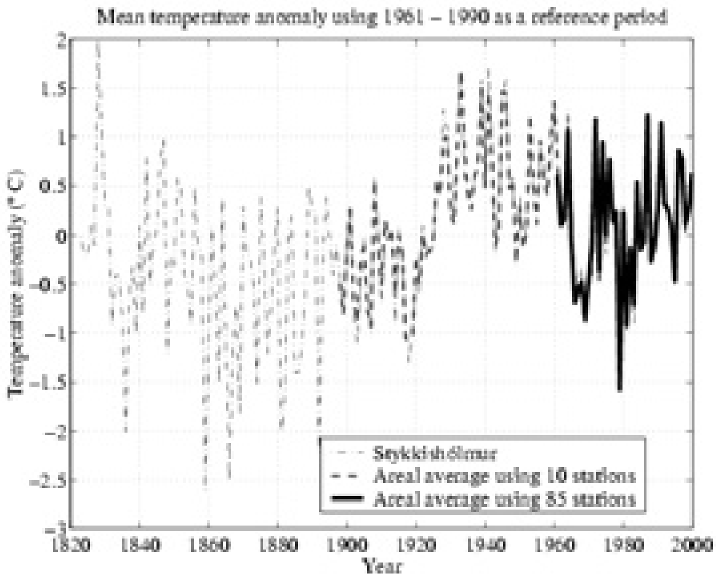

Figure 2. Temperature variations in Iceland since the early 19th century. Shown are annual anomalies from 1961 to 1990 climatology. The thin line shows results from Stykkisholmur, the thicker dashed line shows the areal average obtained using 10 stations that were in operation during all of the 20th century. The solid line shows the results obtained using more than 80 stations.

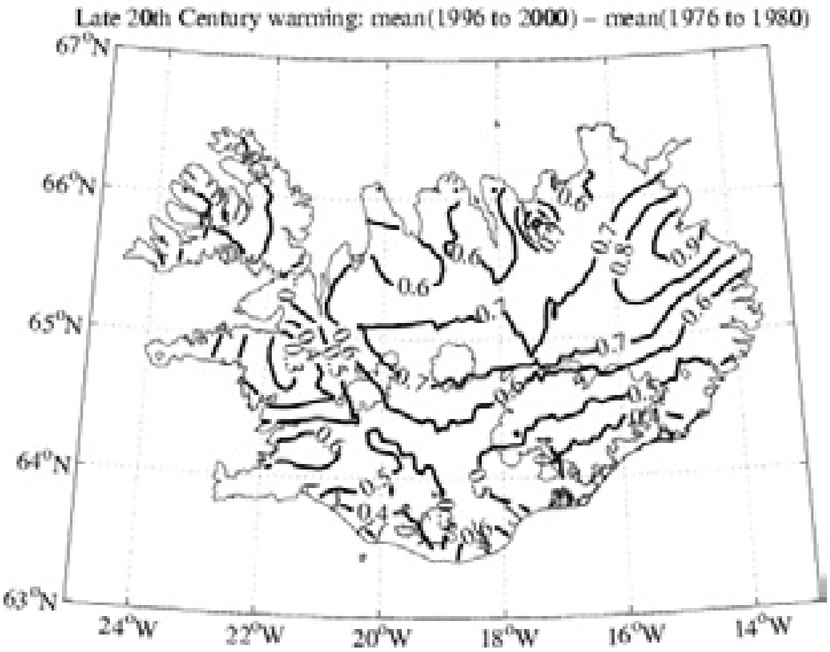

Figure 3. Temperature change in Iceland during the last decades of the 20th century. The figure shows the 1996 to 2000 average minus the 1976 to 1980 average.

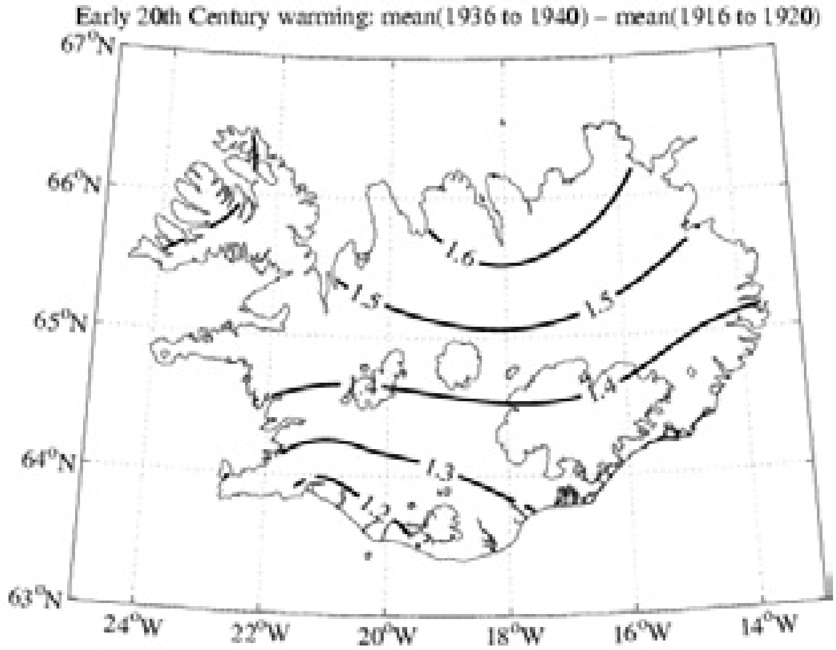

Figure 4. Temperature change in Iceland during the rapid warming phase in the first half of the 20th century. Shown is the 1936 to 1940 average minus the 1916 to 1920 average, The data used is comes from the 10 station grid.

Joint Roles of the Panarctic Shelf Break and Retreating Summer Ice in Arctic Warming

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[3] (Deceased) Woods Hole Oceanographic Institute, Woods Hole, MA, USA

Large continental shelves comprise about 50% of the surface area of the Arctic Ocean, and play a key role in establishing property distributions within the arctic basin (Aagaard et al., 1999). For a great part of the year the ocean is covered by ice, and this significantly affects hydrographic conditions and the dynamics of wind forcing. As such, the efficiency of shelf/basin exchange (SBE) in the Arctic Ocean is strongly moderated by the location of the ice edge relative to topography, and this in turn affects heat, salt, nutrient and carbon budgets. Summer melt-back, which proceeds from the coast seaward, currently allows only brief exposure of the ocean surface to upwelling or downwelling favourable winds. Idealized model calculations (Carmack and Chapman, 2003) suggest that upwelling-favourable winds generate little SBE so long as the ice edge remains shoreward of the shelf-break, but abruptly increases when the ice edge retreats beyond the shelf break (Figure 1). But the ice cover is changing (Comiso and Parkinson, 2004). Under scenarios of climate warming used in the ACIA analysis, both the extent and duration of summer melt-back are predicted to increase, so that this 'tipping point' may routinely be reached by the middle part of the 21st century. Here we discuss this condition from a panarctic perspective and note potential consequences to SBE and new primary production. To do this, we use NCEP re-analysis wind field data and existing nutrient data to estimate the potential increment in new productivity that may follow from a reduction in summer ice extent.

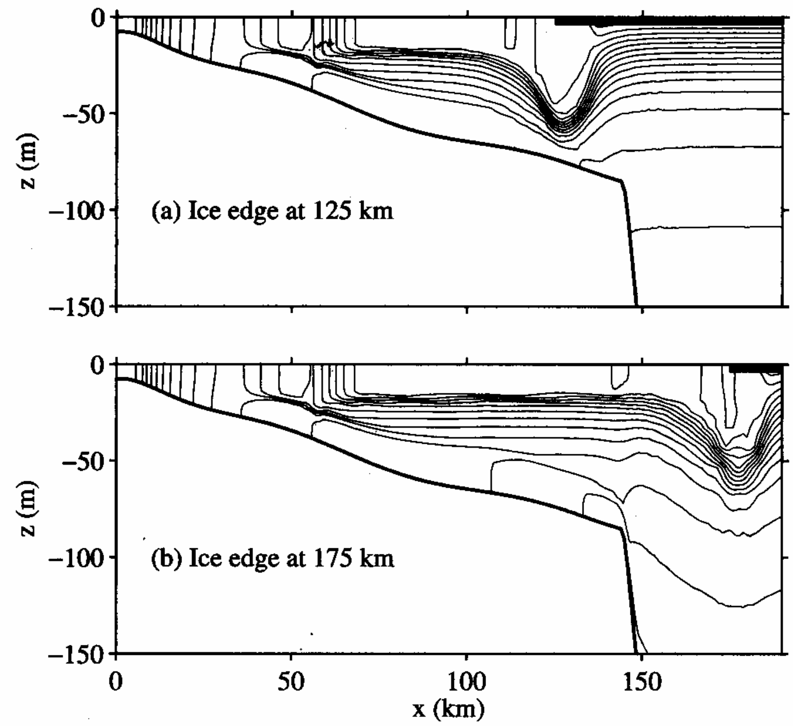

Figure 1: Model results for upwelling favourable winds blowing parallel to the coast for 15 days with a stationary ice cover located (a) 87 km and (b) 125 km from the coast (from Carmack and Chapman, 2003).

To obtain flux estimates onto the shelf we use the NCEP reanalysis wind field data from grid points near the mid-point of the shelf-break for each shelf sea. Wind-stress is calculated from $\tau = \rho_a C_D|\mathbf{U}|\mathbf{U}$, where τ is wind-stress, $\rho_a = 1.2$ kg/m^3 is air-density, $C_D = 0.0015$ is a drag coefficient and U is the wind velocity (Figure 2). Ekman transport off the shelf is then found from $T_E=\tau/\rho_0 f$, where T_E is Ekman transport, $\rho_0 = 1000$ kg/m^3 is a reference density for seawater and f is the Coriolis parameter. For the purposes of this rough estimate we suppose a three month period of open water at the shelf break (July-September) and further assume that the synoptic, upwelling-favourable events are cumulative, and ignore downwelling events (but, see below). The flux of upwelled water across any given shelf-break is then set equal to T_E as computed from upwelling-favourable winds for a three-month summer period.

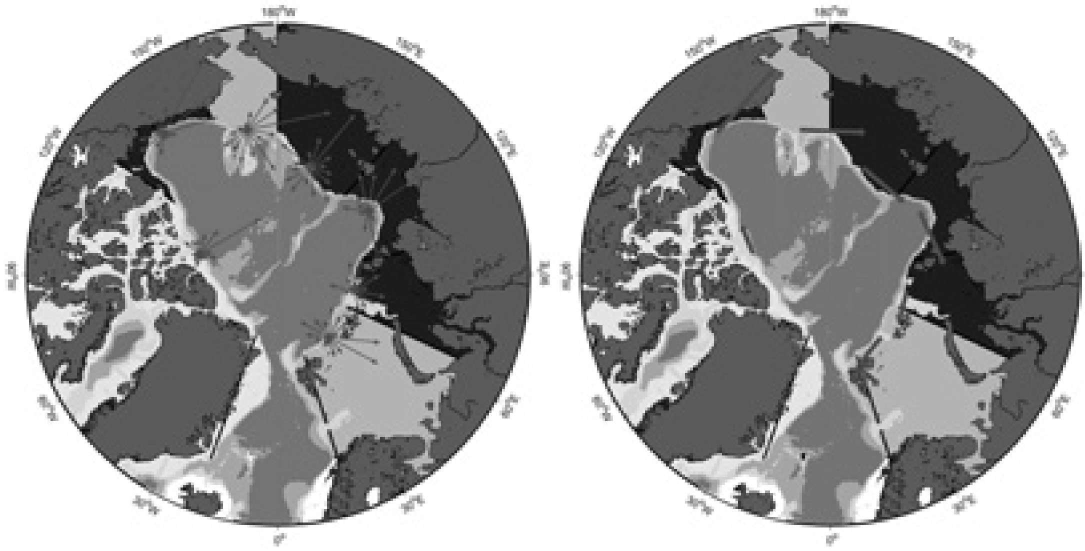

Figure 2: (a) Wind-stress during 'summer' of 1998 at selected NCEP grid points located near the mid-point of shelf-breaks for individual seas. (b) Mean of upwelling-directed wind-stress for 'summer' of 1998 at the same locations.

To estimate primary productivity due to upwelling, we examine nutrient data from various sources (Wilson and Wallace, 1990; Wheeler et al., 1997; McLaughlin et al., 2004); NO_3 was assumed to be the limiting nutrient. For the purpose of this rough calculation we take NO_3 values immediately seaward of the shelf break to be 12 and 15 mmol m^{-3} for the Eurasian and Canadian basins, respectively. Upwelled nitrate is then calculated as the product of $\boldsymbol{T_E}$ times the offshore concentration. Upwelled nitrate is assumed to reach the surface layer, be dispersed equally across the surface area of individual shelves and be completely utilised in new production; the latter is calculated here using the Redfield ratio of 106:16.

Table 1 compares present measurements of new production with estimates of the increase in new production (ΔNP), resulting from upwelling, for each shelf using NCEP data from 1998. (This year, one of strong positive Arctic Oscillation (AO), was chosen because climate warming scenarios suggest that the Arctic may tend towards this state.) Two estimates of ΔNP were calculated: one using the mean upwelling-directed wind-stress and one using the difference between the mean upwelling and the mean downwelling-directed wind-stress; but only the former is shown in Table 1.

Large differences in ΔNP are seen among the various shelf seas due to variations in (a) magnitude of upwelling, (b) offshore NO_3 value, and (c) the width of individual seas; the latter had the largest effect on our estimates. In the Canada Basin, the narrow shelves of the Beaufort and northern Canadian Arctic Archipelago give the largest increases in new production per unit area whereas the wide shelves of Chukchi and Eurasian basin result in low

Shelf	Shelf Area 10^3 km^2	Shelf Length km	NP gC m^{-2} y^{-1}	Ekman Flux m^2 s^{-1}	Nutrient Flux mmol m^{-2} y^{-1}	ΔNP gC m^{-2} y^{-1}
Barents	1512	771	16*	0.16	7.79	0.62
Kara	926	555	7 - 12	0.15	8.15	0.65
Laptev	498	863	6 - 10	0.25	40.81	3.24
East Siberian	987	1018	6 - 10	0.24	28.34	2.25
Chukchi	620	771	5 - >160	0.29	42.14	3.35
Beaufort	178	1140	7 - 17	0.38	284.30	22.60
North CAA	146	2065	5 - 10	0.13	220.86	17.56

* For Barents Sea north slope

Table 1: New production estimates for Arctic shelf seas taken from Sakshaug (2003) and estates of the increase in new production due to upwelling wind-stress during ice-free conditions.

values. The estimated wind-stress is also a factor, largest upwelling wind-stress being found in the Beaufort which combined with the relatively narrow shelf gives the largest estimate of increase in new production. Inclusion of downwelling wind to the wind-stress estimate causes an even greater difference between the Beaufort and CAA and the remaining shelves. Relatively persistent upwelling winds over the Beaufort and Chukchi shelves give larger estimates of mean wind-stress whereas in other areas wind-stress estimate is reduced to close to zero or is negative.

It is crude to assume that all upwelled nitrate reaches the euphotic zone uniformly over the shelf. Indeed, vertical exchange in Arctic seas is strongly constrained by salt stratification and the flux of nitrate to the surface is likely achieved either near the coast, which requires the deep water transit from the shelf break to the coast, or is mediated by vertical mixing, as the nutrient rich water floods the bottom of the shelf. In either case smaller scale processes, such as coastal upwelling, topographically enhanced vertical mixing due to tides, canyons and variations in shelf direction, can be anticipated to be important factors to onshore and vertical nitrate flux. It is perhaps the efficiency of these localised processes that is the controlling factor. Our upwelling fluxes are also reliant on assumptions concerning air-ice-water coupling and internal ice-stress (cf. Carmack and Chapman, 2003).

In a panarctic sense it is useful to distinguish among “inflow” shelves, “interior” shelves and “outflow” shelves *viz* their response to enhanced upwelling. On inflow shelves incoming water from the Atlantic (Barents Sea) and Pacific (Bering & Chukchi seas) supply nutrients independent of upwelling. Interior shelves (Kara, Laptev, East Siberian and Beaufort) – though fed by the major arctic rivers - are strongly affected by SBE exchange processes. The outflow shelves along the east coast of Greenland and various passages of the Canadian Arctic Archipelago allow passage of Arctic waters back into the North Atlantic, and thus draw water from the offshore basins independent of upwelling. The estimates provided here are likely more applicable to the interior shelves.

Acknowledgement

We would like to acknowledge Dr. Robie Macdonald, who first wrote about the difference between a good ice year and a bad ice year on the Canadian Shelf of the Beaufort Sea, and Dr. Terry Whitledge, who first ask us to think about a link between the shelf-break and climate change.

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The Ob River: Is there Arctic Inflow Increase?

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Introduction

It is known importance of the Arctic for global climate system. Also it is well known that hydrologic cycle is one of main component of the arctic climate and changes in the terrestrial hydrologic budget influence the extent of sea-ice cover, freshwater transport into the North Atlantic and deep ocean convection. The annual freshwater inflow of arctic rivers reaches a total of 3300 km^3 (Stein, 2000).

It notes increase of annual precipitation over the northern Hemisphere during the last 50-70 years, especially for the cold seasons (Serreze et al., 2000). The same is impartially for the West Siberia (Agafonov et al., 2004). Also some authors note that the average annual discharge of fresh water from 6 largest Eurasia rivers to the Arctic Ocean increased by 7% from 1936 to 1999 (Peterson et al., 2002).

The Ob river is one of the great rivers of the northern Hemisphere (the Ob + Irtysh channel length is 5410 km; catchment basin is about 3 millions km^2, floodplain area is 75 000 km^2, average runoff is 429 km^3 yr^{-1}) and transports from south to north an amount of heat of more than 10^{10} MJ. The Ob plays a crucial role for climate of the floodplain and adjacent uplands during the ice-free period. There are both cooling and warming effects of the Ob's streamflow to air temperature (Agafonov and Mazepa, 2001).

Materials and Methods

Records of annual precipitation over the Ob catchment basin southward from 60°N and the daily water Ob levels of the ice-free period in 5 gauge stations (Khanty-Mansiisk, the Irtysh river, 60°58′N, 69°04′E, 1200 km from the Ob estuary, 1894-1995; Surgut, 61°15′N, 73°30′E, 1502 km from the Ob estuary, 1894-1993; Oktyab'rskoe, 62°27′N, 66°03′E, 907 km from the Ob estuary, 1922-1996; Muzhy, 65°23′N, 64°43′E, 450 km from the Ob estuary, 1934-2002; Salekhard, 66°31′N, 66°36′E, 280 km from the Ob estuary, 1934-1996) for the last century were analyzed.

There are no water discharge measurements on the foregoing gauges (except Salekhard) and we used daily water levels to estimate the Ob flow because of correlation between a hydrograph of water level and a water discharge hydrograph is very high for years with low as well high water discharge (r = 0.97 for the Salekhard gauge).

Really, more than 80% of the Ob's runoff supplies from the southern part of the Ob catchment basin (2.72 millions km^2). Cold season precipitation records from October to May (CSPR) from 61 meteorological stations on that area were compared against the total daily water levels (TDWL) of the ice-free period of the Lower Ob river.

For precipitation analysis the Ob catchment basin was shared 4 basins of the large confluents out: the Tobol (426x10^3 km^2, 12 meteorological stations), the Ishim (177x10^3 km^2, 6 meteorological stations), the Irtysh (1643x10^3 km^2, 24 meteorological stations), the Upper and the Middle Ob (1047x10^3 km^2, 19 meteorological stations).

Results and conclusions

There is significant positive correlation (r = 0.37-0.67) between the CSPR of the Tobol, Ishim, Irtysh and the Upper and the Middle Ob river basins. Also they display positive precipitation trends since 1950th (Fig. 1). Correlation between the TDWL for the ice-free period of the Lower Ob and the average CSPR on the Upper and Middle Ob, the Irtysh, the Tobol and on the Ishym basins is 0.26, 0.52, 0.26, 0.36, respectively.

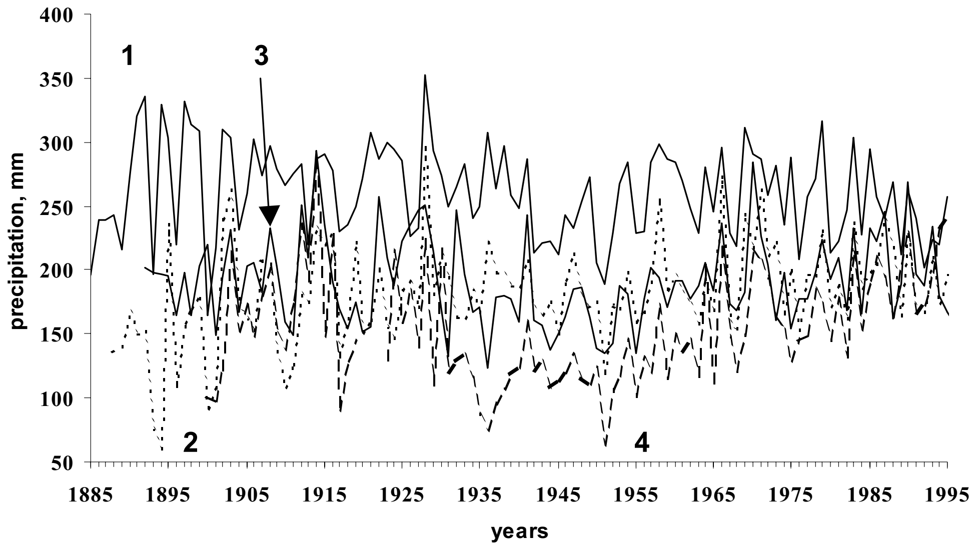

Fig.1. Average cold season precipitation from October to May (CSPR) on the Upper and Middle Ob (1), on the Irtysh (2), on the Tobol (3), on the Ishym (4) basins.

Significant positive correlation (r = 0.38) between the summary CSPR of the four basins and the TDWL of the Lower Ob river (Oktyab'rskoe gauge) was revealed. At the same time, there are differences in the long-term dynamics for the both parameters: positive trend for precipitation and negative one for TDWL (Fig. 2). What is more, the decrease of the TDWL is observed on the whole 4 gauges regardless of the fact that there is increase of the CSPR on the whole Ob catchment basin.

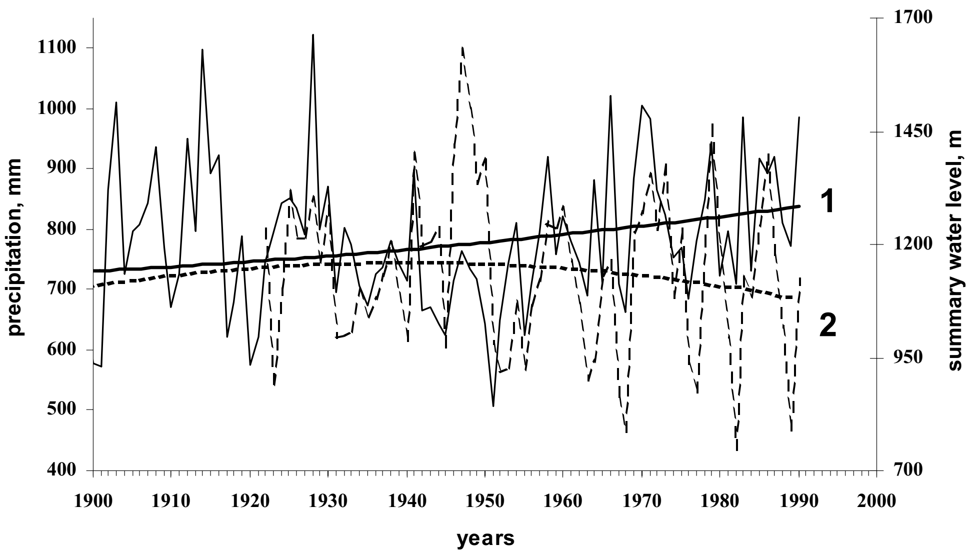

Fig. 2. Summary CSPR of the four basins (1) compared against the TDWL (2) of the Lower Ob (the Oktyab'rskoe gauge station) and their trends by polynomial function.

Deferent tendencies for the annual maximal water levels (AMWL) are observed on the gauges. Surgut, Khany-Mansiisk and Oktyabr'skoe display obvious decrease of the AMWL whereas Muzhy and Salekhard show weak apparent increase tendency (Fig. 3). Perhaps, this phenomena is explained by distribution of extensive floodplain which is the vastest on over the Ob and reaches here up to 60 km from the west to the east. Moreover, extensive peatlands are widespread in this part of the West Siberia and they can control drainage regime of the region too. Also dates of the AMWL had a tendency to come earlier from year to year during a period of records on the whole gauges (Fig. 4).

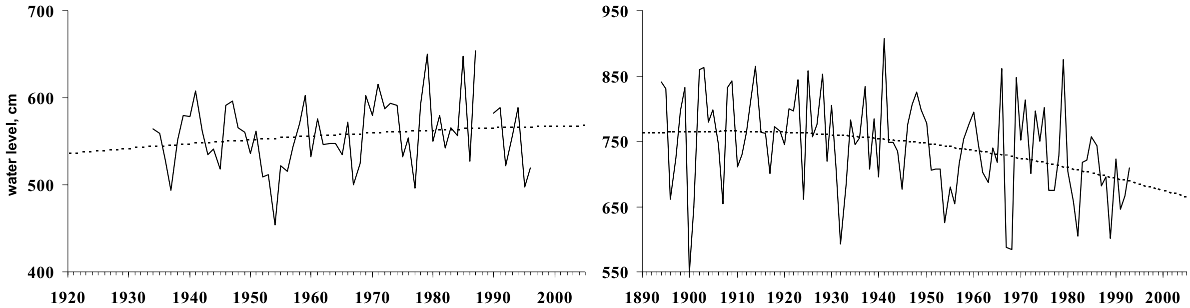

Fig. 3. The maximal Ob water level of the ice-free period in Salekhard (left) and Surgut (right) and their trends by polynomial function.

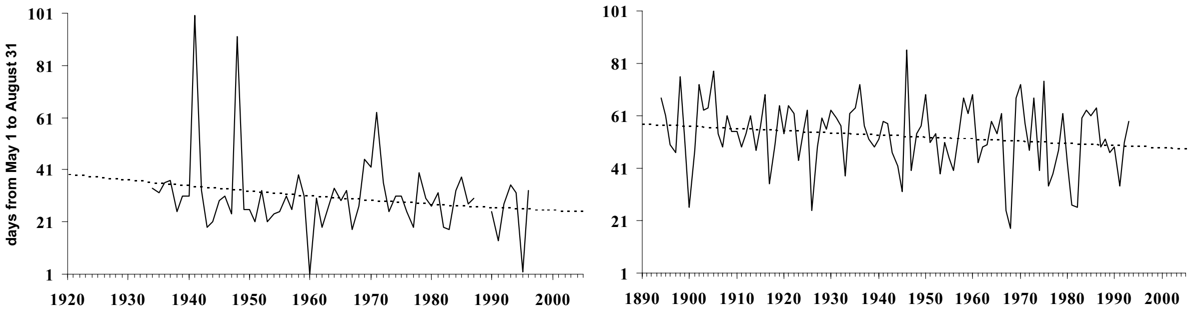

Fig. 4. Dates of the maximal water level for Salekhard (left) and Surgyt (right) gauges and their trends by polynomial function.

Other hydrological events changed during the last century too. Breaking-up dates come earlier from year to year on over the Ob river basin. Quite the contrary freeze-up dates come later from year to year and duration of the ice-free period is extended. At the same time, it is to be noted that a submergence duration of the Ob floodplain either do not changes or has a tendency to decrease on the whole basin.

Thus, our results don't allow to affirm that one of the largest rivers of the northern Hemisphere displays the inflow increase to the Arctic Ocean regardless of the fact that there is some increase of the cold season precipitation on the whole Ob catchment basin. From our point of view there are several causes of this phenomena. One of theirs is, perhaps, an physical evaporation increase on the whole basin duo to significant increased air temperatures (Moritz et al. 2002). Other important cause is connected, most likely, with the changes of spatial and age structure of forest cover over the Ob basin which have a strong influence on physical evaporation and redistribution of precipitation. Illustration for these suppositions is the changes of breaking-up, freeze-up and flood crest dates which were determined for the Ob river.

Acknowledgement

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Linkage between Sea-ice Distribution and Snow-precipitation may considerably affect Terrestrial Ecosystems in Future High Arctic Climates

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1. Introduction

The Intergovernmental Panel on Climate Change (IPCC)'s Third Assessment Report (TAR) (2001) gives projections for global-mean warming from 1990 to 2100 within a range of 1.4º to 5.8ºC in the case that no measures are taken to limit climate change. Further, research demonstrates that based on this assumption, a global-mean temperature increase around 3ºC by the end of the 21st century is the most likely; and that probabilities of global-mean warming values at both the high and low ends of the TAR range [1.4ºC , 5.8ºC] are very low (Wigley and Raper, 2001). General Circulation Models (GCM) predict global warming to be most pronounced at high latitudes, especially during winter time when temperature increases of up to 6ºC can be expected by the end of the 21st century (Hadley Centre, Max Planck Institute of Meteorology).

Arctic ecosystems are strongly influenced by snow cover and temperature, and may be expected to be markedly altered by climate change (Phoenix and Lee, 2004; Stone et al., 2002; Weller, 1998). Besides increases in winter temperatures in the Arctic, decreases in sea-ice extent are expected to occur correspondingly (Johannessen et al, 2004), which may significantly influence the regional climate. Here we present an empirical analysis from Northeast Greenland, which shows that reduced amounts of sea-ice in the region will most likely lead to increased snow-precipitation. Due to a shorter snow-free season this might have consequences for High Arctic ecosystems that at a first estimate are unexpected in a future warmer climate.

2. Methods and Analysis

We have calculated end-of-winter snow-precipitation amounts at two different scales – local and regional, using two different modeling approaches: The first approach, which is used at local scale (covering 12 years: 1988-2000, except 1990) exploited data from Zackenberg Research Area (ZRA), Northeast Greenland (74.5ºN, 21.6ºW) obtained during the melting season (June-August). It is based on snow cover maps derived from remotely sensed image data, melt energy inferred from daily mean air temperatures, and measured snow depths. The image data types are digital orthophotos covering approximately 17 km^2 (Hinkler et al., 2002), and high resolution satellite images (Landsat Thematic Mapper (TM) & SPOT High Resolution Visible (HRV)). Daily mean temperatures are from automatic weather stations at Zackenberg and Daneborg (located 23 km southeast of Zackenberg). The second modeling approach is used at regional scale and deals with relative humidity and temperature (Liston and Sturm, 1998) during winter time (October-May). It simply assumes that snow-precipitation falls when the air temperature is below freezing and the relative humidity is greater than 80%. For this purpose we used daily values (air temperature and relative humidity) during 1981-2000 of a 2.5º×2.5º lat-long-grid-cell from the National Centre for

Environmental Prediction (NCEP) reanalysis project. The spatial coverage of the grid-cell is approximately 21,000 km^2 (Fig. 1). The least-squares fit, reveals that the local snow-precipitation at Zackenberg is significantly correlated with what is modeled at a much larger scale. However, it also reveals that local snow-precipitation in some winters can differ significantly from regional precipitation. This is probably because the area is characterized by strong topography, which complicates the local wind patterns and thereby also precipitation distribution.

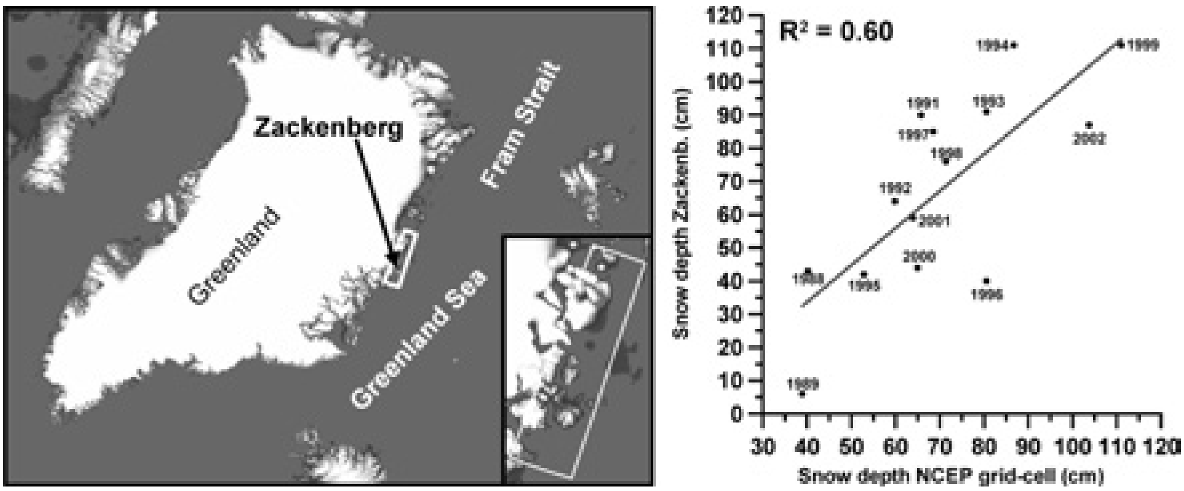
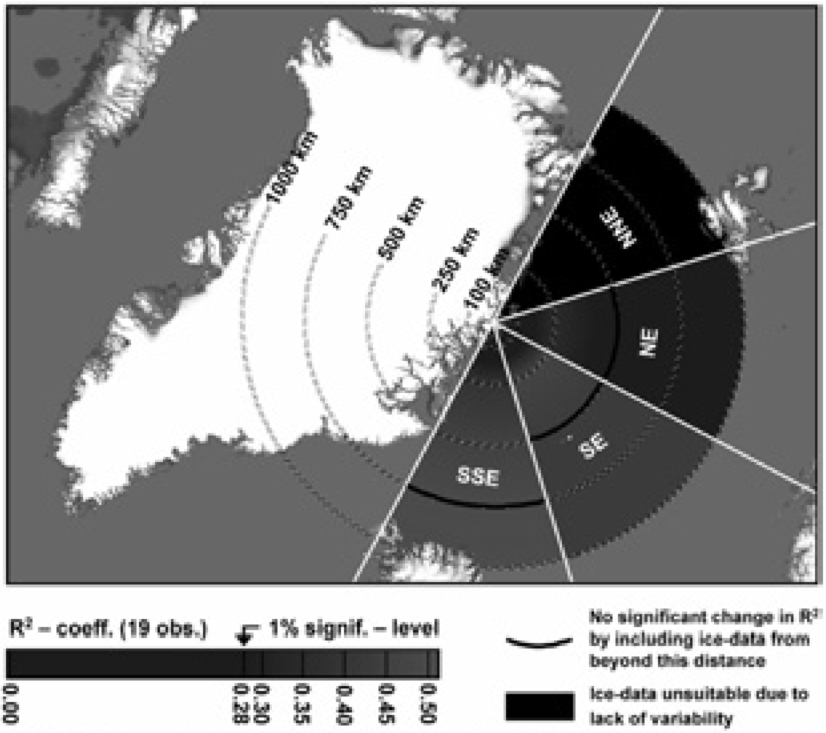


Fig. 1. (Left) Location of the Zackenberg Research Area (red cross). The rectangular area indicated by white lines corresponds to the 2.5º×2.5º lat-long grid cell (21,000 km2) from the NCEP reanalysis data, which includes the Zackenberg Research Area (ZRA). (Right) Modeled snow depths: ZRA versus entire area in NCEP grid cell (Normalized to Zackenberg, 1999).

To analyze the relation between duration of periods with extensive sea-ice within the Greenland Sea and snow-precipitation at Zackenberg we analyzed more than 8000 sea-ice maps derived from SSM/I passive microwave satellite data (Fowler et al., 2000). We divided the Greenland Sea into 4 main regions based on direction from ZRA, and each of them was further divided into 5 sub-regions based on distance from ZRA (Fig. 2). For each season (December-August), and each of the 20 regions, the time-duration (number of days with sea-ice percentage above a certain threshold) was calculated and compared to the end-of-winter snow accumulation at ZRA. To validate our results we calculated correlation-coefficients between snow accumulation and sea-ice extent using end-of-winter snow accumulations calculated from both of the above mentioned approaches. The correlation between sea-ice extent within the Greenland Sea and snow accumulation around ZRA is visualized spatially in Fig. 2. All of the regions show an inverse relationship between extensive sea-ice duration and snow accumulation (the more sea-ice the lesser the snow accumulation and vice versa), and the further one goes to the south and southeast the higher the correlation. This pattern seems to be evident (see the tables in Fig. 2) no matter which of the snow modeling approaches applied. The highest correlation occurs in the SSE region when ice-data up till a distance of 750 km from ZRA are included. This leads us to the conclusion that a “center of action”, which highly influences winter-precipitation amounts in Northeast Greenland is centered within this region – around 500 km north of Iceland between Greenland and the Island of Jan Mayen.



R^2 – Coefficients regional (19 years)

	NNE	NE	SE	SSE
100 km	(0.21)	0.22	0.18	0.19
250 km	(0.19)	0.35	0.47	0.39
500 km	(0.50)	0.24	0.43	0.46
750 km	(0.56)	0.25	0.43	0.50
1000 km	(0.57)	0.25	0.43	0.51

R^2 > 1% sig. lev. (0.28 for 19 obs.)

R^2 – Coefficients Zackenberg (12 years)

	NNE	NE	SE	SSE
100 km	(0.20)	0.19	0.19	0.23
250 km	(0.20)	0.35	0.49	0.54
500 km	(0.41)	0.51	0.62	0.61
750 km	(0.42)	0.47	0.63	0.65
1000 km	(0.49)	0.52	0.64	0.66

R^2 > 1% sig. lev. (0.43 for 12 obs.)

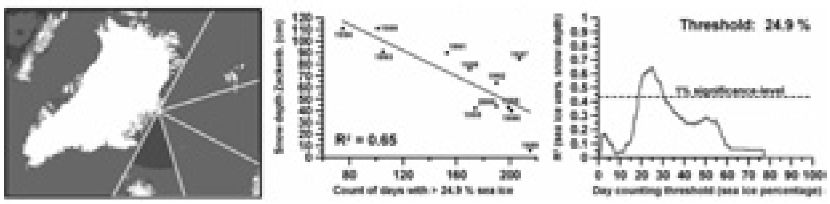


Fig. 2. Spatial distribution of the correlation between (1) end-of-winter- snow-precipitation amount in the Zackenberg Region (21,000 km^2 – regional scale) and (2) the number of days during December to August with sea-ice percentage above a critical threshold (which differs from sub-sector to sub-sector). The Greenland Sea is divided into four sectors based on direction seen from Zackenberg Research Station (ZRA): NNE, NE, SE, SSE, and each sector is further divided into five sub-sectors based on distance from ZRA: 0-100 km, 0-250 km, 0-500 km, 0-750 km, and 0-1000 km (note that a smaller sub-sector is always included in a larger sub-sector). The tables display R^2 coefficients of a least squares fit between end-of-winter snow-precipitation amount (at regional and local scales, respectively) and duration of periods with extensive sea-ice. At the bottom, the sub-region (750 km SSE) that gives the highest correlation between snow-precipitation and time-duration of extensive sea-ice is shown. The linear fit in the middle is based on local scale snow modeling over 12 years, and the diagram to the right shows that in this case a threshold of 24.9% (number of days during December-August with more than 24.9% sea-ice cover), gives the optimum correlation for the region in question (here SSE 750 km sub-sector).

3. Discussion/perspectives

With the prospect of decreasing sea-ice off Northeast Greenland in the future, this study shows that more snow-precipitation can be expected on land. Since limited snow cover and large snow free areas today is an important precondition for the High Arctic "desert" of North and Northeast Greenland, increased snow cover in combination with increased frequency of thaw events will alter the conditions in the direction of present-day Low Arctic Southeast Greenland. For flora and fauna this would mean increased vegetation cover on presently barren lowlands, but also difficulties for herbivores from lemmings to musk oxen due to melting snow and rain in winter resulting in ice crust formation. If summer temperatures, as predicted, do not increase noteworthy, the heavier snow pack may delay spring snow clearance in High Arctic Greenland, as opposite to the predicted prolongation of the growing season in most of the Arctic. This will delay the reproductive phenology and thereby the success of many species ranging from plants to shorebirds (Meltofte 2002). If on the contrary, summer temperatures do increase significantly, the High Arctic tundra and desert may transform into Low Arctic tundra, leaving the High Arctic habitat only as an alpine zone in mountainous areas (Meltofte et al. 2003).

At the time of writing there are still questions that need to be clarified. Thus, more research has to be done in order to explain what mechanisms actually affect the sea-ice distribution within the regions of high correlation. Teleconnection patterns such as the Arctic and North Atlantic Oscillations (AO and NAO) do not seem to explain ice cover variations in these regions very well, and neither does modeled sea-ice fluxes through the Fram Strait (Schmith and Hansen, 2003). However, as the sea-ice distribution in the Greenland Sea is influenced by both local ice formation and a large ice-flux from the Arctic Ocean into the East Greenland Current, it cannot be generalized at a larger scale. Therefore, it might be that sea-ice formation and distribution in the southern Greenland Sea should be addressed to other (more local) factors such as the so called Odden ice tongue phenomenon (Wadhams, 1999) and/or atmosphere-ocean interactions. In this connection e.g. the position of the ice edge plays a crucial role in the formation of polar lows (Rasmussen et al., 1992).

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Climate Records from Temperate Ice Caps in Iceland: Pilot Studies on Hofsjökull

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Introduction

Covering an area of 880 km^2, Hofsjökull is the third largest ice cap in Iceland. Outlet glaciers flow in all directions from the main ice cap, which is almost circular in shape (Fig. 1). The surface and bedrock topography of Hofsjökull was mapped in 1983 [1], revealing the presence of a subglacial mountain massif of volcanic origin under the central part of the ice cap. The average thickness of Hofsjökull is 215 m, but the ice thickness reaches a maximum of 750 m in the center of an ice-filled volcanic caldera, ~40 km^2 in area, situated west of the summit of the ice cap, which is at 1790 m above sea level.

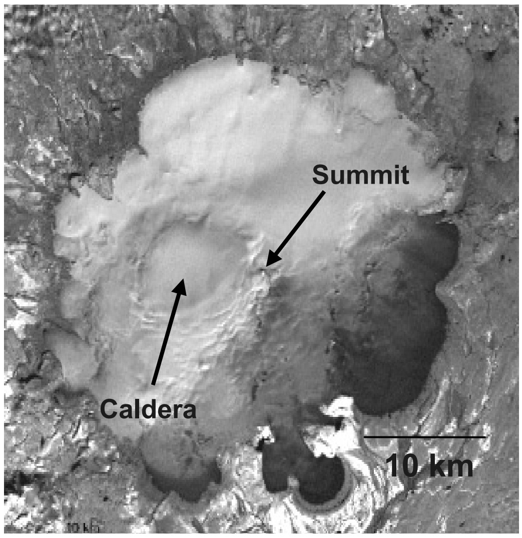

Fig. 1 – Hofsjökull ice cap, Central Iceland

Monitoring mass balance and ice margin positions

The annual mass-balance of Hofsjökull has been measured continuously since 1988 [2,3]. Net balance at the summit site (measured over the 12 month period Sept. 1 to Aug. 31) has varied between 531 cm water equivalent in 1991/1992 and 239 cm w.eq. in 1996/1997. Average net balance in the period 1987/2003 was 340 cm. The net balance on the ice cap as a whole was positive in 1988/89 and in the period 1991 to 1994. In other years it was negative. On average, the ice cap has thinned by about 3-4 m (w.eq.) during the 17 years of mass-balance measurements. All outlet glaciers from Hofsjökull have been receding since 1995 and the total area of the ice cap has shrunk by approximately 3.5 % since 1986.

Ice core study: Identifying annual layers in temperate ice

Accurately dated ice-core records provide a means of prolonging mass-balance data sets further back in time. All ice caps in Iceland are temperate (i.e. at melting point throughout) and summer melt is known to affect the seasonal variation in several parameters commonly used for dating polar ice cores. In spite of these problems, temperate ice caps around the world are now receiving increased attention as potential archives of past environmental changes [4,5]. At high-elevation sites in Iceland (above 1700 m a.s.l.), summer melting is negligible and pilot studies have shown conclusively that windblown dust of local origin, deposited on the top of Hofsjökull during the summer, produces well-defined horizons that can be used for annual layer counting in ice cores [4,6]. A total of 33 annual layers could be identified in a 100 m ice core drilled at the Hofsjökull summit in 2001 [3,4,7]. The thickness of each annual layer was converted into ice-equivalent thicknesses and a model describing the plastic thinning of annual layers with depth [8] was then used to calculate the original thickness of the layers at the surface, providing information on the net annual balance in the period covered by the ice core.

Precipitation and temperature proxy records from the Hofsjökull core

Fig. 2 shows the calculated annual balance for the period 1971-2000. The 1988-2000 yearly mass-balance record is shown for comparison, revealing an excellent match between the two records. The data set reveals considerable variability in annual precipitation on Hofsjökull in the above mentioned period, but a definite trend is not observed. Precipitation at the nearby weather station Hveravellir, located 35 km west of the drilling site, 650 m a.s.l., is shown for comparison. As indicated by the scatterplot in Fig. 4, the two records match each other reasonably well. A sharp drop in precipitation from the 1975-76 glacier year to the 1976-77 year is seen in both records, and the 1988-89 and 1991-92 peaks are prominent in each of the three records.

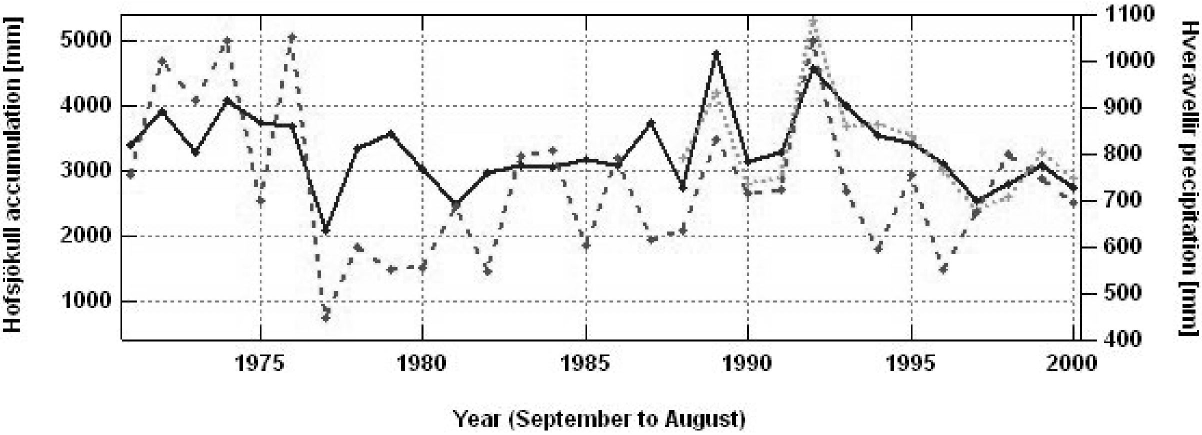

Fig. 2 – Full curve: Net accumulation from ice core, Hofsjökull summit. Glacier years 1970-71 to 1999-2000. Dotted curve: Net accumulation at Hofsjökull summit from yearly mass balance measurements on site. Dashed curve: Annual precipitation at Hveravellir (from September to August, to facilitate comparison with the ice core data) – vertical axis on the right.

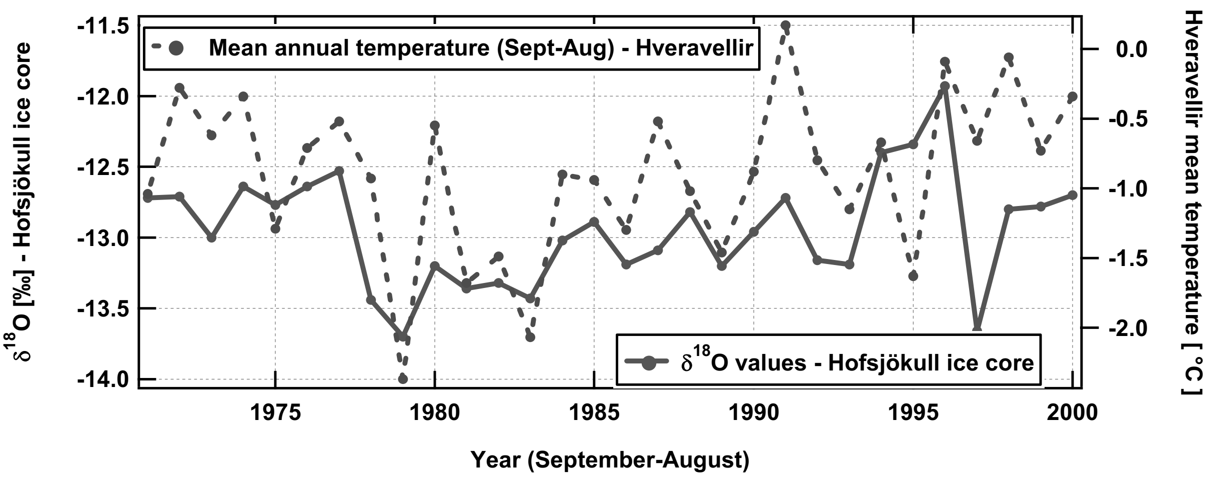

Fig. 3 – Full curve: $\delta^{18}O$ values from the Hofsjökull core (averages for each annual layer, 20 cm samples) Dashed curve: Mean annual temperature (Sept-Aug) at Hveravellir, 1970-71 to 1999-2000.

Measurements of oxygen-isotope ($^{18}O/^{16}O$) ratios on the core yield $\delta^{18}O$-values varying between -8.7 ‰ and -17.2 ‰, with an average of -12.9 ‰. Seasonal variation is observed in the highest 5 annual layers, but homogenization occurs below 20 m depth, although a weak seasonal signal with an amplitude of 0.2-0.5 ‰ appears to be present down to 100 m [4]. Mean $\delta^{18}O$-values for each annual layer in the core are shown in Fig. 3, along with (Sept-Aug) mean annual temperatures at Hveravellir. A correlation is evident from these data and the linear fit in Fig. 5 yields the δ-T relationship: $\delta^{18}O = 0.34*T - 12.63$ ‰; i.e. a δ-T slope of 0.34 ‰/°C. In comparison, the present-day δ-T slope obtained in the central part of the Greenland ice sheet is 0.67 ‰/°C [9].

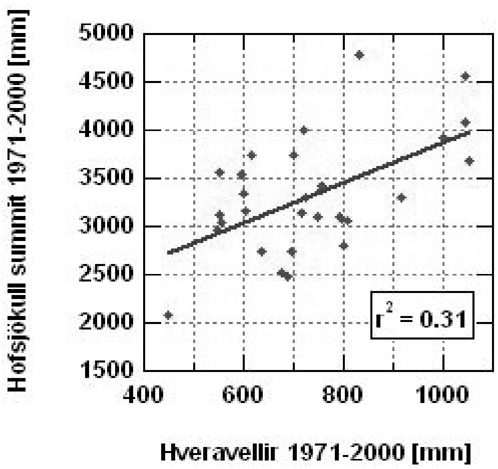

Fig. 4 – Hofsjökull net accumulation vs. Hveravellir precipitation 1971-2000.

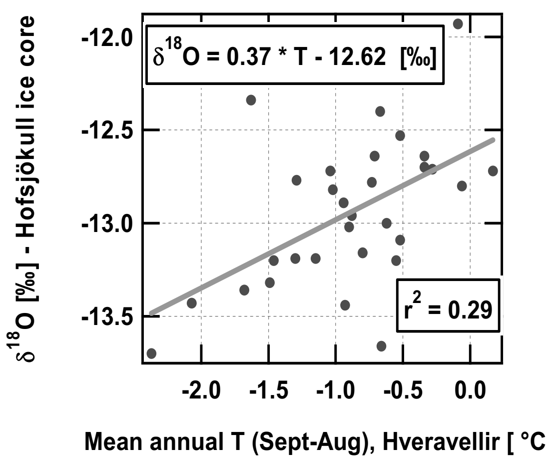

Fig. 5 - $\delta^{18}O$ in the Hofsjökull core vs. mean annual temperature at Hveravellir 1971-2000

Future work

Studies of the 100 m core from Hofsjökull have shown that ice cores drilled at high elevations on the temperate ice caps in Iceland can be accurately dated and can yield valuable information on past variations in climate parameters. A core drill designed for operation in temperate ice is now being built in Iceland and reconnaissance studies in preparation for deeper drillings are ongoing [6]. Model calculations indicate that 500 years old ice could be retrieved at the Hofsjökull summit, where the ice thickness is 300 m, and up to 1000 years old ice could be present near the bed in the central part of the summit caldera, where the ice thickness reaches 750 m. Future ice core drillings on Hofsjökull could thus likely provide climate records for the North Atlantic region reaching through the Little Ice Age and into the Medieval Warm Period. In addition, the calibration of ice core records against instrumental records covering the past 150 years will greatly aid current efforts to calculate the impact of future climate change on glaciers in Iceland and elsewhere [10].

Acknowledgements

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Thermokarst Development in a Changing Climate

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Climatic warming is particularly evident in areas underlain by relatively warm, ice-rich permafrost in Subarctic and Arctic Alaska. Thermokarst topography forms whenever ice-rich permafrost thaws, either naturally or anthropogenically, and the ground surface subsides into the resulting voids (Figure 1). The important and dynamic processes involved in thermokarsting include thaw, ponding, drainage, surface subsidence and related erosion. These processes are capable of rapid and extensive modification of the landscape; preventing or controlling anthropogenic thermokarst is a major challenge for northern development. We will present an investigation of the physical factors that influence thermokarst formation and discuss the implications of this process on local ecology, hydrology and surface energy balance.

The active layer is that portion of the soil above permafrost that annually experiences thawing and freezing. The depth to which the active layer thaws each summer depends upon many interacting factors, especially site hydrology. Other seasonal factors that influence depth of thaw include air temperature and soil moisture, which in turn varies in response to precipitation and evapotranspiration. The inter-annual variation of thaw depth at a site is large. Consequently, utilizing depth of thaw as an indicator of climatic change may be difficult as the climate change response will likely be subtle amidst large annual variations. Nevertheless, the deeper permafrost acts an integrator of meteorological variations and will respond to long-term changes in climate. It must also be recognized that changing the surface configuration and condition will also impact deeper ground temperatures and thus may mask (or overwhelm) changes in temperature due to changing climate.

Thermokarsts play an important role in response to a warming climate by altering hydro-logical flowpaths. Thermokarst may form in continuous or discontinuous permafrost, as controlled by the surface energy balance, soil thermal and hydraulic properties, and snow cover. Permafrost is generally continuous above the Arctic Circle in North America and Eastern Russia, but discontinuous permafrost does extend as far south as 50ºN latitude over Canada and Russia (Brown et al., 1998). Alpine permafrost exists in high mountainous regions throughout the world, even in the tropical latitudes. In the far northern regions of Alaska and Russia, permafrost may penetrate as deep as 600 to 800 m. Even within these bounds, small areas of unfrozen ground called taliks exist beneath large lakes and rivers or near springs (Permafrost Subcommittee 1988). Typically in areas of thick, relatively impermeable permafrost, the surface water is effectively isolated from sub-permafrost groundwater processes. However, in some isolated locations, springs extend through the permafrost to release groundwater at the surface. Groundwater springs may penetrate thick permafrost; the limiting factors of permafrost thickness and ground temperature must be offset by spring flow rate and water temperature. Subsurface hydrologic flowpaths are strongly coupled to thermokarst and talik formation in permafrost regions. In zones of thinner permafrost (tens to hundreds of meters) taliks may extend completely through permafrost allowing groundwater recharge or discharge. These taliks allow connection of deeper sub-permafrost groundwater with surficial water bodies. In some cases (depending upon the thickness of the permafrost), taliks allow ground water recharge as the water from rivers and lakes infiltrates to the sub-permafrost aquifer (Yoshikawa and Hinzman, 2003) or in reverse as groundwater discharge (Jorgenson et al., 2001) as typically occurs in wetlands.

Thermokarst is especially responsive to climatic change and several have been observed in Interior Alaska in recent years. Some of these thermokarsts have been linked to distinct events such as wildfire, floods or road construction, but some appear with no apparent cause for initiation other than perhaps a warming climate. Such thermokarsts may be the first indicator of substantial geomorphological and ecological change. As thermokarsts form, drainage is actually improved in the area immediately adjacent to the pond. Occasionally sloughing of banks enhances thawing and erosion, while exposing buried organics. These processes impact aquatic systems through stream chemistry and sedimentation. Increased thermokarst can result in greater interactions with disturbed organic soils and deeper groundwater systems, yielding greater transport of cations, and dissolved and particulate organic carbon. They also create favorable conditions for establishment of spruce trees and various shrubs (Lloyd et al., 2003). Slightly drier soils along thermokarst banks promote introduction of woody species as compared to adjacent tundra. Such processes may accompany northward expansion of treeline.

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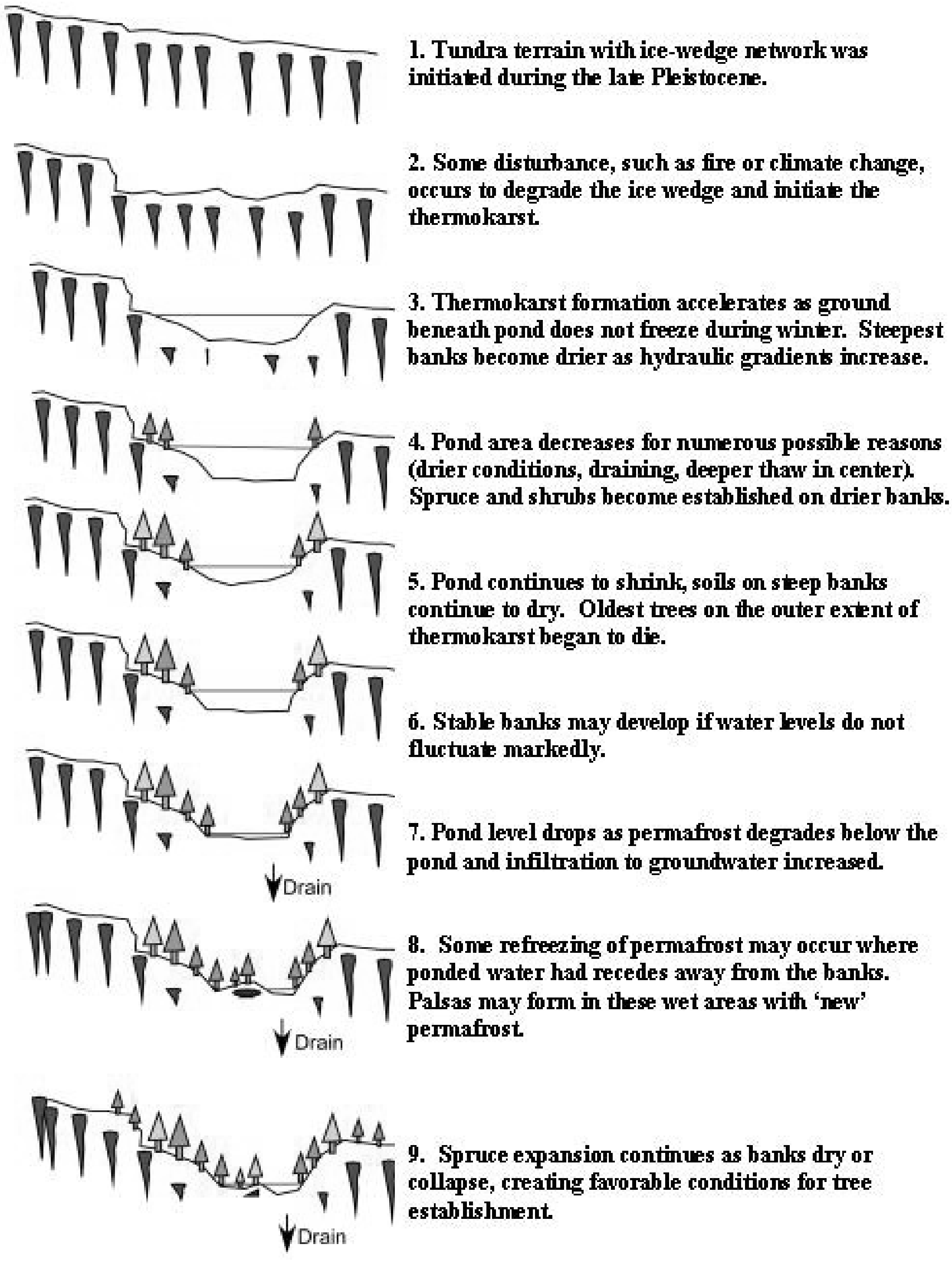

Figure 1. A hypothetical schematic of thermokarst development in a region of relatively thin permafrost. Vertical drainage below the thermokarst is only likely to occur in subarctic regions where permafrost is usually less than 50 m thick and is often discontinuous (occurring primarily on north-facing slopes and valley bottoms). In such conditions, the groundwater gradient could also be reversed and groundwater could flow upwards to recharge the pond (Kane and Slaughter, 1973).

A Climatic Perspective on Observed Arctic Permafrost Changes

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Introduction

Changes in the Arctic atmosphere-ice-ocean system observed in recent years are the background for frequent discussions as to whether these changes represent episodic events or long-term shifts in the Arctic environment. Existing knowledge on Quaternary climate and Global Climate Models (GCMs) predict that the effect of any ongoing and future global climatic change should be amplified in the polar regions due to feedbacks in which variations in the extent of glaciers, snow, sea ice and permafrost as well as atmospheric greenhouse gases play key roles. GCM analyses suggest that the Polar Regions should by now be experiencing a much larger warming than registered at lower latitudes, and sub-continental scale analysis of meteorological data obtained during the observational period apparently lends empirical support to the alleged high climatic sensitivity of the Arctic (Giorgi, 2002). Polyakov et al. (2002), however, questions the concept of polar amplification of temperature changes observed by surface stations at lower latitudes.

There is reason therefore to evaluate recent climate dynamics and their respective impacts on high-latitude ecosystems, including permafrost regions. Permafrost presently occupies about 25% of the Northern Hemisphere land surface (Brown et al., 1997). Permafrost thereby is a significant characteristic in many natural environments, especially in the Northern Hemisphere, affecting hydrology, geomorphic processes and slope stability, although first recently recognized as a potential geohazard factor. Variations in permafrost temperatures and -distribution may have direct consequences for timing and distribution of rock slides and mudflows, safety, building stability and socio-economy.

A persistent research que stion within permafrost science has been the precise nature of the relation between mean annual air temperature (MAAT), the mean annual ground surface temperature (MAGST), and the temperature at the top of permafrost (TTOP). Conventionally, the extent of permafrost has been represented in terms of the regional-scale pattern of air temperature isotherms, although the relation between climate and permafrost has not been explicitly defined. There is reason therefore to consider permafrost regions in the Northern Hemisphere in an overall Arctic meteorological-climatic context.

Modern Arctic climate

Modern climate in the Arctic is to a high degree regulated by the advection of warm North Atlantic waters into the Nordic Seas near Svalbard, the Norwegian- and the Greenland Sea. Maritime climate conditions prevail over much of the Arctic Ocean, coastal Alaska, Iceland, northern Norway and adjoining parts of Russia. In these areas, winters are generally cold and windy. Summers are cloudy and cool with mean temperatures ranging from 4 to 8^{o}C over land areas. Annual precipitation ranges from 400 mm to 1300 mm (w.e.), with a cool season maximum (largely snowfall) and about five to seven months of continuous snow cover. Shallow permafrost (0-250 m) characterise these regions. Forests are absent or found only close to sea level in sheltered positions due to low summer temperatures and windy conditions.

Arctic interior continental climates have more severe winters and precipitation is usually small. The coldest part of the Northern Hemisphere is located in northeast Siberia near the city Verkhoyansk, where present mean winter (DJF) air temperature is around –43°C. Although frost may occur in any month, long summer days usually provide up to three months with mean air temperatures above 10°C, and at some sites in the continental interiors summer temperatures may even exceed 30°C. In such regions, forests extend 200-1000 km north of the southern limit of permafrost and, consequently, permafrost extends far beyond the traditional warm limit of periglacial environments (the tree line). Permafrost is widespread and typically reaches 300-600 m in thickness. Permafrost thicknesses in excess of 1000 m are likely in some areas of northern Siberia, and such permafrost may potentially be of very high age.

The Siberian High is an intense, cold anticyclone that forms over eastern and southern Siberia in winter. Strong cooling in this region results in the lowest air temperatures in the Northern Hemisphere. The Siberian High forms usually in October, mainly in response to strong and continuous radiational cooling in the lower troposphere above the snow-covered surface of Asia, and persists until around the end of April. Being primarily thermally induced, the Siberian High is a shallow cold-core system mainly confined to the lower levels of the troposphere below the 500 hPa pressure level. Another persistent anticyclone or high-pressure ridge called the Arctic High, also known as the Beaufort High, is located over the Beaufort Sea and the Canadian Archipelago in winter and spring. The Arctic High is a relatively weak area of high pressure that covers most of North America during winter, and extends across the Arctic Ocean towards the Siberian High. The interaction between the Arctic High and the Icelandic Low causes frequent outbreaks of cold air masses over eastern Canada and into the North Atlantic east of Greenland. These outbreaks of cold air are the drivers for deep water formation in the Labrador Sea and in the Greenland Sea, background for the thermohaline circulation.

Arctic climate and permafrost

The extensive permafrost areas in Mongolia and in central and eastern Siberia are under the direct influence of the Siberian High and experience extremely cold and dry conditions associated with minimal cloud cover and substantial longwave radiation losses to the atmosphere. Despite its prominence and large spatial extent surprisingly little is known about the temporal variability of the Siberian High and its possible impacts on meteorology, climate and permafrost in the Northern hemisphere.

Siberian extensive permafrost regions spatially fit with the typical winter extension of the Siberian High, suggesting this to be a permanent Holocene weather feature. Also the frequent cold air outbreaks over East Asia from the Siberian High are likely to be of importance for the modern distribution of permafrost in Asia. In Europe, the advection of warm Atlantic air masses is controlled by the interaction of the Siberian High and the Icelandic Low. This large-scale circulation feature limits modern permafrost in Europe to high latitudes near the Arctic Ocean or to high altitudes. In North America, extensive lowland permafrost in Alaska and western Canada is associated with the typical winter position of the Arctic High. Low altitude permafrost is mainly absent in southeast Alaska due to warm Pacific air masses advected by the Aleutian Low. In eastern Canada, discontinuous and sporadic permafrost extends to about 50°N south of Hudson Bay and in Labrador. This sector is strongly influenced by outbreaks of cold air masses from the Arctic Ocean between the Arctic High and the Icelandic Low.

The major Arctic permafrost regions found in Siberia, Canada and Alaska are thus all associated with the typical position of major anticyclones such as the Siberian High and the Arctic High, emphasising the notion of permafrost ultimately being a climatic phenomenon.

Modern Arctic climate variability and permafrost

Projections of future climate changes in the Arctic are complicated by possible interactions involving surface changes, oceanography, stratospheric temperature, stratospheric ozone, and other changes. Thus, current model estimates of future changes in the Arctic disagree as to both the magnitude of changes and the regional aspects of these changes. Moreover, causes of soil temperature changes in the upper few meters in permafrost regions are still not well documented, and one major obstacle to understanding the linkage between the soil thermal regime and climatic change is the lack of long-term observations of soil temperatures and related meteorological variables. The present paper therefore investigates temporal and spatial surface air temperature changes within the entire Arctic, using meteorological data up to December 2002, in order to improve understanding of observed permafrost and active layer changes.

The period 1915-1940 represents the well known early 20th century warming in the Arctic, especially influencing northern Alaska, northern Canada, Greenland and the northern parts of Russia and Siberia. The following period 1940-1965 represents a period of widespread cooling in the Arctic. Temperature changes were most pronounced during the winter and weaker expressed in other seasons. Especially Alaska, northwestern Canada, Svalbard, the Kara Sea and eastern Siberia were affected by this development. The final 35 years of the 20th century (1965-2000) has been a period of renewed warming in many parts of the Arctic. Again this development has been most pronounced in the winter season and less so in other seasons. The late 20th century Arctic warming has affected especially western Canada, Alaska, eastern Siberia and a region east of Svalbard. In western Siberia and eastern Russia the air temperature changes have been limited. Eastern Canada, western Greenland and the northern Pacific have been exposed to a slight net cooling.

The climatic development during the final 10 years of the 20th century (1990-2000), however, deviates from the longer 1965-2000 period. Temperatures are now decreasing in Russia and Siberia, and warming is confined to the Atlantic sector of the Arctic Ocean, West Greenland, Canada and northernmost Alaska. Especially the Hudson Bay region, central West Greenland and Svalbard are affected by this recent warming. The air temperature changes 1990-2000 are highest during the winter and smallest during summer. The autumn season also stands out, with marked warming affecting most of the Arctic Ocean and NW Canada, suggesting increased cyclonic activity and later onset of winter. On the other hand, spring is delayed in parts of Russia, Siberia, eastern Alaska and western Canada. These different late 20th century climatic developments at least partly explain conflicting reports on ongoing permafrost change in different Arctic regions

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Response of Glaciers in Iceland to Climate Change

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Introduction

Global warming due to increasing concentrations of CO_2 and other trace gases in the atmosphere is expected to have pronounced effect on glaciers and lead to major runoff changes from glaciated areas. The research projects *Climate, Water and Energy* (CWE, http://www-.os.is/cwe) and *Climate and Energy* (CE, http://www.os.is/ce) and their Icelandic counterpart *Veðurfar, vatn og orka* (VVO, http://www.os.is/vvo) aim to estimate the effect of global warming in the Nordic countries on renewable energy resources, in particular hydrological effects with possible consequences for the operation and planning of hydroelectric power plants.

Mass balance data from glaciers and ice caps contain implicit information about the dependence of glacier mass balance on climate. The meteorological conditions on typical glaciers and ice caps span a large range of temperature and precipitation due to the large altitude range, which is often on the order of 1000 m. As a consequence, climate conditions in the near future are likely to remain within the already observable range on the glaciers to some approximation, unless the climate changes are so large or rapid that the climate of the region changes in a fundamental way. Thus, parameter values, determined from mass balance observations for the current climate, may be expected to be meaningful for climate change studies.

Melting of all existing glaciers and ice caps, excluding the large ice sheets of Greenland and Antarctica, would raise global sea level by about 0.5 m. Although glaciers and ice caps in Scandinavia and Iceland constitute only a small part of the total volume of ice stored in glaciers and small ice caps globally, studies of their sensitivity to climate changes have a general significance because these glaciers are among the best monitored glaciers in the world. Field data from glaciated regions in the world are scarce due to their remote locations and difficult and expensive logistics associated with glaciological field work. Results of monitoring and research of Nordic glaciers are therefore valuable within the global context, in addition to their importance for evaluating local hydrological consequences of changes in glaciated areas in these countries.

Glacier mass balance depends on the amount of snowfall during the accumulation season and on the melting or ablation of snow and glacier ice during the ablation season. Glacier mass balance observations are sensitive indicators of climate change and they also have several advantages for use in precipitation studies. They are typically from areas where there are few other precipitation measurements, but where precipitation estimates are important for many applications. Precipitation estimates based on mass balance measurements in glaciated areas are also not affected by the undercatch of traditional precipitation gauges, and they may provide a dense spatial coverage with a limited measurement effort because the measurements are only carried out a few times a year. Glacier mass balance measurements are an important component in the monitoring of climate change in Arctic and sub-Arctic areas.

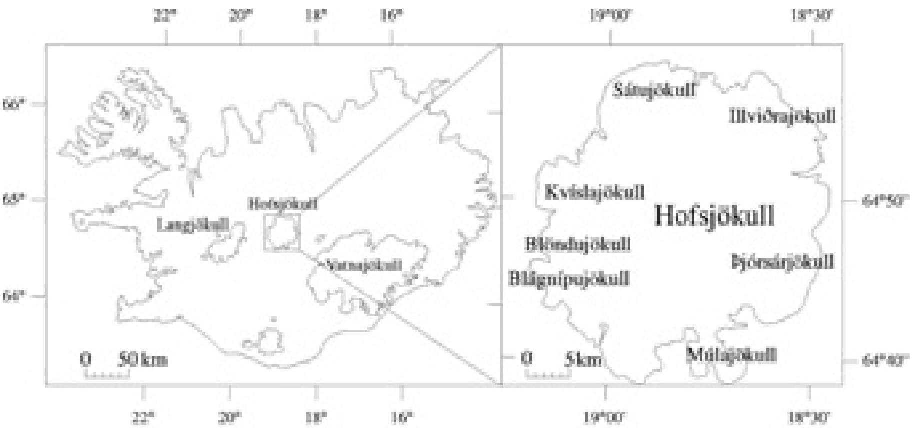

Figure 1. Location map.

This paper summarises some the results obtained by the Glaciers work groups of the CWE, CE and VVO projects for glaciers in Iceland. More detailed descriptions of the results of the projects are described by Jóhannesson *et al.* (2004) and Aðalgeirsdóttir *et al.* (2004) and may be obtained from the web-sites of the projects that are given above.

Climate Change Scenario

The climate scenario for the CWE project is described by Räisänen (2003). It provides a projection of climate change in the Nordic countries for the period from 1990 to 2050. In Iceland it prescribes an approximately sinusoidal temperature variation with a maximum of +0.3°C per decade in winter and a minimum of +0.15°C per decade in summer. The precipitation change in the glacier simulations was specified with a constant relative change of 5% per degree of warming independent of season. In addition, a climate change scenario from a previous climate change project, *Climate Change and Energy Production* (CCEP), was also used in the glacier modelling (Jóhannesson *et al.*, 1995). This scenario prescribes a yearly mean warming of 0.3°C per decade, varying from a winter maximum of +0.35°C per decade to a summer minimum of +0.25°C per decade, and a relative precipitation change of 5% per degree of warming independent of the season as in the CWE scenario. This warming is closer to the projected warming in other ocean areas on a similar latitude as Iceland, although not as high as in Scandinavia or other continental areas in this latitude range. The use of the climate change scenario from the previous CCEP study serves the purpose to investigate the consequences of climate change in case the strength of the thermohaline circulation in the North Atlantic Ocean is not reduced as much as projected by some coupled OAGCMs.

Results of Glacier Modelling

Degree-day mass balance models and 2D finite difference dynamic models were calibrated for the Hofsjökull ice cap, central Iceland, and for the southern part of the Vatnajökull ice cap, south-eastern Iceland (Figure 1). In these models, glacier accumulation and ablation are computed from daily temperature and precipitation observations at nearby meteorological stations and depth-averaged ice flow is computed from local ice thickness and surface slope. Figure 2 shows the projected reduction in ice volume corresponding to the climate scenarios described above. The volume of ice is in both cases reduced almost by half (little less relatively for Hofsjökull) within 100 years and the ice caps have almost disappeared 200 years after the start of the simulations. The northern and western flanks of Vatnajökull are

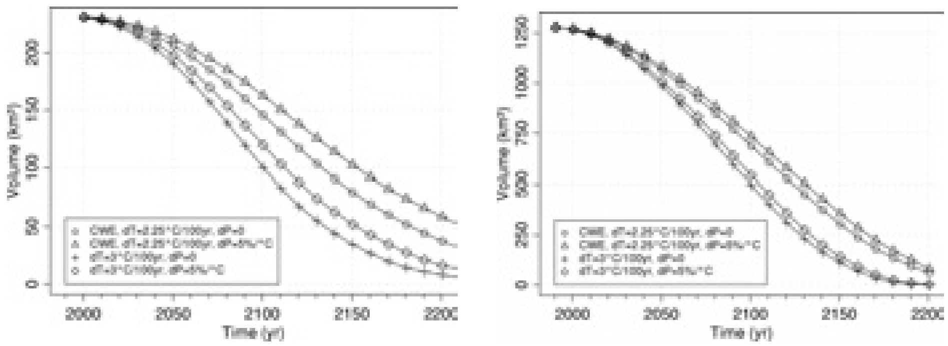

Figure 2. Projected volume of the Hofsjökull ice cap (*left*) and the southern part of the Vatnajökull ice cap (*right*) according to four climate scenarios.

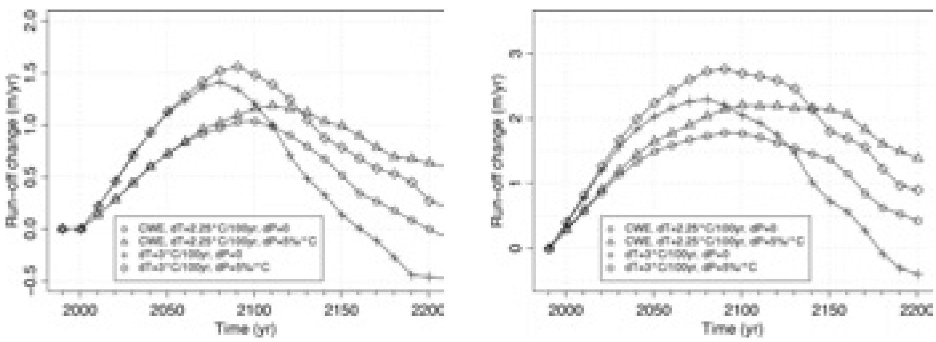

Figure 3. Projected runoff increase from the area initially covered by the Hofsjökull ice cap (*left*) and the southern part of the Vatnajökull ice cap (*right*) according to four scenarios.

excluded from the dynamic computations due to surges in these parts of the ice cap which are not adequately described by the dynamic model.

The reduction in the volume of the ice caps leads to a substantial increase in glacier runoff as shown in Figure 3. At about 2030, the runoff change is in the range 0.5–0.8 ma^{-1} for Hofsjökull and 1.1–1.7 ma^{-1} for the southern part of Vatnajökull, which is approximately 30% of the current average runoff from the ice caps. The projected runoff change increases approximately linearly to a maximum of 1–1.5 ma^{-1} for Hofsjökull and 1.75–2.75 ma^{-1} for the southern part of Vatnajökul in about 2100 after which it levels off and decreases due to the decreasing area of the ice caps.

Conclusions

Changes in glacier runoff are one of the most important consequences of future climate changes in Iceland, Greenland and some glaciated watersheds in Scandinavia, with important implications for the hydropower industry. Rapid retreat of glaciers also has other implications, for example changes in fluvial erosion from currently glaciated areas, changes in the courses of glacier rivers, which may affect roads and other communication lines, and changes that affect travellers in highland areas and the tourist industry. In addition, glacier changes are of international interest due to the contribution of glaciers and small ice caps to rising sea level.

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Establishment of Decadal-scale UV Climatologies for High-latitude Ecosystems Studies

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Introduction

Solar ultra-violet radiation (UVR) is an important natural geophysical parameter influencing terrestrial and aquatic eco-systems all over the globe *(Häder, 1997)*. In the Arctic, UVR, though on an average being much weaker than at low latitudes, can be an important stress factor mainly due to high surface reflectance from snow and ice, very high transparency of water and extended daylight at the beginning of the biologically productive period. This role can be further reinforced under special conditions such as polar ozone depletion occurring during spring. A comprehensive documentation of UV and its effects on ecosystems in the Arctic is given in *Hessen (2002).*

To understand eco-system responses to UVR changes, both process studies and long-term correlation studies using realistic input data are necessary. However, in-situ UVR measurements with sufficient accuracy and adequate quality assessment and control only have existed for about a decade. In order to establish UV series for a longer time scale, one has to combine measurements of the most important parameters influencing UVR with radiation transfer models, which have experienced a considerable improvement in recent years, both due to the development in methodology and increasing computing capacity. These goals were addressed in two subsequent international projects, MAUVE and UVAC. The first project had its focus on development and testing methods to derive UVR from satellite measurements, while UVAC addressed a concrete application in the high-latitude marine environment. In the following we give a short description of the UV climatologies for the Lofoten region, North-Norway, derived from two independent methods based on satellite data and one based on ground-based measurements and the application in the frame of the UVAC project.

Methods

Apart from the "fixed" parameters solar elevation/geographical latitude and surface elevation (topography), the most important parameters influencing UV radiation levels at the surface are: total ozone, cloud coverage and thickness, surface albedo and atmospheric aerosol optical thickness. The method developed at JRC uses METEOSAT cloud data, which have been available since 1984. The geostationary orbit of this instrument implies a less favourable geometry at high latitudes causing a decrease of spatial resolution to some tens of km. On the other hand, it provides approximately half-hourly cloud scenes allowing, in principle, to follow variations in cloud cover throughout the day. The method developed at DLR uses cloud data from the AVHRR instrument which also is available since the mid-1980s and which has a polar orbit. These give a much better spatial resolution of about 1x1 km, but usually have only one overpass per day over a site. Both methods use total ozone data from the TOMS instrument, which has been available since 1979, complemented with other data sets, such as GOME and TOVS, in data gaps especially in the mid-1990s. Also with respect to other parameters the two methods differ: The JRC method includes a topography model, and visibility data to estimate the aerosol content of the air, while the DLR model uses an aerosol climatology and no topography, thus mainly being usable for marine applications. A detailed description of the two methods is given in *Verdebout (2000)* and *Meerkötter and Bugliaro (2002).* A systematic comparison of the two resulting datasets has yielded a remarkably good agreement *(Meerkötter et al., 2003).*

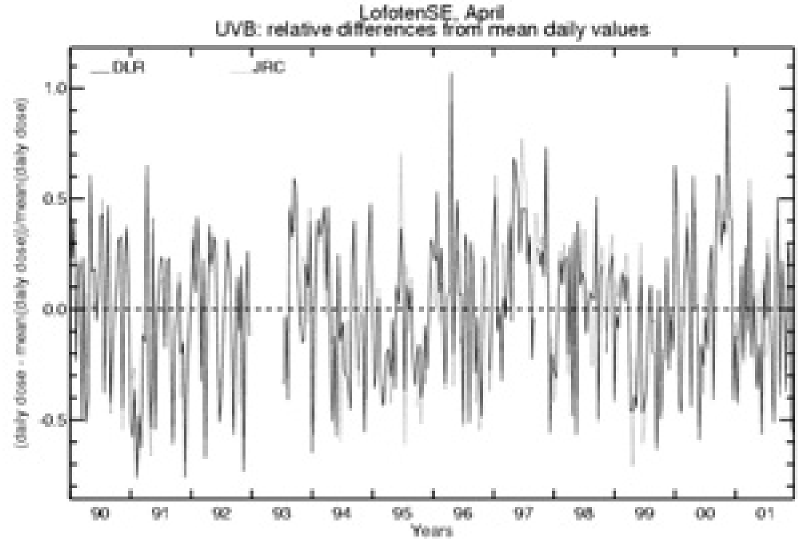

Figure 1. Relative deviations of the satellite derived surface UV-B radiation (DLR and JRC method) to the mean value for April in the period from 1990 to 2001.

Figure 1 shows daily UV doses in April throughout the years 1990-2001 as derived with both satellite-based methods. Obviously, the general agreement is very good on most days in April, but the DLR method shows more pronounced extreme values, which is not unexpected due to the higher spatial resolution. The figure also shows an increased number of days with higher-than-average daily doses in 1997 and 2000, two years with severe ozone depletion and high albedo due to large amounts of snow.

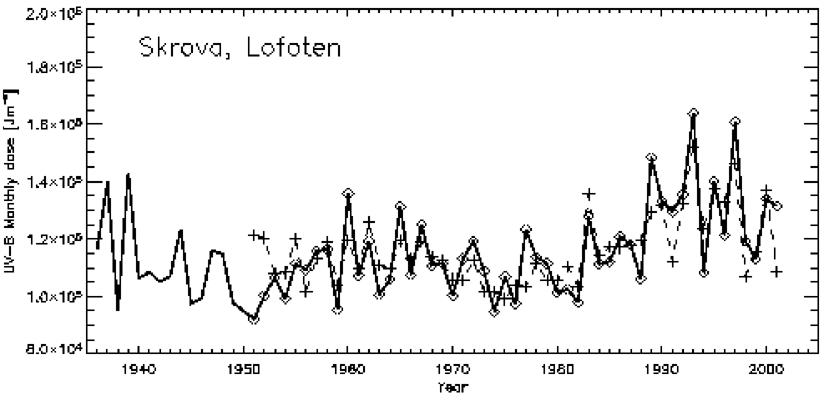

Figure 2. Monthly UV-B dose in April at Skrova, Lofoten, calculated from Tromsø total ozone and local meteorological cloud observations. Dashed line: fit derived using a multi-linear regression model (Hansen et al., 2004).

A third climatology, which covers a much longer time period, but is limited to one geographical location, was established at NILU. It is based on the 68-year records (1935-2003) of total ozone in Northern Fennoscandia (Tromsø, complemented with data from Murmansk, Sodankylä, and Andøya) and cloud coverage (visual observations) at Skrova, Lofoten. The cloud information in this method is very crude (cloud fraction in octals, i.e. a value between 0 and 8), but comparison with UV measurements has shown that aggregated UV data, such as weekly and monthly means as well as maximum daily doses agree quite well *(Engelsen et al., 2004).* The April monthly doses of this series are depicted in Figure 2. They show an overall increase especially since the 1970s, but also significant decadal-scale variations with intermediate maxima at the end of the 1930s, around 1960 and in the 1990s. As pointed out in *Hansen et al. (2004)*, this variation is mainly due to variations in cloud coverage, while the UV increase since the 1970s is mostly due to the depletion of the stratospheric ozone layer.

Applications

When applying such climatologies in ecosystem studies, the crucial question is in which way the geophysical parameter influences biological systems. Concretely spoken for this case: Are aquatic ecosystems mostly influenced by short-time maximum UVR doses or integrated doses, say over a week or even a month, and at which time of the year or of biological cycle?

In the frame of the UVAC project, a number of geophysical parameters (NAO index, AO index, Gulf Stream Index (GSI), turbulence, UVR monthly doses, UVR maximum daily doses around 1 April and 1 May etc.) were correlated against cod recruitment (ICES 0-year class strength 1967-2000), as well as abundance of *Calanus Finmarchicus* (1984-2001). A strong positive correlation was found between cod recruitment on one side and GSI, turbulence and UVR maximum daily dose around 1 May on the other side. There is also a strong positive correlation between the recruitment and the NAO index two years earlier.

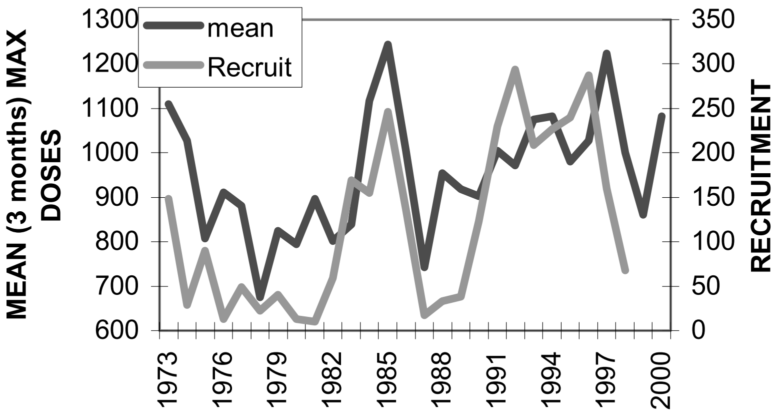

Figure 3. Cod 0-year class strength (light grey) from ICES and UVR maximum daily dose on 1 May (± 5 days) at Skrova, Lofoten (dark grey).

The strongly significant positive correlation between UVR maximum doses around 1 May and cod recruitment, shown in Figure 3, was a major surprise, contradicting the basic work hypothesis of the project, namely that UVR has an adverse impact on cod eggs and larvae. There is no obvious dependence between UVR maximum dose and other geophysical parameters correlating with cod recruitment, such as the GSI, so that one has to consider the found correlation as a true one. However, a plausible mechanism has not been found so far. What further complicates the situation is the fact that the cod recruitment correlates most clearly with UV-B dose, not with UV weighted with a cod egg mortality action spectrum. The spatially resolved satellite climatologies were used for correlation studies between UVR doses from limited regions and zooplankton population and recruitment. Due to the limited number of data pairs, the correlations found are not significant at the 95% confidence level, but the coefficients are all negative.

Acknowledgments

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Marine Ecosystem Responses to the Warming of 1920s and 1930s

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Introduction

In the 1920s and 1930s there was a dramatic warming of the air and ocean temperatures in the northern North Atlantic (Rogers, 1985; Johannessen et al., 2004). This warm trend continued through to the 1950s or 1960s, with the timing of the decline varying with location. These high temperatures match, and in some cases exceed, the present day warming. Large and significant changes in the marine ecosystems occurred as a result of the earlier warming. Some of these changes are documented herein for comparison with present warming and as a guide to predicting future effects of anthropogenic-induced climate change.

Ecosystem Responses

This warming lead to dramatic changes in the distribution, abundance and migration patterns of marine flora and fauna. Some examples of the observed responses from five different regions of the North Atlantic are presented.

West Greenland

The most well documented change was the increase in abundance of Atlantic cod (*Gadus morhua*) off West Greenland. From the late 1910s to the early 1930s, they not only increased in numbers but spread gradually northward from their location near the southern tip of Greenland prior to the warming to Upernavik in West Greenland after the warming was fully established, a distance of over 1500 km. This is believed to be due to both increased transport of larvae from Iceland and better survival of those once they reached West Greenland waters (Jensen, 1949). The increased cod abundance led to the development of a large cod fishery, which replaced seal fishing as the main industry in the country, and it remained dominant until the collapse of the cod in the 1970s. Jensen (1949) also documented changes in many other species. These included haddock (*Melanogrammus aeglefinus*), halibut (*Hippoglossus hippoglossus*), and herring (*Clupea harengus*), which also spread northward and whose abundances increased. On the other hand, colder-water species such as capelin (*Mallotus villotus*) were found not to migrate as far south along the coast as before and their abundance in southwestern Greenland decreased while it increased in the north as far as Thule. In northwestern Greenland, white whales (*Delphinapterus leucas*) and narwhals (*Monodon monoceros*) arrived earlier and left later on their annual migrations. New immigrants came to Greenland including tusk (*Brosmius brosme*), ling (*Molva vulgaris*), witch (*Pleuronectes cynoglossus*) and the jellyfish (*Halopsis ocellata*), probably through advection from Iceland.

Iceland

Prior to the warming in the 1920s, the Atlantic cod spawned almost exclusively off the south coast of Iceland. As the waters warmed, cod spawning spread northward until there were major spawning locations completely surrounding Iceland (Sæmundsson, 1934). Capelin, which also principally inhabited the southern waters off Iceland prior to the warming, moved to the north coast with the rise in temperatures and became scarce on the south coast. Being a major prey for adult cod, the absence of capelin on the south coast resulted in a decrease in the condition of cod that remained there. Several warm-water species, such as basking sharks (*Selache maxima*), tunny (*Orcynus thynnus*), mackerel (*Scomberus scomberus*) and sunfish (*Orthagoriscus mola*), appeared occasionally and sometimes frequently in Icelandic waters, while previously they had been rare or absent altogether (Sæmundsson, 1934; Fredriksson, 1949).

Faroe Islands

Surrounded primarily by Atlantic waters, none-the-less the Faroes also experienced ecosystem changes during the warm period. Most noticeably was the invasion of the Atlantic horse mackerel in relatively large numbers (Tåning, 1949). In addition, several other warm water species became occasional visitors to the Faroe Islands, including swordfish (*Xiphias gladeus*), twaite shad (*Alosa finta*) and pollock (*Pollachias pollachias*) (Cushing and Dickson, 1976).

Barents Sea

With the warming in the 1920s and 1930s, cod appeared in large quantities on Bear Island Bank, which resulted in the reestablishment of a cod fishery there after an absence of almost 40 years (Blacker, 1957). Cod, as well as haddock, expanded eastward to Novaya Zemlya. The abundance of Norwegian spring-spawning herring increased in parallel with the temperatures recorded at the Kola section, a hydrographic monitoring section off Northern Russia (Toresen and Østvedt, 2000). A herring fishery developed along the Murman coast of Russia, whereas previously this species was almost unknown in this region (Beverton and Lee, 1965). The capelin feeding migration is believed to have also spread farther north and east in the Barents Sea during the warm period as they migrated to and from the Polar front that separates the cold, low salinity Arctic waters from the warm, high salinity Atlantic waters. The responses were not limited to fish. Russian studies revealed a retreat of Arctic benthic species and an increase in the number of boreal species along the Murman coast such that the relative amount of boreal species doubled between the period prior to and during the peak of the warming (Nesis, 1960).

Svalbard

Atlantic cod spread northward into the area off West Svalbard in large numbers during the 1920s (Beverton and Lee, 1965). Comparison of benthos prior to the in the 1930s with those of the 1950s indicated that Atlantic species spread northward by approximately 500 km (Blacker, 1957). It was suggested that this was a result of an increasing effect of the Atlantic waters in the region.

Conclusions

With the warming of the waters during the 1920s and 1930s, significant changes in the distribution, migration patterns and abundances of numerous species occurred in the Northern North Atlantic. Most prominent was a northward movement of many species with a retraction of Arctic species and a spread of boreal and subtropical species. The most significant change occurred off West Greenland where the economy of the region switched from seal fishing to one based almost exclusively on Atlantic cod. While more intense fishing pressure exists today and no doubt does and will influence the ecosystem responses, it is clear that much can be learned from examining the response to past climate changes.

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Biological Implications of Arctic Change

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Introduction

The detection of biological change in the Arctic marine environment can be expected to coincide with recent patterns of high-latitude environmental change, including a seasonal reduction in the extent and duration of sea ice, increased seawater temperature, and changing hydrographic conditions (e.g. Serreze *et al.,* 2003; Overland and Stabeno, 2004). The shallow, productive features of the Bering Strait region in the Ameriasian Arctic may accentuate its role as a sentinel indicator of global change effects (Grebmeier and Dunton, 2000). Ecosystem change on the shallow shelves of the northern Bering and Chukchi seas are intimately connected to systems further to the north (Figure 1). Current studies undertaken as part of the Bering Strait Environmental Observatory (BSEO; http://arctic.bio.utk.edu/AEO/index.html) are occupying time series sites in the northern Bering and Chukchi seas to evaluate basic hydrographic and biological parameters. The Western Arctic Shelf-Basin Interactions (SBI; http://sbi.utk.edu) project is also investigating the production, transformation and fate of carbon at the shelf-slope interface in the northern Chukchi and Beaufort seas in the context of Arctic environmental change.

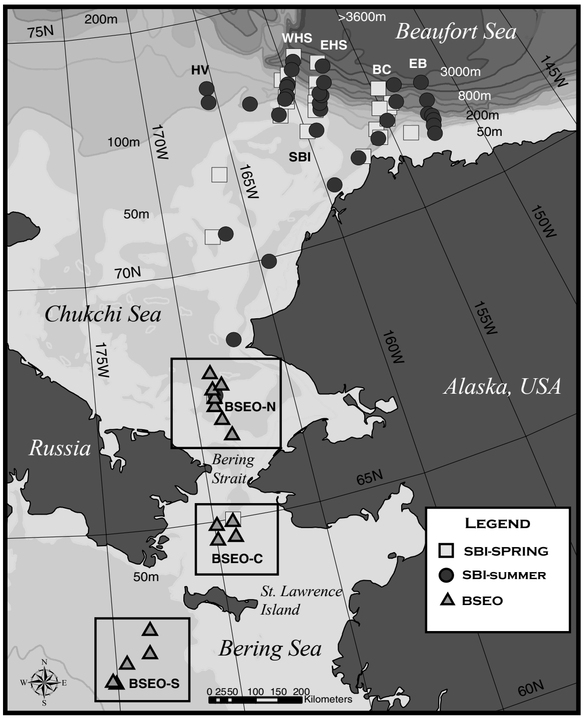

Figure 1. Location of time series oceanographic data for the Bering Strait region maintained by the Bering Strait Environmental Observatory (BSEO) and the western Arctic Shelf-Basin Interactions (SBI) study area. The BSEO sites are designated as BSEO-S (south of St. Lawrence Island), BSEO-C (Chirikov Basin) and BSEO-N (north of Bering Strait). The SBI transects are HV (Herald Valley), WHS (West Hanna Shoal), EHS (East Hanna Shoal), BC (Barrow Canyon) and EB (East Barrow).

Recent studies show that the northern Bering Sea is shifting towards an earlier spring transition between ice-covered and ice-free conditions, with coinciding changes in both primary and secondary trophic level production (Stabeno and Overland, 2001). These changes could have dramatic impacts for higher-trophic level fauna, including some species such as benthic-feeding walrus, bearded seals, gray whales and diving sea-ducks that are of cultural and subsistence significance to Arctic Native residents. Studies in the northern Bering and

Chukchi seas over the last two decades provide many indications of ecosystem change. The tight pelagic-benthic coupling observed between seasonal water column carbon production processes and underlying short- and long-term benthic carbon transformation processes provide a "footprint" in the sediments of persistent ecosystem events and subsequent time-series changes. Pelagic-benthic coupling can be studied via underlying sediment processes on various time scales. Sediment metabolism can be an indicator of weekly-to-seasonal carbon depositional processes, while benthic faunal populations can act as multi-year, long-term integrators of a variety of marine processes.

Methods

Biological time series sites south of St. Lawrence Island (BSEO-S), in the middle of Chirikov Basin to the north of St. Lawrence Island (BSEO-C), in Bering Strait, and just north of Bering Strait in the southern Chukchi Sea (BSEO-N) have been occupied since the late 1980's and in some cases, earlier (Figure 1). Hydrographic measurements of seawater temperature and salinity, along with nutrients and chlorophyll content, were made at these sites using CTD/rosette systems. Hydrographic analyses, benthic population structure, sediment tracer analyses, biomass and sediment oxygen uptake rates that were measured during these studies have been documented elsewhere (e.g., Grebmeier and Cooper, 1995; Cooper *et al.*, 1997; Cooper *et al.*, 2002). Similar methods were utilized during the SBI studies from 2002-2004 (Figure 1).

Results and Discussion

An overall decline in both sediment oxygen uptake (an indicator of carbon supply to the sediments) and overall benthic standing stock from the 1980's to the present has occurred in the Bering Strait region, with probable impacts upon higher trophic organisms that are dependent upon benthic prey. For example, declining bivalve populations south of St. Lawrence Island suggest that the decline in the bivalve prey source could be playing a role in population declines for the spectacled eider (Lovvorn *et al.*, 2003). Other studies indicate that a change in hydrographic forcing and nutrient supply is limiting primary production in the region (Figure 2; Grebmeier and Dunton, 2000; Grebmeier *et al.,* in prep). In addition, recent

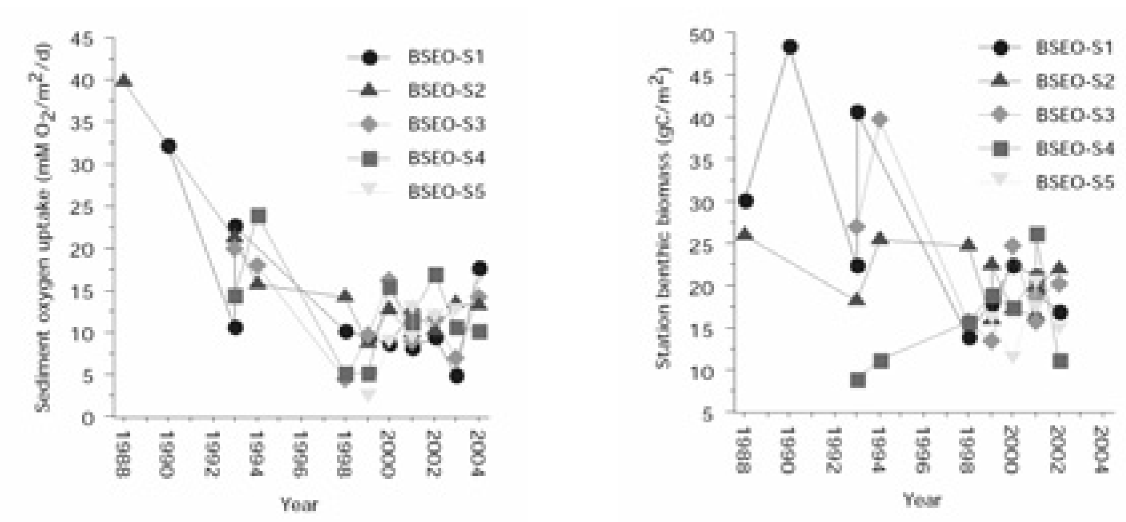

Figure 2. Time series measurements of total sediment oxygen uptake (an indicator of carbon supply to the benthos) and benthic biomass in the region southwest of St. Lawrence Island in the northern Bering Sea (BSEO-S).

studies of gray whale feeding areas and benthic time series measurements data in the Chirikov Basin also indicate a decline in the benthic amphipod prey biomass in the region over the last decade, with indications that gray whales are feeding predominantly north of Bering Strait (Moore *et al.,* 2003). Recent data also indicate gray whales are feeding in new areas along their migration path to obtain food without reaching historical feeding areas in the Bering and Chukchi Seas (Grebmeier *et al.*, unpubl. data).

Thus, biological populations are exhibiting ecosystem change on the shallow shelves of the northern Bering and Chukchi seas, and this ecosystem is intimately connected to the larger Arctic systems further to the north. Current studies as part of the SBI project at the shelf-slope interface in the northern Chukchi and Beaufort Seas are downstream of these productive shallow western Arctic shelves. In these recent studies (2002-2004) sediment oxygen uptake, nutrient flux and benthic faunal populations were highest on the Chukchi shelf, with rates decreasing in the Beaufort Seas as well as from the shelf to deep basin in all transect lines (Grebmeier and Cooper, 2004, submitted). Sediment nutrient exchange indicates high levels of silicate and ammonium effluxing from the sediments in the Chukchi and Beaufort shelves and being transported into the deep basin at the level of the Pacific-influenced Arctic upper halocline. In addition, Barrow Canyon is a key exchange site for both particulate and dissolved carbon. Any change in hydrographic forcing and benthic processes on the productive northern Bering and Chukchi shelves will directly impact carbon and nutrient export from the shelf regions to the deep basin. These current and planned shelf-basin studies are providing key baseline data for research planning efforts on Arctic environmental change (see Arctic Ocean Sciences Board; http:www.aosb.org), International Conference on Arctic Research Planning II (http://www.icarp.dk/), and planning for the International Polar Year (http://www.ipy.org/).

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Ecosystem Changes in High Arctic Marine Ecosystems

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Since the late 1970s, an overall decrease in sea ice distribution has been observed in the Arctic. This decrease has led to prolongation of the ice-free period off the north coast of Russia, in the Greenland Sea, the Barents Sea, and the Sea of Okhotsk. Higher atmospheric temperatures will increase the transport of water vapor toward the North Pole, resulting in an increase in precipitation and freshwater (snow) supply to high latitudes. An overall presentation is given of results obtained in the integrated ecosystem study CAMP (Changes in Arctic Marine Production) in the high-Arctic fjord, Young Sound (75°N), NE Greenland. The aim of this study is to link biological production to sea ice and hydrographic conditions in order to predict how expected changes in snow, ice and hydrographic conditions will affect high-Arctic marine ecosystems in the future.

Young Sound is a deep-sill East Greenland fjord similar to numerous other large, deep fjords in the region that often penetrate hundreds of km inland. The fjord is connected to the East Greenland Current, which consists of polar water in the upper 150-200 m and carries large amounts of sea ice with it. Sea ice begins to form in September, growing to a thickness of 1.5 m before it breaks up in mid-July the following year. The average ice-free period (1958-1990) is 80 d but has shown a dramatic increase during 1990-2004 with up to 140 ice-free days during 2003. Typically, meltwater from the Greenland Ice Sheet and rivers drain into the inner parts of the East Greenland fjords. The total freshwater discharge in Young Sound takes place over a 3-month period during June-September. During the ice-free period freshwater input and mixing by wind and tides result in an estuarine circulation, by which lighter water of salinity <30 is moved seaward above denser water from the East Greenland Current with salinities of 31.5 – 34.4.

Following the break-up of ice, the immediate increase in light penetration to the water column causes a steep increase in primary production. In the shallow parts covering the photic zone (0-40 m), benthic primary producers dominate primary production. As a minimum estimate, primary production fixes 50 g C m^{-2} yr^{-1}, of which phytoplankton assimilates 12%, sea ice algae <1%, benthic macrophytes 46% and benthic microphytes 41%. Tight coupling between primary producers and grazers has been observed in these high-Arctic areas. Grazing in the water column, primarily by copepods, leads to pulsed vertical export of organic matter to the sea floor where benthic animals and microbes are responsible for further degradation of the organic matter and regeneration of nutrients. In the shallow parts of the fjord, carbon fixation by algae balances carbon consumption resulting from grazing, mineralization and burial. Bivalves constitute an important part of the benthic fauna, especially in shallow waters (<40 m) and represent a plentiful inshore food resource for walruses. As a solid layer of ice covers Young Sound, except during the short open-water period, the fjord is inaccessible to walruses most of the year. Thus, the population of walruses in the area is only able to consume <3% of the standing stock of bivalves or less that half of the annual somatic bivalve production.

In the deep, central parts of the fjord the only primary producers are phytoplankton and sea ice algae, which represent a carbon fixation of 10 g C m^{-2} yr^{-1}. In contrast to the shallow-water parts of the fjord, the carbon consumption of 49 g C m^{-2} yr^{-1} in the deep parts due to grazing, mineralization and burial differs greatly from the carbon production from phytoplankton. The difference of 39 g C m^{-2} yr^{-1} is balanced by the input from the Greenland sea (15-45 g C m^{-2}

yr^{-1}). The input of organic C from land to the outer regions of the fjord accounts for only 2-3% of the total input, although, in the short term, it may be responsible for a substantial fraction (59%) of the settling material in connection with peak discharge in the rivers. Overall, input from the Greenland Sea is essential to sustain the ecosystem in the fjord.

A regional atmosphere-ocean model predicts a temperature increase of up to 6-8°C at the end of this century (2071-2100) that will lead to increase in freshwater runoff, thinning of the sea ice, and an increase in ice-free conditions from 2.5 months to 4.7-5.3 months in Young Sound. Evaluation of the effect of increased freshwater flux into the fjord reveals that in fjords dominated by entrainment mixing, the surface-layer thickness (e.g. upper low-salinity layer) will change only marginally. In contrast, the transport of saltwater from the Greenland Sea to Young Sound below the halocline will increase significantly due to increased estuarine circulation. An increase in the ice-free period will enhance biological productivity in the area due to increased light availability for primary producers. Because the surface layer thickness will have changed only marginally by the end of the century, the phytoplankton bloom will continue to occur in a subsurface layer, but as net input increases, production will benefit from an increased import of nutrients and organic matter from the Greenland Sea. Improved food availability will stimulate bivalve growth and production in the area. Furthermore, an increase in the ice-free season will prolong the period in which birds and marine mammals, e.g. walruses, have access to the food-rich coastal area and thus improve their foraging conditions.

The predicted changes in temperature, ice-free conditions, and precipitation in the area at the end of this century suggest that physical conditions in Young Sound will become more similar to present-day conditions farther south, e.g. at Kap Tobin (Fig. 1). Thus, the area extending from Young Sound and a few hundred km south represents a climate gradient reflecting this century's climate change. We suggest that investigations along north-south transects in this region may be highly valuable in evaluating adaptations of biological processes and species to different physical settings brought about by future climate change in the Arctic.

Supplementary information can be found on the Internet:

www.dmu.dk/LakeandEstuarineEcology/camp

www.zackenberg.dk

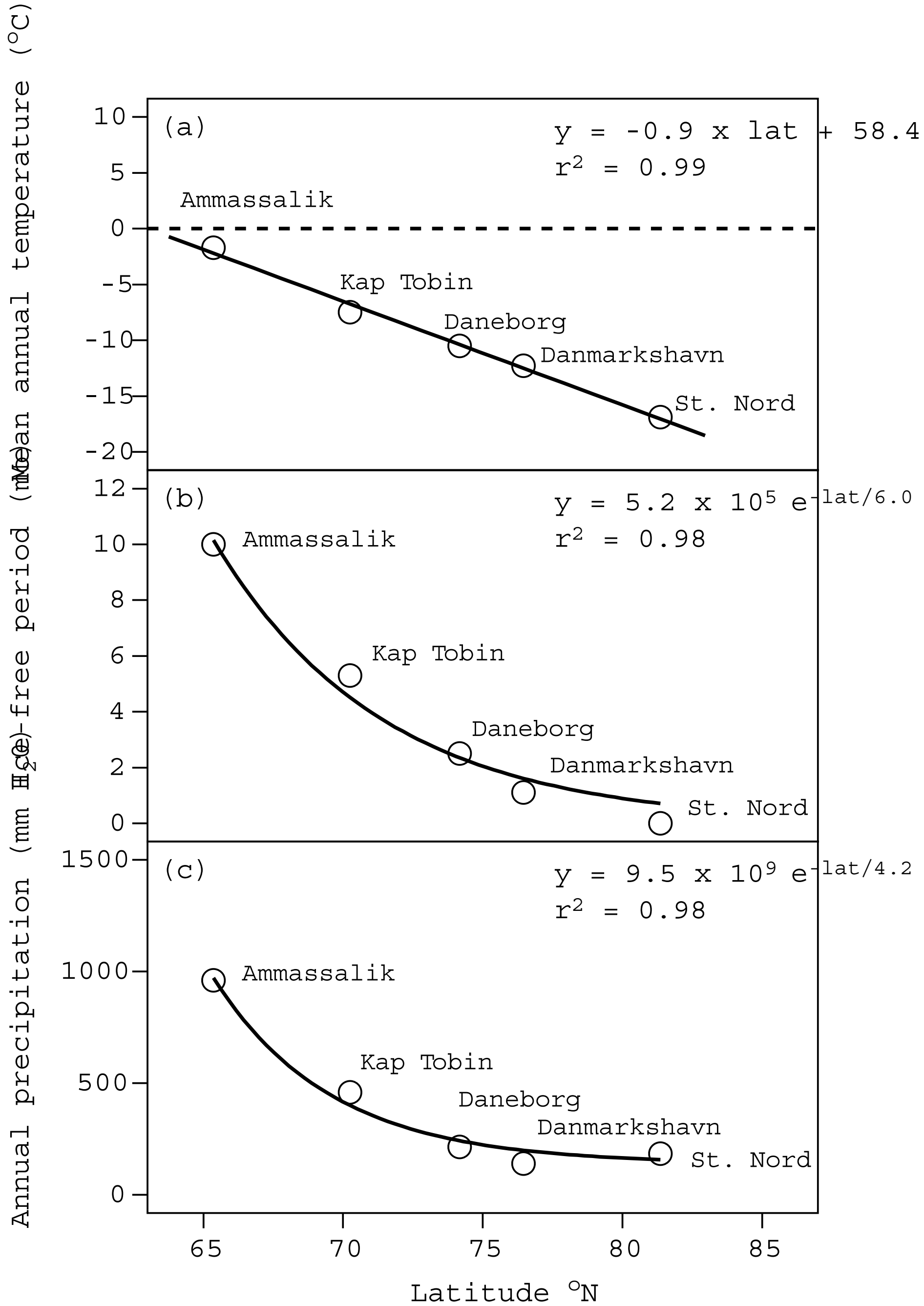

Figure 1. (a) Mean annual temperature in Northeast Greenland versus latitude. (b) Annual ice-free period versus latitude. (c) Mean annual precipitation versus latitude. Daneborg is situated in the outer region of Young Sound.

Anadromous Arctic Fishes and Impacts of Climate Change

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There are several Arctic species within the families Acipenseridae, Coregonidae, Gasterosteidae, Osmeridae, Petromyzontidae and Salmonidae that exhibit anadromous behaviour i.e. spend part of their lives in the marine environment and migrate to freshwater to spawn. Two species, Arctic cisco (*Corengus autumnalis*) and rainbow smelt (*Osmerus mordax*) are considered to be obligatory anadromous (Craig, 1989), that is all individuals in a population reside for some time in a marine environment before they reproduce. However, most anadromous species in the Arctic are considered to be facultative (Craig, 1989) since all individuals of a population do not necessarily migrate to sea. Typically, anadromous behaviour is most dominant at nothern latitudes (McDowall, 1987) because oceans are more productive than freshwater habitats in temperate zones (Gross *et al.*, 1988). For a number of facultative anadromous species (e.g. Arctic char, dolly varden, brook trout, brown trout, 3-spine sticklebacks), anadromous behaviour ceases towards the southern portion of the species distribution range (several references in McDowall, 1987). It is likely that facultative anadromous species exhibit such behaviour in polar regions to take advantage of marine coastal productivity and escape extreme oligotrophic conditions that typify Arctic lake systems. Generally, individuals of a population that exhibit anadromous behaviour have a larger maximum size and higher maximum age, indicating some benefit to seaward migration and feeding (Gross, 1997).

Overall projected impacts of climate change on Arctic lakes suggests that productivity of these limited systems will increase. Ice-off is expected to occur earlier in the season and ice formation to occur later, thereby extending the ice-free, growing season. As a result, primary productivity should increase. In addition, reduction of the permafrost will increase the supply of organic material and nutrients from terrestrial systems which should also increase primary productivity. Productivity in streams is also expected to increase. If increases in primary productivity cascade to secondary and tertiary productivity, fihs populations should initially benefit with increases in abundance and size. However, there will be a carrying capacity at which growth and abundance will be regulated by density. Ice cover on Arctic lakes is expected to be thinner allowing increased solar radiation penetration during fall and spring. Photosynthetic production of oxygen during these times will increase and will reduce the potential of winter fish kills. If the benefits of increased productivity and reduced winter fish kills in freshwater systems (lakes and streams) persist, then facultative anadromous species may actually exhibit less and less anadromous behaviour if the benefits for migrating to coastal areas for summer feeding are outweighed by the benefits of remaining in freshwater systems. Nordeng (1983) reported that when the freshwater food was experimentally increased, the incidence of anadromous migration by Arctic char decreased.

The variability associated with projected changes in productivity is uncertain. The anadromous species found in the Arctic are typically long-lived (20-50 years) compared to other Arctic fish species. Longevity benefits a species by ensuring a relatively long reproductive cycle, which minimises the risk that prolonged periods (5-15 years) of unfavourable environmental conditions with result in the loss of a spawning stock (Leaman and Beamish, 1981). The anadromous forms of Arctic fish species are long-lived (longer than their freshwater forms) and are likely suited to cope with increased variability. Initially as environmental conditions improve, successful spawning episodes will increase in frequency. Anadromous fish that are short-lived (<20 years) will likely exhibit more variability in abundance trends with increased variability in environmental conditions.

The anadromous species found in the Arctic also inhabit streams or rivers in addition to lakes. Projected climate impacts on Arctic hydrology suggest that runnoff will be driven by increased precipitation and will no be as seasonally variable. There will be enhanced winter flow and reduced summer flow. Warmer conditions will reduce the length of winter and shorten ice season along with a reduction in the thickness of ice. Streams that were previously frozen solid will retain water beneath ice. This will benefit anadromous species that utilize streams for winter habitat. Overwintering habitat is critical for Arctic species and are typically of limited capacity (Craig, 1988). However, the shortened ice season and thinner ice will redcuce the severity of ice-jamming. This will have implications for productive river deltas that require flooding. There are several anadromous species, such as Arctic cisco, that rely on deltas as feeding areas, particularly in spring (Craig, 1989).

There are a number of anadromous species whose nothern limits of distribution will likely expand to include many regions within the Arctic. Pacific salmon species will likely expand into Region II. Sockeye and pink salmon have already been recorded from Banks Island, NWT, Canada which is outside their normal range of distribution (Babaluk *et al.*, 2000). Similarly, anadromous species such as Atlantic salmon, alewife, brown trout and brook trout could also extend their northern range of distribution into Regions I and IV. Invasion of new anadromous species to Arctic regions will likely have negative impacts on species already present.

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Char as a Model for Assessing Climate Change Impacts on Arctic Fishery Resources

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Introduction

Arctic char (*Salvelinus alpinus*) is a circumpolar species that occurs across a wide latitudinal range (~85°N to ~45°N) from the High Arctic to temperate areas (Johnson, 1980). Given this distribution, char appear particularly flexible with respect to life history, ecology, and adaptability to a variety of conditions. In the north, char exhibit sea-run (migratory, anadromous) and freshwater (resident, non-anadromous) life histories with different types variously occupying lakes, rivers, estuaries and nearshore environments seasonally and/or throughout life (Klemetsen et al., 2003). Wherever they occur, but especially in northern areas where they are often the only fish species present in freshwaters, char may also differentiate into a variety of co-occurring growth or morphological forms. Such differentiation may arise for ecological or genetic reasons, and when coupled with life history variability adds complexity to attempts to understand northern aquatic ecosystems. For example, within a particular lake-river system with sea access, some non-anadromous individuals may assume the role of apex predators as cannibals consuming other char, others may exploit lower trophic levels in pelagic, littoral or benthic areas of the lakes, and still others may migrate annually to and from the sea to feed during summer in estuarine and nearshore areas. The various traits described above all suggest that char populations will variously integrate at several levels many of the effects of climate variability and change (CVC), and biologically they appear to be ideal for investigating and monitoring CVC effects on arctic aquatic ecosystems.

In addition to these biological advantages of using char to monitor CVC effects, they are important in arctic freshwater and nearshore fisheries, and of emerging importance in aquaculture. In the Canadian North, significant commercial char fisheries occur along the Labrador coast (DFO, 2001) and at Cambridge Bay (Victoria Island) (DFO, 2004); trophy sport fisheries occur in many areas with perhaps the best known in Tree River (Moshenko et al., 1984); and, Aboriginal subsistence fisheries occur throughout the area (Huntington et al., 1998). Similar levels of use occur throughout the Arctic. Thus, char are important culturally, economically and for sustenance. As a result, considerable management and research effort has been, and will continue to be, directed towards understanding population perturbations, impacts and ensuring sustainability. The importance of char requires the development of both appropriate projections of potential CVC effects and management responses to CVC issues to ensure conservation and sustainability under all possible future climate scenarios.

The biological traits and importance noted above make char an ideal organism for understanding higher-level effects of CVC on both the ecological and human systems of the Arctic. The aims of this work are to: 1) examine the relevance of char generally for assessing CVC impacts; 2) provide some examples of studies of CVC-biological interactions using char; and, 3) explore the utility of char in research and future monitoring programmes to assess CVC impacts, with particular emphasis on those that can be at least partially implemented by local communities and fishers.

Methods

Establishing reasonable understanding of climate-driven temporal variation in a char population and differentiating this from other factors such as exploitation are major undertakings for any single population. Further, a key handicap in understanding climate-related effects on char populations is the paucity of temporal and spatial studies linking climate variables, arctic aquatic ecosystem processes and char population biology. These both hamper our ability to project future states, thus alternative approaches must be found to understand char-CVC interactions and to develop plausible scenarios for char. Various approaches for linking char biology and climate variation are available (see Box 7.8 in Wrona et al., 2005), but most interactions are summarised to the first order only (e.g., temperature effects on individual fish with no extrapolation to consequences for the population). Despite the elegance of the experiment, monitoring char population changes over the course of climate change for >100 years is too long a time horizon to be immediately useful in developing effective adaptive responses useful for conservation and management. Thus, similar to studies of past climate variation, proxy measures are necessary to estimate the effects of CVC on char populations. We offer two examples of recent and ongoing studies aimed to redress some of these needs.

Conclusions

Labrador Char Temporal Variation: Power et al. (2000) examined environmental associations with char population parameters. Biological data (mean catch at age, length, weight) from a 21-year time series were matched to climate parameters (air temperature [T], precipitation, sea surface T, salinity). Summer air and sea surface T's affected the biological system on an annual basis likely by increased nearshore marine productivity which for individual fish led to increased weight, length and growth, and thus to better overall condition for the population. Winter precipitation the season before the first summer of life of individual fish increased the snow pack and decreased seasonal freezing thus indirectly provided more overwintering habitat; this led to increased overwinter survival thence to more fish in the population. Similarly decreased energetic demands over winter increased growth, leading to earlier recruitment to the fishery (measured as lower age at catch). Finally, summer air T and precipitation during the fourth year of life (~first year at sea for most char) increased nearshore nutrient loading and productivity which led to increased growth and survival of this age class as seen in increased weight and decreased age of fish at catch. Thus, where data exist climate variability is important for understanding inter-annual dynamics of char populations. The potential coupling of these findings with climate change projections at the regional and sub-regional level may also allow for extrapolation of long-term future scenarios for char fisheries in many areas of the Arctic.

Latitudinal Variation in Char Population Parameters: We have assembled biological data for approximately 100 char populations spanning the latitudinal range of char in eastern North America from Maine to northern Ellesmere Island (unpublished data). This latitudinal range can be divided into Temperate, Sub-Arctic, Arctic and High Arctic zones that differ greatly in basic climate parameters (e.g., annual mean daily T is >0, -3 to -10, -10 to -17, and -20 ^{o}C respectively). Thus, climate variation across latitudes can be used as a proxy for future climate change and within- and between-population analyses of char biological parameters may offer clues to both the range and the direction of future responses of char populations. For example, fecundity, a measure of reproductive potential, when corrected for individual size of the fish showed significant negative linear trends with increasing latitude. This suggests that a) this measure of char reproductive capacity will shift with climate change with higher latitude populations becoming more fecund as local areas warm; and, b) char forms differ in the strength of their response, with anadromous and dwarf types possibly responding to a greater degree than the normal lacustrine type, thus loss of the latter type especially at lower latitudinal areas is a real possibility.

The examples outlined above suffer from two fundamental flaws – insufficient basic data and poor understanding of causal linkages between environmental and biological parameters. When linked to imprecision of climate change scenarios, our ability to project reasonable future scenarios for aquatic biological resources such as char is severely compromised. Redress of this is required and we offer here some elements of a strategy for monitoring and ground-truthing CVC impacts on char populations. First, a programme must be developed to monitor parameters of the fish population, their aquatic environments and climate over space and time, and it should be conducted in the context of biodiversity of char present in the area so as to increase precision in our understanding. This can best be implemented for a few, national and international, linked arctic sites that span the latitudinal and regional range for char. Studies must be coordinated with the same protocols used over the longer term to document shifts in local char populations and ecosystems as climate change develops. Even a modest programme for the Arctic is a huge undertaking, thus a manageable programme can best be conducted by enlisting the aid of local communities, resource users and arctic residents to gather both the necessary local biological and climate data. Second, in order to provide much of the interpretative context and in-depth understanding for these monitoring data, to differentiate change from variability for biological parameters, and to ascribe proper causation for such change, a substantive parallel research programme is required to investigate char biology and ecology and climate system linkages to these. The monitoring programme would provide many of the required temporal and spatial data whereas the research programme would provide detailed understanding of general effects of climate parameters on char populations, assessments of char responses to CVC effects, and verification of projections over time. Programmes such as these would offer great promise for understanding and preparing for CVC impacts on aquatic resources across the Arctic.

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Trend Coincidence of Pink Salmon Catch Dynamics among the Odd-years and Even-years Populations as an Evidence of Large-scale Physical Factors Effect

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Introduction

Coastal catch dynamics remained one from the basic index of Pacific salmon stock conditions until the present time. Several cyclic patterns of long-term dynamics of Pink salmon abundance were previously revealed from the catch data and could be considered as generally recognized regularities. Biannual cyclic recurrence of spawning approach and catch is inherent for the most of pink salmon regional groups due to interchanging of the odd-years and even-years populations. These populations usually differ markedly by level of spawning stock abundance and progeny, consequently. Due to long-term domination of even-years or odd-years population, the opposite dynamics of Pacific salmon stocks exist even in some neighboring regions, i.e. western and eastern Kamchatka coast.

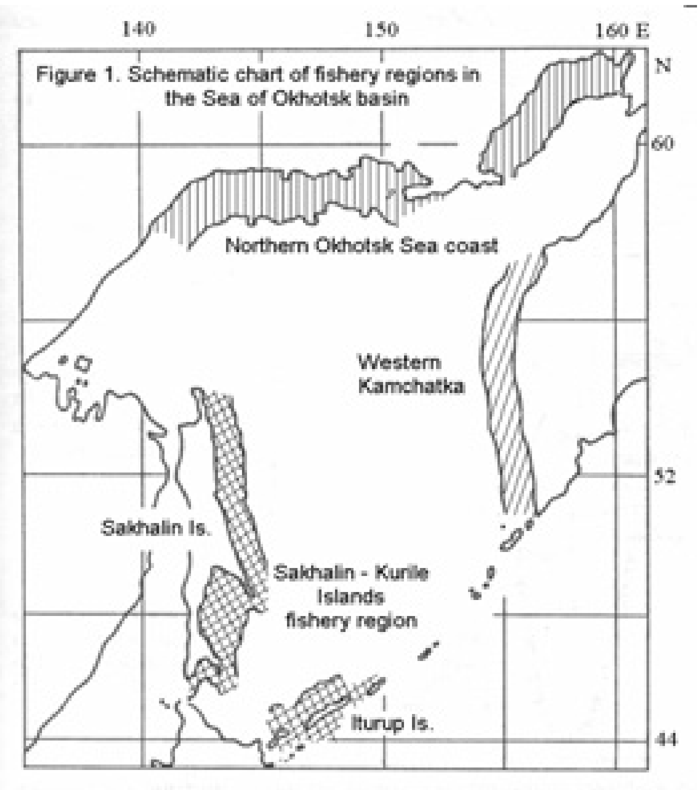

Figure 1. Schematic chart of fishery regions in the Sea of Okhotsk basin

Several long-period oscillations of pink salmon stocks were revealed as in the different fishery regions, as in the North Pacific on the whole (Beamish and Bouillon, 1993; Chigirinsky, 1993). The oscillation periods were estimated as close to so called "planetary cycle" in 50 - 60 years, in some studies - as close to 11-years solar cycle (Sukhanov, 1997). For increasing catch forecast correctness, it is necessary to reveal the most important factors among the natural and anthropogenic ones, which generates the abundance fluctuations, and also "change of dominants" as a specific event for the pink salmon stock dynamics. It means sharp drops in abundance of prevailing population far below the average abundance level of population of adjacent years.

Methods

For this purpose, the abundance dynamics of the odd-years and even-years pink salmon populations were analyzed separately by the methods, which make possible to level the differences in absolute values of the stock abundance. In our study, catch dynamics trends of pink salmon were calculated as arithmetical difference of "expected" catch calculated as the mean value of four previous years in the odd-years or even-years cycle and factual catch. Such technique of calculation was applied to suppress the noises and yield a clearer picture of the dynamics trend. The curves of the moving average are used for the graphic representation of the trends of long-standing dynamics; a smoothing factor of three was applied. All salmon catch values are given in metric tons (mt).

Results

Singular coincidence of catch dynamics among the almost independent odd-years and even-years populations was found for the Sakhalin – Kurile Islands fishery region (Figures 1, 2). Further analysis covered neighboring coastal fishery regions: the eastern Kamchatka, the western Kamchatka, and northern coast of the Sea of Okhotsk. No coincidence was found between catch dynamics of adjoining pink salmon populations on the eastern Kamchatka coast. Two other regions demonstrated satisfactory coincidence. However, the fluctuations there occurred rather smoothed in periods of pink salmon population depression and low catches: less than 1,000 mt in 1966-1982 on the northern coast of the Sea of Okhotsk, and less than 5,000 mt (with one year of exception) in 1958-1974 and, for odd years only, since 1987 until present time. This evening-out of trends negatively influence reliability of dependences between catch dynamics of odd-years and even-years pink salmon populations (Figure 3). Comparison between southern Sakhalin – Kurile Islands region and two northern regions suggests opposite dynamics of catch trend there. Such regularity was fixed previously for northern and southern salmon stocks along the west coast of North America (Gargett, 1997).

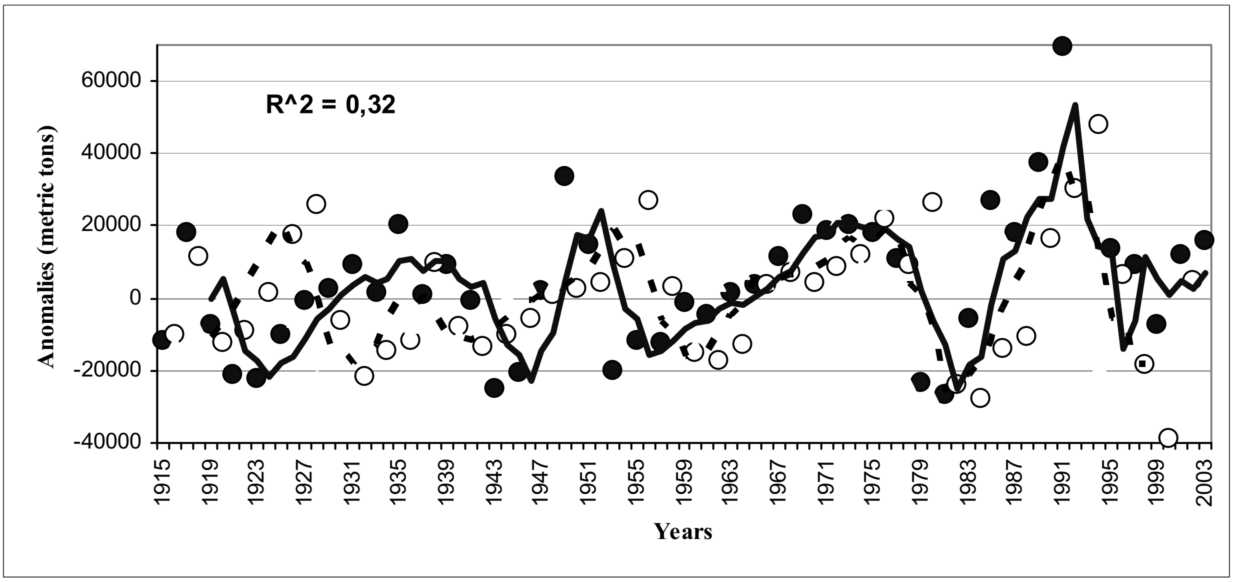

Figure 2. Anomalies of expected pink salmon catch value in the Sakhalin – Kurile Islands region, 1915 – 2003. Coincidence coefficient of trend curves for the odd-years (solid line, dark circles) and even-years (dotted line, open circles) populations is given. Trend curve for even-years population was moved back on two steps (four years) for the purposes of illustration.

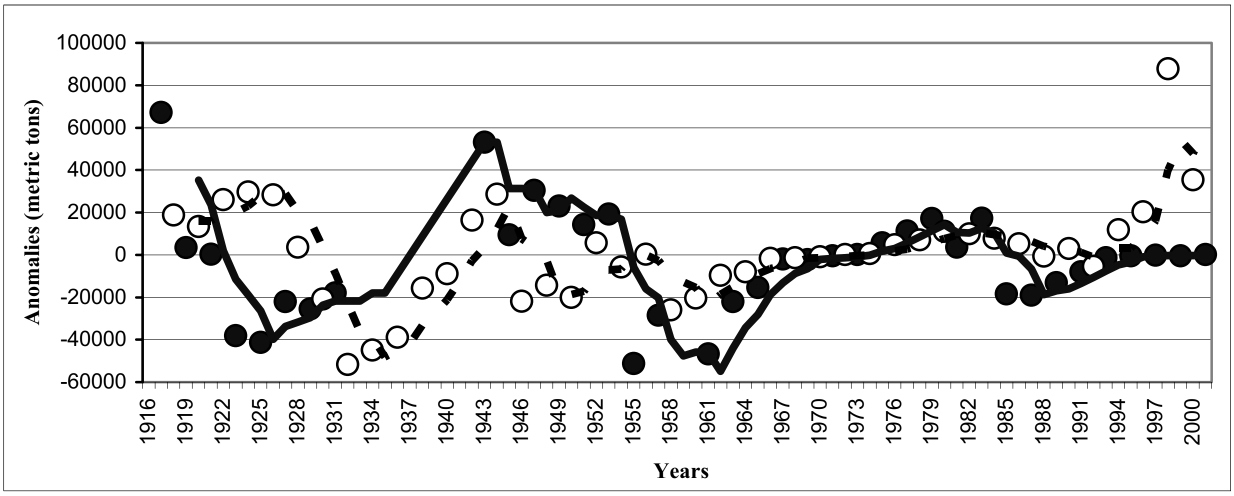

Figure 3. Anomalies of expected pink salmon catch value on the western Kamchatka coast, 1916 – 2001. Coincidence coefficient of trend curves for the odd-years (solid line, dark circles) and even-years (dotted line, open circles) populations is given.

For the Sakhalin – Kurile Islands region, alternation of uptrend and downtrend periods roughly coincided with 22-years (or double solar) cycle. Another feature is a rough coincidence of peaks of the odd-years trend curve with the generally recognized years of climate and oceanological «regime shifts» in 1950, 1976, and 1989. Coincidence of trend curves for the odd-years and even-years population has become more apparent in the second half of XX century (R^2 = 0.7) than for all data series since 1915. Among smaller fishery areas inside the Sakhalin – Kuriles fishery region, the Aniva Bay catch series demonstrated the highest coincidence of the trend curves (R^2 = 0.84). It creates expectations to develop a model for catch forecasting.

Discussions

The coincidence can not be explained by biological effects of odd-years and even-years population interference since fish of both generations spend a brief time in the same waters simultaneously. Divergence level along the genetic markers between them is higher than between the different local groups inside each of these generative lines (Glubokovsky, 1995). However, liability to the same trends of the salmon spawning approach dynamics in the even and odd years was recently noted for pink salmon on the Iturup Island, south-eastern Sea of Okhotsk (Kaev & Chupakhin, 2003). In their opinion, it indicated the fundamental similarity of interrelations in the system of "organism – environment" in the different pink salmon populations, together with the identical changeability of reproduction coefficients, which characterize survival in freshwater and marine life periods.

Observed relation between the pink salmon catch trends of even and odd years supposes an existence of the strictly determined internal response of populations to the periodic dynamics of global factor or the complex of factors, to a considerable extent determining the existing conditions of salmon reproduction and survival. A. Goryainov and T. Shatilina (2003) have found reliable correlation between sea-level atmospheric pressure in regions of Southern Asian Low and pink salmon catches in one year later. Variability of the Southern Asian Low effects monsoonal circulation of air masses and, then, synoptic conditions of salmon embryonic and early larval development during cold season. A. Gargett (1997) connected variation in the strength of the wintertime Aleutian Low pressure area with the water column stability characteristics, hence primary production value that further effect the forage success of salmon during marine life period.

Conclusions

Odd-years and even-years populations) of pink salmon in different regions of the Sea of Okhotsk coast demonstrate coincidence of catch dynamics through the whole existing catch series. That supposes an existence of the strictly determined internal response of salmon generative lines to the periodic dynamics of global factors, which effecting environmental conditions of salmon reproduction and survival. However, salmon dynamics trends obtain own regional features determined by local factors as natural, as anthropogenic ones.

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Palaeolimnological Evidence for Recent Climate Change in Lakes from the Northern Urals, Arctic Russia

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Introduction

General circulation models predict that warming in the Arctic will occur more rapidly than elsewhere, and there is growing evidence from palaeoclimatic studies that unprecedented climate warming has already taken place in many parts of the Arctic during the twentieth century (Overpeck et al., 1997). Lake sediment records in these regions are especially useful in identifying the extent of warming. Here we examine results from the Bol'shezemel'skaya Tundra in the northern Ural region of the Russian Arctic and assess evidence for climate change and also evaluate the impact of atmospheric pollution from local sources.

Methods

The recent sediments from two deep lakes, Mitrofanovskoe and Vanuk-ty, situated in the permafrost belt within the Bol'shezemel'skaya Tundra were studied for diatoms, chironomids, lead isotopes and spheroidal carbonaceous particles. The cores were ^{210}Pb dated. Rate-of-change analysis (Birks et al., 2000) was used to quantify the total amount of biostratigraphical change in both the diatom and chironomid assemblages per unit time. Summer, June, July, August and September temperatures from Vorkuta weather station (64º 01'E; 67º 17'N) were used to assess statistically the amount of variance in diatom and chironomid data explained by temperature. Similar methods to those described in Battarbee et al. (2002) were used to harmonise the climatic predictors and the response variables prior to least square regression. A LOESS regression (Cleveland et al., 1993) was used to smooth the climatic variables along a time axis.

Conclusions

There is evidence that recent diatom and chironomid changes at both Mitrofanovskoe and Vanuk-ty lakes have been driven, largely, by temperature. At Mitrofanovskoe Lake the evidence is clearer, the major compositional changes in diatom and chironomid communities are synchronous, and they are supported by the increase in total diatom accumulation rate and loss-on-ingnition. The chironomid-inferred summer temperature increases by c. 1° C during the last c. 100 years. The rate of change in diatom assemblages from the end of the 1960s is statistically significant at Mitrofanovskoe Lake, and the diatom changes are correlated with September air temperature changes during this period. We suggest that the mechanism behind the changes in the diatom community is related to an increase in the length of the ice-free season. The increase in deep-water chironomid taxa may also be in response to reduction in ice-cover and the consequent reduction in oxygen stress. At Mitrofanovskoe Lake the levels of global and regional pollution are relatively low, and the pollution signals are not correlated with the changes in diatoms and chironomids. We can therefore conclude that at

Mitrofanovskoe Lake the major driving force behind the diatom and chironomid changes since c. 1907 are temperature changes.

At Vanuk-ty Lake, diatom changes show a clearer response to temperature changes during the last 30 years whereas chironomid evidence is more ambiguous. The compositional changes in many planktonic and benthic diatom taxa are strongly correlated with August temperature and are coincident with the increase in diatom species richness and diatom production. Although these changes are predated by the rise in SCPs, it is unlikely that global and regional atmospheric contamination have had a pronounced effect on diatom composition as the overall pollution level is low and there is no evidence of acidification or eutrophication. We therefore suggest , that the mechanism behind the changes in diatom assemblages at Vanuk-ty Lake is similar to Mitrofanovskoe Lake and is dependent on temperature. However, there is no strong evidence for warming from changes in the chironomid fauna. One of the reasons behind an ambiguous chironomid evidence from Vanuk-ty Lake might lie in its complex morphometry with extensive shallow littoral and profundal zones, which allows for a coexistence of ecologically different chironomid groups.

Acknowledgement

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Climate, Snow and Hydrology in Tundra Ecosystems: Patterns, Processes, Feedbacks and Scaling Issues

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Introduction

Tundra extends over > 5.5 x 10^6 km^2 of the Arctic and has acted as a long-term carbon sink, sequestering atmospheric carbon in soils that today contain *ca.* 11% of total world carbon. Tundra is also characterised by a prevalence of high albedo surfaces (snow, ice and low tundra vegetation). Because of these attributes, tundra has a key role in moderating the global energy budget. In the future, however, warming of high latitude land areas is likely to reduce the spatial and temporal extent of high albedo surfaces and may switch tundra from a sink to a source of atmospheric carbon. Both impacts would generate positive feedback, enhancing the rate of future global warming.

Figure 1. Tundra mosaic (wet, mesic, dry ridge) at and beyond the tree-line at Abisko, N. Sweden.

Tundra exhibits hierarchically-scaled spatial heterogeneity, with plant community mosaics at landscape scales and variation in predominant mosaic elements at regional (Fig 1.) to Pan-Arctic scales. This heterogeneity reflects hierarchically scaled spatial and temporal environmental heterogeneity that has not yet been adequately captured by efforts to model the impacts of climate change upon Arctic tundra. This requires spatially- and temporally explicit process-based modelling at the landscape-scale. Such models must be underpinned by ecosystem studies that will provide the data necessary to achieve adequate representation of landscape processes and of their spatial and temporal variability.

Landscape-scale patterning of depth and duration of snow cover is the single most important meso-scale variable controlling biological systems in the Arctic, and is the primary determinant of landscape-scale ecosystem heterogeneity. Depth and duration of snow cover are consequences of interactions between landscape-scale variability in topography, including microtopography, and climate. Key facets of climatic variability include air temperature, precipitation (form and seasonal distribution), duration and intensity of solar radiation, surface albedo and surface energy balance, and windspeed and direction, all of which affect evapotranspiration, runoff and the distribution, depth and longevity of winter snow-pack. Duration of snow-lie also determines length of the plant growing season and is a primary determinant of the dynamics of soil temperature, soil moisture, depth of freezing and heat flux

(Fig. 2). Snow also stores water and nutrients that are released during the melt. Snow cover insulates the surface and reflects energy because of its high albedo, thus protecting vegetation from winter thermal extremes but also suppressing spring warming of the soil. Duration and extent of these seasonal effects have major impacts upon both plant communities and the soils with which they are associated, generating landscape mosaics ranging from exposed snow-free ridges to depressions characterised by deep snow accumulation. (Figs. 1, 2).

Through a series of measurements at complementary spatial and temporal scales, coupled with suitably robust up-scaling and modelling approaches, we aim to provide an improved spatially and temporally explicit representation of trace-gas and energy flux across the tundra landscape. The project builds upon existing work carried out in programmes in the American Arctic and the European Arctic. The key aims are three-fold: (i) A clarification of spatial

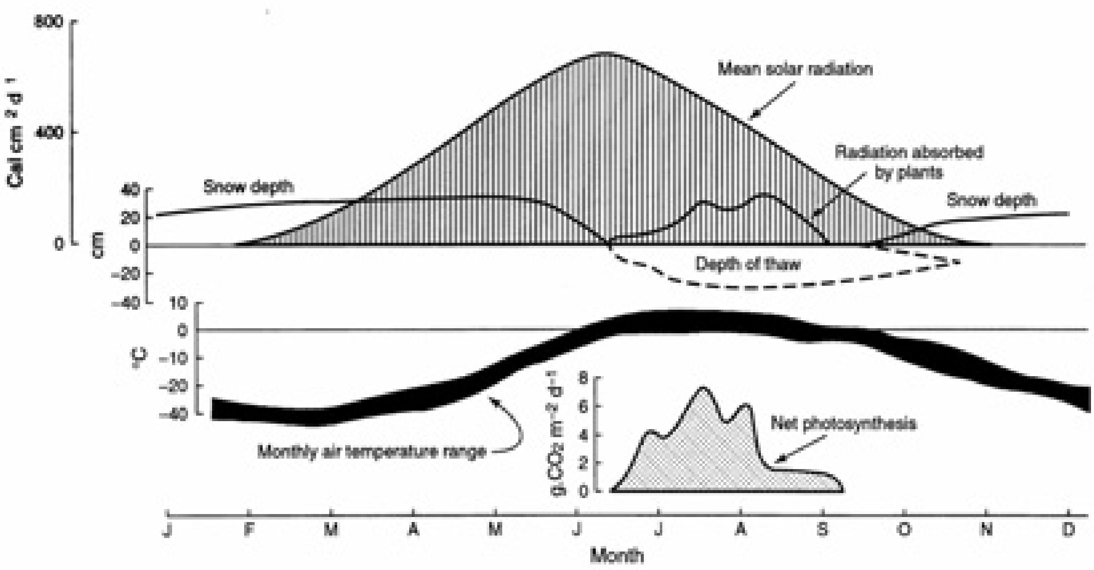

Figure 2. Snow-radiation-temperature-gas exchange interrelationships in northern tundra envionments (after Wookey PA (2002)).

scaling issues in trace-gas and energy exchange in tundra ecosystems. (ii) An improved understanding of the seasonal controls over trace gas and energy exchange, particularly the poorly-studied winter and early spring period; (iii) The provision of a northern European perspective on spatial and temporal scaling issues in tundra ecosystems.

Methods:

Fieldwork is being carried out on sub-Arctic tundra ca. 7 km from the Swedish Royal Academy of Science Abisko Scientific Research Station, Sweden (68°21'N, 18°49'E). We are partitioning ‘field-scale’ measurements of net fluxes across the landscape, made by an eddy flux tower, into components relating to the elements of the tundra mosaic by means of series of plot-scale measurements of trace gas fluxes. These measurements sample the fine-scale mosaic across the landscape and through time, in terms of hydrology and soil processes. We are also attempting to predict trace gas fluxes both spatially across the landscape and temporally through the seasons in terms of contributions from identified soil-vegetation-hydrology associations within particular parts of the landscape mosaic.

Plot-scale measurements within specific components of the landscape mosaic, outside the footprint of the eddy flux tower, include a series of manipulations of winter/late spring snow cover. Snow fences are being used to increase snow depth and duration, and early melt of snow to alter growing season length of the tundra vegetation. Impacts of manipulations upon vegetation phenology and physiological development throughout the growing season are being monitored, along with impacts upon carbon turnover and partitioning (assessed by integrating canopy photosynthesis and ecosystem respiration measurements made using a 'whole ecosystem' cuvette). Soil organic matter mineralisation rates and major nutrient (N and P) fluxes are also being assessed, both during the thaw period and throughout the winter season.

To complement the above studies we are measuring snow distribution across the landscape including snow-pit surveys. Standard measurements of density, temperature, grain-size and type and wetness have been made. Much of the snow cover is highly wind packed, and has high densities as consequence. In areas where shrub communities dominate there are extensive regions of low-density depth hoar.

Two digital cameras have been sited overlooking the field site, recording two images a day to capture the large variation in snow cover as regular snow fall is redistributed by the wind and melts. These images are being ortho-corrected and used in conjunction with a high resolution DEM to generate snow covered area maps of the site (Fig. 3).

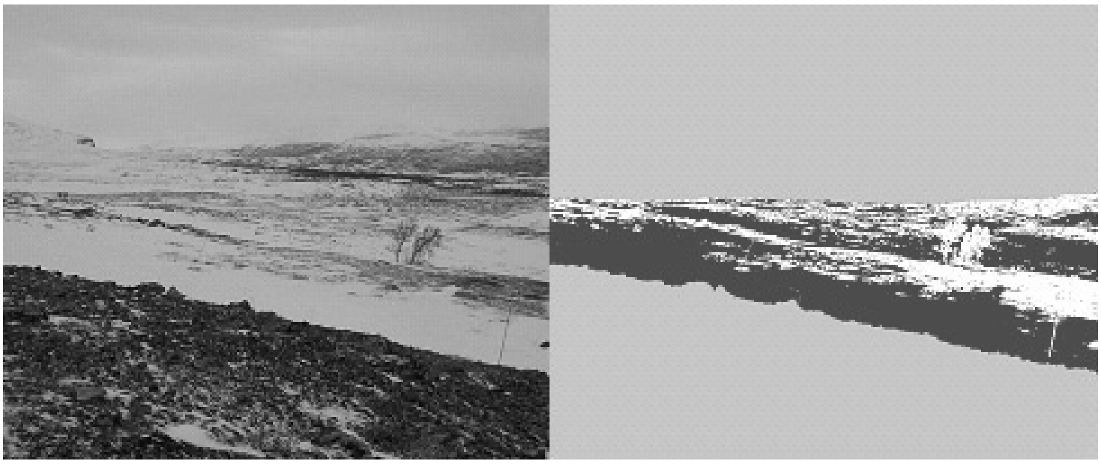

Figure 3. LEFT- example photograph of snow-lie (light) from automatic camera overlooking the research site. RIGHT- corresponding processed image of proportion of snow-lie (dark) on the landscape.

The hydrology of the study site is also being determined by a combination of measurement and modelling approaches. Measurements include the use of a grid of soil moisture determinations across a hill-slope, coupled with logging of water-table depth. Modelling approaches are being further developed at CEH Wallingford, utilising the MOSES model (Met Office Surface Exchange Scheme) - a comprehensive model describing energy, water and carbon exchanges between the land surface and the atmosphere.

The presentation will cover aspects integrating the key areas above with the aim of a better understanding of the key processes as we scale from plot to landscape responses of the soil-plant-atmosphere continuum of the Arctic tundra landscape mosaic.

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Responses of Tundra Ecosystems to Environmental Change: Observational and Experimental Results from the International Tundra Experiment (ITEX)

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Introduction

Evidence of environmental changes due to human-enhanced climate warming continues to accumulate from Polar Regions. However, the responses of tundra and taiga ecosystems to climate changes have been variable because of the wide range in process reaction rates, from metabolic processes to adjustments in ecosystem carbon balance, and the variability in environmental setting across local to regional scales. For example, relatively strong increases in rates of plant growth and changes in species composition and abundance have been observed in the Low Arctic, especially northern Alaska. However, very little change in tundra ecosystems has been measured in the High Arctic. These complexities in time and space scales make it difficult to predict trajectories of ecosystem change. It is also difficult to design field and modelling experiments to properly tease out answers to some of the questions that arise from the complexities. In addition, the basic responses to environmental variability and change are largely unknown for many northern systems, and differ because of initial conditions of the carbon and nutrient economy. In this presentation, I will examine some of the key scale issues and how studies along environmental gradients across the tundra biome will help to improve our ability to predict responses and feedbacks in these northern ecosystems to climate change. Results from the International Tundra Experiment (ITEX) will serve to illustrate the benefits of a multi-site approach to understanding the responses in these systems at local to regional scales.

Key Issues: scales and complexity

Arctic tundra ecosystems cover one fifth of the planet, and exist under a myriad of local and regional conditions. As Figure 1 illustrates, gradients in vegetation cover, soil carbon, and space vary (predictably) with latitude. Vegetation cover, and soil C and N contents decrease

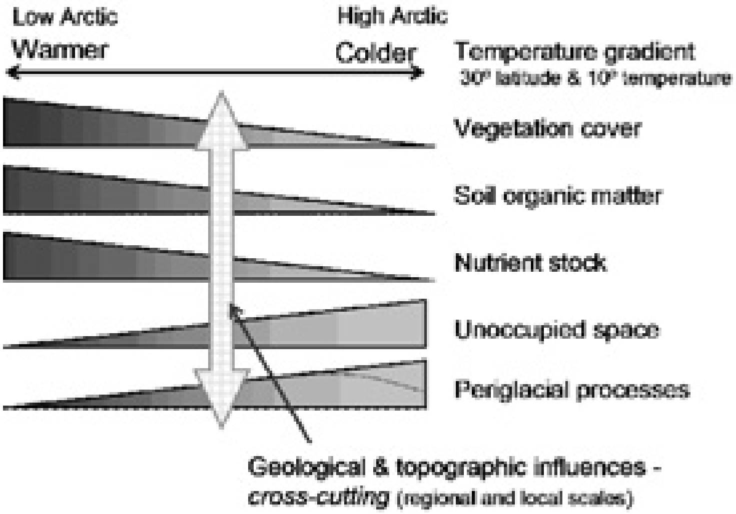

Figure 1. Latitudinal gradients in ecosystem characteristics. Local gradients imposed by geology and topography cut across these characteristics at specific sites.

and bare soil increases from low to high arctic systems. However, at the local scale there is considerable variability imposed by topography, geology, and other factors that cuts across and incorporates the latitudinal gradients. Soil moisture availability is an important factor influencing ecosystem characteristics at local scales. Components and processes respond to environmental changes at different rates: metabolic processes such as photosynthesis and respiration may respond in seconds to hours; allocation of nutrients and carbon within individual organisms may take hours to weeks; while changes in abundance and diversity of organisms through migration and genetics may take decades to centuries (Figure 2). Adding to this complexity are the multiple facets of environmental change linked to the changing climate. While warming is the best known of the drivers of environmental change, CO_2 fertilization, changes in UV radiation and increased atmospheric N deposition will have important and synergistic effects (Shaver et al., 2000). Clearly, there are no experimental approaches that can incorporate all of these temporal and spatial scales, appropriately. Ecosystem models provide tools to investigate potential effects of environmental change that incorporate processes at most scales, although the models themselves are based on the limitations of observational and experimental studies.

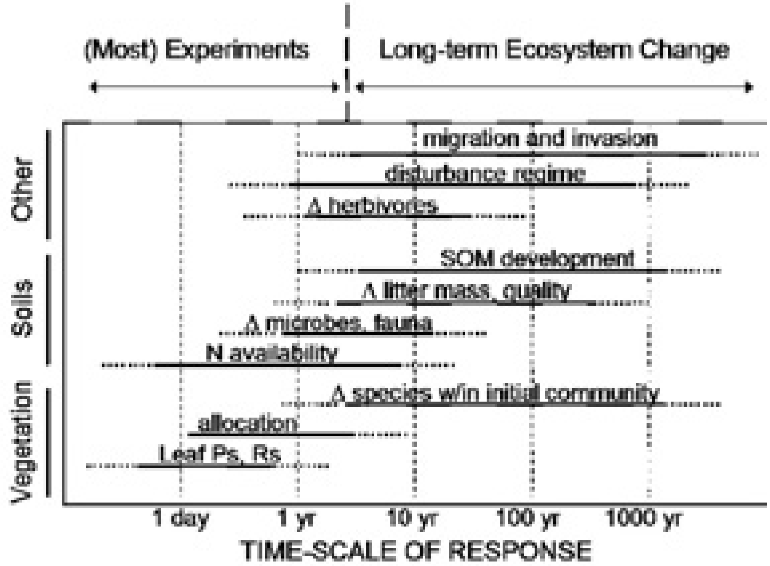

Figure 2. Response reaction times for various ecosystem processes (after Shaver et al. 2000).

Using gradients: observations from ITEX

Some of the limitations imposed by the complexities outlined above can be overcome by conducting experimental studies along environmental gradients where the long-term adjustments to processes with slow time-constants can be compared across ecosystem types. In addition, maintaining these studies over sufficient time periods to allow for adjustment in ecosystem conditions greatly increases the value of the results. These approaches are incorporated in the International Tundra Experiment (ITEX), where similar environmental manipulations have been maintained for >10 years at sites throughout the Arctic and in alpine tundra. ITEX sites span the biome (including alpine tundra), and studies at a number of site are conducted along local moisture gradients. Research at ITEX sites has focused on responses of individual plant species and of plant communities to experimental warming and annual climate variability (Henry, 1997; Arft et al., 1999; www.itex-science.net). Simple, passive warming devices (open top greenhouses) established at most sites, raise the temperature by 1-3 C during the growing season, but minimize the effects on precipitation and gas exchange. The temperature increases match the predictions of general circulation models for much of the Arctic.

Common methods at ITEX sites have allowed syntheses of results using meta-analysis that provide insight to variation in responses at different scales. Plant species found throughout the Arctic showed differential responses depending on geography and growth form. For example, low arctic species showed strong increases in growth, while those in high arctic sites had increased reproductive responses to warming (Table 1; Arft et al., 1999). Short-term growth responses were stronger in herbaceous than woody plants. However, these short-term, species level results could not predict the changes in composition and abundance at the community level. At the plant community level, cover (a proxy for biomass) and height of shrubs significantly increased in the warmed plots across the sites, whereas the cover of forbs has remained unchanged (Table 1). Cover of lichens and bryophytes was significantly reduced, likely due to shading. These changes occurred in just three years at some sites. These experimental results confirm observations of increased plant growth and shrub cover in low arctic areas of northern Alaska over the past two decades (Sturm et al. 2001; Serreze et al. 2000), but have also pointed to regional differences in responses. Shrub cover increased in the warmed plots at high arctic sites, although there have been no changes in the control plots. Much of the increase in cover and height is due to deciduous shrubs. Such a major change in the dominant functional group of these ecosystems (from low herbaceous to taller woody species) has important implications for feedbacks within the systems (e.g. increased wood and leaf litter, greater snow depth) and to the atmosphere (e.g. decreased albedo).

ITEX researchers have also used the long-term warming experiments to investigate ecosystem CO_2 flux responses across regional and local gradients, and have found important differences due to location and moisture conditions. In general, respiration is greatly increased by warming in the southern sites, leading to carbon losses, while a positive carbon balance is strengthened in northern sites; however, the responses vary in relation to soil moisture (Oberbauer et al., in prep) (Table 1). In addition, studies of soil nutrient dynamics have shown the warming experiments can greatly increase the availability of organic N, and stimulate microbial immobilization (Rolph et al., in prep.) (Table 1). Increased N availability will be required for the continued growth stimulation and will play a major role in how the

Table 1. Summary of results from ITEX research, based on responses to passive warming over 2-12 years.

Ecosystem component/process	**Important responses to experimental warming**
Plant species (Henry, 1997; Arft et al. 1999)	• Accelerated reproductive and vegetative phenology in nearly all species • Increased growth, especially in herbaceous species • Greater growth responses in low arctic sites • Greater reproductive responses in high arctic sites
Plant communities (Walker et al., submitted)	• Increased cover and height of shrub and graminoid species • Decreased cover of lichens and bryophytes • Decreased diversity
Net Ecosystem CO_2 Exchange (Oberbauer et al., in prep.)	• Increased ecosystem respiration • Increased carbon loss in low arctic sites • Variation in response due to moisture status • Strong annual variation in some sites • Greatest effects in moist and dry sites
Soil carbon & nutrient dynamics (Rolph et al., in prep.)	• Greatest changes in moist and wet sites • Increased availability of organic nitrogen • Increased nitrogen immobilization • Increased soil carbon concentration

carbon balance of these systems changes through time (e.g. Mack et al., 2004). Given that taiga and tundra ecosystems hold 20-25% of the soil carbon of global terrestrial ecosystems, it is critical that we understand the responses to environmental change in these systems in order to better forecast effects at all scales. Continued long-term research using coordinated networks such as ITEX will help to ensure that we capture important temporal and spatial variations in tundra ecosystem responses to climate variability and change. This will also help to improve modelling efforts to predict future response.

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Climatogenic Dynamics of Biota within the Current Distributions of Organisms and their Communities in the Arctic and their Implications for Response to Climate Change

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Many predictions on probable responses of Arctic plant cover to projected global climate changes can be made by studying biodiversity at a range of levels along differing scales of environmental gradients both within and between landscapes. Changes in biota composition and plant cover along latitudinal, longitudinal, altitudinal, inter- and intra-landscape gradients can be estimated without need for new investigations: there is enough information already available for this approach, but the data require analysis. This approach seems to be one of the most suitable in terms of time and the cost of new research, although monitoring from field sites that need to be established along environmental gradients is included in the approach.

Projections of vegetation zone shifts within the Arctic under expected climate warming can be determined from existing latitudinal gradients because the current pattern of species and community distribution along them reflect their dependence on macroclimate. It is a relatively easy task to estimate species diversity, spectra of life forms, plant functional types, geographical groups and other parameters of structure and composition of plant communities at any point on the gradient under known climatic conditions and then to compare the information with that from points south or north that are currently warmer or colder and represent future climate warming or cooling. It is also possible to estimate impacts of future changes in moisture conditions by analyzing current moisture gradients. There is sufficient information for this approach on vascular plants and vertebrates (mammals and birds), but less for cryptogamic plants, insects and soil invertebrates while changes in species number and distribution along latitudinal gradients are known only for restricted areas of the circumpolar Arctic.

The best studied area is Taymyr Peninsula (Siberia) that is the only location that offers a complete and continuous gradient from timberline to the polar desert and can be considered as a microcosm of the Arctic. The range of mean July air temperatures of 12ºC near tree line to 2ºC in the polar desert zone exceeds the expected increase in warming over the next 100 years along most of the gradient. Perhaps the main feature of the Arctic biota along this gradient is the sharp decrease in species diversity northwards of the timberline that takes place in all organisms but most noticeably in the advanced groups like vascular plants and birds than in the more primitive ones like cryptogams (lichens in particular) and soil invertebrates. However, the first response to climate change will be changes in species abundance and their within-landscape distribution. A careful study of species and plant community diversity and distribution along toposequences (from fell-fields to snow beds, from south to north facing slopes, from dry hill and hummock tops to wet depressions, from silt landslides to sand screes) can predict impacts that will occur in response to natural or man-made changes in climate. Such studies can assess the consequences of changes in biodiversity in the Arctic, as well as the causes.

The most suitable system for assessing quantitative (number of species and their abundance) and qualitative (species and plant functional type composition, spectra of geographical elements) changes over time in response to climate change is zonal vegetation that best corresponds to macroclimate. A good modeling object for this purpose is the plant association Carici arctisibiricae-Hylocomietum alaskani Matveyeva 1994. This is distributed throughout the tundra zone on Taymyr and is represented by longitudinal vicariants or vicarious associations in other territories of the Arctic. Its three well recognized latitudinal vicariants are connected with three tundra subzones. They have similar vegetation structure, physiognomy, dominants, and many common constant species but there are differences in their total species composition and abundance connected with species re-distribution within the landscape from one sub-zone to another. Along a south-north gradient, some species disappear, whereas some remain in the plant association. However, many of those that remain change their ecological range and move into intrazonal habitats. Similar changes occur in other associations in various environments like south-facing slopes, snow beds and wetlands.

Although the information at the species diversity level is relatively rich (however is far from to be complete for many groups), information at the community level is much worse and biodiversity at this level is unknown. There is not even a list of the community types (associations) in the Arctic, and even the most common community types are not well described throughout the whole range of their distributions. However, the study of the diversity of syntaxa is an aspect of circumpolar Arctic terrestrial biodiversity equally as important as existing studies that are creating pan-Arctic check-lists of different plant groups. Also, the detailed investigations on plant physiology, gas flux, measurements, net primary productivity, ITEX and other experiments have been undertaken in few sites, and within these few sites, only in a few types of vegetation. The information from these studies are not representative of the variation expected throughout the Arctic. In order to model, and generalize to the whole Arctic from the often important data arising from these studies, it is necessary to determine the distributional areas and structural variations in all published syntaxa and to recognize the position of each plant community type in a system of Arctic syntaxa.

We can predict but we cannot prevent the future changes in the Arctic. Facing these changes, we should study existing biodiversity and its differentiation along broad and small-scale gradients. The resulting data and understanding will contribute to parameterization of ecosystem function models, the testing of ecological theory, the restoration of ecologically damaged areas, and other fundamental challenges.

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Integrated Carbon Balance Studies for European Arctic Catchments

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Introduction

Carbon pools and fluxes were measured in two study areas in the European Arctic, the Usa Basin in Komi/Nenets (Russia) and the Teno Basin in Lapland (Finland) and Finnmark (Norway). Carbon pools were measured in phytomass and soil, and upscaled using GIS-based regional land cover and soil classification schemes (Kuhry et al., 2002; Kuhry and Virtanen, 2002; Mazhitova et al., 2003; Virtanen et al., 2004). Forest line location in GIS-based land cover classifications was modelled in relation to topography, regional climate (Christensen and Kuhry, 2000), permafrost distribution (Oberman and Mazhitova, 2003) and/or a landscape wetness index (see Virtanen et al., in press; Mikkola and Virtanen, submitted). Land/atmosphere carbon fluxes were conducted using chamber techniques (CO_2 and CH_4) in a variety of land functional types in the tundra (Heikkinen et al., 2002a/b, 2004) and using tower measurements (CO_2) in a mixed spruce forest in the northern taiga (Bobkova et al., unpublished data). Changes in river discharge of the Usa River and two of its tributaries in relation to regional climate, vegetation and permafrost dynamics were modelled with a GIS-based hydrological model (van der Linden et al., 2003). Runoff and water chemistry (TOC) were measured in a number of subcatchments (Huitu and Arvola, 2003, unpublished data). Results from many of these studies have been published for the Usa Basin, and, to a lesser extent, for the Teno Basin. At present, the results from these separate components are being combined into integrated carbon balance assessments for both regions. First results will be available for the Usa Basin, based on flux studies conducted in the year 2001.

Study Areas

The location of the Usa and Teno Basins, investigated subcatchments (Khosedayu, Utsjoki) and carbon flux study sites (Lek Vorkuta, Zelenoborsk) are indicated in Figure 1. The Usa Basin is mostly lowland, 30% forested, with isolated to continuous permafrost. The forest line, formed by spruce, follows approximately 67º N latitude. The Teno Basin is an area of valleys, low mountains and upland plateaus, 40% forested, with only isolated patches of permafrost. The mountain birch forest limit is located between ca. 250-350 m altitude.

Methods

Regional integration of the different component studies in the Usa Basin is achieved through a combination of approaches, including past analogues, geographic analogues, monitoring, process studies, GIS and modelling. The integration is facilitated by the choice of a common study area, the implementation of a regional GIS and the application of the same climate change scenarios.

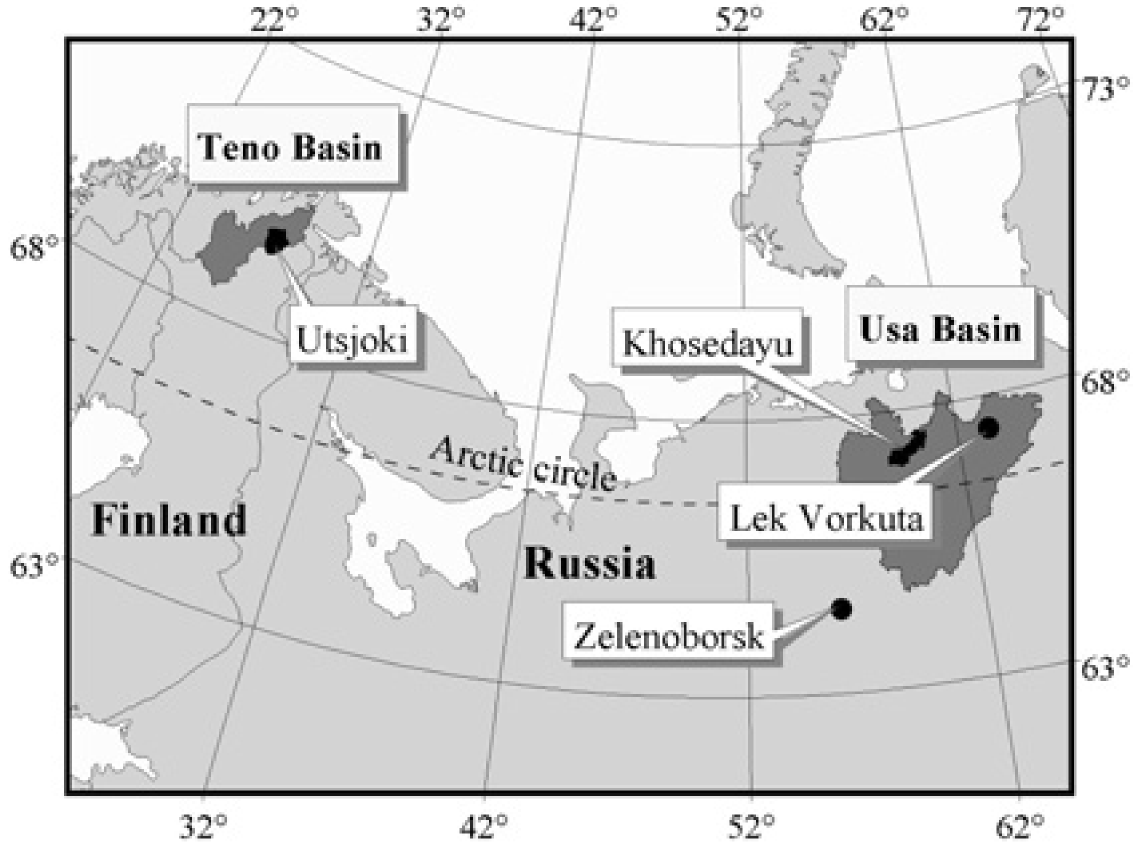

Figure 1. Location of study areas and sites in the European Arctic.

The following GIS layers are available for the Usa Basin:

- Regional topography, with a derived landscape wetness index
- Regional hydrology, with discharge measurements from river stations
- Regional climate model, validated with meteorological data from climate stations
- Regional land cover classification, with ground truth plots and phytomass measurements
- Regional soil classification, with pedon descriptions and soil carbon measurements
- Regional permafrost map, with landscape features and borehole data

Carbon flux studies in or near the Usa Basin were carried during the growing season, with some winter time measurements. The year 2001 is the period with a nearly complete overlap of flux studies. The techniques, localities, and time period of monitoring were (for location see Figure 1):

- Chamber measurements in the southern tundra at Lek Vorkuta from all surface functional types, except willow (1999 and 2001)
- Tower measurements in the northern taiga near Zelenoborsk in the dominant mixed spruce forest (2001-2002)
- River runoff and TOC estimates in the tundra from the Khosedayu River (1998-2002), with some measurements in the Lek Vorkuta River
- (No local measurements in taiga wetlands, lakes and rivers)

Carbon pools and fluxes were upscaled using GIS-based regional land cover and soil classification schemes. Climate change scenarios for 2080 (transient +2.8 °C) and 2230+

(equilibrium + 4.1 °C) were obtained from the HadCM2S750 integration (Hadley Centre, Bracknell, UK) through the Climate Impacts LINK Project (Climatic Research Unit, University of East Anglia, Norwich, UK).

Results and Discussion

Preliminary calculations based on available flux studies complemented with published data indicate that the Usa Basin was near carbon neutral (2 gC m^{-2} yr^{-1} sink; range -4 to +8 gC m^{-2} yr^{-1}) in the relatively warm and dry year 2001 (losses from tundra and rivers, gains in wetlands and taiga). In the colder and moister year 1999 the area was most likely a carbon sink (no net loss from tundra).

The extensive data set on land functional types with associated flux measurements and phytomass and soil carbon estimates permits a sensitivity analysis of the Usa Basin carbon balance to future global warming using analogue and modelling approaches. Results will be presented that compare the impacts of changes in different landscape components, including forest growth/migration vs tundra soil organic matter decay, forest growth/migration vs thermokarst erosion and forest growth/migration vs paludification. The important difference between a transient 'disturbance' response and a new 'equilibrium' condition will be discussed.

Acknowledgments

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Effects on the Carbon Balance of High-Arctic Tundra: Entire Growing Season Warming Versus Heat Wave Exposure

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Introduction

Besides the general warming, the IPCC climate scenarios also project extreme climate events (a.s. more hot days, heat waves) to increase in frequency during the next century (Houghton et al., 2001). Nevertheless, we are not aware of any research that investigates possible stress effects of extreme temperature events on the vulnerable arctic tundra. For this purpose, we exposed plots of tundra vegetation to both a small temperature increase (+ 2.5°C) during an entire growing season and to an experimental heat wave (+9°C during several days). To generate these increments we used the Free Air Temperature Increase-method, designed to homogeneously heat limited areas of short vegetation (Nijs et al., 1996; Nijs et al., 2000), while previous research mostly used greenhouses or open top chambers (Dormann and Woodin, 2002). Our first objective was to detect possible changes or stress caused by warming. A second objective was to assess whether warming influenced the carbon exchange rates (i) uptake of CO_2 by photosynthesis, (ii) loss of CO_2 by below ground respiration and (iii) loss of CO_2 by canopy respiration. Because tundra ecosystems constitute large stocks of carbon (Schlesinger, 1984), they can, when warming releases carbon, attend a positive feedback and stimulate climate change. Otherwise carbon uptake can retard this effect.

Material and Methods

The study site is located in the vicinity of the Zackenberg research station on the Northeast coast of Greenland (74°28'N, 20°34'W, 25-m elevation). We selected six similar tundra plots (40 x 50 cm) with *Salix arctica* Pall., *Arctagrostis latifolia* Griseb., *Carex bigelowii* Torr. ex Schwein and *Polygonum viviparum* L. as dominants, and we estimated living plant cover. Then, we appointed the plots to two treatment groups (each 3 plots) to have approximately similar cover and species composition in both. In 1999, temperature was increased with 2.5°C during the entire growing season (from the end of June till the end of August). From 14 July to 22 July 2001, we increased temperature for 13 days with 9°C, the maximum reach of the equipment, to simulate a heat wave. Each time three plots (one group) were continuously heated with infrared radiation (0.8 – 3 µm) from FATI-units (two 1500-W sources in a waterproof housing on a tripod). The surface temperature of the vegetation, soil temperature at 2.5, 7.5, 15 and 30 cm depth, air temperature at 5 cm height and photosynthetically active radiation (*PAR*) were measured with sensors and recorded with data loggers every 30 minutes. We measured soil volumetric water content, thawing depth, green cover, species composition, growth rate, chlorophyll content and chlorophyll fluorescence. Gross photosynthesis (P_{gross}), below ground respiration (R_{soil}) and canopy respiration (R_{canopy}) were regularly determined with closed dynamic CO_2 exchange systems, and the whole-growing season C-balance was reconstructed by relating these components to potentially controlling factors.

Results and conclusions

During the entire growing season warming, thawing depth and green cover increased in heated plots, while soil moisture was not significantly affected. P_{gross} increased 24.2%, owing to both a green cover and a physiological influence of warming. Below ground respiration was enhanced 33.3%, mainly through direct warming impact and in spite of lower Q_{10} in the heated plots; the factors controlling R_{soil} were day of the year and soil moisture. R_{canopy} did not differ significantly between treatments, although green cover was higher in the heated plots. This tundra ecosystem acted as a relatively small net sink both under current (0.86 mol CO_2 m^{-2}) and heated (1.24 mol CO_2 m^{-2}) conditions (Figure 1A). Nevertheless, turnover increased, which was best explained by a combination of direct and indirect temperature effects, and delayed senescence (Marchand et al., unpublished).

During exposure to the experimental heat wave, leaf growth rates of *Arctagrostis latifolia* and *Carex bigelowii* were increased. Furthermore, increased green cover and higher chlorophyll concentrations of all four dominant species at the end of this heat wave, are also indications of vegetative growth stimulation. Another confirmation for improved plant conditions during the heat wave, was a higher photochemical efficiency (F_v/F_m) and photosynthesis of plants in heated plots compared to plants in unheated plots (Figure 2). Nevertheless, during the period after the heat wave, heated plants were more stressed than unheated plants, probably because they were exposed to lower ambient conditions to which they could not acclimatize. In spite of that, photosynthesis was still slightly enhanced in this period, which indicates indirect effects of warming. In addition, the reconstruction of the carbon balance by its three components (photosynthesis, soil and canopy respiration), revealed that soil respiration and canopy respiration were stimulated by the instantaneous warmer soil and vegetation, respectively (Figure 1B). Thus, during the heat wave, the heated ecosystem was a smaller sink compared to the unheated ecosystem. This indicates that, if more heat waves will occur in the future, this ecosystem may become a source and stimulate climate change by a positive feedback.

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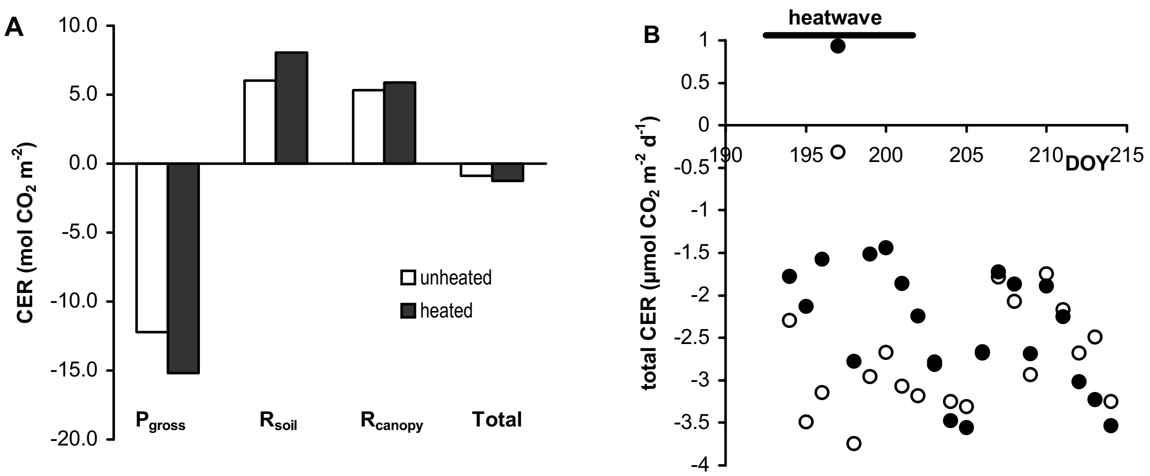

Figure 1. (A) Cumulated CO_2 exchange rate (CER) over the entire growing season of 1999, separated by the three components: photosynthesis (P_{gross}), soil respiration (R_{soil}) and canopy respiration (R_{canopy}). (B) Reconstructed time course of daily total net $CER_{ecosystem}$ during the 2001 heat-wave experiment. Values are averages for the three control plots (open symbols or bars) and the three heated plots (filled symbols or bars). Positive values are CO_2 release. DOY: day of the year.

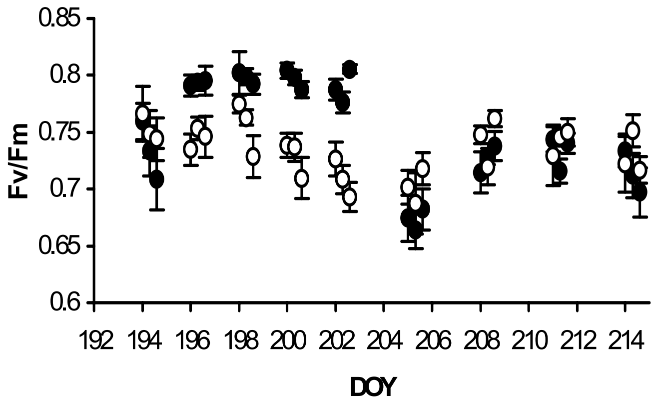

Figure 2. Time course of photochemical efficiency (F_v/F_m) of *Salix arctica*. Averages ± 1 SE of 15 plants per species of both heated (●) and unheated (❍) treatment (5 per plot). Each measurement day (DOY) has a morning (9h00), noon (13h00) and evening (18h00) measurement.

Land Surface Radiation Budget Response to Global Warming: Case Study for European and Asian Radiometric Network

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Introduction

The land surface albedo is a key parameter influencing the climate near the ground. Forecasting the Earth climate for the next few decades is indeed a great concern of the mankind since it yields severe implications for delineating the future human being, preserving the biodiversity, enhancing the renewable resources, and restricting the hazardous events. A geographic reallocation of the terrestrial climates is even seriously envisaged for the future. The climatic system was originally rhythm by the time duration of the summer season. However, the enhanced anthropogenic pressure seems to have modified the environmental mechanisms in perturbing the atmospheric fields, namely the air temperature and the rainfall distribution. Owing to strong feedbacks effects, the role of the sun as an energy source is still fundamental for determining the weather at the atmospheric boundary layer (Noilhan, and Planton, 1989). In particular, the determination of a surface albedo, that is the ratio of incoming to reflected solar radiation, is mandatory (Sellers, et al, 1986). The albedo quantifies the proportion of absorbed energy that can be later transformed, in a more or less straight mode, into the heat and latent fluxes (Ross, 1981). It accounts for eight percent of Earth radiation budget. Therefore, it must be determined with a sufficient accuracy (Pokrovsky, and Roujean, 2002a,b). High latitude area proved to be extremely sensitive to recent climate change. Therefore, main attention in this study was drawn to high latitude stations located in the East and West Siberia.

Datasets

The twenty years (1976-1995) monthly data of 12 representative radiometric stations located in European and in Asian parts of Russia were used in this study (Pokrovsky, and Makhotkina, 2002). Hourly global, diffuse, direct and reflecting radiation data were digitized and checked. Short wave radiation budget (RB) data were also available in this study. Simultaneous meteorological parameters (air temperature and humidity, precipitation amount, wind velocity and direction, soil temperature/moisture at surface and 5, 10, 15 cm depths) were provided at the same sites. Cross-correlation features were investigated and physical explanation of found trends in the RB components was provided.

Method

Along with linear tend computations we carried out alternative studies of time series (quadratic, cubic and non-liner approximations). All mentioned approaches with the exception of non-linear trend technique are known and widely used. Therefore, we consider non-linear technique (Pokrovsky, et al, 2004). Let us assume that $x_1,...,x_n$ is an input time series. Our task is to recover it from short-term disturbances and to reveal non-linear long-term components. We transform input data $x_i\,(i=1,...,n)$ to smooth values $\hat{x}_i\,(i=1,...,n)$ in accordance to formula: $\hat{x}_i = \sum_{k=1}^{n} \rho_{ik} x_k$. The set of the weight coefficients $\rho_{ik}\,(i,k=1,...,n)$ should be determined from following relationships:

$$\sum_{k=1}^{n} \rho_{ik} = 1, (i=1,..k)\,;\ \sum_{\substack{k=1;\\ k\neq i}}^{n} \rho_{ik} = \alpha\rho_{ii}, (i=1,..k), (0 \le \alpha \le 1)\,;\ \rho_{ik} = 1/(i-k)^2\,(i,k=1,...,n; i \neq k)\,.$$

Thus smoothing estimate $\hat{x}_i\,(i=1,...,n)$ is obtained from all input data, but with different weights. Smoothing coefficient α regulate smoothing rate. When α=0, smoothing is absent. Smoothing rate is maximal when a =1. Figure 1 demonstrates that this trend technique provides the most reliable trend results when compare with other approaches.

Results

An analysis of linear and short-term nonlinear trends for land surface albedo and radiation budget components has been carried out. Linear trend investigation showed that albedo, reflected and global radiation fluxes increase in summer, while radiation budget decrease at most continental sites. More rapid increasing of reflected radiation is a reason of negative trend in radiation budget time series. We demonstrated that reflected radiation time series is coherent with air temperature and precipitation time series. We suppose that temperature increasing and precipitation decreasing (fig.2) are main factor of soil and grass dryness, which is a reason of albedo dropping in hot period of year. In contrast, the global and reflected radiation fluxes decrease at North-East Asia and North-West European regions, which are greatly impacted by growing cyclonic activity. We showed that positive trend in precipitation in these areas might be a cause of more rapid decreasing in global radiation then in reflected radiation because of positive trend in air and soil temperature, which accelerate an evaporation process at land surface. Latter phenomenon is a cause of negative trend in radiation budget time series for both: continental and non-continental stations at summer season. In winter seasons we found out inverse tendency. Albedo and reflected radiation time series have negative trends, while those for global radiation have positive trends. Hence, radiation budget time series has a positive tendency for most continental stations. Snow cover reflection properties depend on roughness and wetness of snow. The roughness of fresh snow is higher than those of old snow cover. Therefore, a positive trend in precipitation time series revealed at most sites might explain albedo dropping. Wetness of snow is depended on air temperature. Positive air temperature trend delivers another factor of albedo decreasing in winter season. So, radiation budget decreases in summer and increase in winter. But annual total effect is negative. Therefore, this feedback mechanism might be considered as negative and compensation loop to global warming of Earth climate system.

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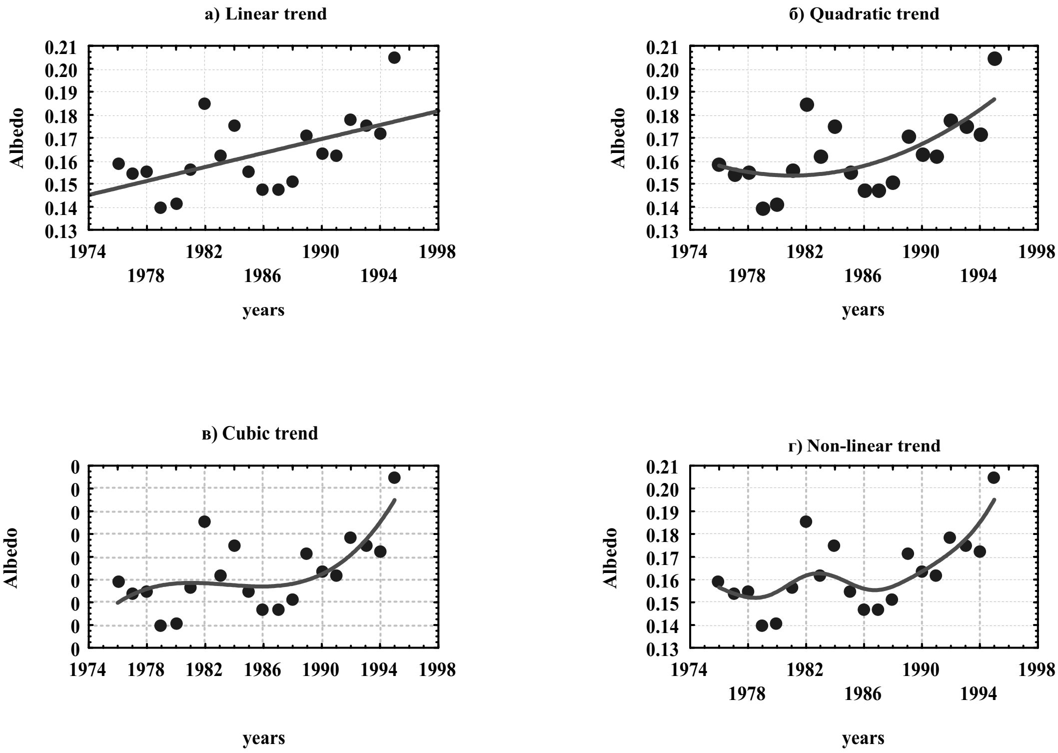
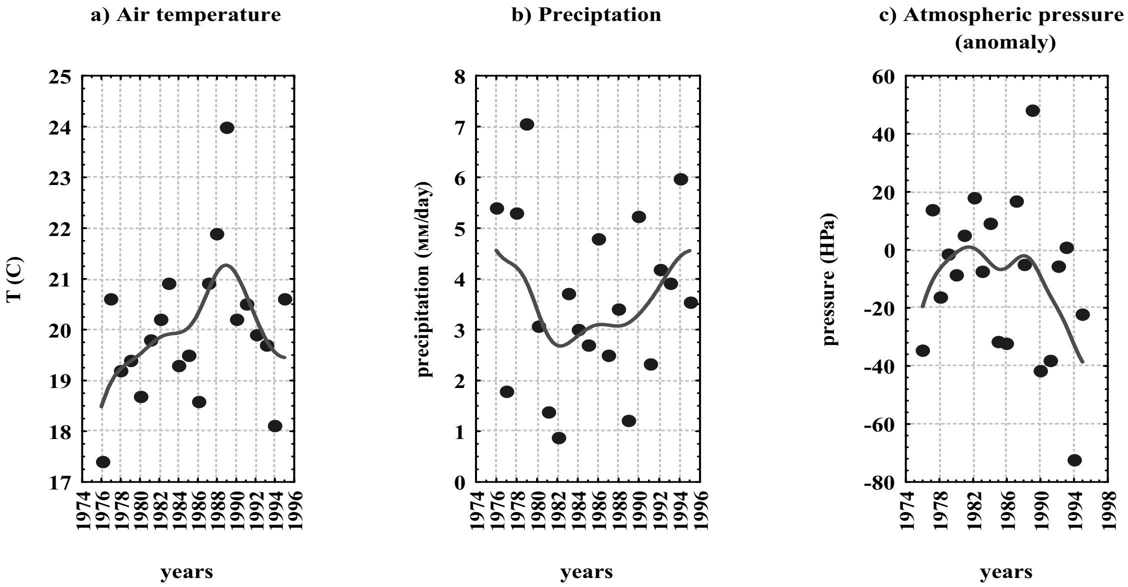


Albedo trends: Irkutsk, July

Figure 1. Comparison of various trend approximation techniques.



Meteorological parameter time series: Omsk, July

Figure 2. Relationship between series of major meteorological parameters.

Possible Feedbacks on Arctic Cloud Formation: Can the Arctic Biosphere Affect the Melting of the Ice?

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Introduction

Clouds have a profound impact on the radiation budget of the Earth and calculations show that small changes in cloud cover or optical thickness may offset – or double - even at a doubling of greenhouse gas concentrations. In contrast to the mid-latitude oceans, low-level clouds are a warming factor in the central Arctic through most of the year. In winter the effects of low-level clouds are the single most important local factor determining the stability of the lower troposphere. In summer, with frequent low clouds, changes in their microphysics can alter their reflectivity for solar radiation as well as cloud lifetimes. These processes are very poorly described in current climate models and because of the potential for a large effect, it is essential that we should understand the sources, nature and controls on the supply of cloud droplets.

Formation of clouds requires the presence of small airborne aerosol (particles), so called cloud condensation nuclei (CCN). While the amount of condensed water in a cloud is determined by thermodynamic and dynamic properties, the number of droplets is regulated by the abundance of CCN. With many CCN, the condensed water is distributed over many small droplets rather than over a few large. This in turns makes the cloud look "whiter", thus reflecting more solar radiation back to space. This is known as the "indirect effect" of particles on climate.

The well-known hypothesis of *Charlson et al*. (1987) proposed one biological influence on radiation and climate based on the indirect effect of aerosols. The gas dimethyl sulfide (DMS), produced by marine phytoplankton, is oxidized in the atmosphere to sulfuric acid, nucleating particles that grew to become CCN. It was suggested that climate change would change DMS production to form a negative feedback through its effects on CCN.

Sulfate-containing aerosols are ubiquitous in the atmosphere and usually the most numerous particles capable of acting as CCN, so that the theory seems reasonable. But does DMS alone control the number of CCN or could there be other biological controls on CCN formation in marine air remote from land sources? The central Arctic Ocean in summer provides an ideal laboratory for studying that question. Excursions of continental and most likely polluted air into the basin are infrequent, and low cloud and fog at the fringes of the pack ice rapidly remove aerosols. A shallow boundary layer capped with a temperature inversion limit mixing from above the clouds (*Tjermström et al.,* 2004), where long-range transported aerosols from distant sources may reside.

Cloud Forming Particles over the Pack Ice

An expedition in 1991 (*Leck et al*.,1996) revealed strong summer sources of DMS near the ice edge and adjacent waters and the dominant sulfate and methane sulfonate ions in the accumulation mode (diameters 100 to 1000 nm) aerosol (*Leck and Persson, 1996a,b*).

However, as these particles become CCN while traveling in over the pack ice, they become parts of clouds droplets that eventually deposits at the surface and are lost forever. The number of CCN with a source at the ice edge thus decreases with time of transport away from the ice edge. This has a profound impact on the properties of Arctic clouds, making them “grayer” than their mid-latitude counterparts.

Can climate change alter the Arctic system such that more biogenic particles are produced locally by generating larger areas of open water in the pack ice? Are there already other processes that produce biogenic aerosols in the pack ice? Will an enhanced production of CCN in the central Arctic Ocean act as a negative feedback, producing brighter clouds reflecting more solar radiation back to space?

To help answering these questions, Arctic Ocean summer Experiments were launched the same area north of 80°N, in 1996 (*Leck et al., 2001*) and 2001 (*Leck et al., 2004*) on the Swedish icebreaker *Oden*. We found clear evidence that local aerosol production at the ocean surface occurred even when the fraction of ice was large (~ 95%). These novel conclusions were based on *in situ* measurements of atmospheric aerosols, boundary-layer structure, and of the film on the surface of the open leads, the “surface microlayer of the open leads” (SMOL).

A radio-controlled miniature boat was used to collect the <100 μm thick surface film of the open water between ice floes (*Knulst et al.*, 2003), and the water from the collected film was examined. Aerosol particles were simultaneously collected from the atmosphere. Similarity in morphology, chemical and physical properties of the numerous aggregates and their building blocks, and of bacteria and other micro-organisms was found in both the air and water. This strongly suggests that the airborne particles were ejected from the water by bursting bubbles (*Bigg et al*., 2004*; Leck and Bigg*, 2004).

On average during the five weeks spent in the pack ice region during 2001, SMOL-derived particles represented more than one-third of the collected airborne particles; more than two-thirds on sunny days. Instead of being liquid sulfuric acid, these particles were water insoluble, often having a crystalline appearance, either as aggregates or individuals (*Leck and Bigg,* 1999), Figure 1. This invalidates the hypothesis that DMS oxidation products alone produces particles of this size (*Charlson et al*.,1987).

One feature of SMOL particles was that they were joined together and surrounded by a diffuse electron-transparent material. Close examination of airborne particles revealed its presence on them as well. Examples are shown in Figure 1. The gel-like secretions of microalgae and bacteria known as “exopolymer secretions” (EPS) are well known to marine biologists, but not to aerosol scientists. EPS consists mainly of polysaccharides and has a number of properties (*Decho*, 1990). The molecules are highly surface-active, take up water like a sponge and release it very reluctantly. They capture heavy metal ions and readily bind other molecules, large and small, into their structures and spontaneously assemble into gels. The gels collapse under the influence of ultraviolet light and acidification (*Chin et al.* 1998). Their lifetime in the atmosphere is therefore limited and the collapse of the structure having such strong water retentive properties explains some of the puzzling features of the aerosols observed over the pack ice. For example the expulsion of water as the gel collapses may explain why airborne aggregates and bacteria very rarely have attached sea salt. The breakup of aggregates when the joining EPS gel collapses is also a sufficient reason why the airborne aggregate size distribution so closely resembles that of the SMOL aggregates but is shifted to a smaller size. Comparison of the size distribution of airborne aggregates and particles with the size distribution of the total aerosol provided by a differential mobility sizing system strongly suggests that broken aggregates provide almost all the particles between 10 and 70nm diameter, the Aitken mode.

Implications of a Local Pack Ice Source of Cloud Forming Particles

Fresh aggregates with gel on them could act as CCN directly because of the gel's strong surface active properties. Aqueous oxidation of sulfur dioxide could then produce sulfur-containing particles with aggregates inside. Those that have lost their gel could still act as sites for the condensation of the oxidation products of DMS, and so could also lead to production of sulfur-containing aerosols. DMS concentration will determine the mass of sulfate produced but will have only a minor influence on the number of CCN and thus cloud droplets, which will be dictated by the number of airborne particles originating in the SMOL.

Boundary layer clouds are frequent in the summer Arctic, are optically thin and have low concentrations of CCN, compared to boundary-layer clouds at lower latitudes. These are conditions that maximize effects of changes in CCN and cloud droplets on short-wave radiation. On a regional scale there is therefore a potential for a biological impact on climate, but the emphasis has shifted from phytoplankton beyond the ice edge to bacteria and microalgae, and their secretions, within the pack ice. While there can at present be no definite answer to the question in the title, it does look to be a tentative "yes", and the marine biosphere will affect the melting of the ice.

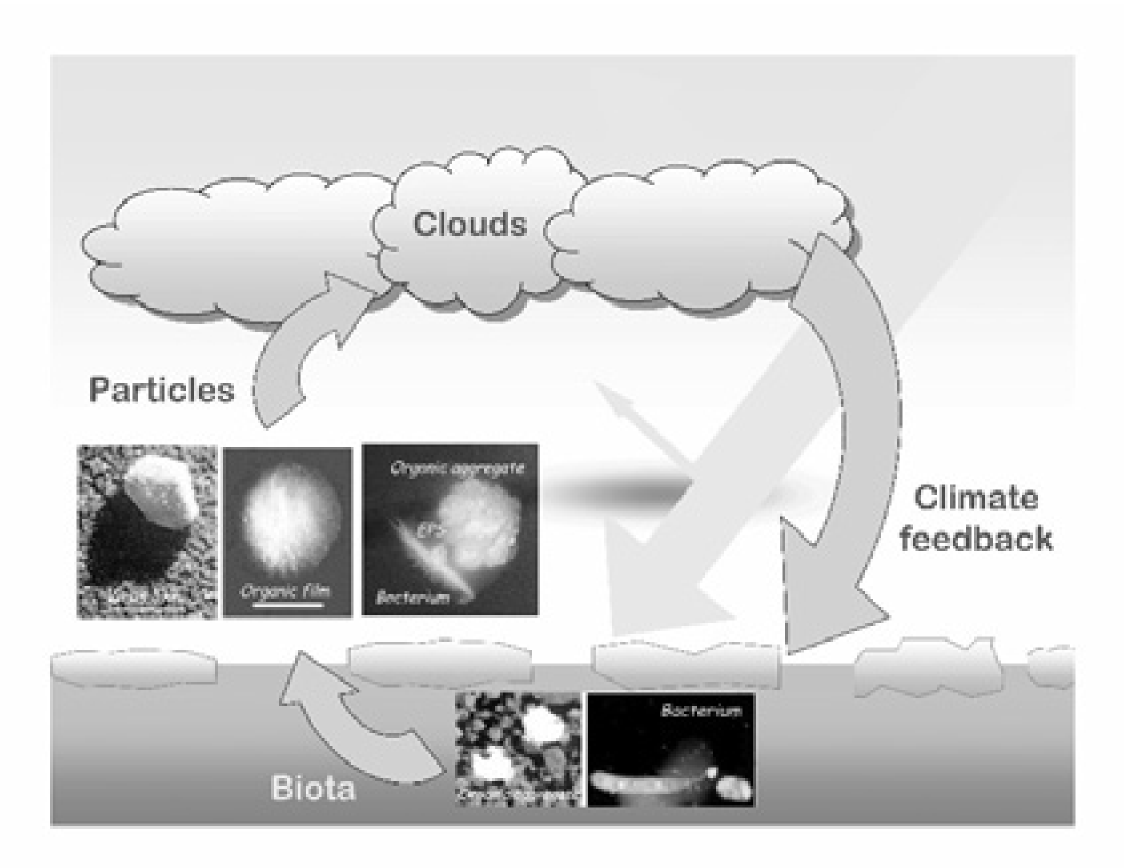

Figure 1. A simplified picture of the relationships between the processes described and how they are connected to cloud–aerosol interactions.

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How Good is the Surface Energy Balance in Current Atmospheric Climate Models?

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1. Introduction

Climate forcing, as well as the drivers of climate change, are parameterized in all climate models. There is a controversy within climate modeling, if the so called "model physics" has anything to do with actual physics or if it is just a package of tunable statistic relationships of a more obscure nature. Given how climate is generated in a climate model, it is exceedingly clear to us that unless the "model physics" at least attempt to mimic the actual physics, climate modeling is not meaningful.

Arctic is more sensitive to climate change than other regions. On average in 19 CMIP (Meehl et al. 2000) climate-change simulations, the Arctic warms 2.5 times the global average warming (Räisänen 2001). We see today signs that global warming has started to impact the Arctic (Serreze et al. 2000, Comiso 2002). Still, the inter-model spread in the CMIP ensemble is by far the largest in the Arctic (Räisänen 2001) and current GCM have problems reproducing today's Arctic climate (Walsh et al. 2002).

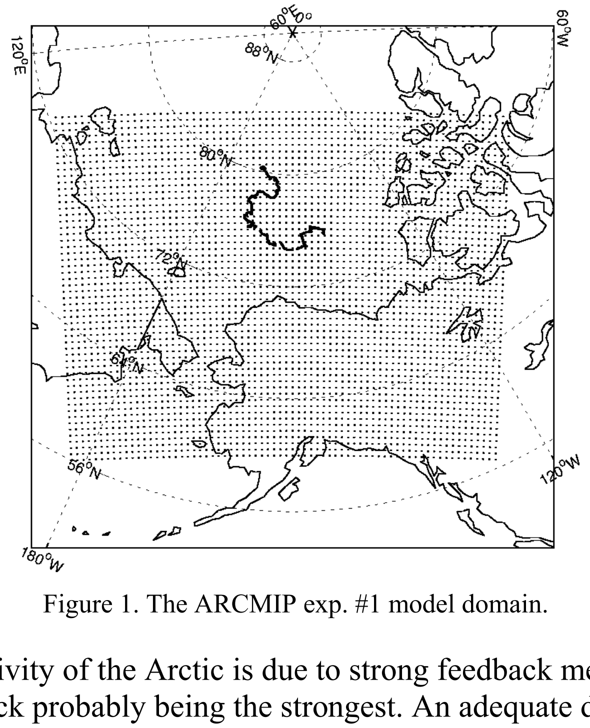

Figure 1. The ARCMIP exp. #1 model domain.

The large climate sensitivity of the Arctic is due to strong feedback mechanisms, the ice/snow-albedo feedback probably being the strongest. An adequate description of the fluxes of heat and momentum at the ice surface lay at the heart of a proper representation of this feedback. An evaluation of surface fluxes has been difficult due to lack of adequate data. The Surface Heat Budget of the Arctic Ocean (SHEBA, Uttal et al. 2002) experiment now makes this possible.

The aim of the Arctic Regional Climate Model Intercomparison (ARCMIP, Curry and Lynch 2002) project is to improve climate models for the Arctic, by comparing models to each other and to SHEBA data. In this experiment all models were set up on a common domain with the same resolution, centered on the SHEBA ice-drift track (Fig. 1). All six models (see acronyms in Fig. 2) used the same 6-hourly lateral boundary conditions from operational ECMWF analyses. Sea and ice surface temperatures and ice fractions were prescribed from satellite observations. The models were run 13 months, from 1 September 1997. In this paper we focus on an evaluation of the surface fluxes and the boundary-layer vertical structure (Tjernström et al. (2004).

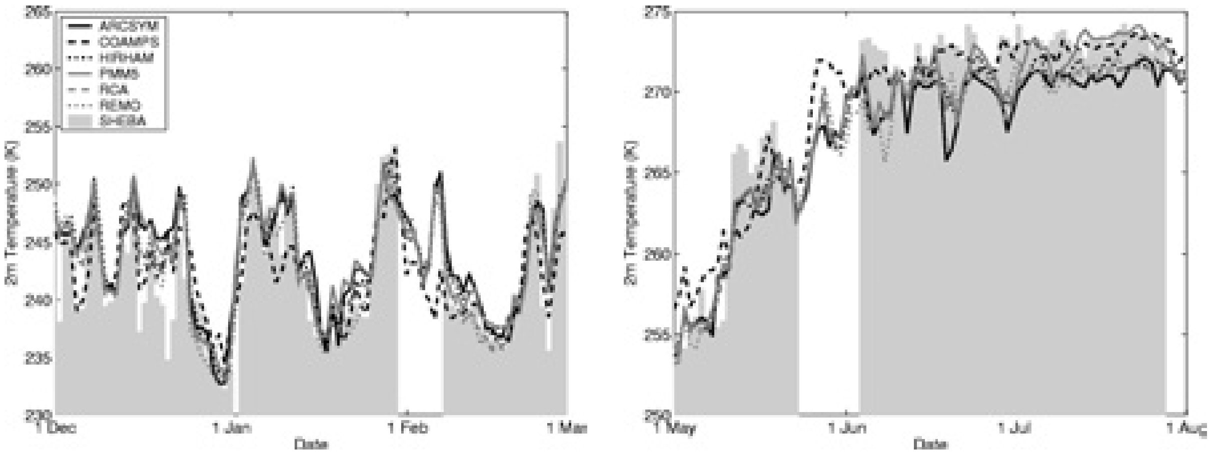

Figure 2. Siurnally averaged 2-meter air temperature during (left) winter and (right) summer for the different models and from SHEBA data, as indicated in the legend.

2. Results

In general the relatively small domain ensures that all models larger-scale dynamics adhere to that of the driving analyses, although smaller differences do occur (Rinke etal. 2004). Fig. 2 shows daily averaged 2-meter air temperature in all the models, for some winter and spring/ summer months. While the ice-surface temperature was prescribed, the models are expected to follow the observations closely. It is surprising to find some rather large differences between models and observations. During cold periods in December 1997, many models are ~ 10 ºC too warm, even as weekly averages. The coldest period, around 1 January 1998 is, however, well captured by all models. In summer, the differences are smaller, but with a systematic disparity between models close to ~ 0 ºC (the melt-point of fresh water) and others closer to ~ -1.8 ºC (the melt-point of ocean water).

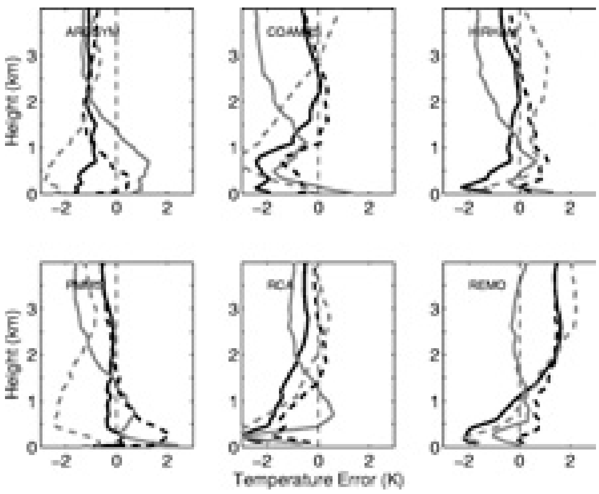

Figure 3. Seasonal averages of temperature bias profiles. Fall and winter are shown with solid, black and grey, and spring and summer by dashed, black and grey.

Seasonally averaged temperature bias profiles are shown in Fig. 3; two things are obvious. First, the biases are much larger and more variable below ~ 1 km. Second, different models behave very different also in the free troposphere. Larger biases closer to the surface indicate deficiencies in boundary-layer parameterizations, probably often related to formation of low-level clouds; note the summer low-level cold-bias in all models, presumably due to overestimated cloud-top cooling. Although all models should be constrained by the prescribed lateral boundary conditions in the free troposphere, the errors aloft are also significant, mostly as a cold bias. While some models have a consistent bias through the year, others are very variable from season to season.

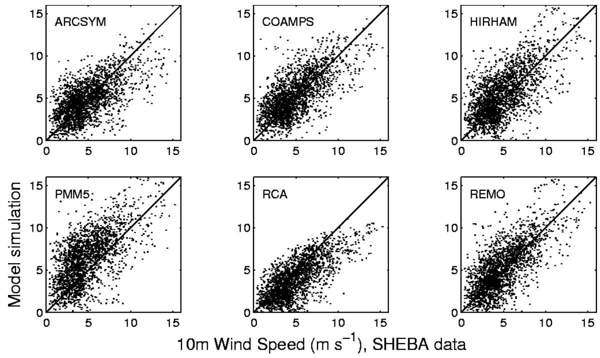

Figure 4 Scatter plot of the modeled 3 hourly wind speed compared to SHEBA measurements.

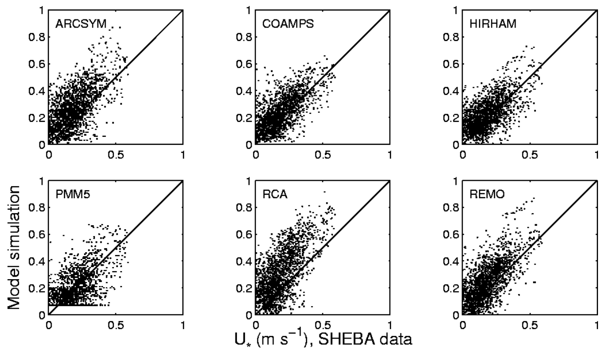

Figure 5. Scatter plot of the modeled 3 hourly friction velocity compared to SHEBA measurements

Near-surface wind speeds (Fig. 4) follow the observed variability well in all models, but with systematic biases in addition to the scatter. Annually averaged biases range from ~ -1 ms^{-1} in RCA to ~ 1.5 ms^{-1} in Polar-MM5. In some cases, this bias is consistent with similar biases in the momentum flux, expressed as friction velocity in Fig. 5, for example the high bias in RCA friction velocity is consistent with the low wind-speed bias.

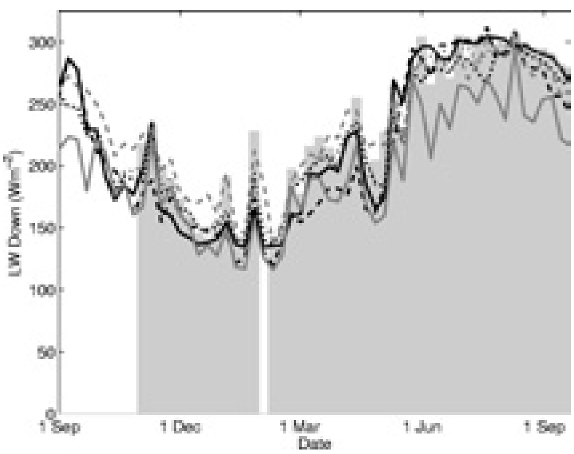

Figure 6. As Figure 2, but for weekly averaged down-welling long wave radiation.

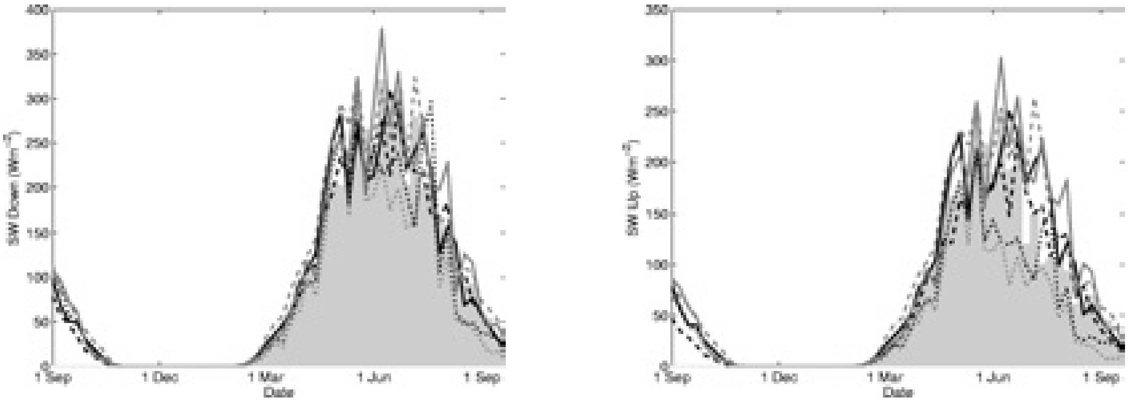

Figure 7. As Figure 2, but for weekly averaged (left) down-welling and (right) up-welling short wave radiation.

Given the difficulties to model clouds, the surface radiation fluxes are surprisingly accurate (Figs. 6-7). While some models do have biases ~ ± 20 Wm^{-2}, the correlation to the observations is high. Concerning turbulent heat fluxes the picture is distinctly more depresssing. All models fail badly (Fig. 8). Although the annual bias is small, the correlation to the observations is low. Annually accumulated heat flux errors are an order of magnitude.

3. Discussion

We believe that surface friction in these models was originally tuned against surface pressure to ensure reasonable development of synoptic systems, worrying less about the actual friction. Turbulence then "picks up the slack" from other unknown deficiencies in the models. Non-linear feedbacks between wind speed and turbulence then adjust to an unrealistic state, disrupting the turbulent heat fluxes. The results are superficially nice representations of Arctic climate, often for the wrong reason. If coupled to an ocean model with sea-ice, the result may instead be a very poor representation of current conditions. We will leave the consequences for the reliability of Arctic climate change simulations to the reader to ponder upon.

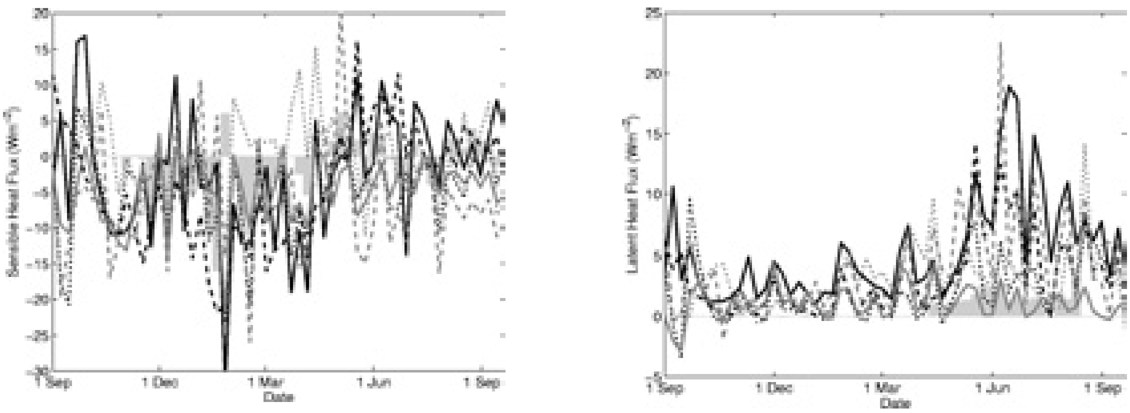

Figure 8.As Figure 2, but for weekly averaged turbulent (left) sensible and (right) latent heat flux..

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

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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 mollissiama 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 and Gilchrist 1998). 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^{o} 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 (-38C) 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.

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Climate Change and Goose Grazing on Svalbard's Tundra

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

		Ambient	Open Top Chamber	Temperature difference
Above ground				
	Mesic	10.1	11.3	+1.2
	Wet	9.2	9.7	+0.5
Below ground				
	Mesic	4.9	6.5	+1.6
	Wet	5.5	5.3	-0.4

Table 2. Grazing pressure in experimental plots compared to observations made of natural goose populations on Svalbard.

Habitat	Type of grazing		Grazing pressure min/ m^2	Reference
Mesic	Experimental	1 hr	**9**	This study
	Experimental	5 hr	**22**	This study
	Natural		4	Drent et al. 1998
Wet	Experimental	1 hr	**14**	This study
	Experimental	5 hr	**46**	This study
	Natural		9	Drent et al. 1998
	Natural		6	Prop et al. 1984
	Natural		22	Loonen et al. 1998, Stahl and Loonen 1998.

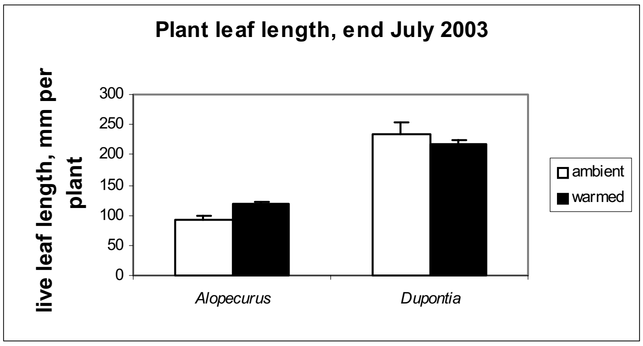

Figure 1. Length of live leaves (mm per plant) at the end of July 2003. n = 25.

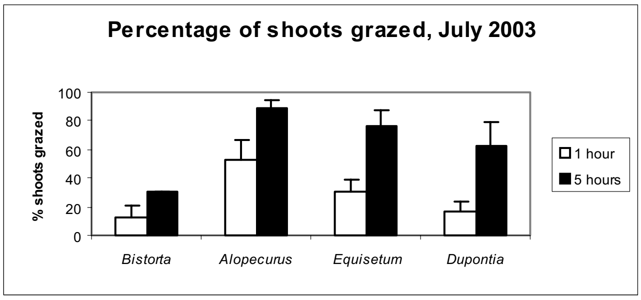

Figure 2. Percentage of shoots present which were grazed.n = 5.

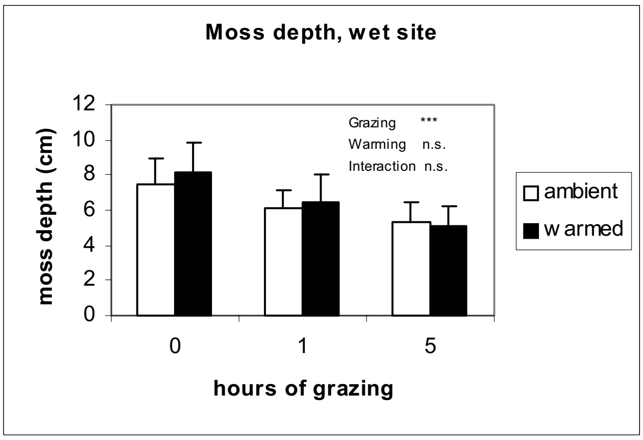

Figure 3. Moss depth after one season of treatments. n = 5.

Vulnerability of Arctic Shorebirds to Climate Variability and Change

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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 time-scale, 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

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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 8.5C and development rates increasing up to approximately 24C (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 1C 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 1C increase in temperature allowed larval development within a single summer and the first L3 would be expected by August 16; an 8C 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 8C vs. 1C.

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.

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

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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 (Hg^0), divalent mercury (Hg(II)), and particulate mercury (Hg^P). Anthropogenic emissions of Hg^0, Hg(II), and Hg^P are estimated by the GEIA emissions inventory at 1446, 774 and 204 Mg, respectively (Pacyna and Pacyna, 2002). Oceanic emissions of Hg^0 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 Hg^0 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 Hg^0 was incorporated based on the locations of mercury mines worldwide (Frank, 1999).

Two oxidation pathways are included in the model: Hg^0 can react with either OH (Sommar et al., 2001) or O_3 (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 Hg^0 and $HgCl_2$.

The results from our initial simulation agree to a reasonable degree (+/-20% on average) with measured values of total gaseous mercury (TGM=$Hg^0_{(g)}$ + $Hg(II)_{(g)}$) 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.

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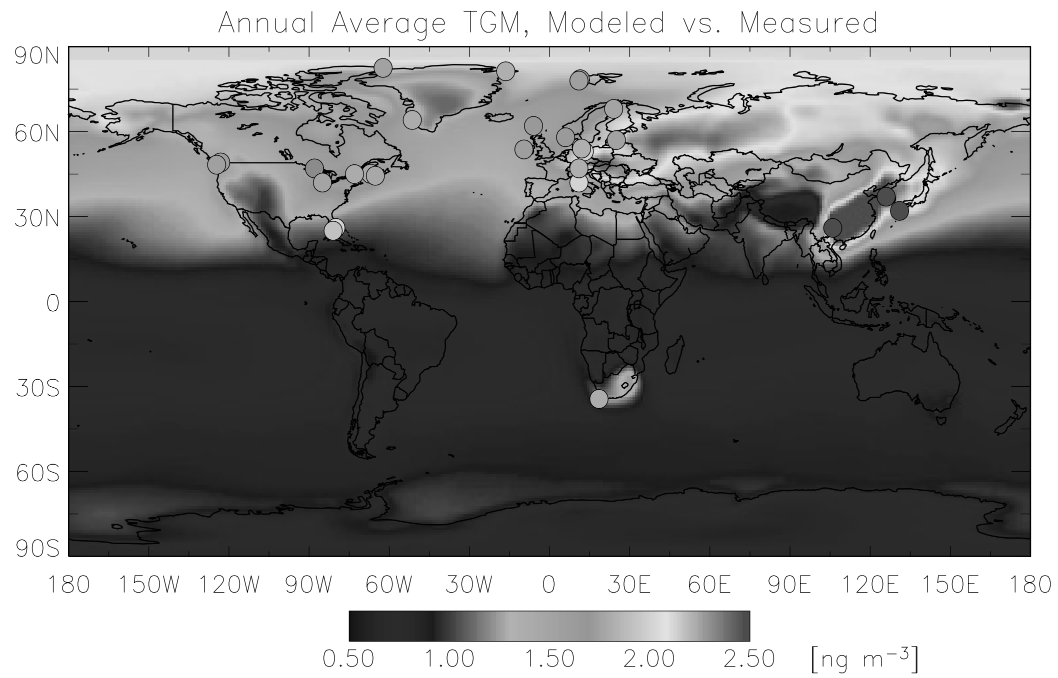

Figure 1. Annual Average TGM, modeled vs. measured. Measurements are presented as round circles superimposed on model results. The high end of the color scale is cut off at 2.5 ng/m^3 for ease of presentation.

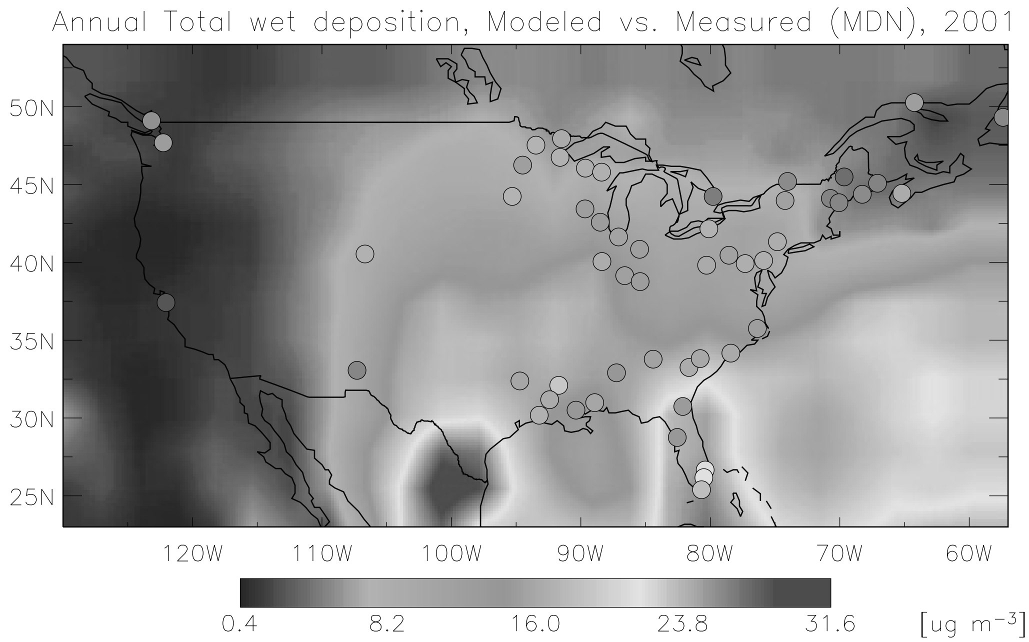

Figure 2. Annual Total wet deposition, modeled vs. measured, for 2001. Measurements are presented as round circles superimposed on model results. Measurements are from U.S. Mercury Deposition network.

Biodiversity of Arctic Sea Ice Biota and Possible Effects of Oil Spills during Oil Transportation

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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) untill 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, subpspecies, 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 micrscope, 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 nutirents (N and P).

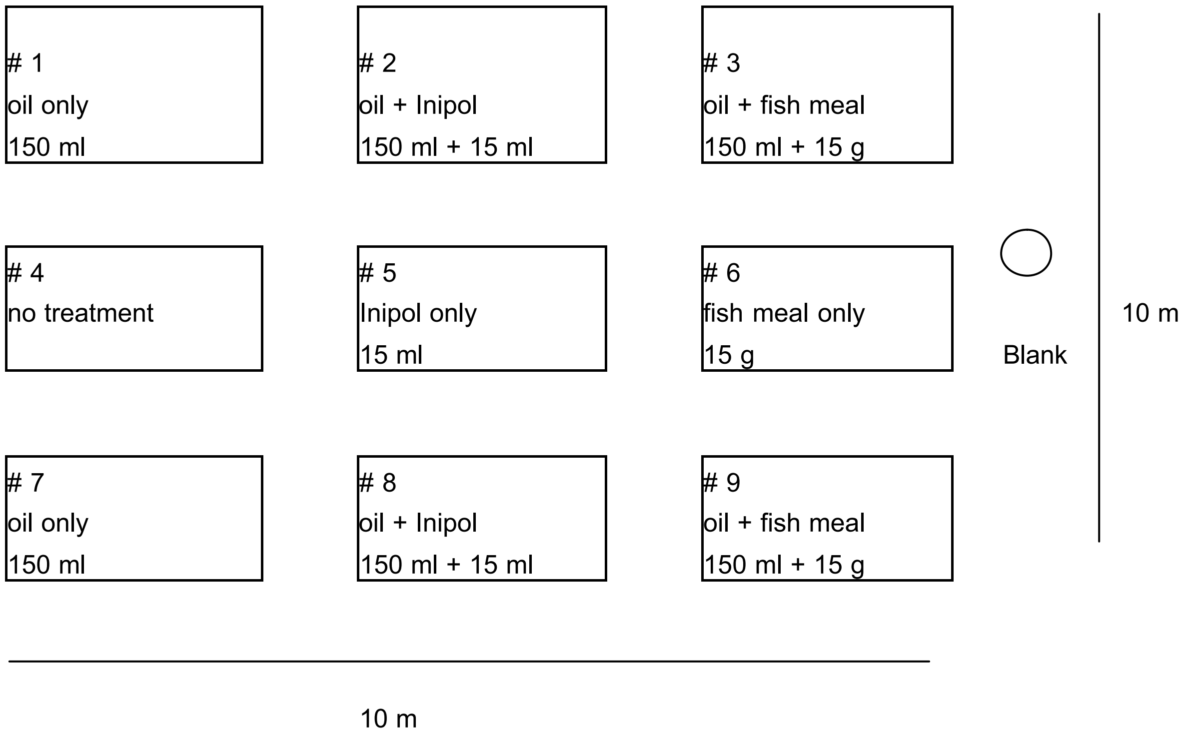

Figure 1. Experimental design for the study of effects of oil spills on the arctic sea ice biota.

Results

Organisms from the following systematic ranks have been recorded living assosciated with arctic sea ice: Cyanophyta, Cryptophyceae, Dinoflagellata, Chrysophyceae and Dictyochophyceae, Bacillariophyceae, Pedinellales, Xanthophyceae, Haptophyceae, Chlorophyceae, Euglenida, Pedinophyceae, Prasinophyceae, Raphidophyceae, Straminopiles, Heliozoa, Amoebae, Choanoflagellida, Foraminifra, 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.

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Why Do Global Climate Models Project So Different Climates for the Arctic?

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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 single 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

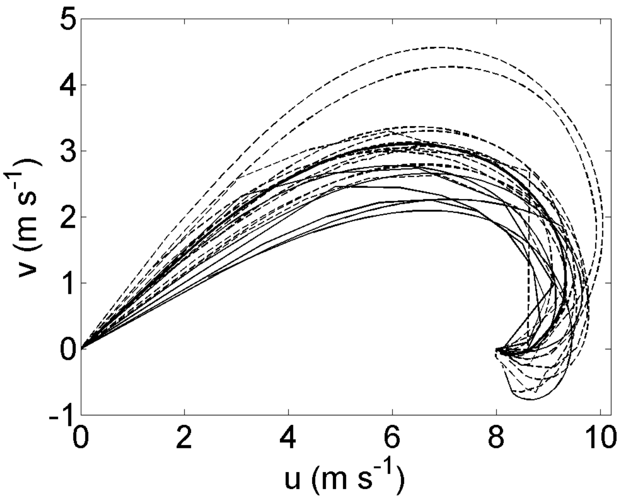

Figure 1. Hodographs for the models included in the GABLS study. Solid line – operational models, dashed line – research models and the thick solid line is averaged LES results.

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).

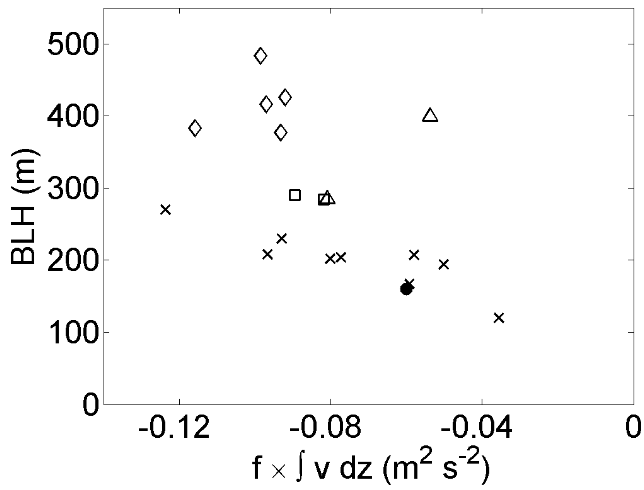

Figure 2. Integrated cross-isobaric flow plotted against the boundary-layer height. Diamonds – operational models with first-order closure, squares – operational models with higher-order closure, triangles – research models with first-order closure, crosses – research models with higher order closure, and solid dot – LES.

3. Observations

Analysis of turbulence measurements taken in stably stratified conditions is difficult since the energy levels decreases 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.

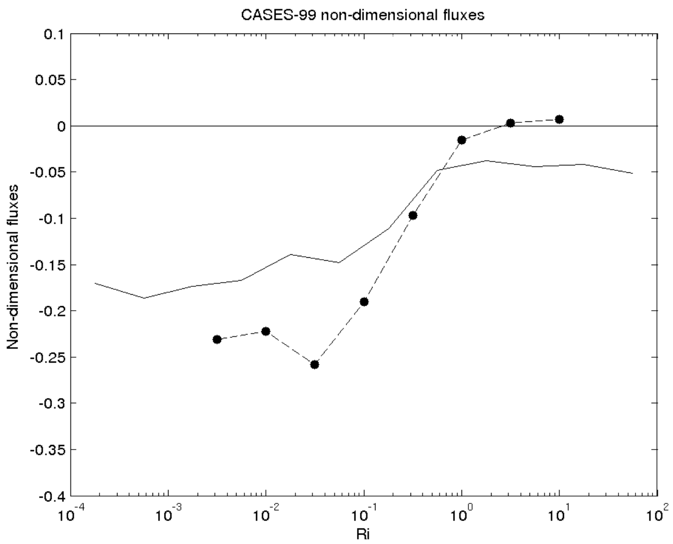

Figure 3. Normalized turbulent fluxes of heat (dashed line), and momentum (solid line), as function of gradient Richardson number. The data are from CASES-99 field program.

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.

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The Sensitivity of Arctic Climate Projections to Natural Variability

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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 gasses, 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 gasses 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 CO_2 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 CO_2 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 CO_2).

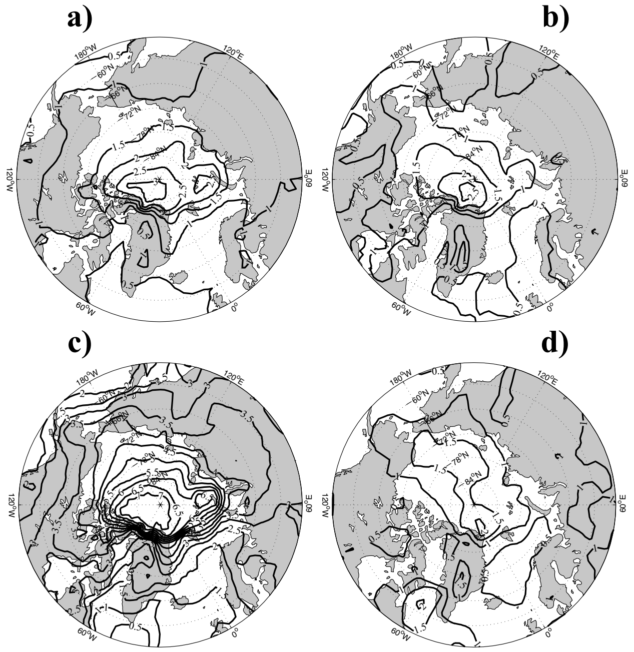

Figure 1: Ensemble mean (a,c) BCM annual temperature change (ºC) and spread (b,d) calculated as maximum-minimum change (ºC) among the 5 different members of the ensemble at two different times corresponding to weak (year 20-40, upper) and strong (year 60-80, lower) external forcing.

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 CO_2). 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 CO_2 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%.

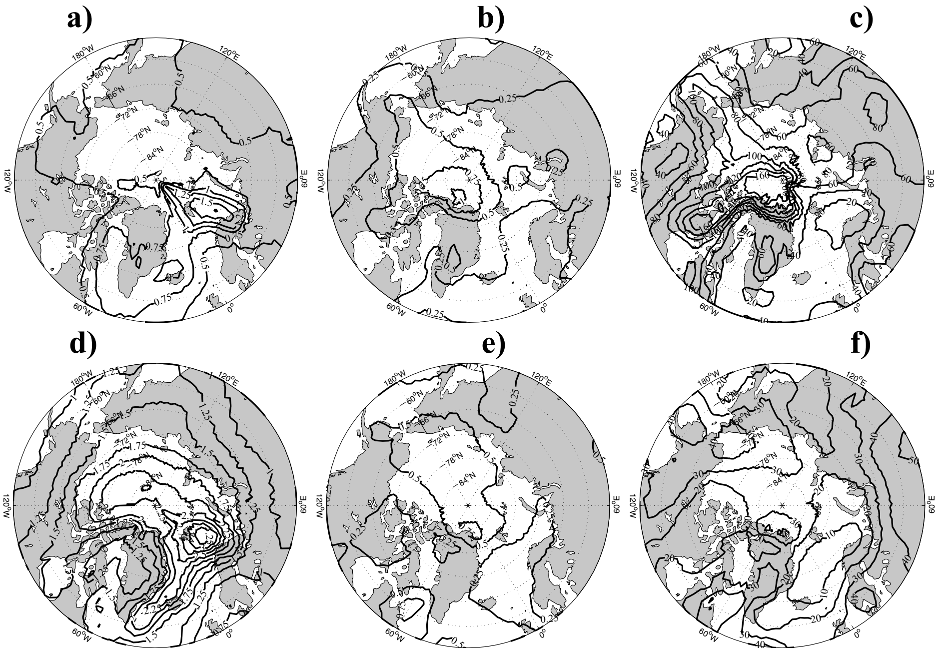

Figure 2: The multimodel spread (a,d), BCM spread (b,e) and ratio (%) of the standard deviation of the BCM spread and the standard deviation of the multimodel spread (c,f) for annual temperature at two different times corresponding to weak (year 20-40, upper) and strong (year 60-80, lower) external forcing.

Conclusions

An ensemble of CMIP2 (1% increase in CO_2 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 CO_2 showed large differences among the different members. This was especially pronounced during weak CO_2 forcing and pinpoints the importance of internal natural variability on the Arctic climate system. As the CO_2 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 CO_2) 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

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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.

Acknowledgements

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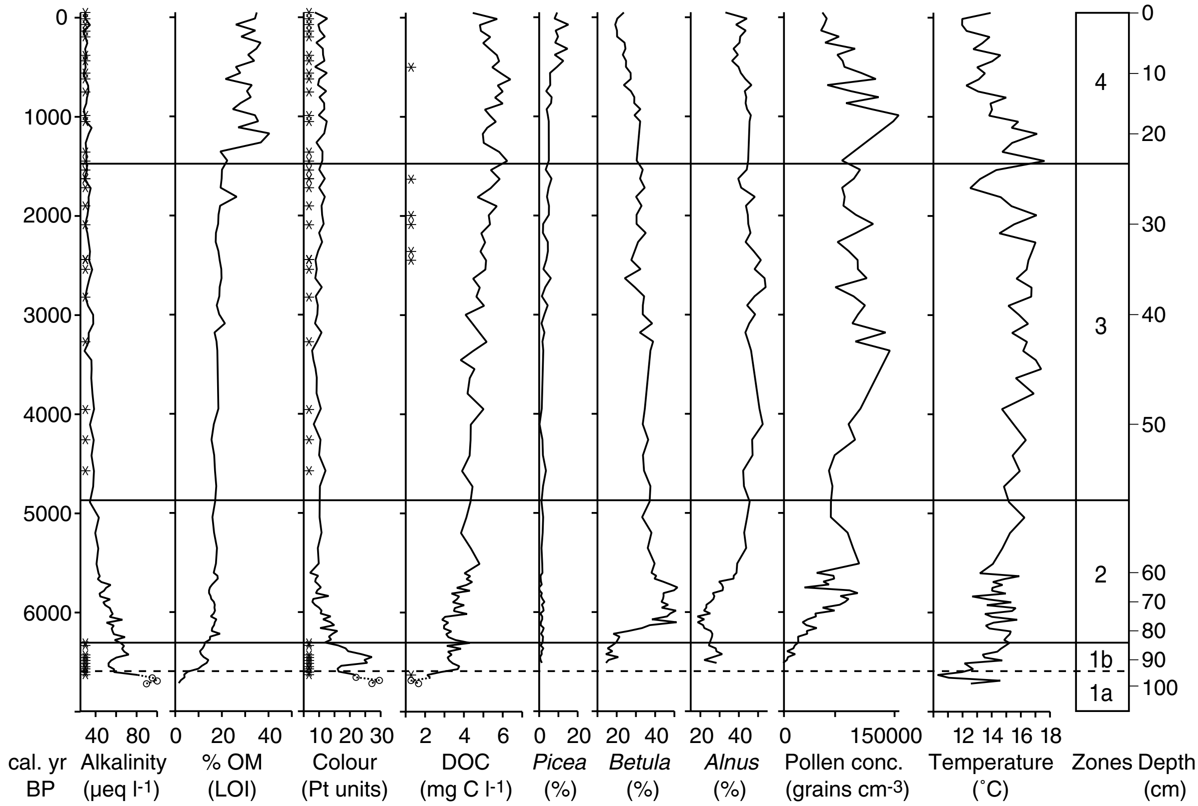

Figure 1. Synthesis of paleoenvironmental data for Lake K2, northern Québec (58˚44'N, 65˚56'W). After Fallu et al. 2004, in press (Palaeogeogr. Palaeoclim. Palaeoecol.).

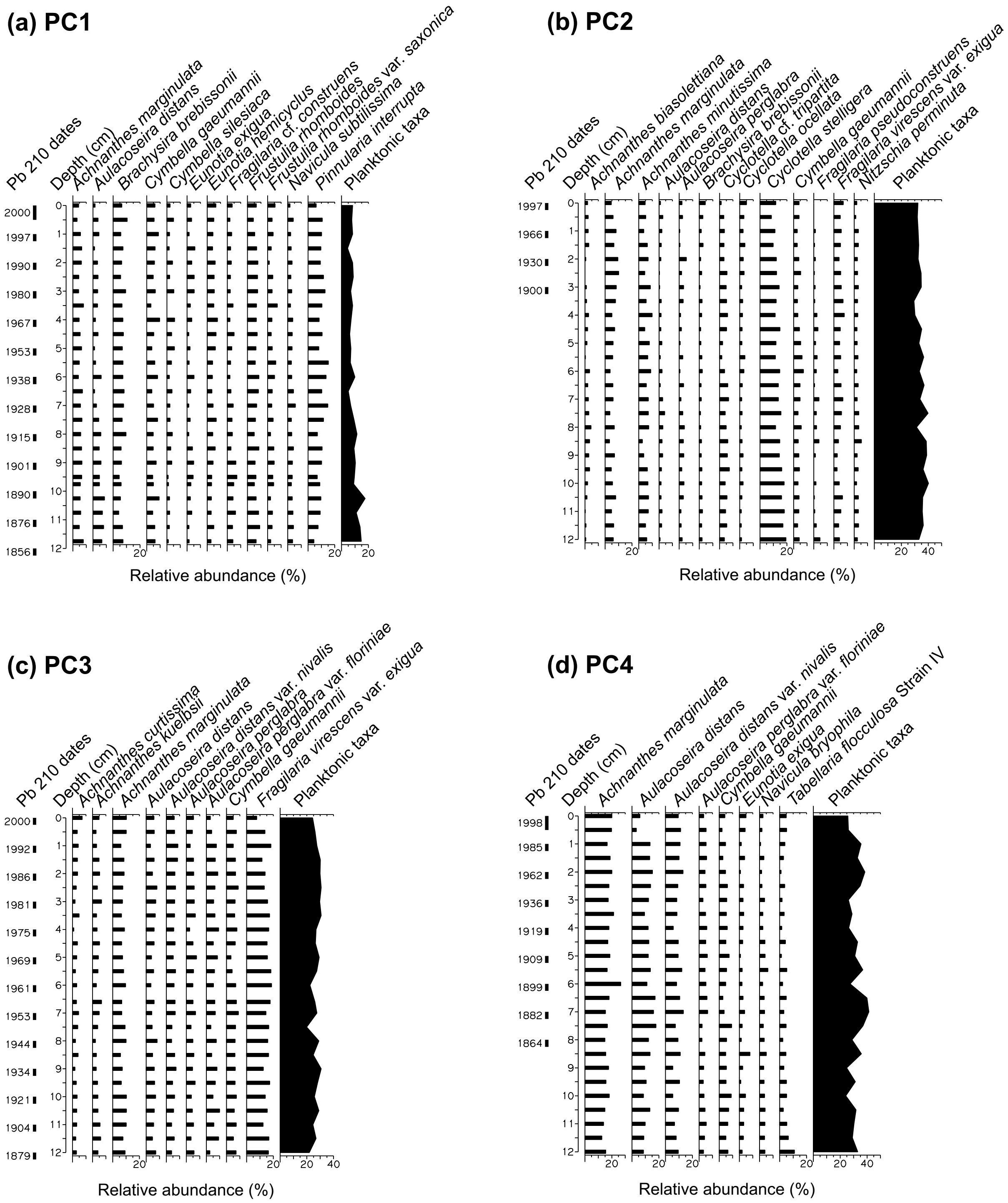

Figure 2. Stratigraphy of the most abundant diatom taxa in four sediment cores from the Rivière George region, northern Québec (58˚30'N, 65˚30'W). After Laing et al. 2002 (Arct. Ant. Alp. Res. 34: 454-464)

Climate Change and Hydrology of the Large Siberian Rivers

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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 45^{o} N, and only 30% of these basins are located within the Polar Circle.

Table 1. Characteristics of the largest Siberian rivers.

River	Drainage area		Water discharge	
	M km^2	World ranking	km^3/a	World ranking
Ob	2.990	3	404.0	13
Yenisey	2.590	7	620.0	5
Lena	2.490	8	525.0	8
Kolyma	0.660	29	132.0	29
Khatanga	0.364	41	85.3	44
Indigirka	0.362	42	61.0	53
Yana	0.238	55	34.3	96
Olenek	0.219	59	35.8	92

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 lat 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 malts 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 km^3), according to the second one – 21% (110 km^3). 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 km^3.

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 km^3, 5140 km^3 of which belong to the surface runoff (including 470 km^3 from icebergs and glaciers), and approximately 80 km^3 – 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 km^3 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.

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Variations in Arctic Sea-Ice

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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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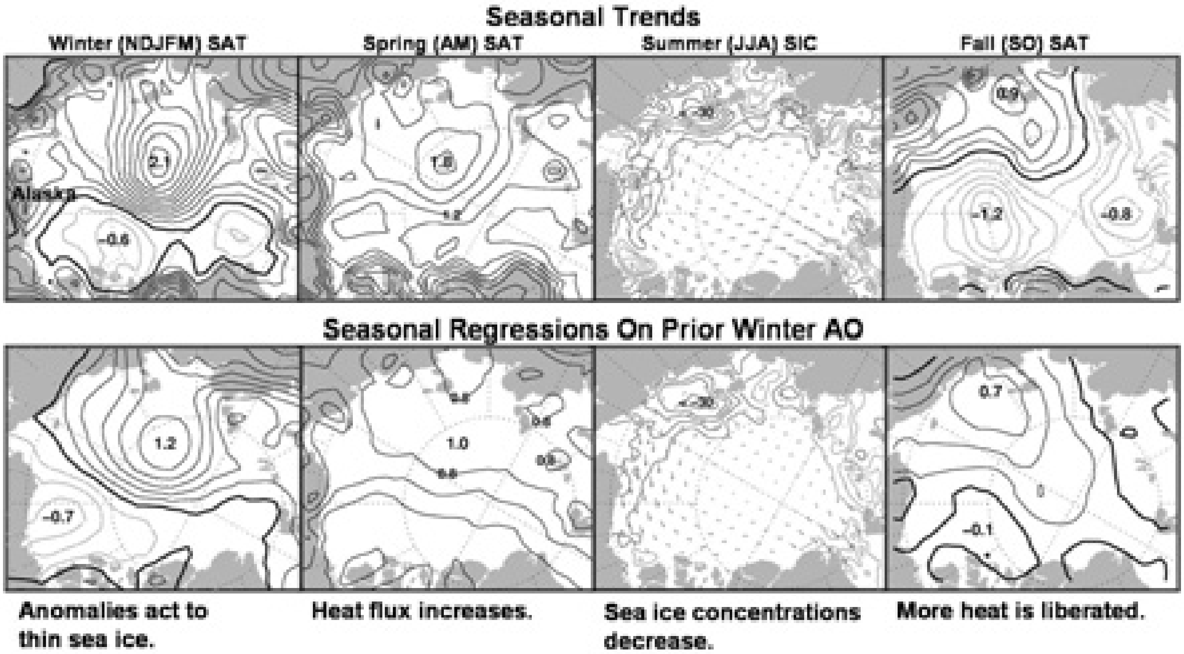

Figure 1. Seasonal memory of the prior winter AO. This figure shows the trends in surface air temperature and sea-ice extent from 1979 – 1998 (top), and the regression of these fields on the prior winter Arctic Oscillation index (bottom). Note the remarkable similarity between the trend and regression 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.

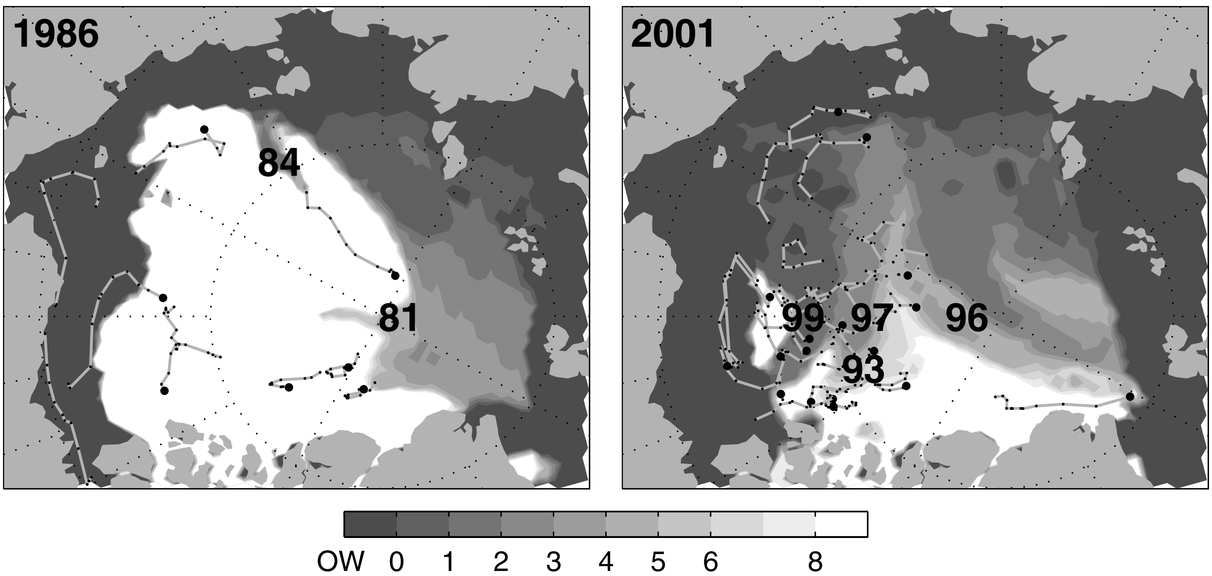

Figure 2. These maps show the changes in the age (thickness) of sea ice from the 1980's (left) to the present. Open water (OW) is shown as dark blue, and the oldest ice is shown as white. The drift of buoys that reported for at least 8 months of the year are also shown. The larger area of younger, thinner 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

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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 varia-bility 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 proecess 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 dy-namics 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 Micro-wave/Imager (SSM/I) is used with the Polynya Signature Simulation Method (PSSM) (*Mar-kus 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 mini-mum 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 M_2-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**).

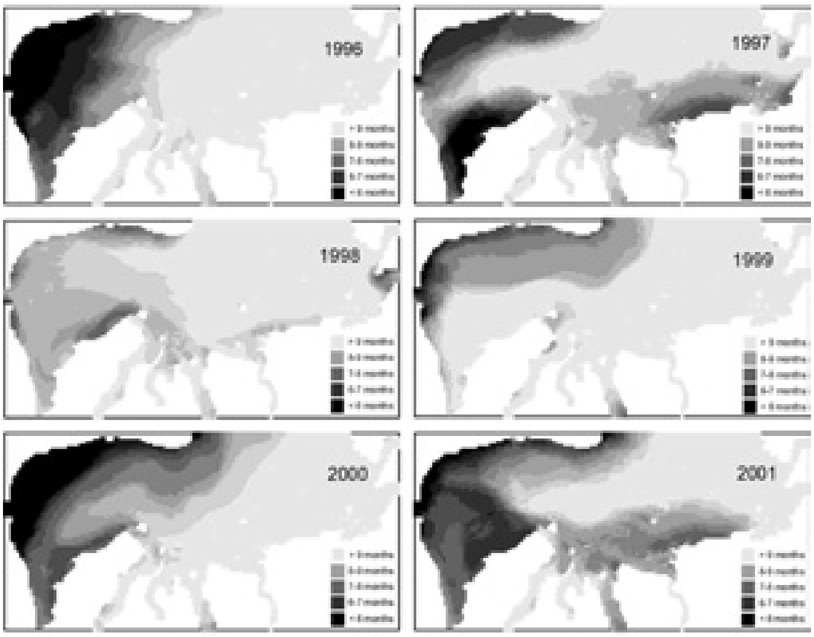

Fig. 1: Number of ice-free months in the Kara Sea as obtained with the Kara Sea model.

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 pat-terns of 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 com-parable 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).

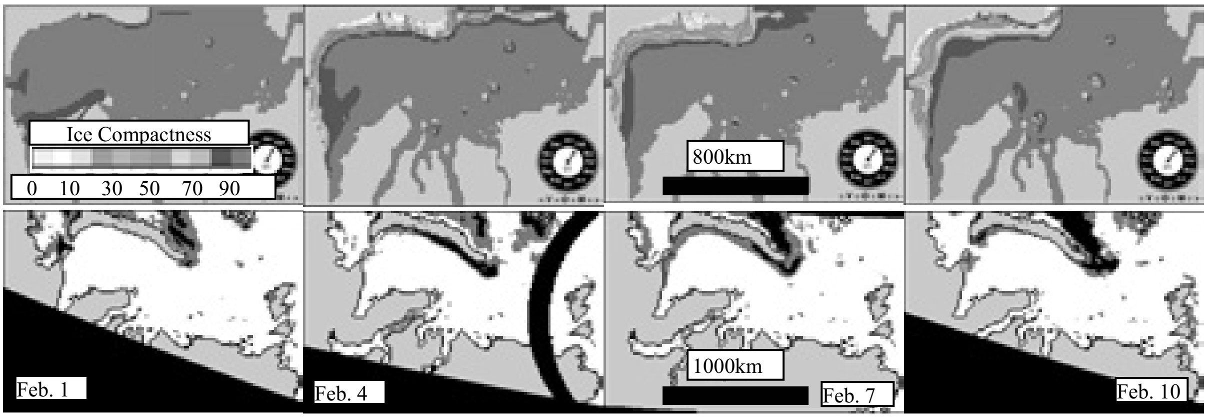

Fig. 2: Modeled ice compactness (top, legend in leftmost image) and PSSM thin ice/open water area (bottom, white: first-year ice, gray: thin ice, black: open water) for Feb. 1, 4, 7, and 10, 2001.

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.

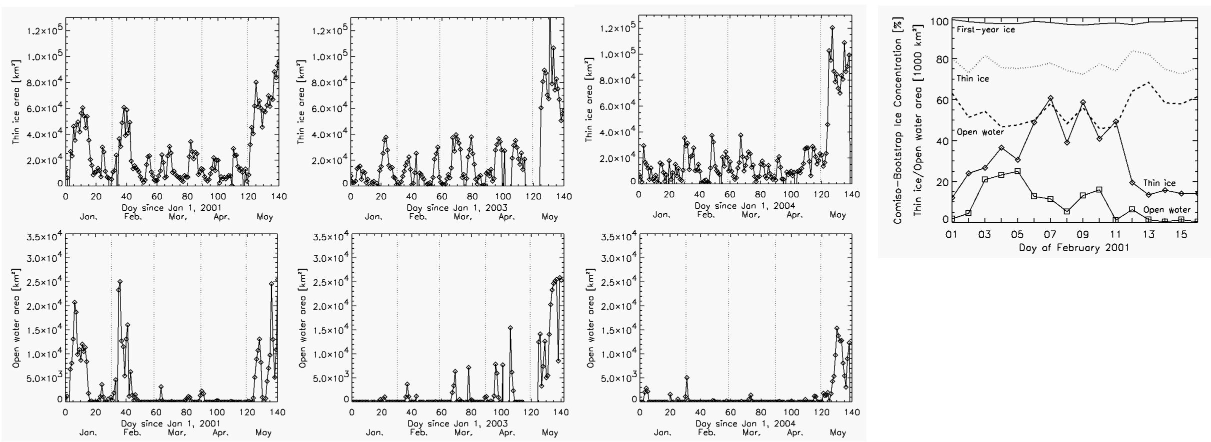

Fig. 3: Time-series of thin ice area (top left) and open water area (bottom left) as obtained with the PSSM for the Kara Sea for Jan.-May 2001, 2003, and 2004 (going from left to right). Missing areas are set to below zero. Image on top right shows a comparison between PSSM thin ice/open water areas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

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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 etal. (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 9.29ºC and 9.73ºC, 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 (1.32ºC), 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.

Passage	Dir	Model	Observation	References
DS	N	1.1	1.0	Hansen & Østerhus (HØ, 2000)
	S	6.9	4.3	HØ (2000), Fissel et al. (1988)
IFR	Net	2.2	2.3	HØ (2000)
FSC	N	4.3	4.4	Orvik & Skagseth (2003)
	S	1.1	2.6	HØ (2000), Turrell et al. (1988), Østerhus et al. (1999), Ellett (1998)

Table 1: Simulated (80 km configuration) and observation-based mean northward (N) and southward (S) volume transports in Sv (10^6 m^3s^{-1}) over the GSR. The model transports are mean values for the periods of available observations, typically from the 1990s.

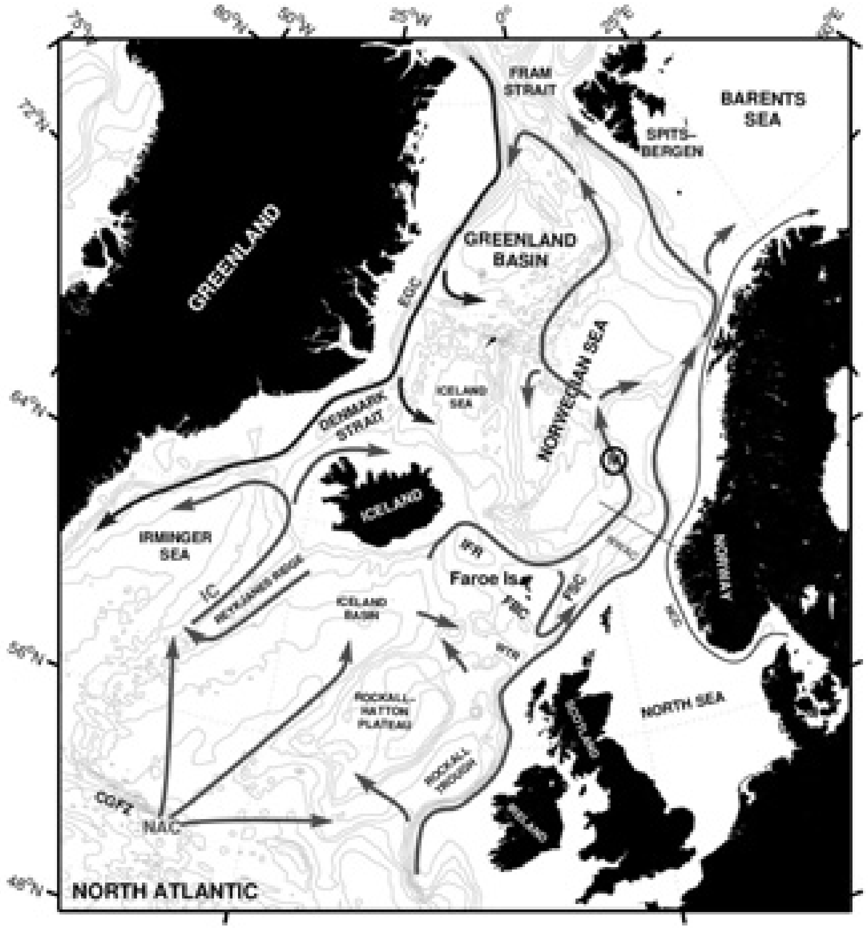

Figure 1: The northern North Atlantic and the Nordic Seas. Isobaths are drawn for every 500 m. Schematic upper layer currents are based on literature. See text for abbreviations. Circled M shows the position of Ocean Weather Station M and thin line indicates the Svinøy Section. From Furevik and Nilsen 2004).

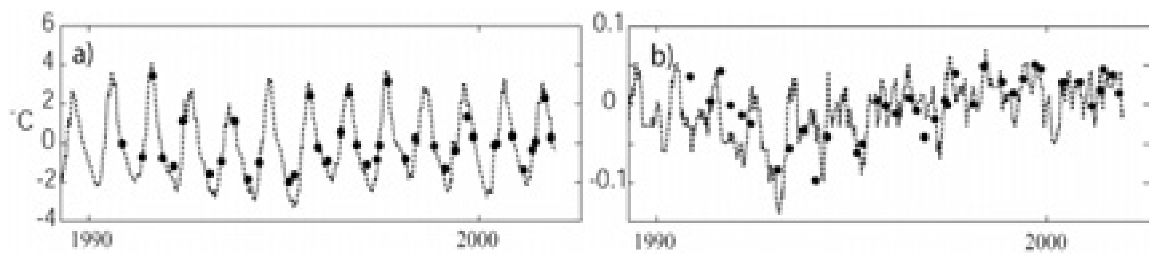

Figure 2: Simulated (dotted line) and observed (points) section maximum of temperature (a) and salinity (b) in the Faroe North Section.

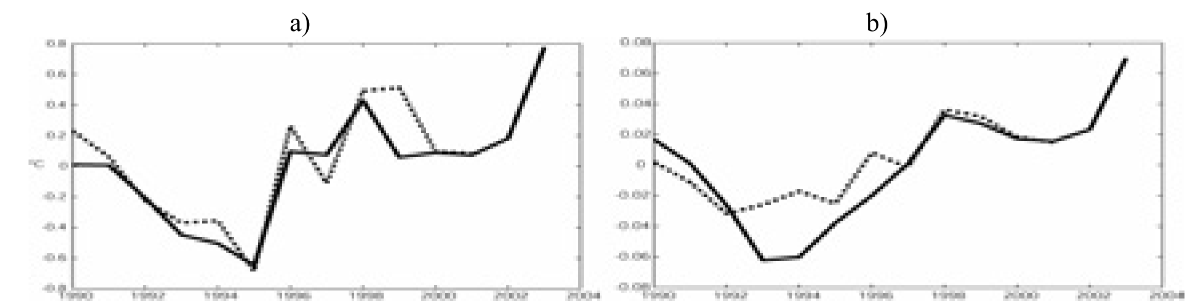

Figure 3: De-seasoned observed (full line) and simulated (dotted line) temperature (a) and salinity (b) in the core of the Faroe Current.

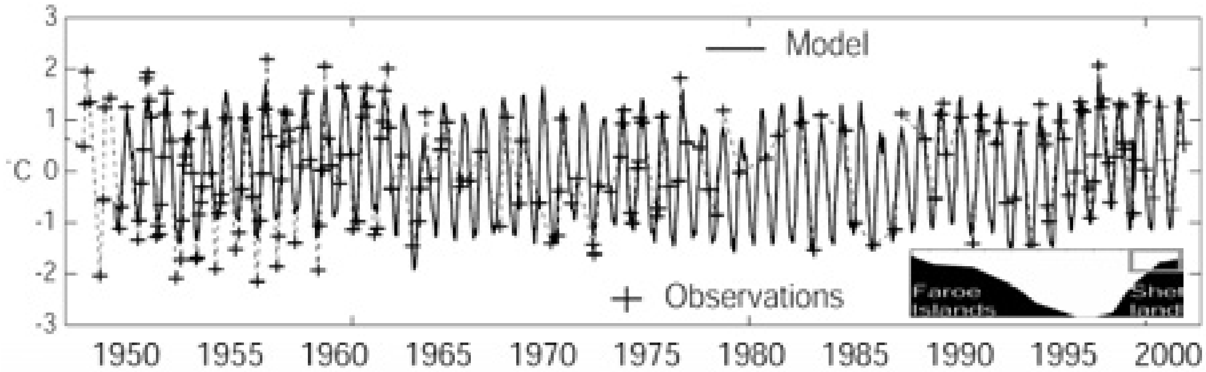

Figure 4: Temperature series of the FSC inflow 1948-2002, calculated as spatial averages over the grey frame in the inlay (Hátún et al., 2004).

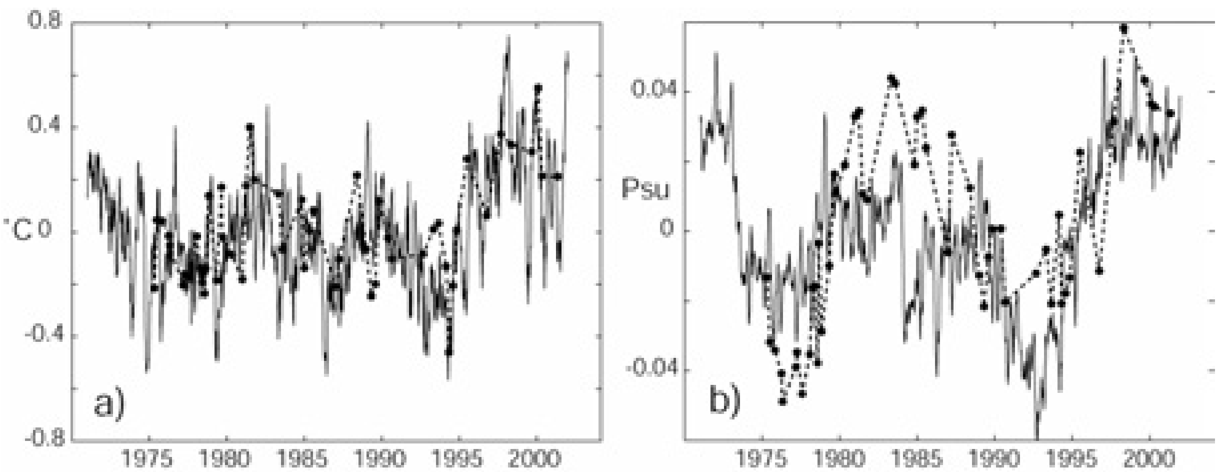

Figure 5: De-seasoned anomalies of temperature (a) and salinity (b) horizontally averaged over the uppermost 800 m in the Ellett Section in the Rockall Trough (Holliday et al., 2000; points on dashed lines) and the simulated time series processed in a similar way (Hátún et al., 2004; full lines).

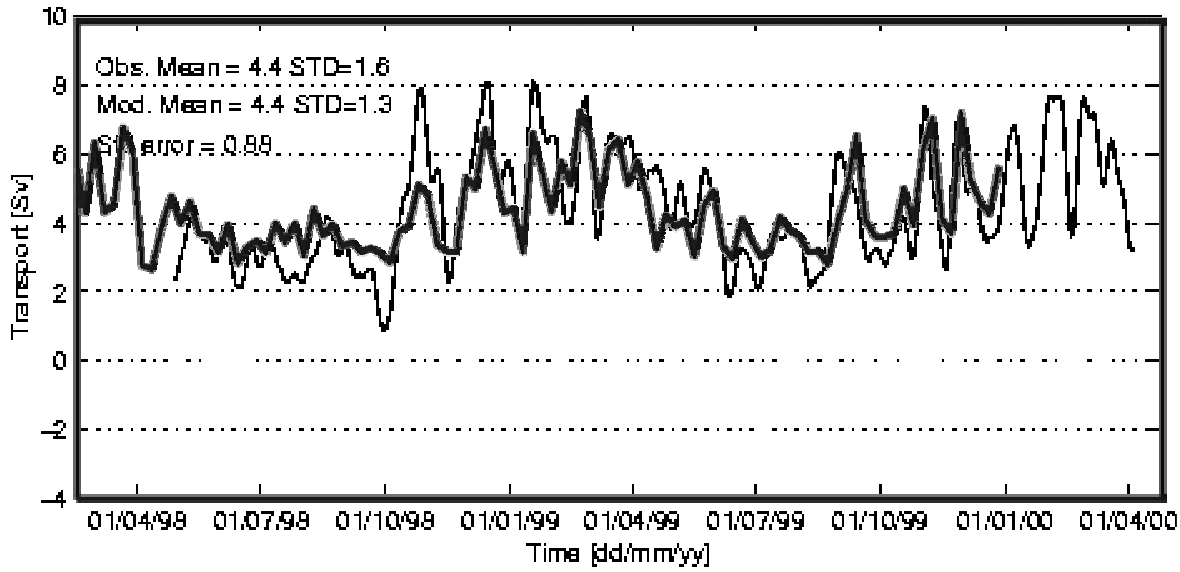

Figure 6: Simulated inflow through the FSC (thick grey line) compared with seven days low pass filtered transport estimates for the eastern branch of the NWAC, from current meter measurements and hydrography at the Svinøy Section (thin black line; Orvik and Skagseth, 2003).

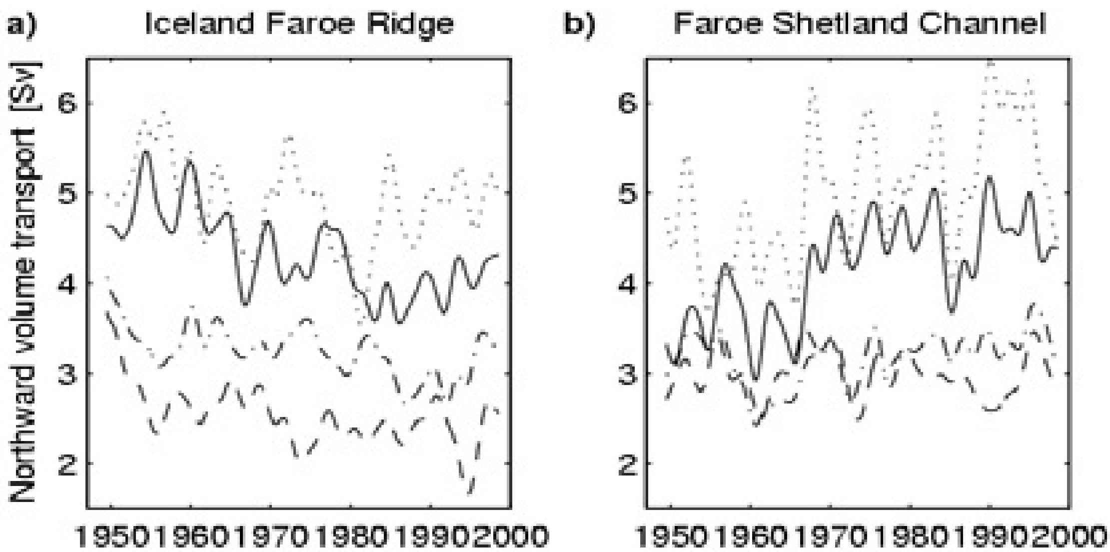

Figure 7: Temporal variation of the 3-years low-pass filtered simulated inflow through the IFR (a) and FSC (b) for normal (full line), zero (dashed), half (dash-dotted), and double (dotted) wind stress.

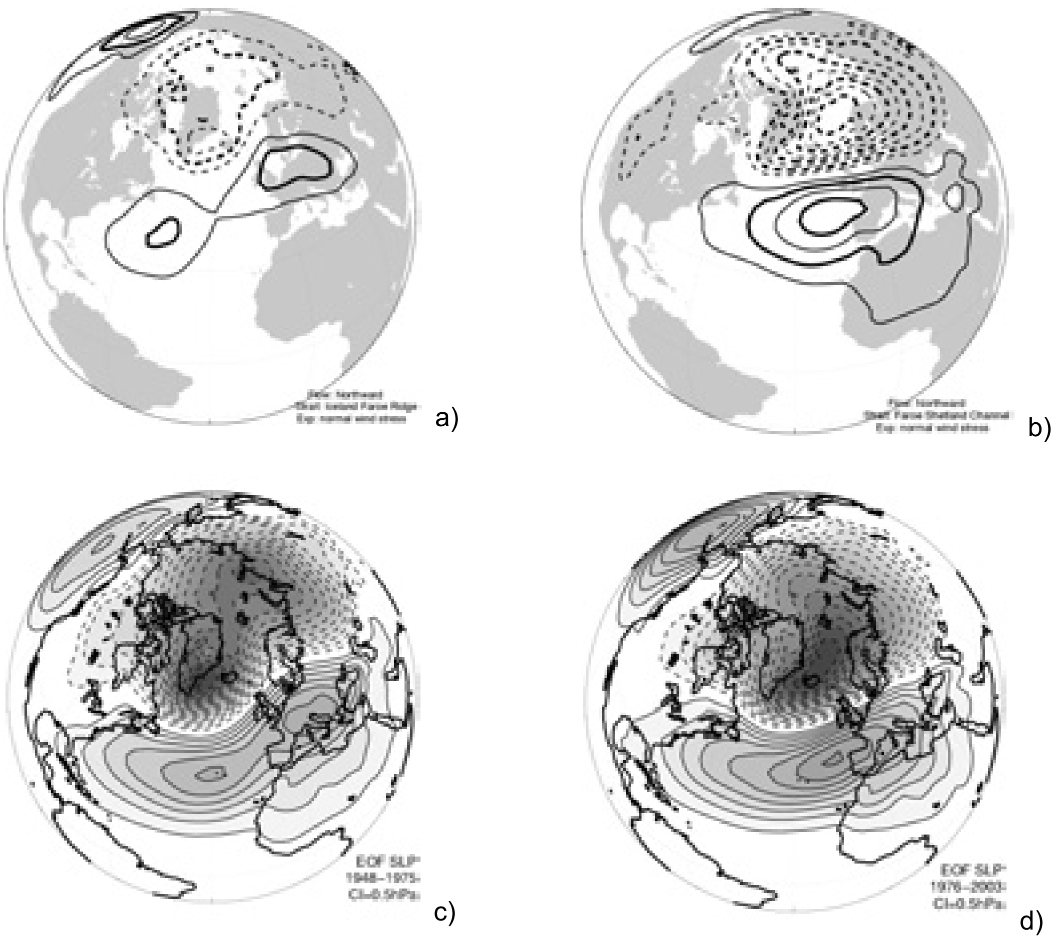

Figure 8: Upper panels: Regression maps showing the NCAR/NCEP winter (December–March) mean SLP regressed on standardized simulated inflow through IFR (a) and FSC (b). Isolines are drawn at 0.5 mb intervals. Correlations in the centers of action reach 0.6 (northern) and 0.5 (southern) and are highly significant. 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.

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

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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.

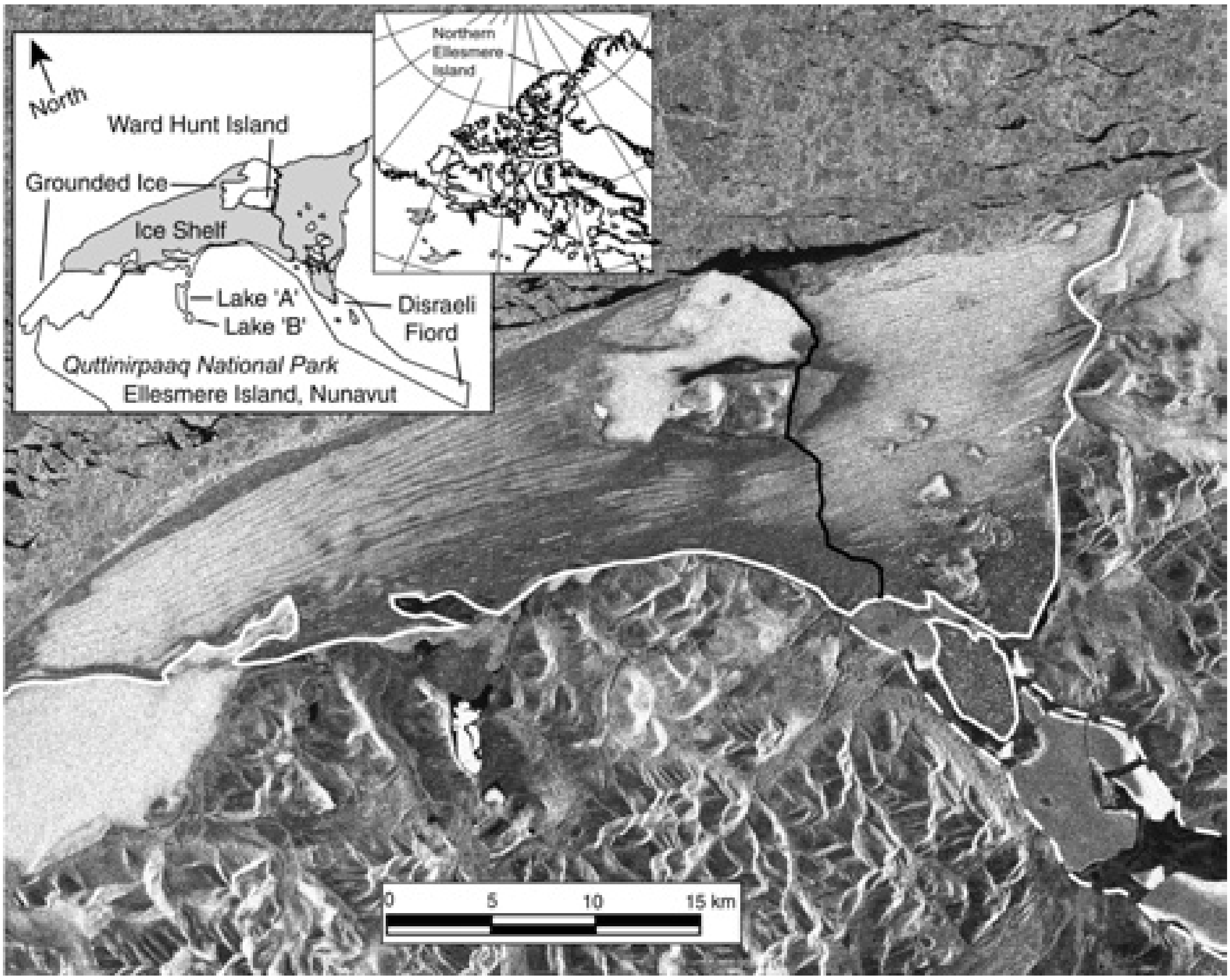

Fig. 1. Fine Beam RADARSAT-1 image of the northern end of Quttinirpaaq National Park, Nunavut, Canada (September 27, 2003). The main crack in the Ward Hunt Ice Shelf is traced in black, the southern edge of the ice shelf is traced in white. We noted further widening of this crack during our fieldwork 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).

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

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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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Empirically Based Modelling of Variability and Trends in Local Snow Conditions

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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 (ΔSD_m) basically depends on temperature conditions (represented by the average monthly temperature T_m) and precipitation (represented by the monthly precipitation sum R_m), while the average snow-depth of the previous month (SD_{m-1}) is the upper limit for melting. An estimate for the change in monthly mean snow-depth may thus be expressed as:

$$\Delta SD_m = \max\{f(T_m, R_m); -SD_{m-1}\} \qquad (1).$$

It is suggested that the function *f* may be written on the form:

$$f(T_m, R_m) = a\,R_m + b\,T_m\,R_m + cT_m \qquad (2).$$

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:

$$f(T_m, R_m) = \left\{ \begin{array}{ll} a_1 R_m + b_1 T_m R_m & \text{when } T_m < TT1 \\ a_2 R_m + b_2 T_m R_m + c_2 T_m & \text{when } TT1 \geq T_m > TT2 \\ c_3 T_m & \text{when } T_m \geq TT2 \end{array} \right\} \qquad (3).$$

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.

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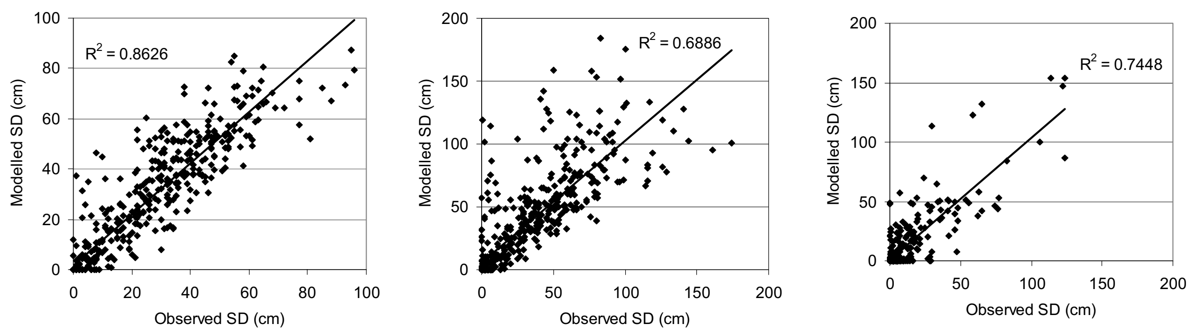

Figure 1. Model fit at 3 stations in different parts of Norway. Left: Karasjok in Northern Norway; Middle: Røros in Mid-Norway; Right: Kjevik in Southern Norway. R^2 between observed and modelled snow-depth is given in each plot.

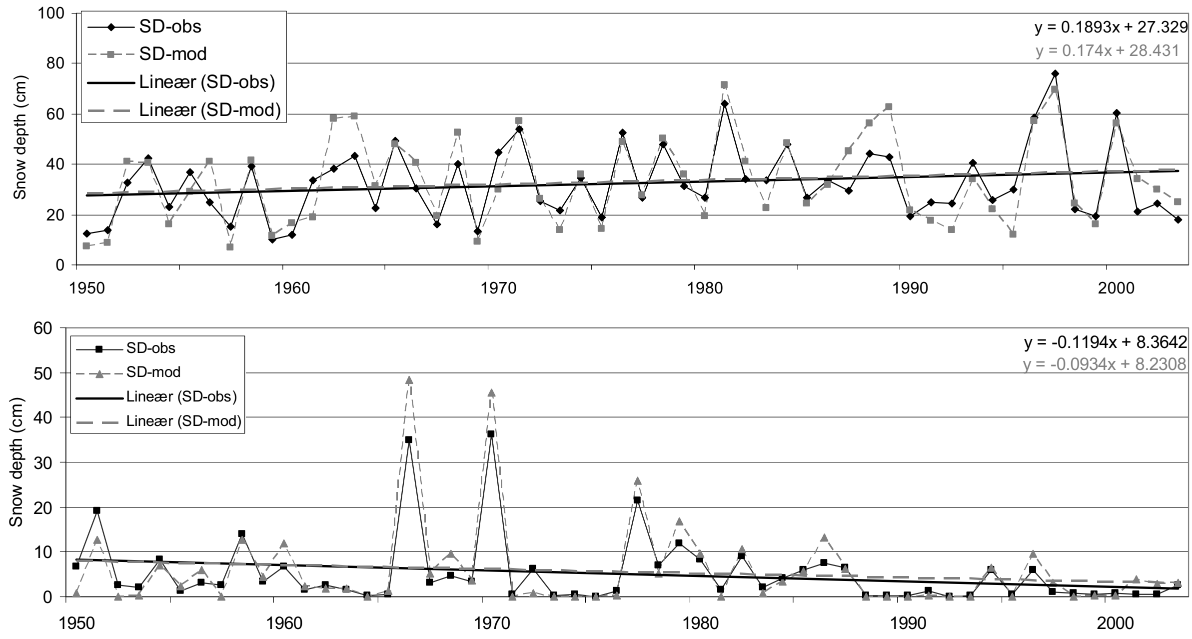

Figure 2. Observed and modelled annual mean snow-depth in Tromsø, Northern Norway (upper panel) and Kjevik, Southern Norway (lower panel). Linear trends are shown.

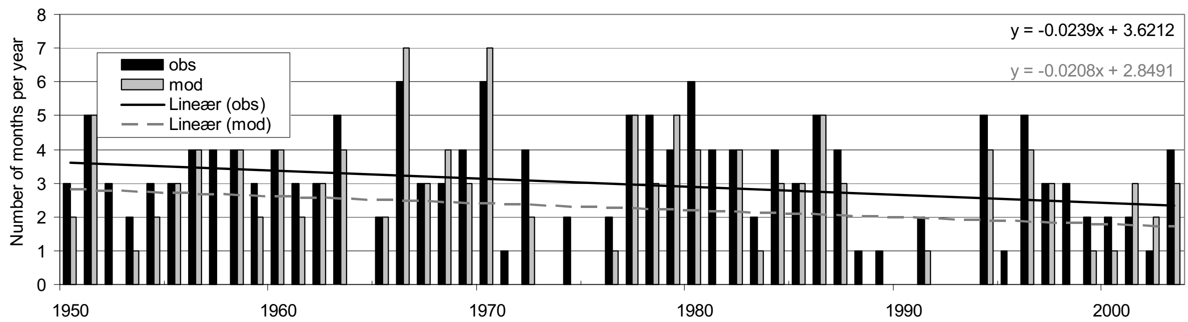

Figure 3. Observed and modelled number of months with average snow-dept >1cm at Kjevik, Southern Norway. Linear trends are shown.

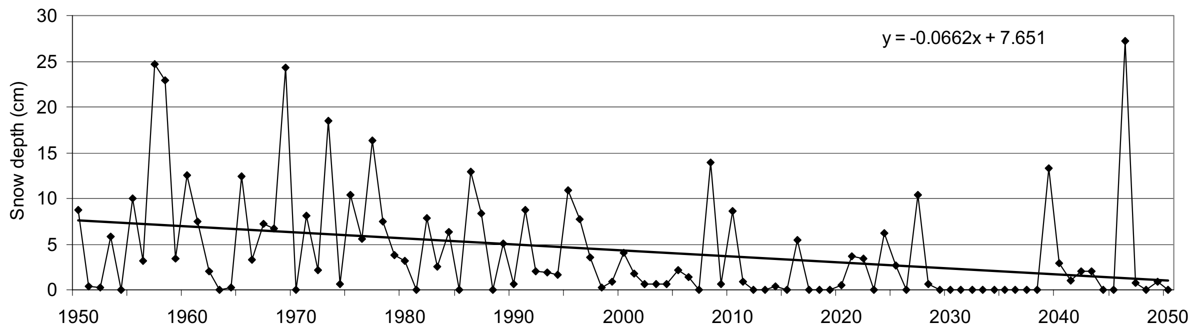

Figure 4. A scenario for annual mean snow-depth at Kjevik, Southern Norway.

Variations in Climatic Constraints on Living Conditions in the Nordic Arctic, 1900-2050

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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°W30°W-52°N80°N); Fennoscandia and Iceland: Domain II (40°W40°E-52°N80°N); Svalbard (Bjørnøya and Svalbard Airport): Domain III (35°W40°E-67°N85°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^oC. 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 $\hat{T}$ = 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 $\hat{T}$ = 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.

	TEMPERATURE		GROWING SEASON				HEATING SEASON			
Station Name	T	ΔT	LG	GDD	ΔLG	ΔGDD	LH	HDD	ΔLH	ΔHDD
Upernavik	-7,32	1,6	36	12	38	167	365	8850	0	-591
Nuuk	-1,41	1,2	68	83	32	138	365	6705	0	-428
Narsarsuaq	0,96	1,3	129	445	19	172	335	5640	-36	-662
Tasilaq	-1,66	0,4	67	76	-2	23	365	6799	0	-126
Stykkisholmur	3,51	1,6	141	452	19	229	341	4750	-35	-720
Akureyri	3,31	2,0	140	522	24	348	314	4654	-57	-940
Reykjavik	4,31	1,7	161	570	17	293	319	4325	-34	-690
Torshavn	6,46	1,3	207	729	25	295	312	3492	-29	-514
Karasjok	-2,41	3,6	119	620	28	229	300	6751	-18	-1351
Vardø	1,32	2,5	116	344	32	221	365	5707	-53	-1236
Tromsø	2,53	2,3	134	577	32	218	305	4933	-26	-978
Bjørnøya	-2,35	4,4	0	0	68	87	365	7050	0	-1594
Svalbard Airp.	-6,67	4,8	43	34	23	53	365	8618	0	-1769
Jan Mayen	-1,42	2,0	19	3	27	22	365	6711	0	-729
Stensele	0,50	3,3	140	780	19	213	283	5631	-22	-1229
Abisko	-0,83	2,9	115	457	27	139	320	6212	-11	-1077
Karesuando	-2,20	3,6	117	594	25	148	299	6647	-29	-1485
Sodankylä	-1,04	3,6	128	733	18	187	289	6245	-14	-1333
Copenhagen	8,66	1,6	229	1780	14	354	204	2708	-26	-502
Oslo-Blindern	5,69	2,5	188	1388	29	285	237	3794	-18	-808
Helsinki	5,24	2,9	183	1380	22	310	239	3972	-15	-920
Stockholm	6,61	2,2	196	1513	29	331	228	3484	-18	-694

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Climate, Water and Renewable Energy in the Nordic Countries

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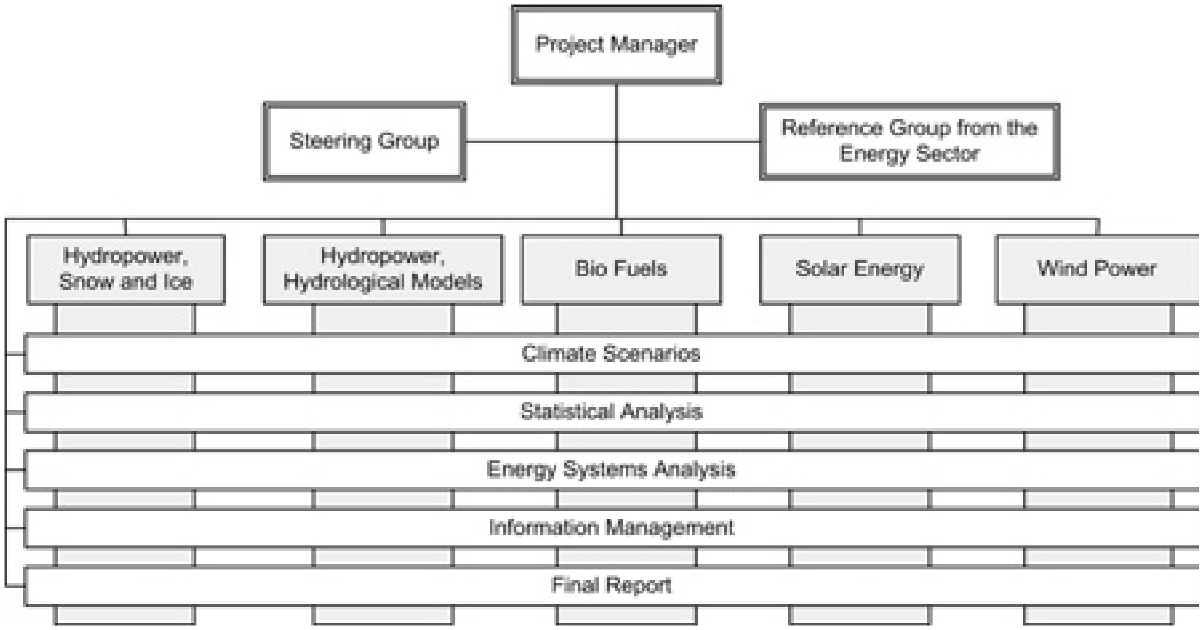
Introduction

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

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

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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

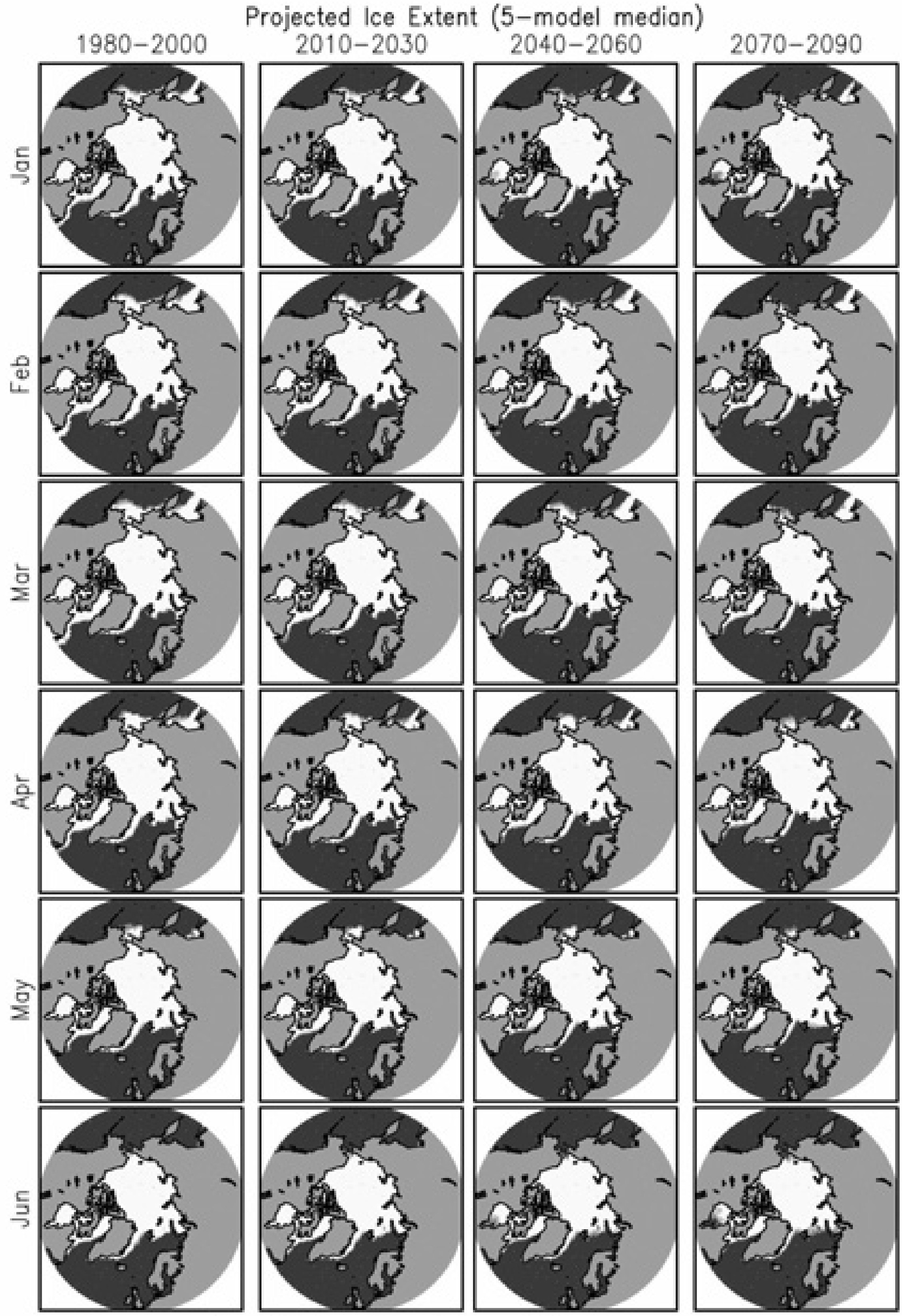
Within ACIA, projected changes in Arctic sea ice coverage were evaluated in the context of potential improvements in marine access. The evaluation is based on monthly fields of sea ice from simulations by five different global climate models (GCMs), each forced by the conservative, Intergovernmental 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

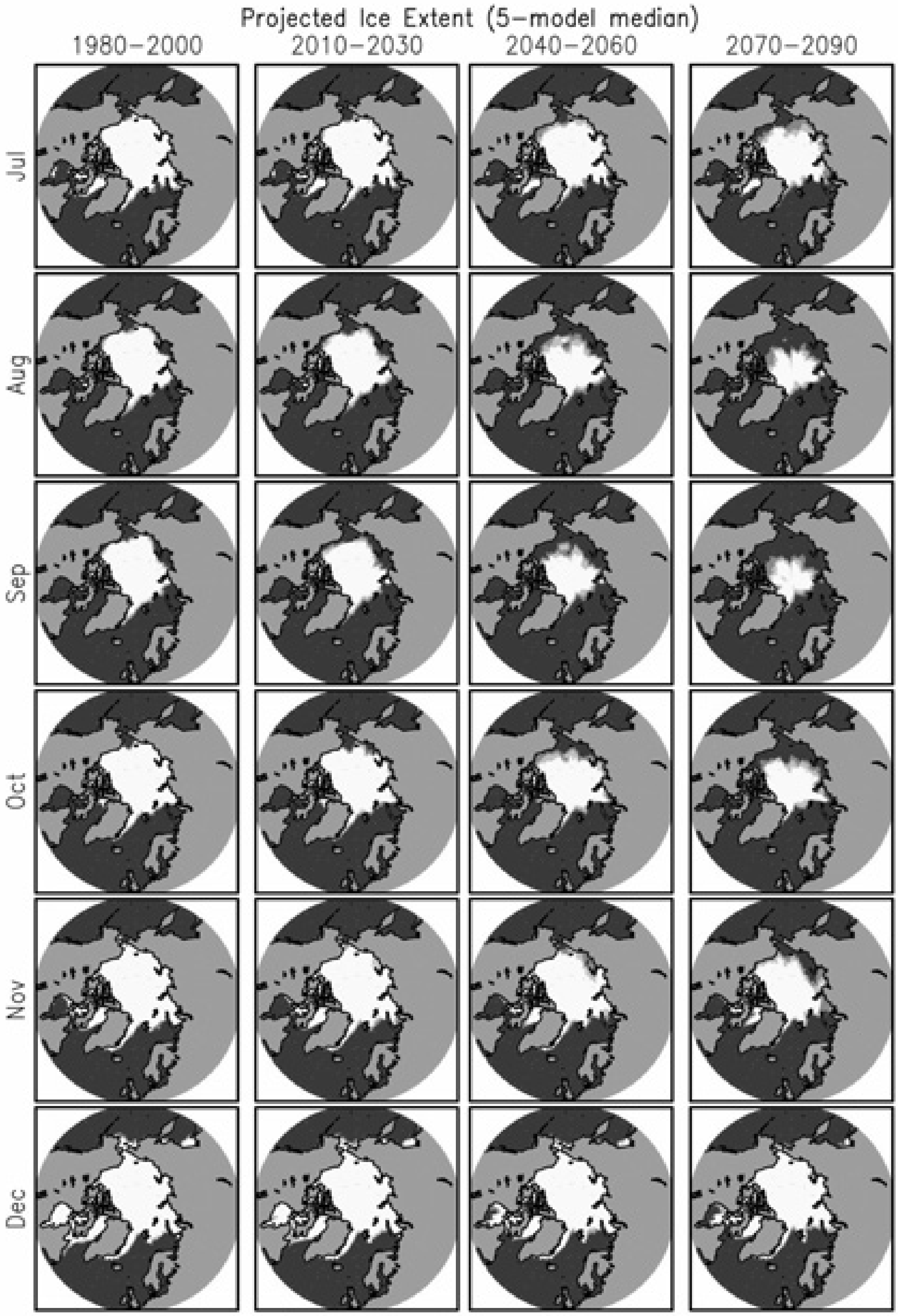
The work of ACIA also included first-order attempts at regional assessments for the Northwest Passage (NWP) in the Canadian Arctic and the Northern Sea Route (NSR) along the northern Eurasian coast. Two serious constraints limited an adequate ACIA assessment of the NWP: the GCMs could not resolve the 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)



Arctic Sea Ice Atlas of the Future:
ACIA Projections (July - December)

Have Recent Biological Changes in Newfoundland Capelin (*Mallotus villosus*) occurred because of Physical Changes in the Arctic?

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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 0^0 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 Δy, Δf, Δk, and Δl represent percentage changes in the gross domestic product (GDP), the production of marine products, the physical capital stock and labour, respectively. μ_{t-1} is the error correction term lagged one period. The β's, δ's, γ's and λ are parameters to be estimated and ε 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 α_1 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 α_1 equaling 0.31. With an estimate of α_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:

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

where $\Delta \hat{f}_t$ is the predicted change in fish production, $\sigma(f_t, t)$ is a measure of the uncertainty of that prediction and Δz 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

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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

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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 placed-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 a 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 theYukon 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 *sustainbility 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

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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

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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.

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

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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), Niillas 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

Participants of the community documentation,students, Henry Huntington, RAIPON, Sámi Council, Inuit Tapiriit Kanatami, Inuvialuit Joint Secretariat, Unalakleet Tribal Council, Murmansk Humanities Institute, ACIA, IASC, WWF Finland/Arctic, UNEP-GRID Arendal, Northern Climate Exchange, University of Lapland, Tampere Polytechnic, Aurora Research Institute, Nunavut Research Institute, John Macdonald, Legendseekers and other partners in Snowchange network.

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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

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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.

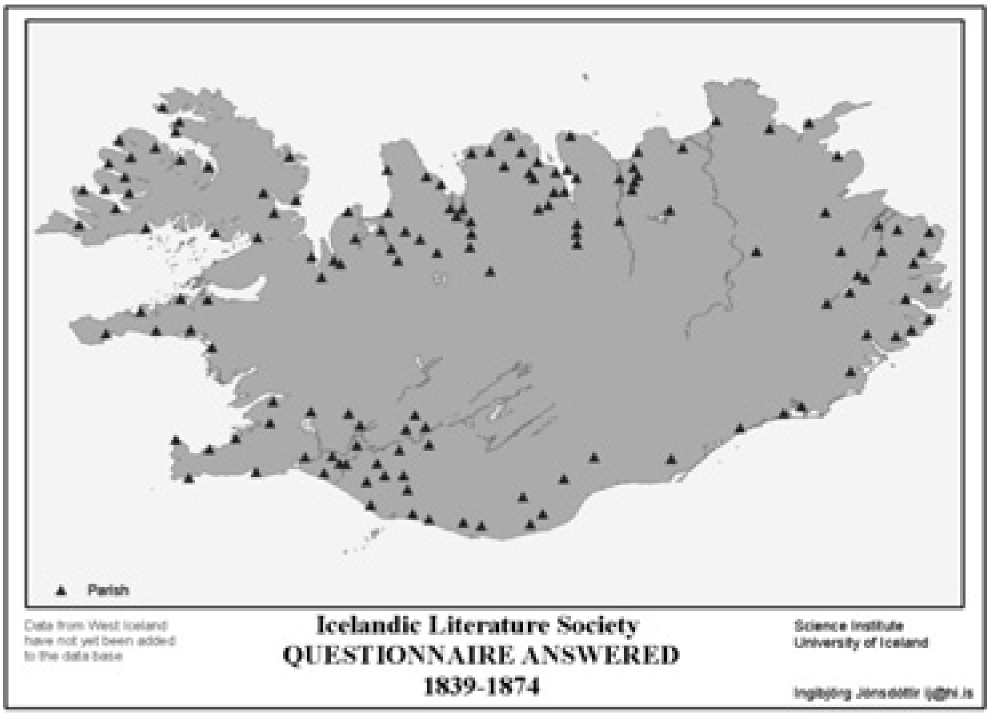

Figure 1. The Icelandic Literature Society sent a questionnaire with 70 questions on people and nature to all priests and sheriffs in Iceland. The questions on sea ice were: "Does sea ice come? And what have people noticed about its behaviour, nature and impacts?" Only 8 of 194 reports are missing and the answers are very useful when studying past sea-ice impacts and people's conception on sea-ice and it's 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

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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.

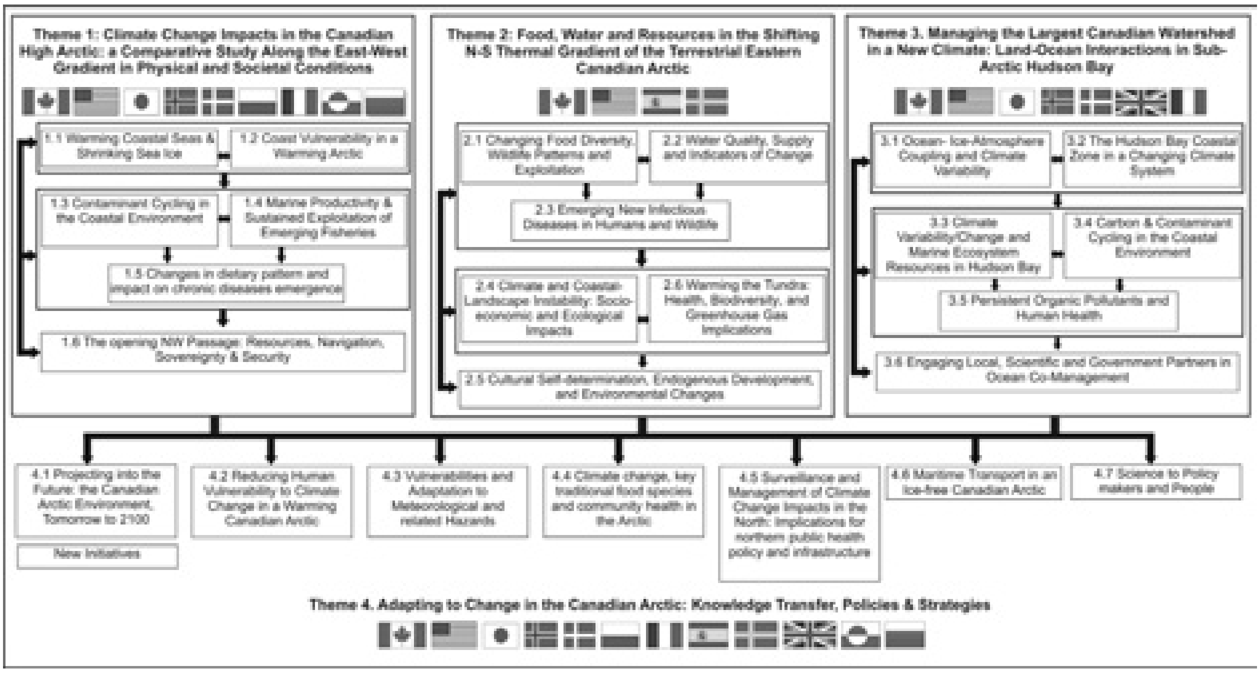

Figure 1. Organization of the research program of ArcticNet showing the conceptual links and information flow among the Research Themes and projects, as well as international participation in each Theme. Themes 1, 2 and 3 each constitute an Integrated Regional Impact Study (IRIS) of a key region of the coastal Canadian Arctic. Theme 4 conducts its own research and also synthesizes information from other Themes towards the formulation of policies and strategies to adapt Canada to the incoming transformation of the Arctic.

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.

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The National Oceanic and Atmospheric Administration (NOAA) Arctic Climate Change Studies: A U.S. Contribution to Arctic Council Response to the ACIA

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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 inter-annual 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 mulit-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

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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 (*Holland and Bitz*, 2003; *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 (*Chapman and Walsh*, 1993; *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., *Callaghan et al.*, 1999; *Lange et al.*, 1999; *Lange and BASIS consortium*, 2003; *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

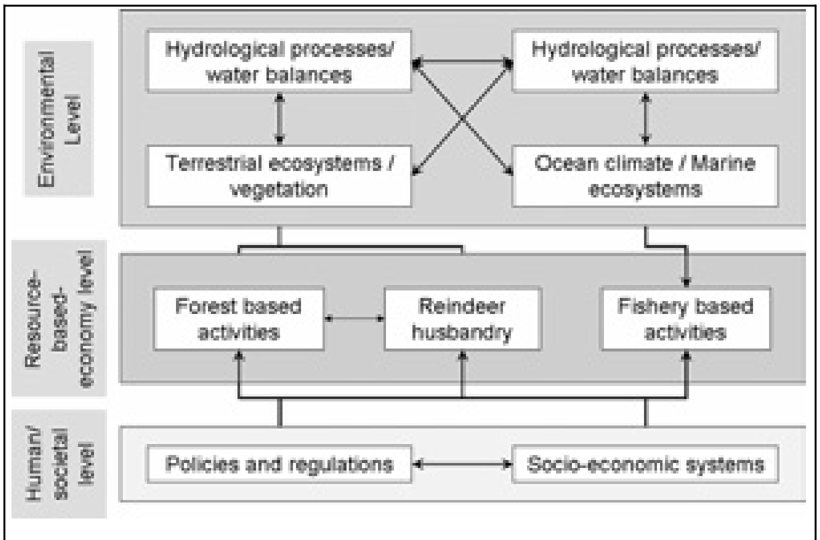

Figure 1: *Major components of the European North and some of their interrelationships*

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

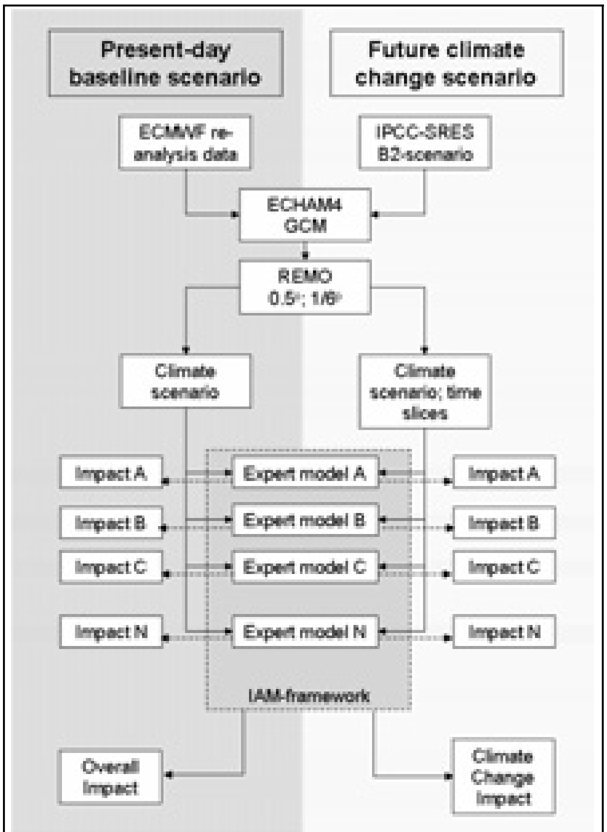

Figure 2: *Basic components of the BALANCE-IAM and modelling strategy*

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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Kola Peninsula Climate Change in the Kola Saami Traditional Ecological Knowledge and Hydrometeorological Data

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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

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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.

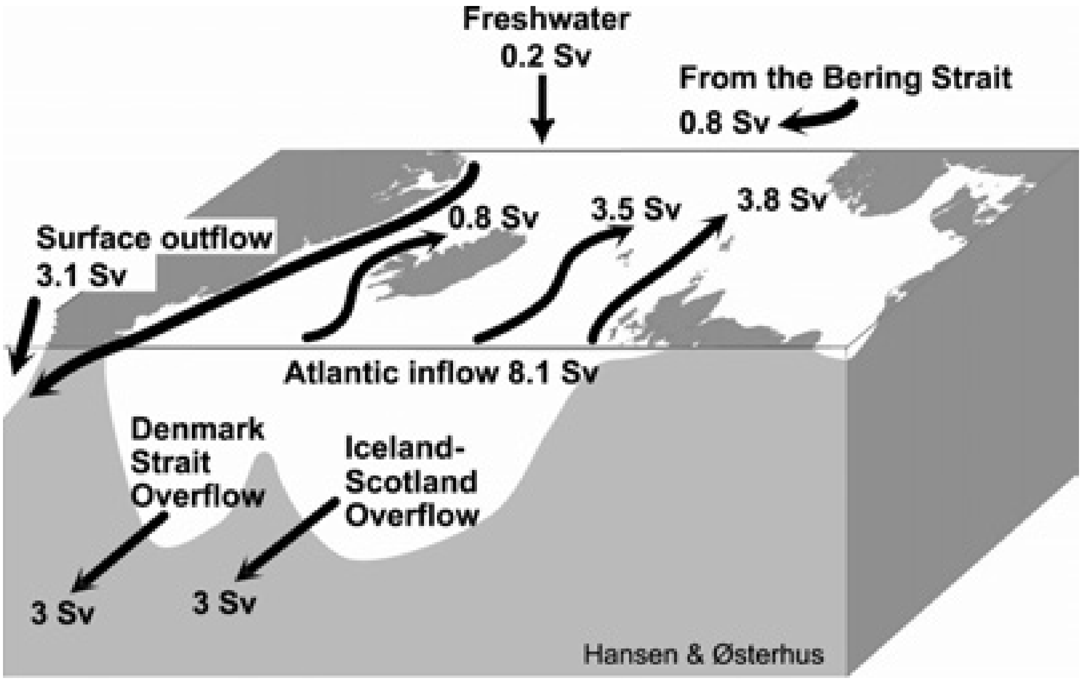

Figure 1. The exchanges of water between the Arctic Mediterranean and the rest of the world in Sv (1 Sv = 10^6 m^3/s) according to recent estimates.

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).

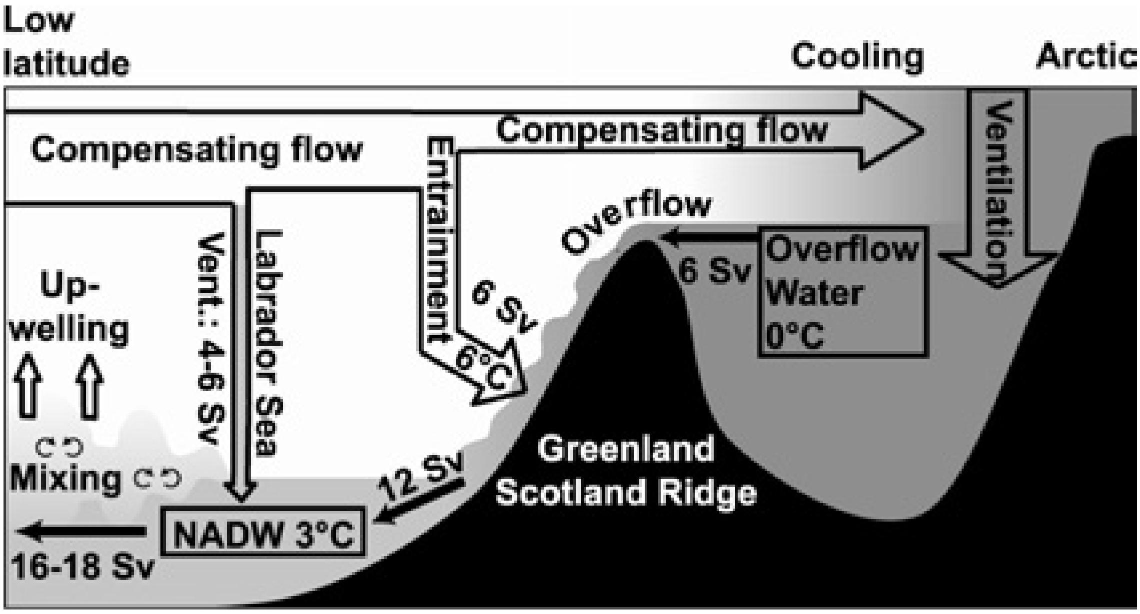

Figure 2. A schematic section across the Greenland-Scotland Ridge. Temperatures in ^{o}C and volume transports in Sv are approximate values.

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

(ASOF), *http://asof.npolar.no*). 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.

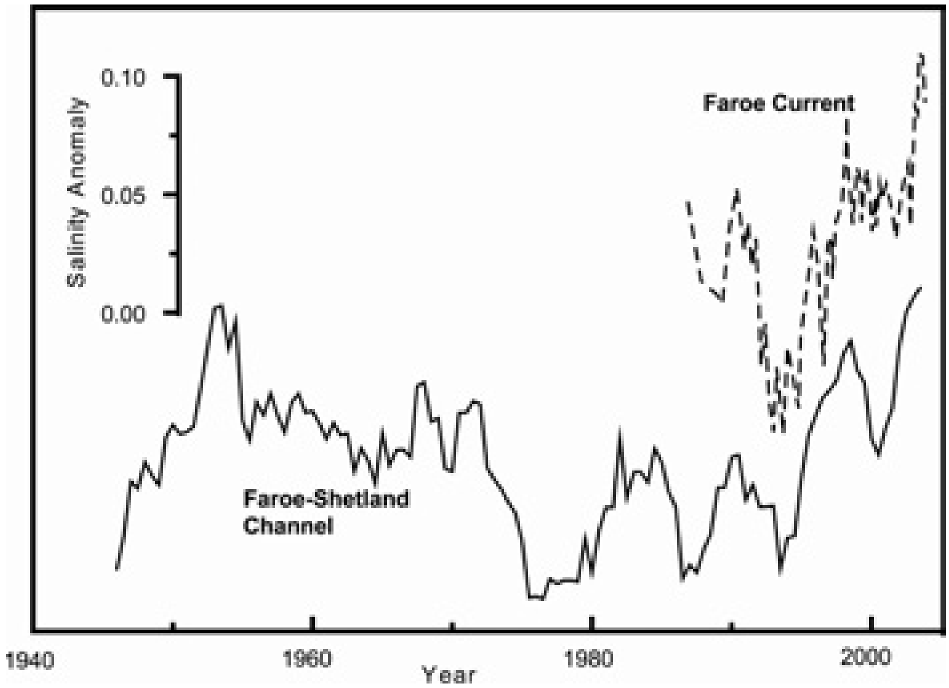

Figure 3. Anomalies of salinity of the North Atlantic Water over the shelf on the Scottish side of the Faroe-Shetland Channel (full line) and in the Faroe Current due north of the Faroes.

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Assessing Vulnerabilities: A New Strategy for the Arctic

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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 ^{o}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

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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

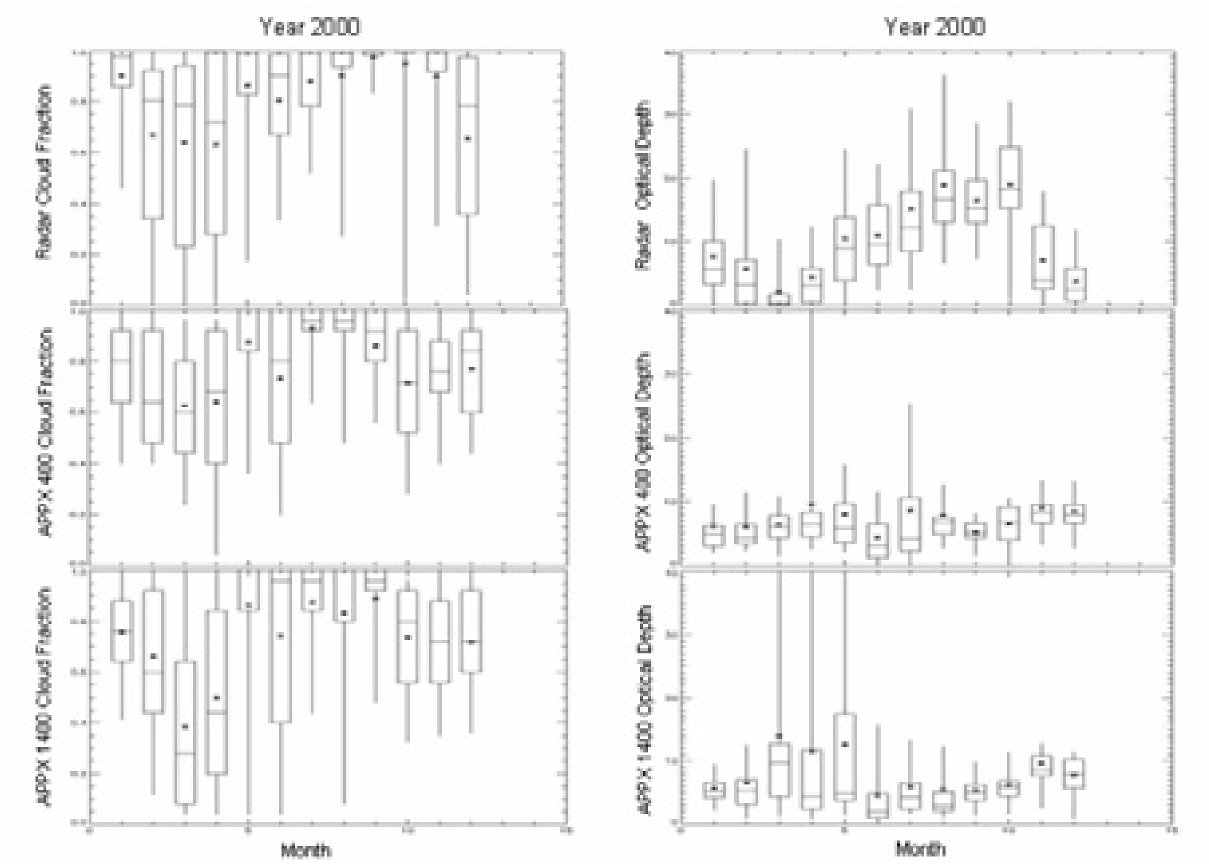

Figure 1 Caption: Monthly mean statistics of cloud fraction (left) and cloud optical depth (right) for the 35 GHz cloud radar (top), the AVHRR Satellite 0400 (middle) and 1400 (bottom). The stars on the box and whisker plots indicate monthly means.

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.

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

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and communities of the regions of Labrador, Nunavik, Nunavut and the Inuvialuit Settlement Region

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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.

"It's Not That Simple": Bringing Together Inuit, Iñupiat and Scientists to Understand the Complexities of Changing Sea Ice and Its Uses in the North American Arctic

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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

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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 CO_2. 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[2], 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.

[2] Dene Nation began as the Indian Brotherhood of the NWT and was the land claims body of the Dene up to the 1990s. The members of the Dene Nation are: Akaitcho Territory Government, Deh Cho First Nations, Gwich'in Nation, Sahtu Dene Council, and Tlicho Government. For more see B. Erasmus, C. Paci and S. Fox 2003. "A study in institution building for Dene governance in the Canadian north: A history of the development of the Dene National Office" *Indigenous Nations Studies Journal* 4(2):25-79

[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

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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).

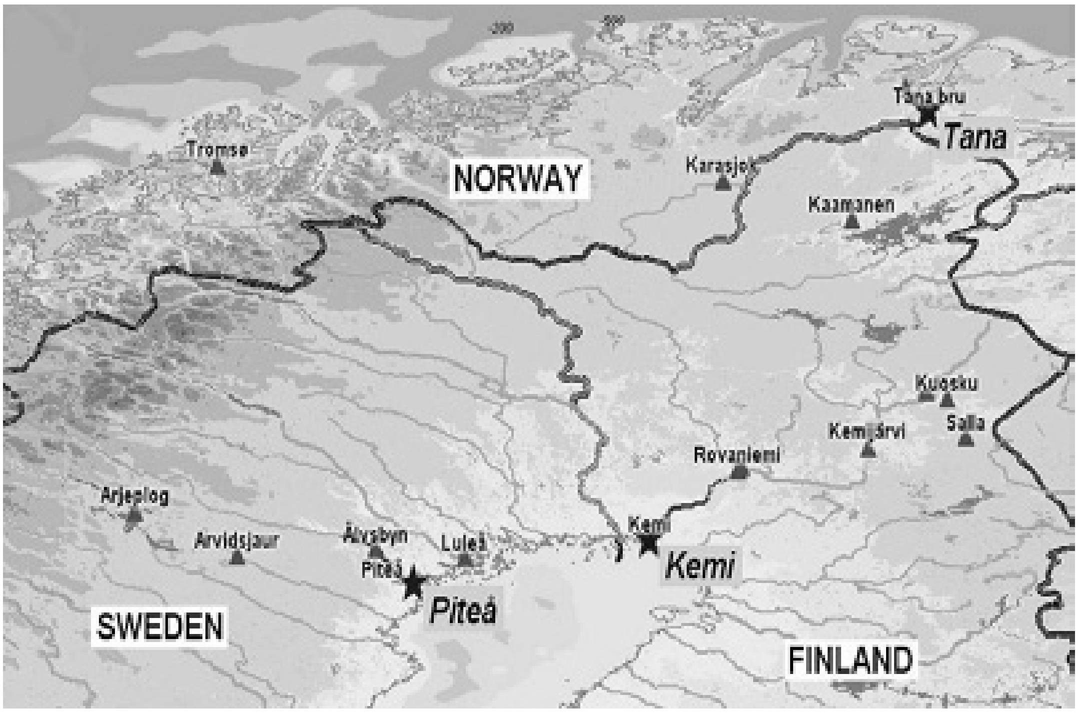

Figure 1. Map of northern Norway, Sweden and Finland with the study locations indicated.

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 and fishing companies; private, public and sectoral interest organisations; local government; forestry machine operators; and individual fishers and reindeer herders. The study focuses on stakeholder who have worked in these sectors for a long time and are thus able to describe their understanding of long-term change. In semi-structured interviews, these actors have been asked, among other things, to describe their everyday situations and problems, and how they can adapt to these problems. They have also been asked to describe whether they have seen any change in the environment in the course of their work, how a number of specified projected changes in climate would affect them, and how/whether they would be able to adapt to these. The aims have thus been to identify both perceived changes and how actors envision the potential changes. In stakeholder meetings with the actors, the adaptation options and differences between areas have been discussed, with these sessions taking up suggestions for policy that will be considered in final decision-maker interviews on the national level at the end of the year.

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 Kemijärvi 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 (predominantely 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

[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 [allmänningsskog], 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)[2]. 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)[3]. 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)[4]. 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.

[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, Arvidsjaur)

[3] "Vanhat metsät on hakattu ja lisäravintoa ei …. saa. Se on totaalinen uhka, samoten tämä ilmastonmuutos, ettei sitä tiedä millaisia vuosia ennakoida." (Ari Marjala, reindeer herder, Kuosku).

[4] "Vannstanden i elva er viktig. Når laksen gjyter skal den väre lav, for at laksen ikke skal gjyte på områder som blir törre på vinteren." (Geir Hansen, salmon fisher, Rustefjelbma).

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 adaptations 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 provided 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"[5].

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

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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 2001drew 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

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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 bioms 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 meta-data base for such an international arctic residents' network.

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Impacts of Climate Change on the Health of Northern Indigenous People

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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 anadromonous 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

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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.

The Interannual Variability of Arctic Ocean Temperature and Salinity Fields for Fifties-Eighties Derived by Assimilation of the Irregular Spaced Data

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Introduction

Various scientists and, most of all, oceanologists and climatologists have long been interested in the problem of the spatiotemporal assimilation of the data of oceanographic observations for the purpose of obtaining the fields of oceanographic characteristics over a regular grid. A number of methods used in oceanology and meteorology for objective analysis have been developed. These methods can conventionally be divided into two groups. The first group contains traditional methods of spatial interpolation intended for the conversion of the data of observations at irregularly arranged sites to the nodes of a regular grid. This group of methods can be referred to as the grid methods (see Gandin, 1963). The second, less numerous group should be called spectral methods as they are based on the expression of the fields recovered in the form of a linear combination of a number of known spatial harmonics such as analytical functions, for example, Legendre adjoint functions (spherical harmonics) and empirical orthogonal functions (EOF's) obtained on the basis of the statistical analysis of a number of observations as well (Shen et al, 1994). Smith et al (1996) used an analysis of the EOF's for the reconstruction of the surface temperature of the World Ocean. While preparing the Russian-American Oceanographic Atlas of the AO - Arctic Ocean (1997), the spectral method for objective analysis developed by Pokrovsky (1984) was used as the basic method for obtaining the decadal climatic fields of temperature and salinity at the nodes of a regular grid. Among the methods used in the preparation of the Atlas of the AO, the spectral method for objective analysis provided the best results in comparison with five other Russian and American methods for recovering the temperature and salinity characteristics during test experiments.

Datasets

For the analysis, we used the period from March to May, which is best covered by the observation data. These months fall in the winter period for the greatest part of the AO. In addition, in this period (in March-May) eight oceanographic surveys (1957-1956, 1973-1978) covered, in practice, the entire Arctic basin and the majority of the Arctic Seas. The working database contained data on temperature and salinity for each year at standard levels 0, 5, 10, 25, 50, 75, 100, 150, 200, 250, 300, 400, 500, 750, 1000, 1500, 2000, 2500, 3000, 3500, and 4000 m. The quality of the data was checked. The coordinates of every oceanographic station were transformed into the coordinates of the Lambert projection system, which was also used to obtain the fields of oceanographic characteristics over the nodes of a regular grid. Synoptic and mesoscale variations of the oceanographic characteristics were not taken into account and were considered as statistical noise. This assumption was used in the checking procedure performed at two stages: abandoning (by a known method) the values exceeding the level equal to three standard deviations (three sigmas) and inverse interpolation of the observations from 4-5 adjacent points to the point under consideration. The proportion of data abandoned was about 20%. Since the prepared Atlas is a climatic one, we used a seasonal time scale for the averaging of the observations, i.e., the data obtained during the season considered of the current year were regarded as simultaneous. The appropriate filtration was carried out on the basis of the EOF expansions described below. The combined base contains several tens of thousands of measurements carried out during ship observations and by the methods of airborne survey. In addition, we used various expeditionary data. The geography of the data collection includes not only the area of the AO, but the near-shore seas as well.

Method

In order to take into account the spatial-temporal correlation of the observation data, Pokrovsky (1984) proposed to use bi-orthogonal expansions of the oceanographic characteristic closely related to known SVD (singular value decomposition) of observational matrix. These are the EOF's and the corresponding expansion coefficients are usually referred to as the principal orthogonal patterns (POP’s). Former provides spatial variability representation and latter describes the temporal modes. For each temporal mode a separate set of EOF's are calculated. Its values in missed grid points had been interpolated by co-kriging technique. Therefore, an advantage of spatial-temporal expansion allows us to fill both spatial and temporal missing data areas. Spectral method assumes a priori covariance of expansion coefficients to be known. The estimated a posterior error covariance of expansion coefficients and the estimated a posterior error covariance at the grid points are determined by some non-linear relationships contained observation error covariance and a priori covariance of expansion coefficients as well as EOF's values at observational sites and grid points. On the basis of the method presented one can develop a scheme of continuous spatial and temporal assimilation of the data of oceanographic (ship, mooring, air) and remote sensing satellite observations providing for permanent updating of the information for climatic models.

Results

We performed a statistical analysis of the set of temperature and salinity values at standard levels for March--May 1948 -1989 with the use of the procedures discussed in the previous section. The convergence rate of the eigen values of the EOF’s is characterized by the values of the relative accumulated dispersion (RAD). The RAD represents the fraction of the variability of an element that is explained with the given number of the EOF. With the increase in the number of the EOF, the value of the RAD increases. The increase in the RAD is different for the temperature and salinity fields. Moreover, the convergence rate RAD for the salinity fields somewhat drops from a depth of 5 m to 100 m, whereas it increases at a depth of 300 m and deeper. For the temperature fields, the rate of convergence of the RAD increases with depth. The figure shows the salinity contour lines at a level of 5 m and the temperature at a level of 300 m for March-May 1957 and 1977 plotted from the reconstructed values of the oceanographic characteristics. For the sake of comparison, the circles contain the measured values of salinity and temperature of the water in the AO. The results of the reconstruction reproduce well the actual pattern of the spatial distribution of salinity and temperature at all the levels.

A comparison of the distribution maps of the water temperature at a level of 300 m suggests a marked difference in the conditions of the Atlantic water in 1957 and 1977 in the Norwegian Sea and Eurasian sub-basin. It should be noted that, according to the observation data, in 1957, the enthalpy of the Atlantic water was maximum. In the map of the surface salinity distribution in 1957 in the Norwegian Sea, one can see an elongated area with a salinity greater than 35, which indicates that the Norwegian Current is well developed. After crossing the Norwegian Sea, the saline and warm Atlantic water enters the Barents Sea and, via the Fram Strait, is delivered to the Arctic Basin. Meanwhile, in 1957, in the American-Asian sub-basin and in the area near Greenland, the surface water was more freshened than in 1977. These results indirectly indicate that, in 1957, the trans-Arctic current was rather strong. In the Eurasian sub-basin, the salinity contour line corresponding to 32 is extended toward the Fram Strait. In 1977, the 32-th contour line in the Eurasian sub-basin was located further to the north. Thus, the reconstructed fields of temperature and salinity at the nodes of a regular grid 50 x 50 km for March--May from 1948 to 1989 give a good possibility to study the inter-annual variability of the thermohaline conditions of the AO.

We did not perform any special comparison with the studies of other authors. A comparison will make sense only in the future, because to date, the database on the AO we used is the most complete. It is several times greater than its foreign analogs.

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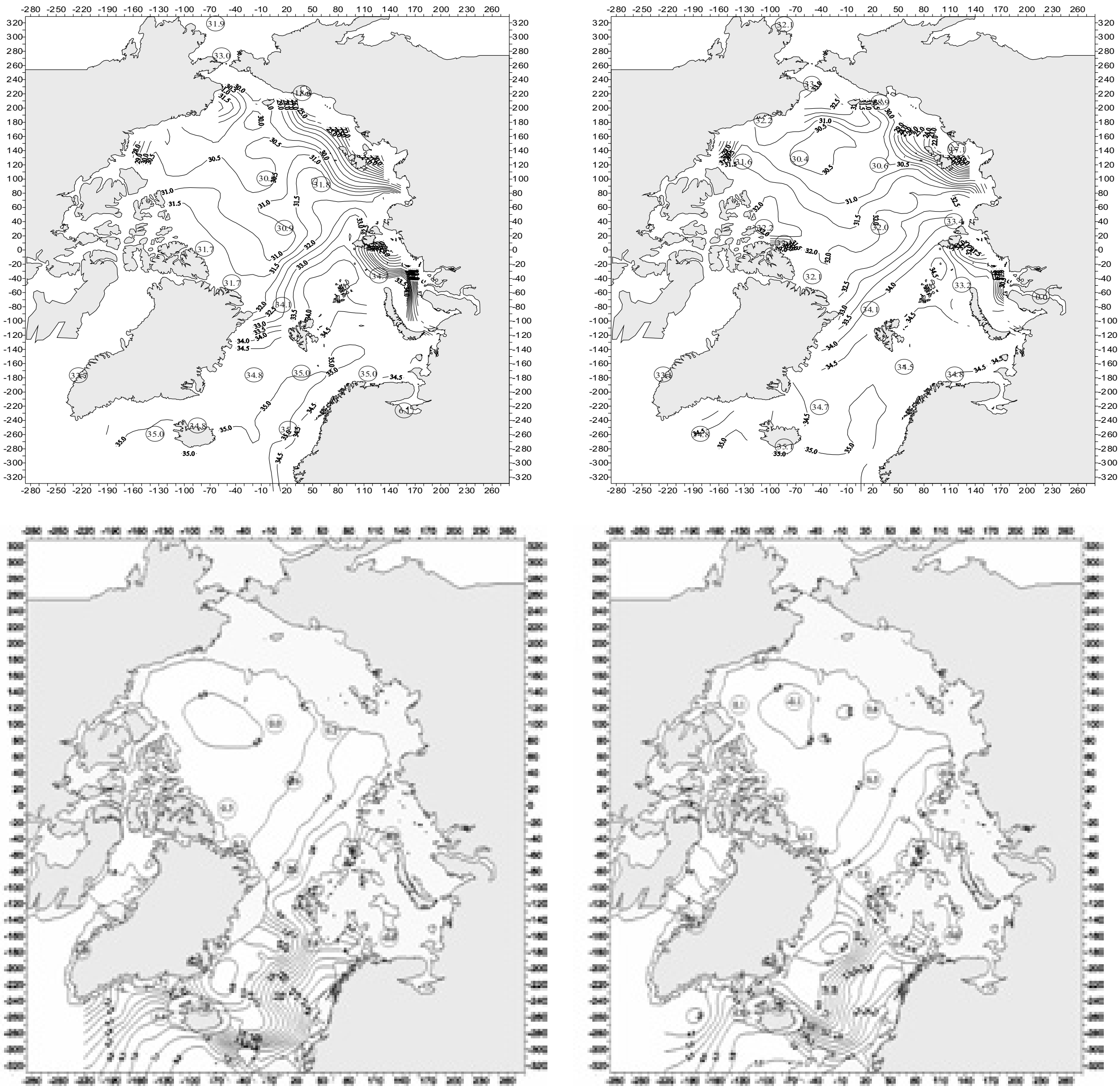

Figure. Annual fields: the salinity at 5 m - upper pictures (left – 1957, right-1977), the temperature at 300 m – below pictures (left – 1957, right-1977).

An Updated Estimation of Ground Ice Volume for Richard's Island in the Mackenzie Delta and an Assessment of Potential Thaw Sensitivity to Climate Change

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Introduction

Field observations and many global climate models (GCMs) suggest that the climate of the western Canadian Arctic is warming (Maxwell 1997). This change is reflected in a warming of the upper part of permafrost, increases in active layer depths, and accelerated rates of thermokarst and erosion (Serreze et al., 2000; Kane et al., 1991). Potential impacts on buildings and infrastructure may prove to be both costly and devasting. In a previous study Pollard and French (1980) produced the first approximation of ice content in the upper part of permafrost and estimates of potential thaw subsidence based on air photo analysis and available drill records for Richards Island. In this paper we re-evaluate the data on ground ice volumes for Richards Island using a combination of new techniques and new data.

Richards Island is located in the Pleistocene Mackenzie Delta and is characterized by undulating tundra terrain that is less than 50 m.a.s.l. The volume of ground ice present in the upper 10 m of the Island was calculated to be 10.27 km^3 or roughly 47.3% of the volume of the upper 10 m of permafrost. (Pollard and French, 1980). In this paper we update this model using digital cartographic data and recent climate change scenarios. Additional drilling and geophysical information as well as a digital version of the Mackenzie Delta Geotechnical Database were not available when the Pollard and French model was created. The additional data together with our GIS approach allow us to consider a wider range of ground ice conditions in the calculations. Landforms associated with massive ice such as polygonal ground, pingos, ice-cored hills and glaciofluvial features are included in our calculations. The main output of these analyses is a Digital Elevation Model (DEM) of what Richard's Island will look like in the future.

A permafrost subsidence map for the circumpolar arctic by Nelson et al. (2001) presents a risk assessment for subsidence due to thermokarst on a 0.5º resolution. By contrast our large-scale model offers a prediction that delivers much greater resolution over smaller areas.

Using our GIS we were able to accurately account for zones that have little ice (e.g. taliks under lakes), with near surface ice (e.g. ice wedge networks and pore ice), and areas with massive ice (hills and glacial-fluvial features), and then make a prediction of the future land surface.

Methods

This study focuses on the top 10.0 meters of the ground for 2 reasons, first it is this part of the subsurface that exhibits the highest ice volume and second, as the interface with the atmosphere it is potentially the most sensitive part of the stratigraphic column to disturbance (Pollard and French 1980).

The various GIS layers related to various types of ground ice were extracted from the Borehole data in the Mackenzie Valley Geotechnical Data Bank (MVDB) and from remotely sensed imagery. Ice contents were converted to ice thickness in order to implement the subsidence calculations. The area considered is this study is lower than the one considered by Pollard and French (1980) (11.2 km² vs. 15.1 km²) and doesn't include the Holocene deposits located on the western edge of the island. The active layer thickness was assumed to be constant throughout the island at 0.5m. The MVDB, which includes 500 boreholes for Richards Islands was used to provide an average value of volumetric pore ice content, which was eventually converted to an ice thickness value. Extraction of the information from remotely sensed imagery was based upon airphotos from the late 1970's, digital topographic data and a mosaic of Landsat scenes acquired over Richards Island. Using digital topographic data extracted from the 1:250000 maps, we separated areas higher than 100 feet (i.e. 61 m) and assigned those with a 4 m massive ice thickness. The 4 m criterion was based upon observations by Rampton (1974) and Mackay (1963) on ice-cored hills on Richards Island. A supervised isodata classification of the island landcover was operated on a false color Landsat-7 composite (green, red and near-infrared channels) in order to distinguish areas of low-centered tundra polygons and poorly developed tundra polygons. Identification of these zones was aided by the observation of the archive airphotos. Areas characterized by low-centered polygons were assigned a volumetric ice content of 16%, resulting in an idealized thickness of 0.8m in the first 5 m (maximum observed depth of ice wedges on Richards Island). Areas of poorly developed tundra polygons were given a 0.4m thickness corresponding to a volumetric ice content of 8% in the first 5 meters. Pingos were extracted from the digital layers obtained from the digital topographic maps and were assigned a 9.5 m thickness (i.e. first 10 m minus the active layer)

The Digital Elevation Model (DEM) of Richards Island was extracted from the digital contour line layer using the TOPOGRID algorithm implemented in Arc/Info. The different GIS layers were aggregated into a total ice thickness layer which was then subtracted from the DEM to provide a virtual topographic surface of Richards under complete melting of the upper 10m of the permafrost.

Results

Statistical analysis led on the resulting GIS layers showed that

(1) the area covered by lakes represents 28.7% of the total island area,

(2) The total volume of ground ice in Richards Island subsurface is 8.3 km³, which represents about 73% of the total subsurface volume considered in the study.

(3) A wide range of locations along Richards Island's coast are susceptible to flooding due to thaw settlement

The main emphasis of this work is a GIS approach aiming at a method for solving the spatial issues associated with ground ice distribution. The results presented remain very tentative and will be refined with the addition of other datasets. However, the methodology presented here can be applied to any area in the cryosphere where limited subsurface data is available.

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Why Is the Arctic Warming?
Do Changes in the Mid-latitude Circulation Have Any Impact on the Arctic Surface Air Temperature Trend?

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Introduction

The warming of the near surface air in the Arctic region in recent decades has been stronger than the global mean warming. There is general agreement that the Arctic warming is partly due to the withdrawing of ice and earlier melting of snow in the Arctic area. Negative trends in ice and snow cover both reduce the surface albedo. Furthermore, as a consequence of the insulating effects of the ice, the negative trend in sea ice cover is believed to have resulted in increased transport of heat from the ocean to the atmosphere. It is less clear whether the Arctic warming is also related to recent changes in the atmospheric circulations. We present results indicating that this might indeed be the case.

We present two studies based on the northward energy transport across 60 N and the Arctic Oscillation, respectively. These patterns both capture fundamental aspects of the atmospheric circulation in the mid-latitudes. We investigate whether changes in Surface Air Temperature (SAT) in the Arctic region is associated with the two patterns.

Methods

The Energy transport is in this study defined as v(cpT+gZ) integrated around 60 N and from 1000 to 300 hPa, where v is the meridional wind, cp the specific heat at constant pressure, T the temperature, g the gravity, and Z the geopotential height. The Arctic Oscillation is defined as the first principle component of the sea level pressure field north of 20 N. In order to manifest whether these quantities are related to the SAT trend in the Arctic region, we used the following methods:

- Projection of the energy transport and the Arctic Oscillation on the SAT field.
- Calculation of the straight line linear trend of the projections by use a least square method. (Wu and Strauss, 2004)

The trend of the projection of for example the energy transport on the SAT field can be interpreted as the portion of the SAT trend which is associated with the energy transport.

The statistical significance of the results is evaluated by use of a Monte Carlo approach. Artificial time series with the same power spectrum as for example the energy transport, but with arbitrary phases of the modes, are projected on the SAT field. These projections with the artificial time series are compared to the original projection.

The energy transport study is based on Jan-Feb-Mar data since the spring season shows the strongest SAT trend in the Arctic area (Rigor et al., 2000). The conclusions presented here do not change if all winter and spring months (December through May) are included in the study. The Arctic Oscillation study is based on Jan-Feb-Mar data. In this period, planetary waves propagate into the the lower stratosphere and the Arctic Oscillation shows its largest vertical extension (Thompson et al., 2000).

The ECMWF ERA-40 data set, provided by ECMWF data server, has been used. The data set include 44 years from 1958 to 2001. The data are monthly averaged and the annual cycle is removed. In the projection studies, we have only included years from 1979 to 2001.

Results

Energy transport: Integration of the Mar-Apr-May energy transport over the area of a tropospheric section around 60 N results in a single time series reflecting the atmospheric flux of energy into the Arctic region during the spring season. It is seen that the transport have increased in recent years (Fig. 1). Furthermore, the transport shows significant influence on the the SAT trend in parts of the Arctic area (Fig. 2). In some of these areas, the SAT trend associated with the energy transport reaches 0.25 °C per 10 years. The Arctic mean, from the North Pole to 60 N, of the SAT trend is around 0.7 °C per 10 years, of which 0.2 °C is associated with the energy transport across 60 N (Fig. 3). This result is significant on a 97 % level.

Arctic Oscillation: In Jan-Feb-Mar, the Arctic Oscillation has increased in recent years. It is significantly associated with positive SAT trend in the northern Euro-Asia and negative SAT trend around Greenland. The pattern is in agreement with the basic concept of the mode. For instance, positive Arctic Oscillation is related to stronger zonal flow in the mid-latitudes and to stronger and more frequent baroclinic systems entering the Euro-Asian continent from the Atlantic Ocean implying warmer than usual continental winter conditions. The polar mean of the SAT trend which is related to the Arctic Oscillation is small and not significant.

Conclusion

A significant portion of the SAT trend in the spring season in the Arctic region is associated with changes in the atmospheric energy transport. In the winter season, the trend towards positive values of the Arctic Oscillation is associated with the SAT trend in some areas, but not with the mean Arctic SAT trend. These results indicate that at least partly, the Arctic amplification in warming is associated with changes in atmospheric circulation patterns in the mid-latitudes.

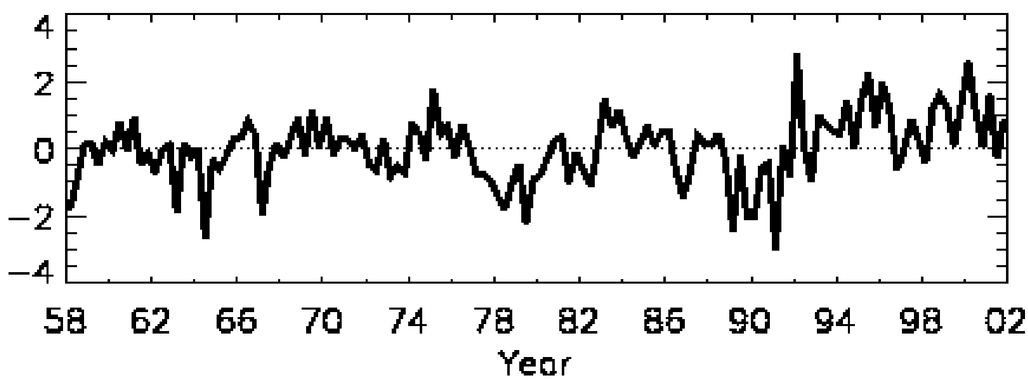

Fig. 1. The normalized time series of the Mar-Apr-May atmospheric energy transport across 60 N.

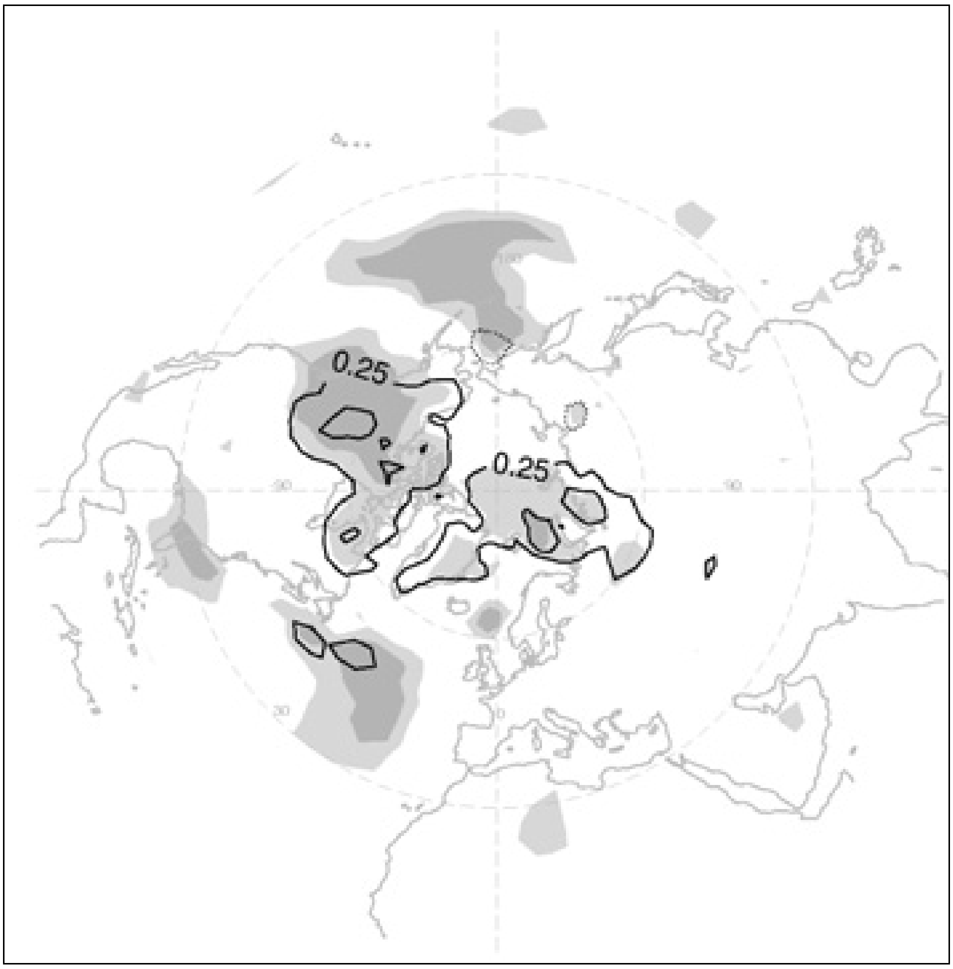

Fig. 2. The portion of the Mar-Apr-May SAT trend which is associated with the energy transport (black contours). Units are °C per 10 years. Solid and dotted lines are positive and negative contours, respectively, and the contour interval is 0.25 °C. The zero contour is omitted. Light and dark shading indicate significance on a 95 and a 99 % level, respectively.

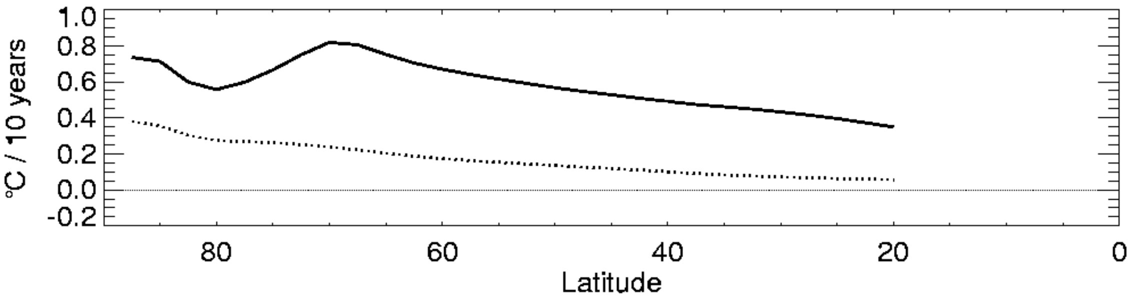

Fig. 3. Polar mean of the Mar-Apr-May SAT trend (black curve) and the portion of the Mar-Apr-May SAT trend which is associated with the energy transport (dotted curve). The curves show means from the pole to a given latitude.

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The Nordic Seas: Observed Changes

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From the 1960s to the 1990s the North-Atlantic sector experienced a large-scale change in the atmospheric circulation, going from extraordinary weak westerlies in the ‘60s to the strongest westerlies ever observed in the ‘90s. Accompanying this low frequency shift in the atmospheric forcing, large changes have been taken place in the Nordic Seas ocean climate, see figure 1. We here review some of the recent findings, including changing in the ice cover (figure 2), the sea ice transport trough the Fram Strait, the freshening of the intermediate water (figure 3), the weakening of the convection in the Greenland Sea, the warming of the deep waters (figure 4), and the possible reduction of the overflow waters feeding the Atlantic meridional overturning circulation.

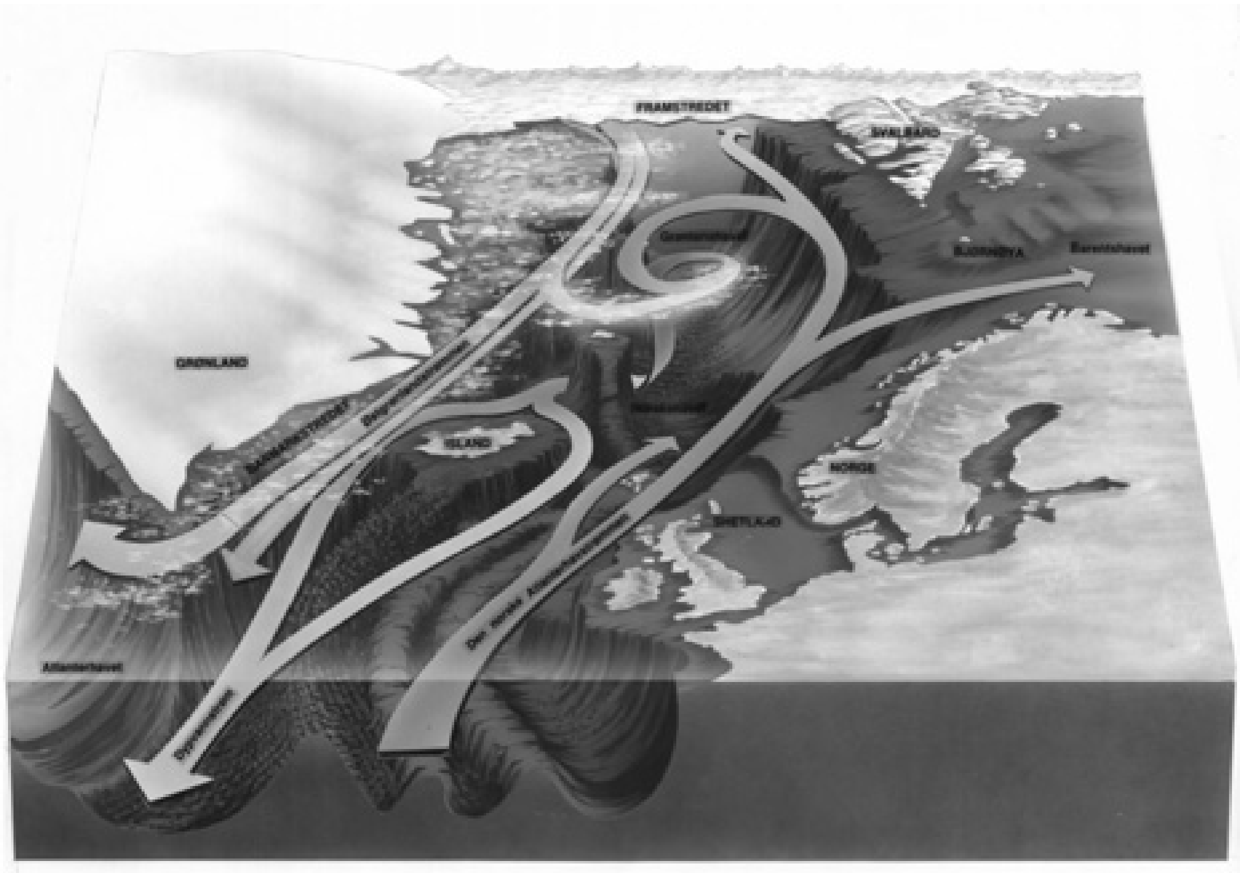

Figure 1. The Nordic Seas current systems.

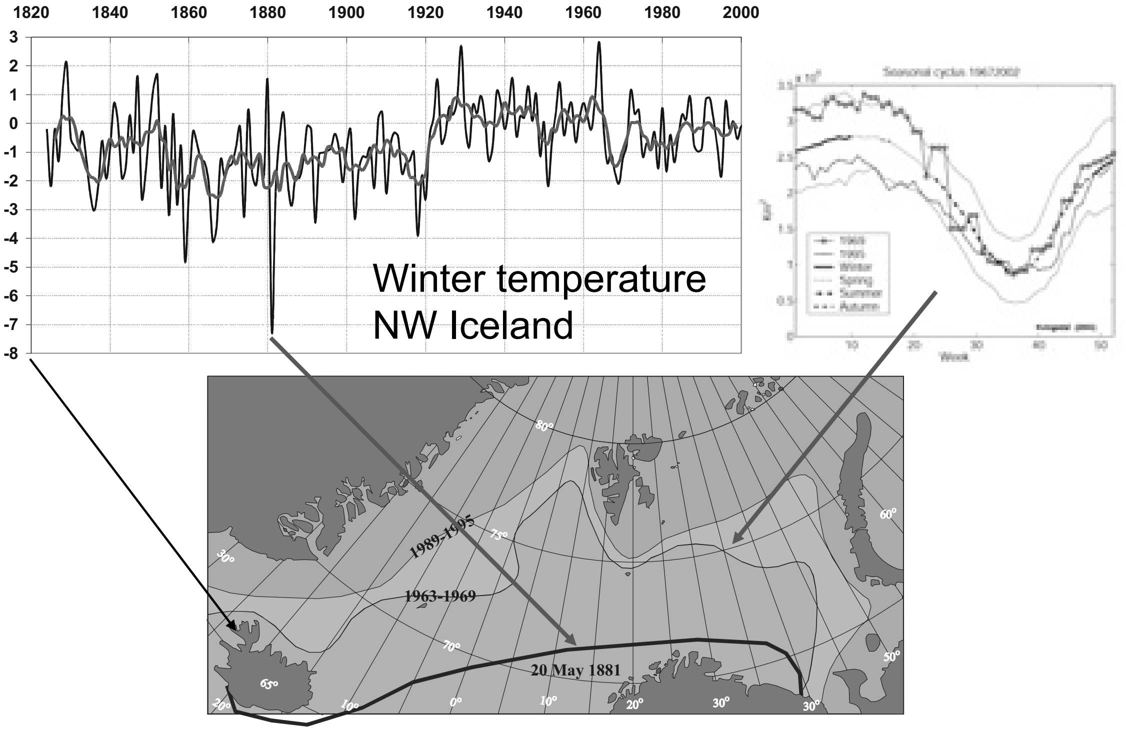

Figure 2. Sea Ice cover in the Nordic Seas for 1981 and between the a NAO low period 1960's and NAO high 1990's.

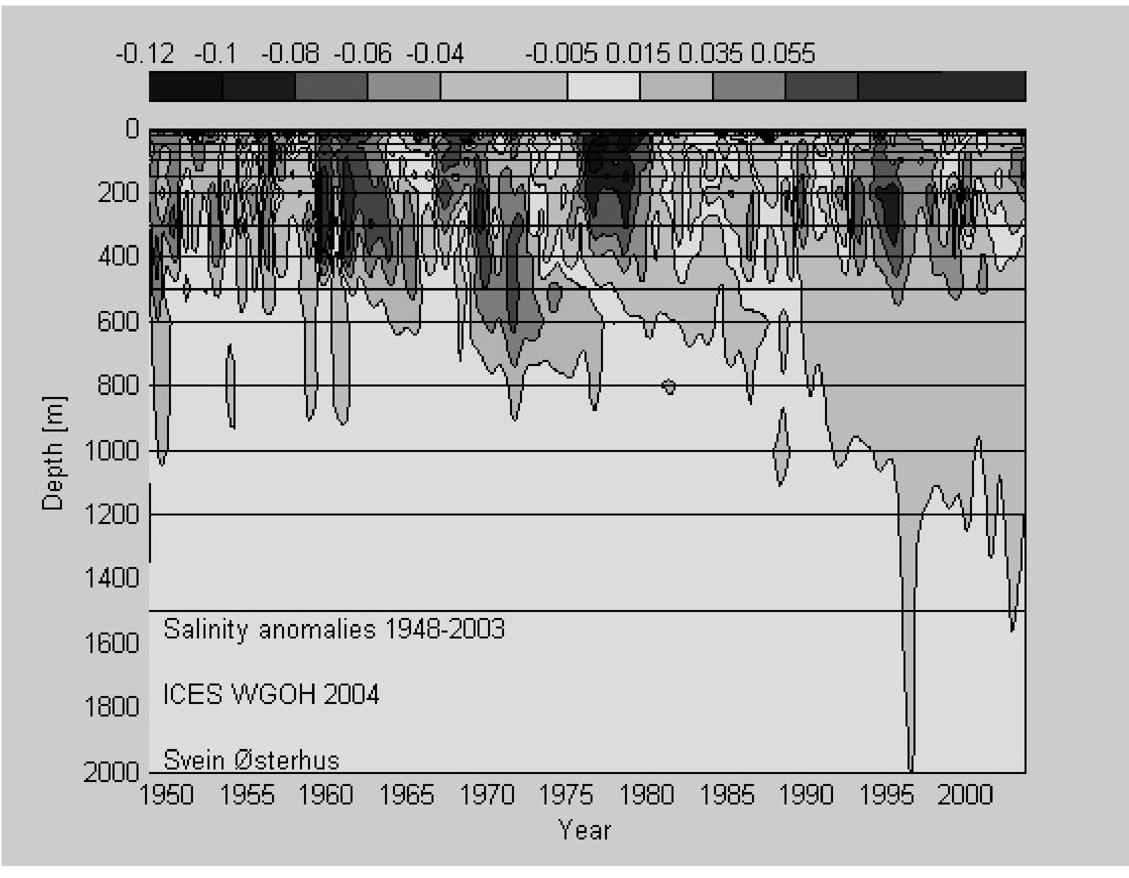

Figure 3. Salinity anomalies at station M (66°N, 2°E). During the last 3-4 decades the Nordic Seas has experience a freshening of the intermediate layer. In the Norwegian Sea at Ocean Weather Station M (66°N, 2°E) the freshening has reach 1200 metre.

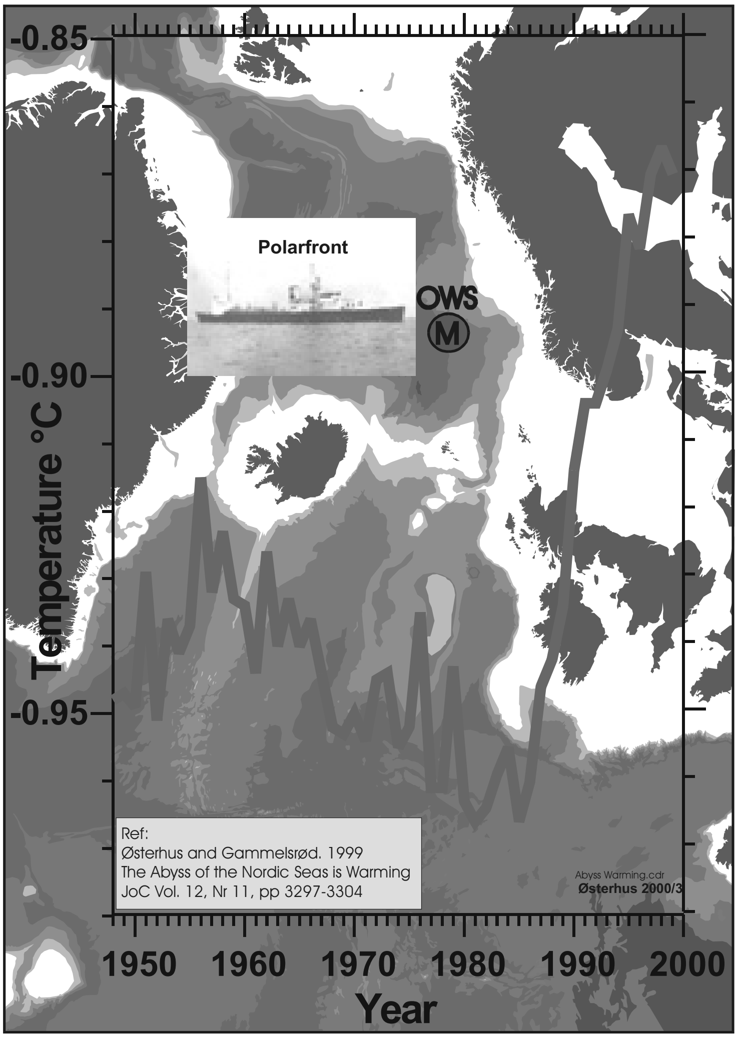

Figure 4. The deep water in the Norwegian Sea has experience a record high temperature as a result of the reduced deep water production in the Greenland Sea

Fluctuations in the East Greenland Current during the Medieval Warm Period and Little Ice Age

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Diatom analyses were carried out in sediment cores collected from Igaliku Fjord, South Greenland, and from the southeast Greenland shelf. The latter coring site is located beneath the Polar Front separating cold, ice-loaded Polar Water of the East Greenland Current (EGC) from warmer and more saline Irminger Sea Water (ISW). The core record from the Igaliku Fjord demonstrates a strong ISW influx between ca. AD1100 and AD1250 concluded to reflect maximum Medieval warming in this area. From about AD1450 the influence of the EGC increases, reaching a maximum between AD 1700 and AD1850. During the past 1000 years, the shelf core record displays significant multi-decadal (c. 45-90 yrs) to centennial EGC oscillations, with (ISW) warming episodes ceasing after c. AD1700 which is coincident with an increase in frequency of severe winters in Europe. Sea ice minima during the 1920-30's and at the end of the 20th century together with the intervening Great Salinity Anomaly of the 1960's provide additional evidence for above multi-decadal EGC oscillations representing a prominent feature which must be accounted for when improving long-term North Atlantic climate prediction.

Determining Sea Ice Extent from Ice Core Records

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Introduction

In a previous study of the Devon Ice Cap, Koerner (1977) showed that a high correlation exists between glacier mass balance (the volume a glacier looses or gains each year) and the number and thickness of ice layers formed in the snow pack at high elevation during the summer melt season. The conditions affecting the Devon Ice Cap in a particular year, were also found to be representative of those occurring on all large ice caps of the Canadian High Arctic. Furthermore, the concentration of ice layers in the snow of the Devon Ice Cap was shown to have a strong relationship with late summer sea ice extent in the channels of the Queen Elizabeth Islands*. Since these ice layers are preserved at depth and are readily identifiable in ice cores, they have been used to derive records of past summer temperatures (Koerner and Fisher, 1990) and for inferring sea ice conditions in the Canadian Arctic, particularly during exploration for the Northwest Passage in the 19^{th} and early 20^{th} century (Koerner, 1977; Alt et al., 1985).

Recently, changing sea ice conditions in the Arctic, particularly record minimum sea ice extent, have been reported. Temperatures have also reached record highs in the late 1990's and early 2000's. In view of these changes, it has become important to re-examine the relationship between sea ice distribution and mass balance/ice layer concentrations in snow pits and ice cores in order to improve paleo sea ice reconstructions based on ice core records.

Methods

In the initial study (Koerner, 1977), the correlation between mass balance and ice layer concentrations was based on 14 years of field observations (1961-1974). We now have 40 years of mass balance data for the Devon Ice Cap and for the Melville South and Meighen ice caps, in the western Arctic. In the late 1990's, three more ice cores were retrieved from the Devon Ice Cap. These cores, combined with pit samples, will allow an update of the ice layer data. The revised data, will provide a 40-year ice layer/sea ice transfer function allowing the development of a sea ice proxy record for the last 1000 to 2000 years. At present, we are only considering the relationship between our mass balance data and sea ice extent (or maximum open water) in the region of the Queen Elizabeth Islands.

We have used data compiled by Jeffers et al. (2001) and Atkinson et al. (submitted) to update our sea ice record. We have also used the same methodology as Jeffers et al. (2001) who divided the Queen Elizabeth Islands region into discrete ice regimes based on freeze-up and break-up patterns, ice age, and mobility or stability.

* Refers to the group of islands north of 74°N, in the Canadian Arctic Archipelago.

Results and Conclusion

The work so far has shown that, while there is a trend for increased melting since the mid-1980's on Canadian ice caps, there is, beginning in the early 1980's, in the sea ice record, a jump rather than a trend, to more open water. Preliminary results also suggest that the original relationship between sea ice and ice cap summer melt has weakened since the late 1990's (e.g. 2001). When breaking the Queen Elizabeth Islands into regions, we find there is a poor relationship between Devon summer melt and sea ice concentration in the waters surrounding the ice cap (Jones and Lancaster sounds and Baffin Bay). The relationship improves significantly with sea ice in the rest of the channels of the Queen Elizabeth Islands, particularly the western part of the Northwest Passage. It is also becoming clear from recent work that Baffin Bay and the North Water do not respond to climatic change in the same way as the rest of the Queen Elizabeth Islands.

The question now is: to what extent is the sea ice/melt layer/mass balance relationship changing? Once the ice layer records have been updated, we will be able to compare the mass balance to the sea ice records to see if the established transfer functions remain valid beyond a certain warming threshold. If not, new functions will be developed based on the extended mass balance, ice layer, and sea ice/open water records.

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Russian Arctic Meteorological Dataset for ACIA Program Development

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Introduction

The global warming signal in sub-polar and polar areas is remarkable and is indicated in different time-series obtained for the Arctic and Siberia. The numerical study of climatic variability formation mechanisms requires information about the statistical structure of meteorological fields. Such investigation became possible after the creation of a database with current surface and quality-controlled daily upper-air measurements at North-European, Arctic and Siberia network for the period of observations. Arctic historic data management has the aim to create a definitive meteorological dataset for use in current climate change investigations and climate modelling. The AARI scientists in close co-operation with experts from other Russian institutions have prepared an information resource about Arctic atmosphere for the Arctic Climate Impact Assessment Program (ACIA).

Data

The initial sources of data are the North Pole (NP) drifting stations, including routine meteorological data (NP-5 – NP-32 for 1955-2003 period) and upper air data (NP-2 – NP-31 for 1950-1991 period), Arctic and Siberian meteorological stations (1932-2003) located in permanent permafrost area. The 3-hourly, 6-hourly and daily mean meteorological data and twice-daily sounding data are collected and important statistics including climatic change parameters are calculated. With the resources available a following key set of meteorological variables is assembled and a definitive dataset is presented for Arctic scientific community:

- surface temperature, maximum and minimum surface temperature, prepared by Russian Hydrometeorological Institute-World Data Center (http://www.meteo.ru) and corrected according to AARI manuscript archive;
- corrected precipitation data for Northern stations network, based on comprehensive bias-correction model (Bogdanova at al., 2002);
- sea level pressure;
- relative humidity;
- snow cover parameters (depth and density),
- total solar radiation,
- surface albedo,
- frequency of exceeding threshold surface temperatures (the number of days with daily mean temperatures exceeding prescribed threshold values is calculated for each year for monthly and seasonal periods, for instance, a number of cold days with temperatures below -20°? per month);
- annual data characterising the steady positive temperature duration period (number of days, dates of Spring and Autumn temperature transition over 0^0C, the beginning of the steady positive temperature period) for 1935-1995;

- soil moisture dataset contains the gravimetric measurements results from agrometeorological, meteorological, heat-balance and water-balance stations over Siberia for 1978-1985 with 10 day temporal resolution. This dataset contains plant available soil moisture for the upper 1-m soil layer;
- quality controlled total ozone column data;
- upper air parameters (air temperature, geopotential height, relative humidity and wind speed at 16 standard levels).

Metadata files contain the list of type of measurements tools used for observa tions, description of meteorological place changes, changes of observing practice and changes of preliminary data processing. To remove the false trends in climatic time-series the time series homogeneity analysis was provided, using different inhomogeneity testing procedures.

During the preparation these data sets were updated, the gaps in historical data were filled up, some non-measured parameters were recalculated and data quality control procedure was applied. The most important point was the returning to individual measurements results based on initial data digitization procedure from hard copy observations books.

Results

Results of stochastic analysis of homogeneous time-series surface air temperature, sea level pressure and precipitation in Arctic region and in surrounding territories are used for definition of inter-annual variability characteristics with account of inter-annual modulation of annual variations, also inter-annual and seasonal variations of synoptic scale variability are presented.

Multiyear data sets are used for analysis of climatic variability parameters in different time scales (from diurnal variation to inter-annual variability). Inter-diurnal and intra-annual variations of monthly mean values make the main input into total dispersion, moreover the temperature inter-diurnal variability explains more than 50 % of dispersion, but for pressure this value is less than 20 %. The mean annual values variability explains less than 5 % of total dispersion.

Inter-annual variability is defined not only by the variation of the annual mean values. Variability features of low frequency (diurnal course) range are considered with account of hour of observation. It can be important when the hypothesis about the nature of interannual variability trend is created.

The interannual variability tr?nd is presented as a power polynomial that includes linear, parabolic and cubic components. The most important characteristic of climatic variability is a linear trend that explains 10-15 % of the mean annual expected values of the dispersion. Time-series of anomalies of mean annual values are non-stationary in dispersion. The results of the statistical analysis of the meteorological components are completed by the study of the parameters describing the ocean climate, the ice condition variability, the synoptic and meso-scale eddies activity.

The surface and lower troposphere (850-400 hPa isobaric layer) air temperature interannual variability demonstrates prevailing negative trends for 1951-1980 period. Then during 1980-2002 period the positive trend of surface and troposphere air temperature was detected. At the same time the air temperature variability in the upper troposphere and in the low stratosphere was characterised as prominent decreasing.

Warming observed in polar troposphere reflects changes in the regional atmospheric circulation as well as in oceanic forcing and tendencies of variations of surface radiative properties.

Estimates of annual cycle modulation in interannual variability range and interannual and seasona l variations of synoptic scale variability are presented. Interannual variability tr?nd is presented as power polynomial which includes linear, parabolic and cubic components. The most important characteristic of climatic variability is linear trend which explains 10-15 % of mean annual expected values dispersion. Time-series of anomalies of mean annual values are as a rule non-stationary in dispersion if time-series is shorter than 30 years.

In anomaly warm conditions, which have been observed during 1980-2002 period, a pronounced trend is detected in interannual variations of cyclonic activity, corresponding to the growing cyclonic frequency, speed of displacement and deepening and decreasing of the square of cyclonic vortices. Thus, the synoptic eddy activity increases due to decreasing of the polar atmosphere vertical stability in global warming regime (Lagun, 2001).

Climatic variability tendencies over Arctic are compared with those for Antarctic (Lagun, 2003), with Hemispheric and Global warming signal and macro-scale circulation indexes.

The very positive example of international cooperation for high quality polar regions climate data set formation is presented by SCAR READER (REferece Antarctic Data for Environment Research) Project (Turner et al. 2004, www.antarctica.ac.uk/met/programs-hosted.html/READER). The realization of analogous Project for Arctic area is very actual scientific problem.

Acknowledgement

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The Analysis of Climatic Changes of Southwest Yakutia for the Centenary Period

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We analysed results of measurements of meteorological parameters and phenological supervision in boreal ecosystems which have been carried out with 1884 on 2002.

Analysis of received information allows making a conclusion that processes of climatic changes are actual for southwest territory of Yakutia. It is expressed by increasing of average annual temperatures, extending frostless period, decreasing the sums of active temperatures and so on (Table 1).

Table 1. Dates (day.month) of temperature transition through ecologically significant intervals

Parameter	Period		
	before 1966 г.	1990-1994	1995-2000
Date of transition through –5° C	14.04 16.10	7.04-21.04 10-29.10	1-6.04 7-27.10
Date of transition through 0° C	27.04 5.10	12-31.04 9-28.10	15.04-1.05 3-17.10
Date of transition through 5° C	12.05 21.09	2-13.05 10-25.09	9-25.05 18-28.09
Date of transition through 10° C	29.05 4.09	21.05-13.06 30.08-13.09	18.05-11.06 29.08-15.09
Date of transition through 15° C	15.06 15.08	15.06-3.07 8.08-29.08	2.06-2.07 7.08-11.09
Date of the first high temperature	-	27.03-22.04	5-19.04
Date of the first low temperature	-	27.09- 9.10	26.09-6.10

Average annual temperature in creased from -7.7°C in 1884-1888 to -6.3°C in 1995-2000. It is increasing begins in the second part of the 80s years and is continuing to the end of the century.

The period with steady frosts decreases and duration of transition of temperatures through 0, 5, 10, 15°C is increased.

The general warming occurs due to spring months. The amplitude of fluctuation of the minimal maximal temperatures of June and January decreases since raise minimal and the maximal values of temperatures go down.

The sum of active soil temperatures is more than the sum of active air temperatures. It may be a characteristic of warn quantity and have a connection with annual sum of radiation balance and it lets define more exactly thermal resources and is index of warm guarantee to agricultural crops and efficiency of woods.

Biota reaction on those changes is not so simple. There are changes in terms of approach of seasonal events. Change of winter temperature, fall of temperature in the summer period and at the same time displacement of the first autumn frosts for later period cause to life various biota adaptation characteristics. Phenological reactions of plants change**.** Within the last decade, especially last five years, frequency of cases of autumn secondary flowering of a dogrose, a cowberry, a blueberry, autumn flowering of a dandelion, a yarrow, is increased. Cases are marked when trees and bushes "leave" for winter, having not lost their foliage.

These phenomena result in weakening the population as to the beginning of the period of "normal" vegetation in the next spring, plants will be weakened. Over the past 10 years a displacement of blooming terms occurs for herbs from the second decade of June to the first decade of June - III decade of May, terms of trees leaves blooming, turning yellow and fall of the leaves change, that means an increase of vegetative and frost free period.

Phenological reactions of animals to the climate change are different as well. An earlier come of sparrows is noted, the birds flying away and coming terms displace in spring and autumn (Fig.1). Beginning in the 70's unusual for typical ornithofauna species appear: lapwing teal, jay.

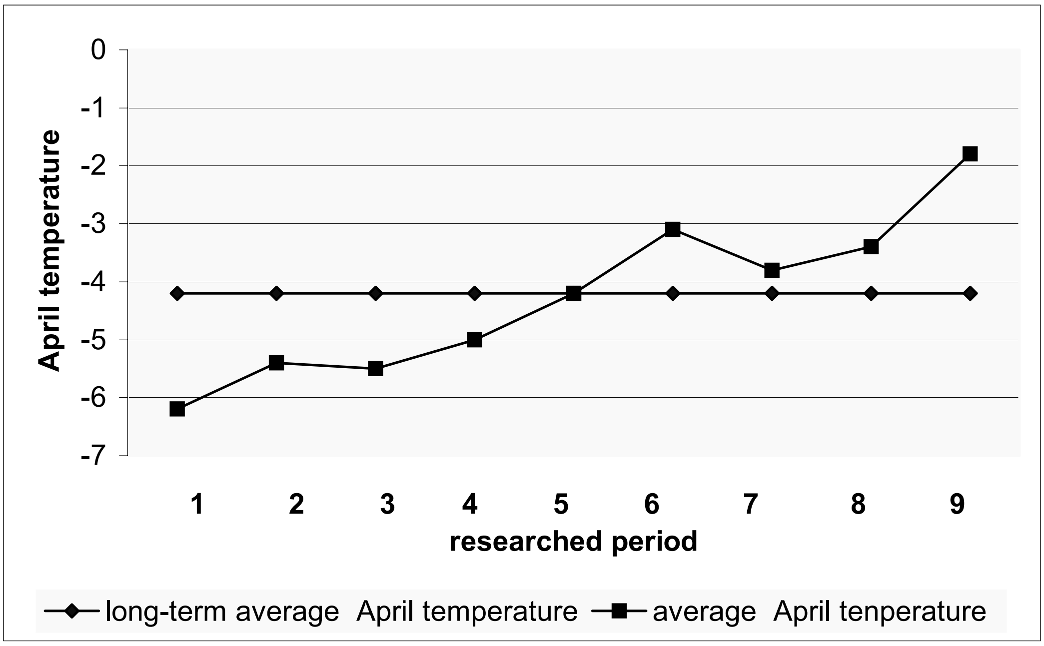

Fig.1. Long-term April air temperature (1884-2000) (1 = 1884-1888; 2 = 1901-1905; 3 = 1911-1915; 4 = 1936-1960; 5= 1966-1970; 6 = 1981-1985; 7 = 1985-1989; 8 = 1990-1994; 9 = 1995-2000)

It is also necessary to note, that exactly since 70th years of the XX century global warming of the climate is observed, and regional as well. During 1990-2000 the number of rooks, ordinary and blue magpies, starlings is increased. Especially over the last decade, an expansion of a noble deer, a grey heron natural habitat and their spread in Central Yakutia is observed.

The analysis of the available information allows to conclude that process of climate change is actual for the Southwest Yakutia region. Over the past 100 years in the investigated region there was significant change of the climate, what is expressed in average annual temperature increase, the frost free period lengthening, total active temperature decrease etc.

These changes had an effect on biota and were showed, basically, in the change of phenological processes terms. However, present day climate warming has not yet become the factor capable to cause essential changes in boreal ecosystem structure and functioning, having a wide range of surviving adaptation mechanisms.

History of Sea Ice in Icelandic waters

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The 1000-year history of sea ice off Iceland provides some indication of changes and long-term fluctuations in the oceans and atmosphere, i.e. climatic variation. Persistent incursions of sea ice indicate that some changes must have taken place, possibly extending far beyond Iceland, at least throughout the North Atlantic. The Icelandic nation's tendency to keep records through the ages, in the form of annals and reports describing sea ice and weather conditions, has provided valuable sources for research into weather fluctuations in the North Atlantic in past centuries.

Sea ice monitoring of Icelandic waters as well as archiving of sea ice observation data is looked after by the Icelandic Meteorological Office. Icelandic waters are defined as the economic zone around Iceland, extending outwards to a 200-nautical miles distance from the coast or to the midline between Iceland and Greenland in the Denmark Strait.

Annual extension of sea ice in the vicinity of Iceland fluctuates between open sea across the Denmark Strait in late summer to sea ice in the Strait in late winter covering the ocean at the coast of East Greenland halfway towards Iceland. Much of the sea ice is carried by the East Greenland Current from the Arctic Ocean and the Northern Greenland Sea but considerable amounts form during winter along the coasts of Greenland further south.

Besides variable amounts being brought south by the East Greenland Current, year-to-year fluctuations in surface ocean conditions in the Denmark Strait and the Iceland Sea give rise to different sea ice extent in Icelandic waters. However, the final cause at present resulting in sea ice reaching as far east as sailing routes around northwest and north Iceland, and even to the coasts, is the effect of prevailing winds, that is, the atmospheric pressure configuration over the North Atlantic. In earlier centuries of colder climate, with more extensive sea ice in the Greenland Sea, Icelandic coasts were visited by sea ice more frequently.

Despite indications of decreasing sea ice amount in the Arctic, in late summer in particular, the East Greenland Current – the main current leaving the Arctic – will continue to bring sea ice long distances south along the coasts of Greenland. Conditions for local sea ice formation en route will also persist. Helped by atmospheric variability, sea ice in Icelandic waters will still in the years to come be of concern to seafarers, be they on board small sailing boats, fishing boats, big tank ships or cruise liners.

Structure of the Plant Communities of Spruce Open Woodland of Different Ages on the Taiga-Tundra Boundary in the East European Part of Russia

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Introduction

The taiga-tundra boundary is very dynamic phenomenon. Its sensitive response to climatic changes finds expression in displacement to the south or to the north.

Therefore it can be used as an indicator of recent and modern climatic changes. Reaction of this zonal boundary toward climatic changes is clearly seen, because it is expressed in occupying of new territories formerly treeless in one case and in aggravation of trees behavior and their death in other. Some signs of vegetation response to climatic changes can be observed by single investigation, but completely they can be revealed only by repeated visits to the same sites, i.e. by monitoring.

Russia has the longest and the northernmost taiga-tundra boundary in the world. Russian scientists were interested for the long time in the cause of the tundra treelessness and in the specific forest tundra vegetation – intermediate belt between taiga and tundra. They visited and investigated a lot of points at the taiga-tundra boundary on plains, mountains and "forest islands" in the subzone of southern tundra boundary from the Kola Peninsula to the Chukotka. The author took part in the investigation of flora and vegetation of the forest-tundra research station in the north-east European part of Russia (Katenin, 1970, 1972). Now, 40 years later after this investigation, we have repeatedly investigated the flora and vegetation of this territory to find the changes in flora and vegetation and to reveal the causes of these changes.

In 1962-1964 years the author studied forest-tundra vegetation in transitional strip between the north taiga and southern tundra. 2000 releves of vegetation were made which served as basement for classification of plant communities. He also compiled vegetation map (scale 1: 12 000) of strip 3 km width and 6 km long (from south to north). The map includes the northern part of forest-tundra and adjacent part of south tundra subzone (Katenin, 1972).

In the south part of forest-tundra strip the spruce and birch forest communities prevail, spruce and birch open woodland occur rarely and the most uncommon are dwarf-shrub and dwarf-birch tundra communities. In the middle part of this strip the spruce and birch open woodland predominate, the forest communities are less represented and tundra communities are more often. In the north part of mapped territory forest communities are absent, birch and spruce open woodlands dominate. Large areas here are occupied by tundra communities.

Birch open woodlands penetrate most far into tundra along the tops of hills and ridges. Spruce open woodlands are restricted to moderately moisten parts of slopes. Trees are absent completely on strongly watered slopes, on exposed dry habitats, as well as in valleys and mires.

Methods

Changes of vegetation for 40 years have been studied within narrow strip of immediate contact of the northernmost spruce and birch open woodlands with tundra communities. Main attention having been paid to spruce woodlands since they predominate in middle and northern parts of forest-tundra ecotone, whereas spruce forests prevail in taiga zone in this region.

In the course of the research profiles were established in south-north direction including the spruce and birch open woodlands with tree stands of various density and height. These two characteristics have been considered by us as the indicators of community ages. Later the community age has been recorded on the base of analysis of cross section of the trunks. On these profiles the releves of standard communities of open woodlands have been made. Within these communities sampling plots of 10 X 10 m were established. The vegetation of plots has been mapped, height and diameters of all trees were measured, the presence of fruits and dying of the terminal parts of crones have been recorded. At every plot trees are divided into height groups. Prevailing group (by number of individuals) has been ascertained. After that in adjacent parts of standard community trees have been selected corresponding to prevailing height group and then their age has been determined.

In spruce open woodlands four standard communities have been established - three on the profile of south-north direction at the slope of hill and one more community – at the contact of the hill slope and valley of creek. These profiles were established according to direction of advance of spruce open woodlands into tundra and into early treeless.

Between spruce open woodlands and tundra birch communities the frontier strip with rare young spruce trees is located – the place of modern forest transgression to the tundra. Here (on two plots) the height, diameter and density of trees were determined. On the base of analysis of the structure of these plots we can see the direction of the process of colonization of tundra communities by spruce and the forming on their place communities of spruce open woodlands. For these purposes several features of plant community structure were chosen which better indicate structure of plant communities of different types - tundra shrub communities and open woodlands. They are: number of trees, their height, degree of coverage as well as degree of coverage of tundra shrubs and dwarf shrubs, lichens and mosses.

Conclusions

In the northern part of the transitional strip (ecotone) one tree falls on the area of 33 m^2 , as well as in the southern part of this strip – one tree falls on the area of 19 m^2 .

In the standard community of the 1st stage of open woodland formation one tree falls on the area of 17 m^2 ; one of the 2nd - on the area of 4 m^2; one of the 3^{d} - on the area of 3 m^2; in the creek valley – on the area 6 m^2. In the northern part of the ecotone strip the spruce trees of 2 m height prevail. The young spruce trees in the northern part of the ecotone are 85 sm height, while in the south part – 45 sm height.

In the standard community of the 1st stage of open woodland formation the trees of 2 m height (vegetative) prevails, the young trees have the height of 70 sm. In the standard community of the 2nd stage - the trees of 3,4 m height (fruiting) prevails, the young trees have the height of 52 sm (vegetative). On the plot of the standard community of the 3d stage the trees of 5 m height (fruiting) prevails, the young trees have the height of 43 sm (vegetative). In the spruce open woodland community of the 1st stage formation in the creek valley the trees of 2 m height (vegetative) prevail; the young trees – 82 sm height, vegetative.

So, the density of spruce trees on the first stages of their introduction into the tundra communities is in 6-10 times less than the same in the spruce open woodland of the 3d stage of its formation. The spruce trees height in the tundra communities (2-3 m) is 2 times less than the same one in the spruce open woodlands of the 3d stage of formation and is equal to those of 1st and 2nd stages of formation. In the same time the spruce density in the open woodlands of 1st formation is 6 times less of the same on the 3d stage of its formation, while the trees height is 1,5 –2 times less. The fruiting spruce trees are absent at the first stages of their penetration into tundra communities; they are common in the open woodlands of 2nd and 3d stages.

Comparing the structure of standard plant communities of spruce open woodlands of 3 stages of formation we see that the trees covering of surface is minimum in the communities of 1st stage on the hill slope (7%) and in the valley (11%). For the communities of the 2nd stage it is maximum (26 %), for the 3d stage - 21 %. The shrub covering is maximum in both standard communities of the 1st stage (65 and 70 %), while in the communities of 2 and 3 stages it is equal – 55 %. For the first stages of formation the dwarf birch, as well as willow shrubs are common. The shrub covering is 15 and 25 % in the 1st stage, and 10 % - in 2 and 3 stages. Herb plants, mosses and lichens are slightly more abundant in the first stage communities than in the communities of the second and the third stages. At the same time in communities of the second and the third stages fruiting trees meet more often (35 and 42%) and there are more spruce young growth individuals (19 and 35%) in comparison with the communities of the first stage (fruiting – 16 and 40%, young growth – 5 and 20%).

So, we can say that in the first stages of open woodlands formation the structural elements of tundra shrub communities occur, while in the final stages they are being depressed.

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Environmental Changes in the North Atlantic Region: SCANNET as a Collaborative Approach for Documenting, Understanding and Predicting Changes

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The lands surrounding the North Atlantic Region (the "SCANNET Region") cover a wide range of climate regimes, physical environments and availability of natural resources. Except in the extreme North, they have supported human populations and various cultures since at least the end of the last ice age. However, the region is also important at a wider geographical scale in that it influences the Global climate and supports animals that migrate between the Arctic and all the other continents of the World. Climate, environment and land use in the region are changing rapidly and projections suggest that global warming will be amplified there whilst increasing land use might dramatically reduce the remaining wilderness areas. Because much of the region is sparsely populated – if populated at all – observational records of past environmental changes and their impacts are both few and of short duration. However, it is becoming very important to record changes that are now in progress, to understand the drivers of these changes, and to predict future consequences of the changes.

To facilitate research into understanding impacts of global change on the lands of the North Atlantic Region, and also to monitor changes in real time, a network of research sites and infrastructures was formed in 2000: this was called SCANNET – SCANdinavian/North European NETwork of Terrestrial Field Bases. SCANNET currently consists of 9 core sites and five sites within local networks that together cover the broad range of current climate and predicted change in the region. Climate observations are well replicated across the network, whereas each site has tended to select particular environmental and ecological subjects for intensive observations. This provides diversity of both subject coverage and expertise.

SCANNET provides an integrated facility enabling students, researchers, managers and policy-makers to access information and expertise at Field Sites throughout this highly sensitive region. This is a "one-stop-shop" providing access to a "platform" of terrestrial field sites throughout the region for research and monitoring. It can also provide a "rapid response system" within which co-ordinated observations could be made at short notice.

The development of SCANNET, supported by the European Commission, has emphasized the value of establishing links among Northern field sites in considering long-term ecological and environmental dynamics. It highlights the benefits of knowledge exchange; combining different types of information and approaches; technology transfer; enhanced data access, and increased communication with local and regional stakeholders together with the research community.

SCANNET partners have compiled environmental information within a series of workpackages.

The *"Presentation of more accessible data on climatic variability"* workpackage has compiled descriptive, local climatological information for all the SCANNET sites. Temperature, precipitation, humidity and pressure are presented for the SCANNET sites on monthly and annual time scales. Because of the importance of winter processes, yet the relatively poor information available, a "Snow-pack-Ice layer model has been used and validated from information from those sites that have snow depth records. Similarly, lake ice duration has also been simulated and validated from the sparse information available (Kohler and Brandt, 2004; Kohler *et al*., 2004).

SCANNET's workpackage *"Regional climate change scenarios"* has compiled a selection of climate scenarios for the SCANNET region and sites. They are derived from several GCMs and regional climate models. They suggest a) air temperature increases of *ca*. 0.35 – 0.4^{o}C per 10 years, b) *ca.* twice the temperature increase in winter as in summer, c) precipitation increases of 1.5 – 2% per 10 years, d) twice as much precipitation in autumn/winter as in summer (Sælthun and Barkved, 2003).

"Standardisation of protocols on spatial and temporal variation in biodiversity" was a workpackage in which a data base was compiled on species richness at the SCANNET sites. At least 7,200 species can be found in the sub-Arctic sites of Kevo, Kilpisjärvi and Abisko. Some groups of organisms are listed at all sites, for example birds, mammals and vascular plants, but information for some other groups such as saw flies and many soil organisms is poor. Recordings of various groups have often been accumulated during long periods, but the intensity, timing and length of the studies vary among the sites (Neuvonen, 2004).

The workpackage *"Reviewing species performance"* compiled a metadatabase on biological long-term monitoring (150 species, 175 variables) in northern Europe, and particularly at the SCANNET sites. The metadatabase is set in the context of the ecosystems and ecological characteristics of the region and is linked to similar networks focusing further south in Europe (Høye and Forchhammer, 2004).

SCANNET's workpackage *"Reviewing land use and society interaction"* held decision-making workshops with local interest groups at six of the SCANNET sites. The results are leading to refined methodology and the identification of "North Atlantic Perspectives". At each site, stakeholder groups have identified the most important indicators of change that could be used subsequently for environmental monitoring. The indicators assessed as most important vary among sites according to local conditions but for the North Atlantic Region in general, include climate, habitat condition, animal and pant communities, primary sector, approved planning applications, and environmental regulation compliance (Bayfield *et al*., 2004).

SCANNET has other workpackages that involve administration, networking and maintenance of SCANNET's web site (www.scannet.nu). SCANNET has a fully functional web site that contains baseline information on the field sites, a metadata base, data base, searchable bibliography from the sites, research project lists, newsletters and reports as well as workpackage final reports. The web site also has a photo-library of the Region.

Extension of SCANNET's observations has begun through a) new monitoring activities at existing sites, b) the addition of new sites to the SCANNET network and c) representation of the North Atlantic Region by SCANNET in wider networks such as the proposed Circumarctic Environmental Observatories Network CEON.

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UV Irradiation of Tundra Soil Microorganisms Varies with Plant Cover

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Introduction

Arctic environmental conditions are changing rapidly. Ozone depletion may lead to an increase in biologically harmful UV-B radiation at ground level, while increasing mean Arctic temperatures may alter tundra plant distribution and biodiversity.

Seasonal increases in biologically damaging UV-B and altered plant distribution may have significant effects on microorganisms associated with soil beneath and around Arctic tundra plants. This in turn, may affect microbially driven biogeochemical cycles. In the past, solar radiative transfer through forest canopies and the consequences for forest floor plants has been studied in temperate and tropical areas. This study measured the level of transmission of UV through a range of Arctic plants and the impact on microorganisms at Ny Ålesund, Svalbard.

Methods

1. UV damage to microorganisms was assessed using bacterial spore biofilm dosimeters. The DLR biofilm system consists of spores of *Bacillus subtilis* ($\sim 5 \times 10^5$ spores cm^{-2}) as UV sensitive targets, immobilized in a dried monolayer on the surface of a polyester sheet. When subjected to UV radiation a proportion of the spores are inactivated. The response is dependent on the total cumulative dose and is independent of the dose rate.
2. UV radiation was measured using a UV digital radiometer.

Results and discussion

Transmission of UV through tundra plant foliage

1. <u>Biofilm biodosimeters</u>: No UV damage was recorded beneath *Drepanocladus sp.*, *Poa alpina* or *Silene acaulis*. In contrast, *Saxifraga oppositifolia* and *Dryas octopetala* allowed penetration of UV through their foliage depending upon the position beneath the plant. (up to 71.5% and 30.1% of ambient UV, respectively).
2. <u>UV radiometer</u>: Figure 1 shows the penetration of solar UV through tundra plants at different distances from the foliage edge. *S. oppositifolia* and *D. octopetala* showed the greatest transmissions of UV through their foliage. In all cases, UV transmission decreased with increasing distance from the foliage edge, although UV was still detected 15 cm from the edge of *S. oppositifolia* and *D. octopetala*.

   Penetration of UV through tundra plants varies depending on plant morphology and can have a significant effect on microorganism viability beneath and around the plants. Low creeping plants such as *S. oppositifolia*, and to a lesser degree *D. octopetala*, allowed penetration of UV through their foliage to the litter layer below while plants with denser foliage and more compact morphologies block UV penetration and protect microorganisms.

Transmission of UV beyond the foliage edge

Figure 2 shows the percentage transmission (± 1 SE) of solar UV through arctic tundra plants measured with a UV radiometer. Shading profiles varied with plant morphology and shading increased further around *S. cespitosa* when flowers were present. The shading influence of grasses such as *P. alpina* extended further than those of cushion plants such as *S. acaulis*. Although *S. oppositifolia* allowed UV transmission within the foliage edge, beyond this point the transmission profile was similar to that of the cushion plant *S. acaulis*. Large flower size in relation to total plant size is a common feature of many tundra plants. The temporary change in plant morphology associated with flower formation had a significant impact on shading profile around *S. cespitosa*; when flowering, the profile of *S. cespitosa* was similar to that of the grass *P. alpina*.

Conclusion

1. The presence of plants dramatically reduces the amount of UV reaching the soil surface.
2. The amount of damage to microorganisms at the soil surface varies depending on the plant type. Creeping plants allowed penetration of more UV than cushion plants or grasses.
3. Shading effects of plants beyond the foliage edge vary with plant morphology and the presence of flowers.
4. If climate change predictions prove accurate, resulting in changes to Arctic plant biology and ecology, the UV flux in tundra soils may change dramatically in the next 50 years, with knock on effects for microbially driven biogeochemical cycling.

Acknowledgements

This work was supported by the British Antarctic Survey's 'Biomolecular Responses to Environmental Stresses in the Antarctic' project and the European Union grant number LSF-NP-65/2001. We thank Ann Cresswell for plant identification and Nick Cox, Maggie Annat (Natural Environment Research Council) and the Norwegian Polar Institute for logistical support.

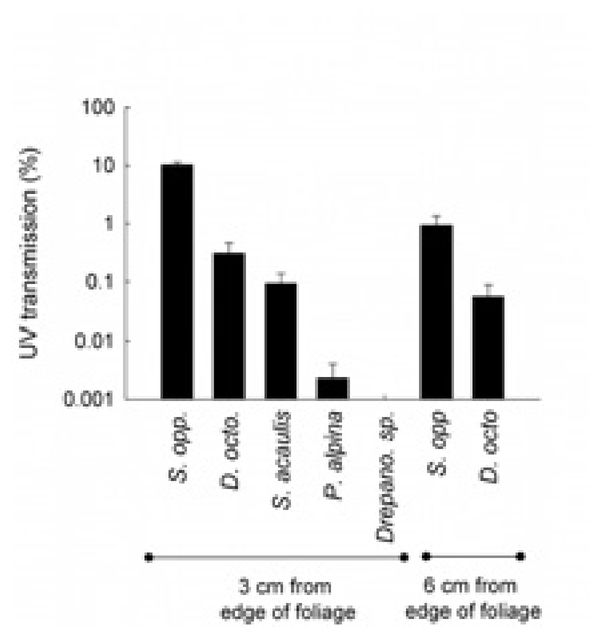

Figure 1. Percentage transmission (± 1 SE) of solar UV through *S. oppositifolia*, *D. octopetala*, *S. acaulis*, *P. alpina* and *Drepanocladus* sp. at 3 cm and *S. oppositifolia* and *D. octopetala* at 6 cm from the foliage edge.

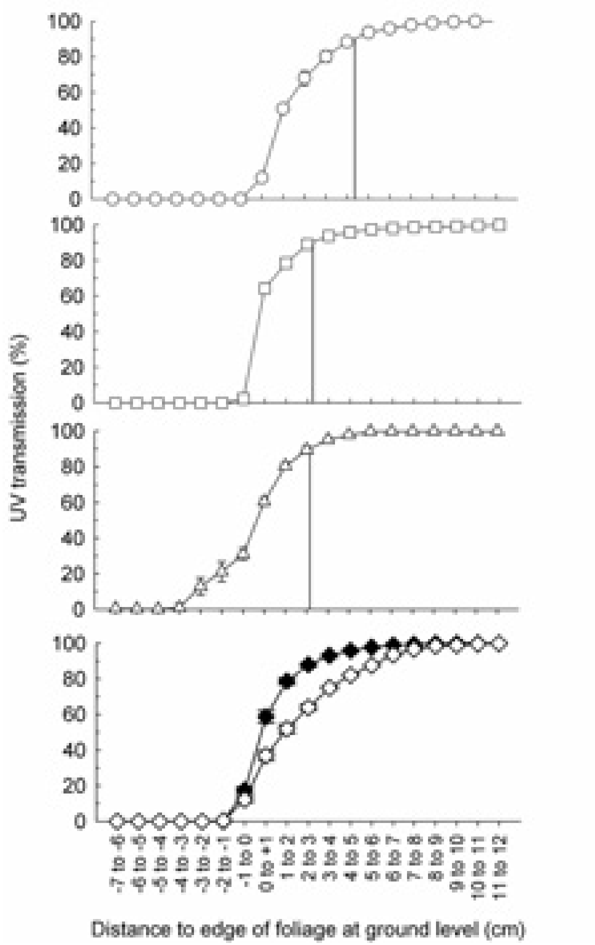

Figure 2. Percentage transmission (± 1 SE) of solar UV through arctic tundra plants measured with a UV radiometer: *P. alpina* (○), *S. acaulis* (□), *S. oppositifolia* (△) and *S. acaulis* with (◆) and without (◇) flowers. Vertical lines indicate the distance from the foliage edge where 90% of ambient UV is transmitted.

The Effect of Climatic Change on Growth of Sub-arctic Birch Woodlands in Iceland

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Introduction

Temperature is believed to have its greatest impact on tree growth at the arctic tree line. Hence, to what extent does climate warming alter growth rate and stature of sub-arctic mountain birch (*Betula pubescens*) woodlands? In the present study this question was addressed by 1) evaluating the spatial variation in tree size and growth rates by growing season temperatures within Iceland as well as by 2) comparing the temporal change in temperature, birch growth rates and tree sizes between the latter half of the 19th century (Little Ice Age) and the warmer 20th century.

Methods

Spatial variation. Mean temperatures for the growing season (June, July and August) were estimated for the location of 286 randomly selected birch trees felled and measured in 1987. Correlations were tested between the estimated temperatures and measurements of tree length, extension growth rate (tree length divided by tree age) and radial increment (mean width of five most recent annual rings) of the birch trees.

Temporal variation. In the year 1899 a sample of 60 birch trees was felled and measured in the sub-arctic birch woods of Fnjóskadalur-valley North Iceland recording tree length and number of annual rings by sections along the stem length (Sigurðsson, 1900). In 1987 a random sample of 29 birch trees were felled in the same woods and measured in the same way as in 1899 (part of the study of spatial variation above). For each tree in the two datasets mean temperatures by months were calculated for the lifetime of the trees as well as for the duration of growth of each stem section. Tree height, stem diameters, tree age, stem extension growth rates and radial increments in addition to the temperatures experienced by the trees during their lifetime were compared between the sampling dates in 1899 and 1987. Furthermore, correlations were tested between extension growth rates and temperatures by stem sections.

Conclusions

Spatial variation. Unexpectedly, significant correlations were not seen between tree lengths, height increment (fig. 1) or radial growth rate and estimated growing season temperatures in the dataset for the 286 trees throughout Iceland. This was so even though growing season temperatures were quite variable between sites. Thus, neither tree stature nor growth rates of birch trees were shown to vary with growing season temperatures in the country.

Temporal variation. Annual and growing season temperatures experienced by the trees in Fnjóskadalur-valley increased, respectively 0.9°C and 0.5°C from 1899 to 1987. Even so, birch growth rates did not change significantly between the two sampling dates, though average tree size increased due to higher tree age in 1987 than 1899 (fig. 2). The increased longevity of the trees was due to longer rotations during the 20th century compared to the 19th century. Hence, increased tree size and age was human induced.

Temperature in June was however significantly and positively correlated with extension growth rates by stem sections in the trees. Even so, this thermal acceleration of growth was both relatively small and explained a comparatively small proportion of the variation in growth rate. Hence, an over all increase in growth rate of birch trees was not observed in the present study between the cold 19th century and the warmer 20th century.

The results from the spatial and temporal studies reported herein indicate that the sub-arctic mountain birch may be rather complacent in its temperature response and that climate warming may have only moderate effect on growth rate and tree stature in sub-arctic mountain birch woodlands and scrub.

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Sigurðsson, S. 1900. The woods of Fnjóskadalur-valley [Skógarnir í Fnjóskadal]. *Andvari*, **25**, 144-175. [In Icelandic].

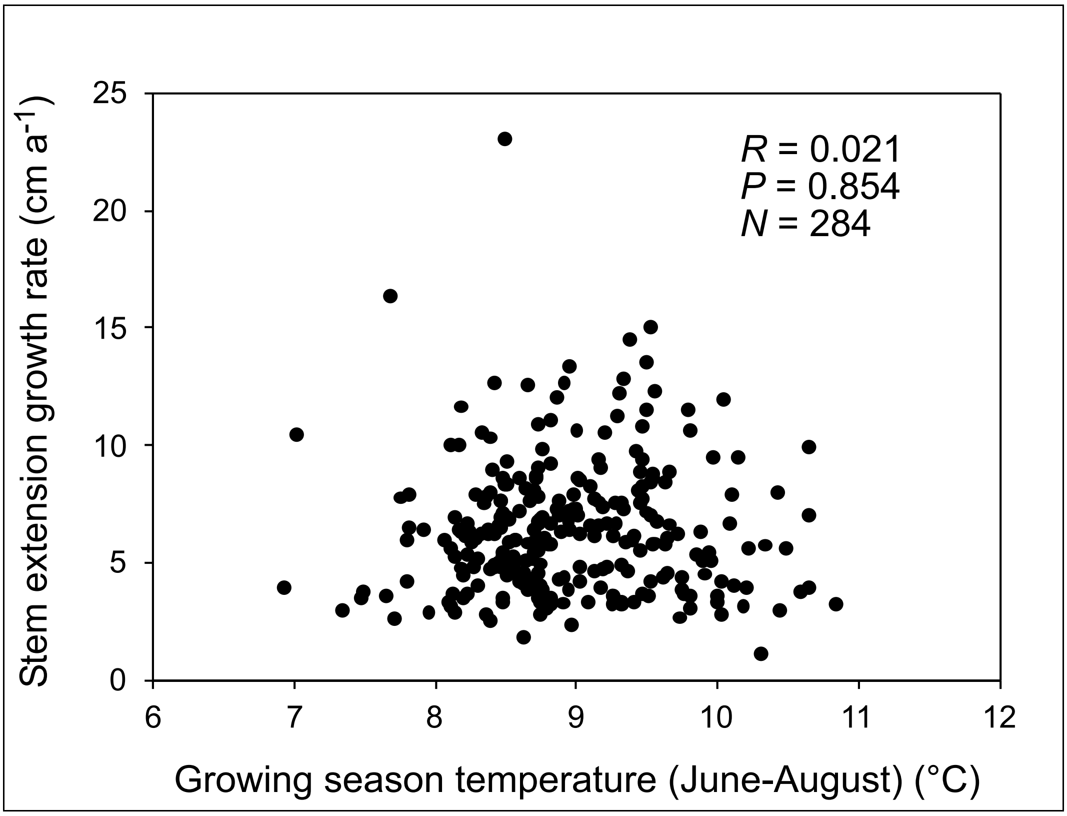

Figure 1. Mean rates of stem extension growth of 286 randomly located birch trees in Iceland by mean temperature for the months June, July and August.

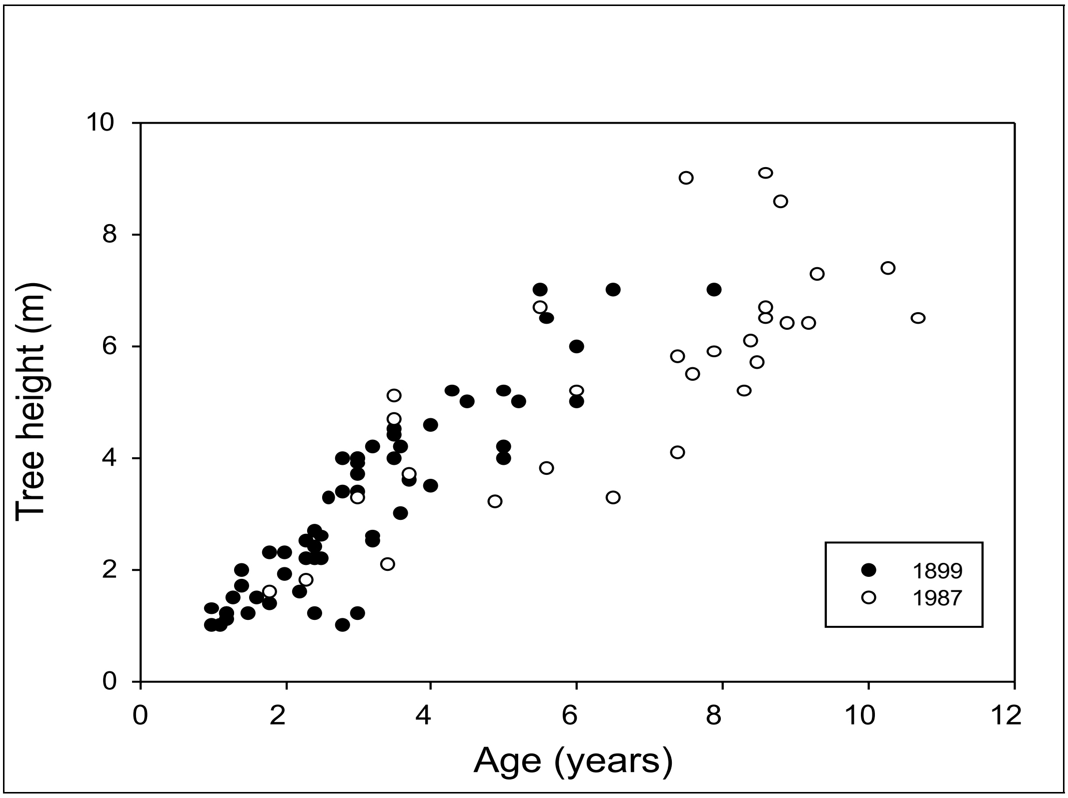

Figure 2. Tree height by age in the birch woods of Fnjóskadalur-valley in 1899 (closed circles) and 1987 (open circles).

The Distribution Areas of Mountain Birch in the North Atlantic Region May Respond Differently to Climatic Warming than Cooling of the Climates

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Introduction

The mountain birch (*Betula pubescens*) forms woodlands and scrub beyond the conifer tree line in the North Atlantic Region from Greenland to the Kola Peninsula of North West Russia. The mountain birch extends its territory by seed but within undisturbed birch woods regeneration is almost entirely by vegetative rejuvenation of existing genets that may thus survive for centuries if not millennia in environments unfavourable for seedling establishment. Other woody species coexisting with the mountain birch including rowan (*Sorbus aucuparia*, *S. groenlandica*), aspen (*Populus tremula*), alder (*Alnus incana*, *A. crispa*), bird cherry (*Prunus padus*) and various willow species (*Salix glauca*, *S. lanata*, *S. myrsinifolia* var. *borealis*, *S. phylicifolia*) are all capable of this dual mode of seedling establishment and vegetative rejuvenation of genets.

Established genets survive and rejuvenate in climatically less favourable conditions than seedlings can establish. Hence, established genets can maintain their stance by vegetative rejuvenation at considerably higher altitudes than seedlings may establish. Thus, we would expect the distribution area of sub-arctic birch and its associate species to respond to climate change according to a hysteresis-like isotherm, i.e. that the distribution limits react differently to climatic warming than a cooling trend (fig. 1). In conditions of climate warming the trees would not gain territory until the seedling establishment limit has surpassed the old distribution limit. However, during climatic cooling the distribution limits would not retreat until the plants at the border can no longer survive the harsh conditions. For this reason the sub-arctic birch ecosystems are much more stable under fluctuating climate than those systems that relay on sexual regeneration alone such as the northern coniferous tree line in Europe.

The hystereses model would predict a much more stable distribution area of sub-arctic birch woodlands and scrub during the Holocene than we would expect if the distribution limit was set by seedling establishment alone (fig. 2).

Methods

Temperature data based on the GISP2 ice core from central Greenland were scaled to sea level temperatures for the three summer months June to August in a hypothetical location in Iceland (approximately mimicking recent temperatures at Stykkishólmur station). Estimated thermal distribution limit of birch in Fnjóskadalur-valley North Iceland (7.6°C for June to August) was used as an approximation for the birch mortality limit and 9.2°C as a rough guess for the seedling establishment limit. It should however be noted that the values for the mortality and seedling establishment limits are only guesses for illustrative purposes.

Conclusions

At the height of the Little Ice Age at the end of the 19th century the upper distribution limits of mountain birch were probably set by the mortality limit (fig. 2). Thus, the upper birch limits may not change much until the climate has warmed to such a degree that the seedling establishment limit has exceeded the old mortality limit of vegetatively rejuvenating genets. However, the difference between the seedling establishment limits of boreal conifers and the mountain birch are smaller than those of the boreal conifers and the birch mortality limit. Thus, under conditions of continuous climatic warming the distribution areas of sub-arctic mountain birch would become much narrower than now or even totally disappear. This may have important implications for species that rely on the birch ecosystem for their existence.

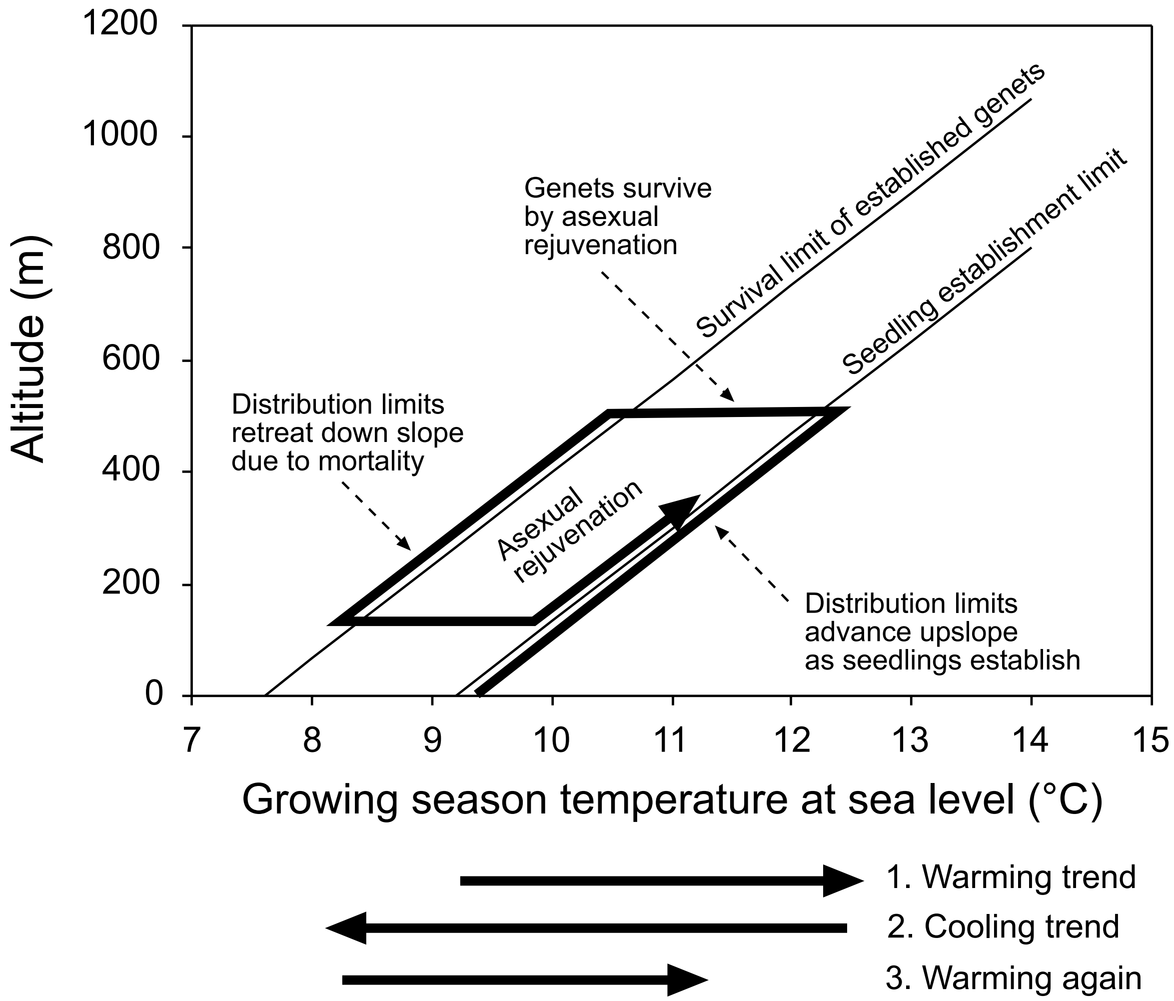

Figure 1. Response of the thermal distribution limits of sub-arctic birch woodlands and scrub based on a hysteresis isotherm.

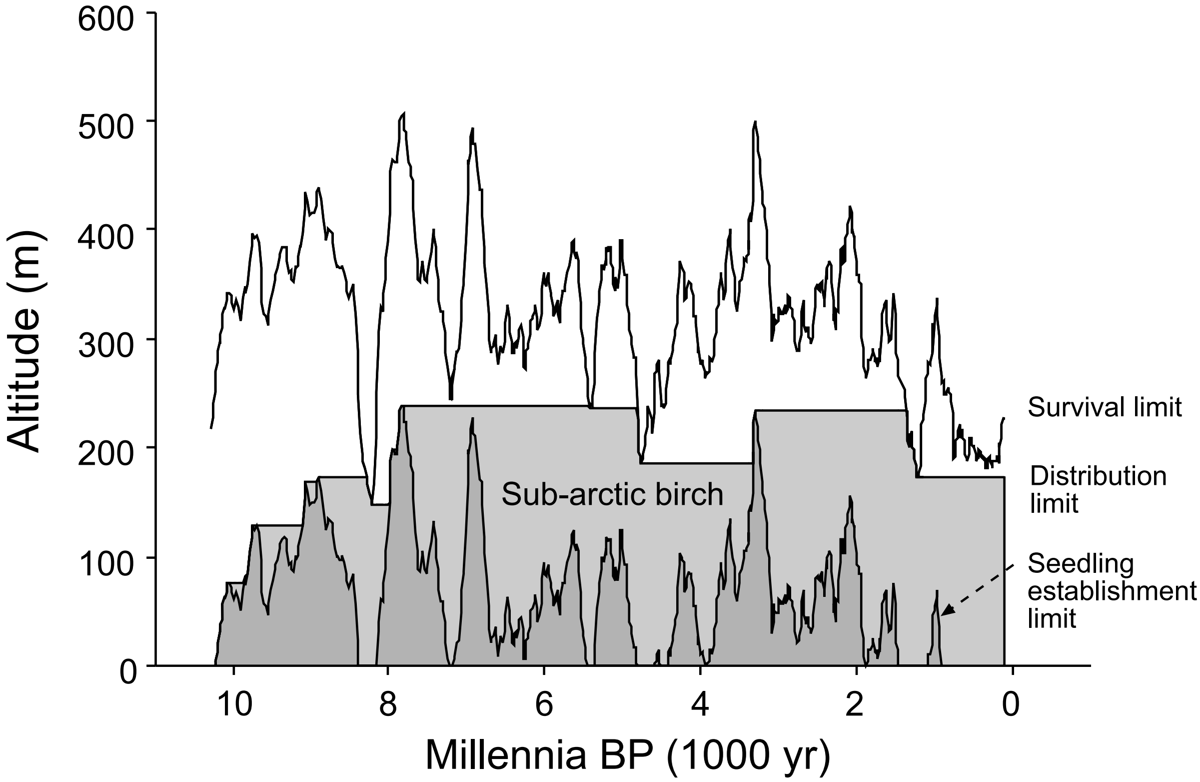

Figure 2. Predicted change during Holocene in altitudinal distribution limits of sub-arctic birch woodlands and scrub in a hypothetical location in Iceland based on a hysteresis isotherm of thermal response (fig. 1). The shaded area is within the predicted distribution limit for sub-arctic birch and the darker shaded area within the limit that seedlings can successfully establish. In this example there would be no birch at present at the site if seedling establishment under recent conditions set the distribution limit.

The Bering Sea is Shifting from an Arctic Ecosystem to a Subarctic Ecosystem

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A major transformation, or regime shift, of the Bering Sea occurred in atmospheric conditions around 1976/77, changing from a predominantly cold Arctic climate to a warmer subarctic maritime climate as part of the Pacific Decadal Oscillation(PDO). This shift in physical forcing was accompanied by a major reorganization of the marine ecosystem on the Bering Sea shelf over the following decade. Fisheries surveys and model calculations show a shift in the importance of pollock to the ecosystem, to over 50% of the energy flow at mid-trophic levels in the 1980s from near 10% in the 1950/1960s. Weather data beginning in the 1910s and proxy data(e.g. tree rings) back to 1800 suggest that, except for a period in the 1930s, the Bering Sea was generally cool before 1977, with sufficient time for slow growing, long-lived, cold-adapted species to adjust. Thus the last few decades are a transition period for the Bering Sea ecosystem.

A major Arctic change influence on the Bering Sea began in the late 1980s, as a shift in polar vortex winds(the Arctic Oscillation – AO) reinforced the warm Bering conditions, especially promoting an earlier timing of spring meltback of sea ice. Warm conditions favor pelagic over benthic components of the ecosystem. Cold water species, i.e. Greenland turbot, Arctic cod, snow crab and a cold water amphipod, are no longer found in abundance in the SE Bering Sea, pollock are expanding their range, and the range of Pacific walrus is moving northward. While it is difficult to show direct causality, the timing of the recent reduction in marine mammals suggests some loss of their traditional Arctic habitat. Although environmental and ecological conditions appear mostly stable over the last decade, the warmest water column temperatures have occurred in 2002—2003 on the southeast Bering Sea shelf, despite considerable year-to-year variability in the AO.

Figure 1 shows the warming of ocean temperatures in the southeast Bering Sea from a mooring. The last three years are warmer than the first three years of the record by nearly 2°C., a large amount. Figure 2 shows an example from 2004 that sea ice in the southern Bering Sea has been nearly nonexistent for the previous 4 years; here we compare ice cover throughout winter and spring 2004 with climatology. Figure 3 shows the response of three fish species to the warming after 1976. The diamonds show the biomass and bars show yearly recruitment. Greenland turbot (top) did well in cold waters before 1977 but has dropped in recent years to 17% of its pre-regime shift peak. Flathead sole, also a bottom fish, had good recruitment in the 1980s due to favorable winds, but has declined in the 1990s. Pollock biomass (bottom) increased 400% following the 1977 regime shift and has maintained high sustained values for the previous decades. Under the warmer conditions, pelagic fish such as pollock and whales seem to be doing well, but Arctic-adapted species such as fur seals, walrus and crab are not doing well.

We hypothesize that the overall climate change occurring in the Arctic, as indicated by warmer atmospheric and oceanic temperatures and loss of 15 % of sea ice and tundra area over the previous two decades, is making the Bering Sea less sensitive to the intrinsic climate variability of the North Pacific. Indeed, when the waters off of west coast of the continental U.S. shifted to cooler conditions after 1998, the subarctic did not change, in contrast to three earlier PDO shifts in the 20th century. Thus we project that the Bering Sea will more likely continue on its current warm trajectory, with biomes transitioning northward allowing pollock a larger domain at the expense of cold and ice-adapted species, rather than transitioning back to a cold regime. A more complete discussion is in Overland and Stabeno (Eos, Vol. 85, No. 33, 17 August 2004).

Acknowledgment

We appreciate the support of the NOAA Fisheries-Oceanography Coordinated Investigations and the NOAA Arctic Research Office.

Figure 1

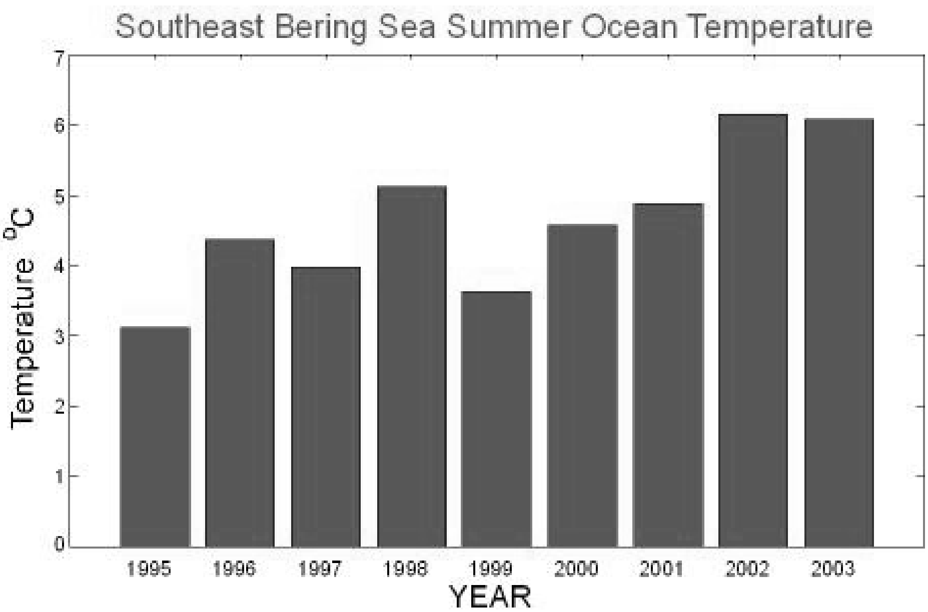


Figure 2

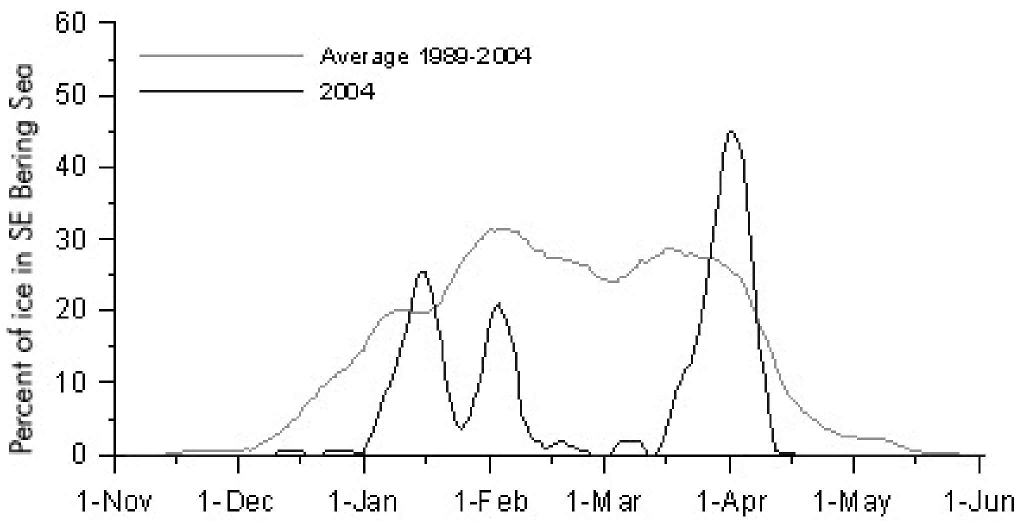
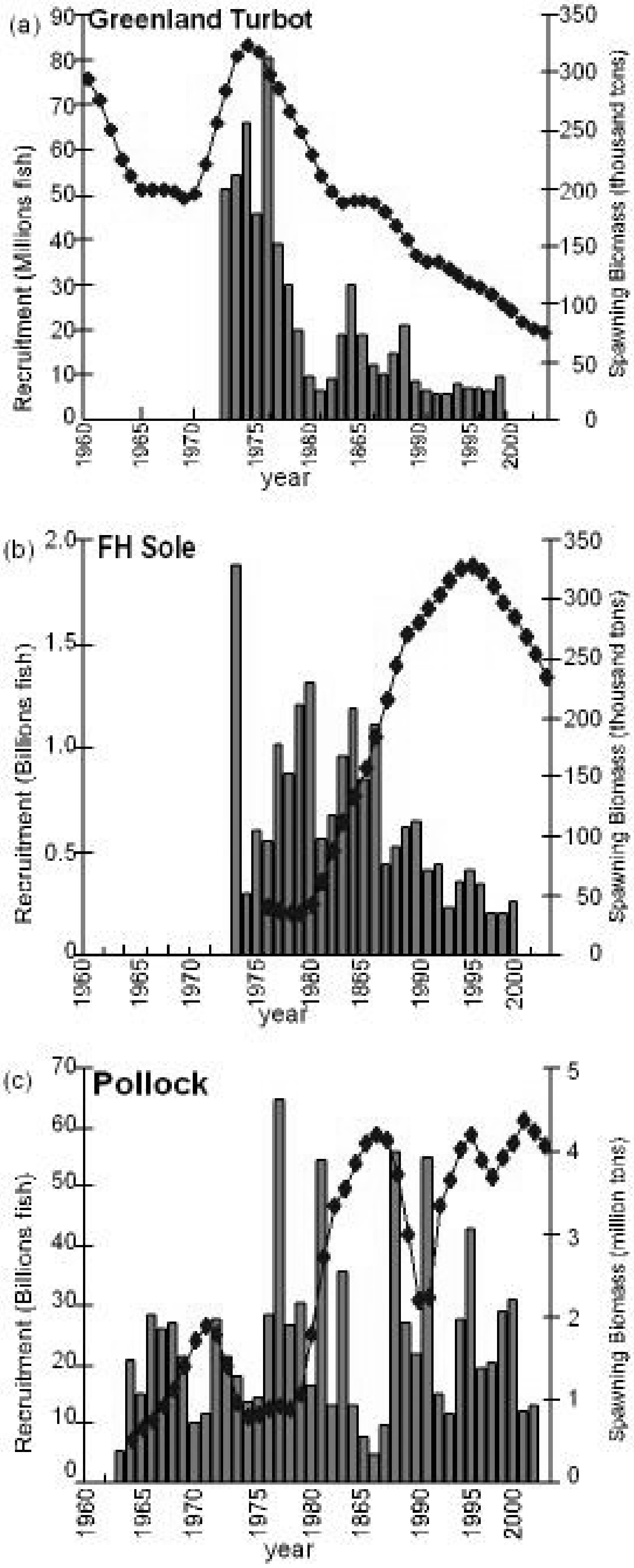


Figure 3


(a)
Greenland Turbot
Recruitment (Millions fish)
Spawning Biomass (thousand tons)
0
10
20
30
40
50
60
70
80
90
0
50
100
150
200
250
300
350
1960
1965
1970
1975
1980
1865
1990
1995
2000
year
(b)
FH Sole
Recruitment (Billions fish)
Spawning Biomass (thousand tons)
0
0.5
1.0
1.5
2.0
0
50
100
150
200
250
300
350
1960
1965
1970
1975
1980
1865
1990
1995
2000
year
(c)
Pollock
Recruitment (Billions fish)
Spawning Biomass (million tons)
0
10
20
30
40
50
60
70
0
1
2
3
4
5
1960
1965
1970
1975
1980
1865
1990
1995
2000
year

Bioclimatic mapping in Finnmark, Northern Norway, using Landsat TM/ETM+ land cover data

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The climate in Norway shows great variations. From its southernmost point, Lindesnes, to its northernmost, North Cape, there is a span of 13 degrees of latitude, or the same as from Lindesnes to the Mediterranean Sea. Furthermore we have great variations in received solar energy during the year. The largest differences we find in Northern Norway, having midnight sun in the summer months and no sunshine at all during winter. The rugged topography of Norway is one of the main reasons for large local differences over short distances. When working out climatic maps temperature, precipitation, wind, radiation and accumulations of snow, combined with variations in the terrain are important parameters to be taken into account. Most of these parameters are recorded at meteorological stations distributed all over the country. However most of the meteorological stations are located to the lowland, and the distance between them are often long. In Northern Norway, few meteorological stations with their punctual measurements make extrapolation and climatic modelling in such areas quite a challenging task.

To predict the future climatic diversity, knowledge of the current climatic diversity is needed. Climate models at local and regional levels have to deal with a complex set of interactions between surfaces and the atmosphere, requiring many simplifications. Two approaches have recently been developed using plant species and vegetation types as input for climatic modelling. Karlsen & Elvebakk (2003) developed a method using indicator plants to map local climatic variation. This method was developed further using indicator vegetation types, and has a potential for bioclimatic mapping of regional climate (Karlsen et al. 2004). In these methods, plants and vegetation types are defined as temperature indicators based on their total distribution patterns. Their indicator values and quantitative recordings are combined in an Index of Thermophily. These Index values show high correlations with temperature data collected in field, and hence reflect the climatic conditions. Both methods have a spatial resolution of 500x500m. The floristic-based method relies on quantitative field recordings of each indicator plant species within squares of 500x500 meters. The method is time consuming and is though limited for small areas. The vegetation-based method highly relies on the quality of the vegetation map. Today methods for vegetation mapping based on satellite data are highly developed. The mapping process involves several operations including spectral classification, class interpretations, contextual correction of classes using ancillary data, and vegetation analysis of each class. When working out vegetation maps for large areas a mosaic of images are to be created constituting a seamless map covering the whole study area.

In this presentation climatic modelling at two different scales are demonstrated, respectively a local scale mapping at the peninsula Varangerhalvøya and a regional mapping comprising the whole Finnmark County, Northern Norway (Fig. 1). On Varangerhalvøya peninsula both methods are tested out and evaluated with respect to degree of coincidence. The test areas are outlined in Figure 1. In the floristic-based method all species within 500 sq. meters are recorded and related to a Floristic-based Index of Termophily. In the vegetation-based method vegetation units derived from classified Landsat TM images are evaluated with respect to climatic demands. The circumboreal-/arctic distribution patterns of the recorded vegetation units and the units high frequency and dominant species, are compared with summer temperatures. The mapped vegetation types are grouped according to minimum bio-temperature demands and assigned indicator values. The indicator value and degree of cover of each thermophilous vegetation types, of each 500 x 500 m study units, are combined into a Vegetation-based Index of Thermophily.

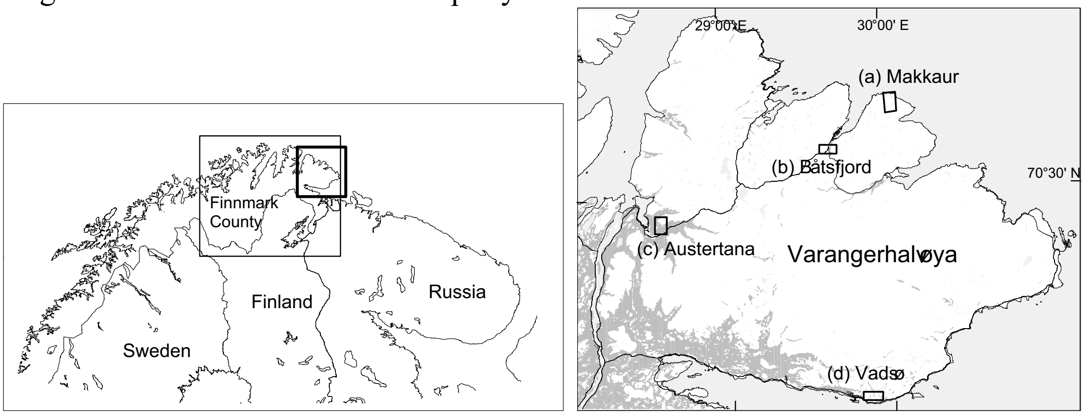

Figure 1. Map of northern Fennoscandia (left) and the Varangerhalvøya peninsula (right) showing the four study subareas.

On Varangerhalvøya peninsula the Index values from both methods showed correlation values (r^2) with ground temperature measurements in the range of 0.79 - 0.90 (Karlsen et al. 2004). The results show climatic gradients with temperatures increasing from the cold coast towards the interior, from wind-exposed convex hills towards wind-protected valleys, and from mountains plateaus towards south-facing lowlands (Fig. 2). The bioclimatic map are converted to a map of local bioclimatic zones, and the northeastern most study area at the coast is related to the arctic shrub tundra zone (ASHTZ). The bioclimatic maps in Figure 2 cover 52 km^2 of the Varangerhalvøya peninsula.

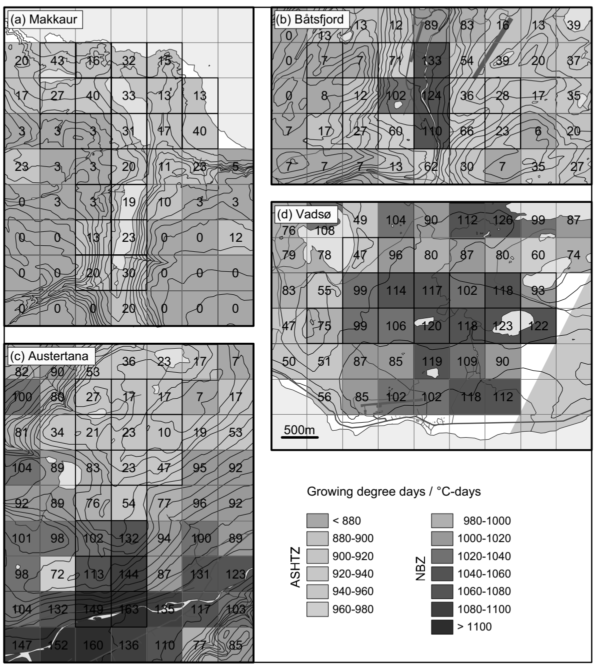

Figure 2. A bioclimatic map of the study areas on Varangerhalvøya peninsula. The numbers are the Modified Vegetation-based Index of Thermophily values of the study units. The Index values are related to growing degree days of a normal year, and the 13 colour codes are each representing a range of 20 growing degree days, or a range of 12.5 Index values. The values are also related to the northern boreal zone (NBZ) and the arctic shrub tundra zone (ASHTZ).

The vegetation map needed for bioclimatic mapping of the whole Finnmark County is shown in Figure 3A (Johansen et al. 1995). The vegetation map, containing 27 vegetation classes, covers an area of 49 000 km^2. Finnmark County is a meeting point for different climatic, geological and phytogeographical elements. The western fjord-zone is considered having the best conditions for plant growth, containing bilberry and low-/tall herb birch forests along hillsides and grey alder forests on valley floors. Some of the inner fjords also contain Pine forests. However the distribution of Pine forests is most common in the Pasvik and Anarjokka area, where these forests are the northernmost outposts of the boreal conifer forest region. A characteristic feature of the western parts of the area is the mountain range running from southwest to northeast all the way to Varanger Peninsula. On eastern side of the mountains we have an undulating landscape constituting the Finnmarksvidda plateau. The climate here is continental, with cool winters, fairly warm summers, and small amount of precipitation during the year. The small amounts of snow on the eastern side of the mountain range, favourable vegetation types like heather and birch woodlands, while snow patch communities are more or less absent. On Finnmarksvidda plateau a high lichen cover and content originally characterize the heather and woodland vegetations. Today lichen resources are highly depleted for large areas due to heavy grazing pressure. The northernmost parts of the area are regarded as parts of the southern arctic sub-zone. These areas are influenced by the cold Barents Sea, which gives rise to harsh climate conditions. Summer temperatures below 10 ^{o}C and low winter temperatures characterize these areas.

When converting vegetation classes in the vegetation map into termophily indexes the units were resized from 500 m to 1 km and the Index values were compared with the bio-temperature (sum of monthly temperatures above 0 °C) from all the climatic stations in the county. Thereafter the Index values were related to bio-temperature and the bioclimatic zones. A preliminary bioclimatic map of the Finnmark County is shown in Fig. 3b.

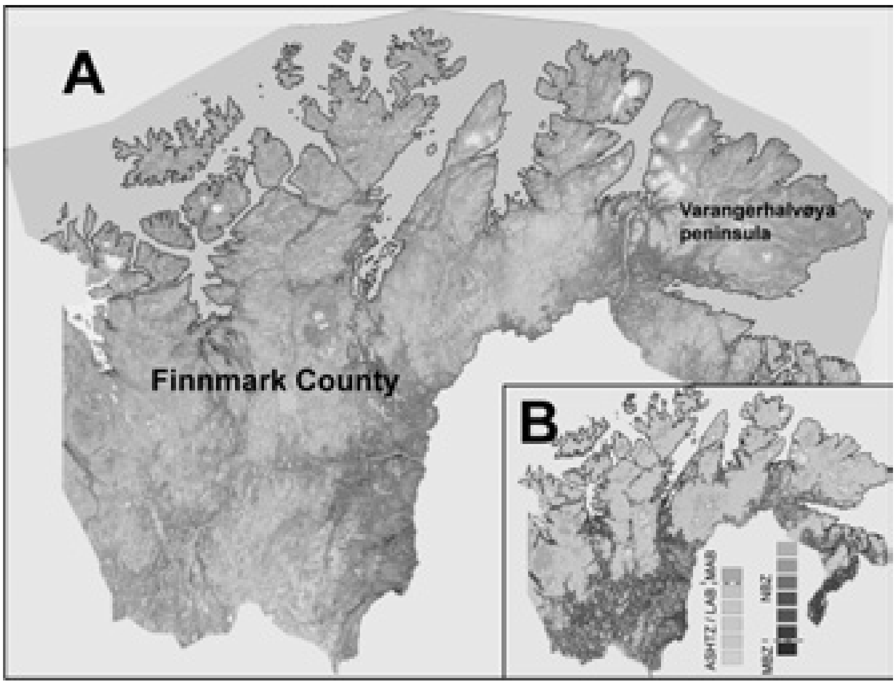

Figure 3. (A) Vegetation map of the Finnmark County based on Landsat TM/ETM+ data. Areas coloured in green represent forests, areas in white are lichen heaths and woodlands, areas in blue are water bodies, pale blue areas are bogs and mires, while areas coloured in orange are heather vegetation without lichen cover. Sparsely vegetated areas are coloured in pink. Mountain areas are coloured in violet. (B) A preliminary bioclimatic map where the Index values are related to the middle boreal zone (MBZ), the northern boreal zone (NBZ), the low alpine belt (LAB), the middle alpine belt (MAB), and the arctic shrub tundra zone (ASHTZ).

Twenty of the 27 mapped vegetation types (Fig. 3a) were defined as thermophilous and contribute to the Index value. However, the grouping of the vegetation types according to their minimum bio-temperature preferences were connected with uncertainty, and further vegetation analysis of each class is needed to identify high-frequency thermophilous species and thereby a better grouping. In addition most of the mapped vegetation types has a potential to further sub-divisions to sub-units with different temperature demands. Despite the future challenges our preliminary map seems reasonable, and has a much higher spatial and climatic resolution compared to previous bioclimatic maps dividing areas into vegetation zones and sections (Tuhkanen 1980, Ahti et al. 1968, Hämet-Ahti 1981, Dahl et al. 1986, Oksanen & Virtanen 1995, Moen 1999).

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Life History Traits of Arctic Charr and Environmental Factors: Local Variability and Latitudinal Gradients

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Introduction

Arctic charr (*Salvelinus alpinus*) is the only Arctic freshwater fish species that has a circumpolar distribution, as well as exhibiting the widest latitudinal range and occurring farthest to the north, to ca. 85 °N latitude. It is also one of the most plastic salmonid species in terms of life history tactics, as well as in morphology, genetics and use of resources (Behnke 1984; Smith & Skúlason 1996; Jonsson & Jonsson 2001; Klemetsen et al. 2003).

In this presentation, the focus is on life history traits of Arctic charr populations in relation to environmental variables of lake ecosystems. The data is derived from the literature (Johnson 1980; Barbour 1984; Sparholt 1985; Venne & Magnan 1989), the NORLAKE-database (Jeppesen et al. 2002; Malmquist et al. 2002) and the ESIL-database (Ecological Survey of Icelandic Lakes, Malmquist et al. 2000). The data covers a latitudinal range of ~ 40 degrees and includes Arctic charr populations from N-America, Greenland, Iceland, the Faroese Islands and Great Britain.

Arctic charr in Iceland – local variability

Multivariate analysis of Arctic charr in Icelandic lakes, including resident and migratory populations, demonstrates that life history traits of Arctic charr are highly variable and associated with several ecological features of the lakes. Lake depth, negatively associated with lake temperature, is a prominent factor influencing Arctic charr life history, generally indicated by faster growth, greater maximum size and better condition factor, but shorter longevity of fish in shallow to medium deep lakes, as compared to large and deep lakes. Lake productivity, as indicated by conductivity, along with origin of lake water also affects life history traits. In spring-fed and run-off lakes characterized by relatively high conductivity Arctic charr grow in general faster and are in better condition than fish in less productive lakes of glacial and run-off origin. Further, the presence of brown trout (*Salmo trutta*) may result in reduced longevity and growth rate of the sympatric Arctic charr.

Analysis of the Icelandic database also reveals that in some lakes, primarily deep and large ones where Arctic charr is the only salmonid species present, the population is split into two, rarely more, different growth forms. One form is small, slow growing and early maturing, and the other large, fast growing and late maturing. Often, the sub-populations also differ in trophic morphology and resource use, with the one morph, either small or large, characterized by silvery coloration, terminal mouth position, pointed head and streamlined body form and primarily exploiting zooplankton and fish in open water habitats. The other morph, usually small, is dark in coloration, with sub-terminal mouth, chubby body form and feeds on zoobenthos mainly in the littoral niche.

Differentiation of Arctic charr into two or more specialized sympatric sub-populations is recognized throughout the northern hemisphere (Behnke 1984; Jonsson & Jonsson 2001), and has a great bearing on the concept of biodiversity in species poor lake ecosystems at northern latitudes. One of the best examples of such a biological diversification is to be found in lake

Thingvallavatn, Iceland, where four highly different Arctic charr morphs coexist (Sandlund et al. 1987, 1989; Jonsson et al. 1989; Malmquist et al. 1992; Snorrason et al. 1994; Skúlason et al. 1996).

Arctic charr – latitudinal gradients

Comparison of Arctic charr populations along climate gradient from Greenland (annual mean air temp. ~ -10 °C), through Iceland (annual mean air temp. ~ 3 °C), the Faroese Islands (annual mean air temp. ~ 7 °C) and to Great Britain (annual mean air temp. ~ 7.0 °C) reveals that longevity, age at maturity and maximum size of Arctic charr increase, but growth rate decreases, as latitude increases. This complies with a north-south latitude variation in life history traits observed for landlocked Arctic charr in Arctic Canada and N-USA, covering lakes from 75 °N to 43 °N latitude (Venne & Magnan 1989).

The life history-latitude relationship for Arctic charr demonstrates great developmental plasticity of the species, making it highly adaptable to a range of lake environments. Slower growth rate and later age at maturity at higher latitudes are probably determined mainly by the short growing season, low temperature and variability in resources, and may be expected to reduce fecundity of the fish. However, congruent with optimization theory (Schaffer 1974; Stearns & Crandall 1984), this would be balanced by greater longevity of the fish, permitting repeated spawning, hence increased reproductive output.

Climate change and Arctic charr

Temperature increase in freshwater ecosystems at higher latitudes may be expected to have great impact on a cold-water species such as Arctic charr. Distributional range will shift towards north and probably become narrower, spawning grounds may diminish, susceptibility to diseases increase and interspecific competition increase due to invasion of new, more heat tolerant fish species. For life history traits and other traits associated with biodiversity, such as morph formation, the overall result may be expected to be reduction and loss of Arctic charr populations, hence diminished biodiversity at the global scale.

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The Problem of Study and Preservation of Bioresources of Reserves in the Russian Far East

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The research into Earth's flora and fauna is a matter of topical interest in XXI century. The significance of reserves in preservation of genetic fund of animals and plants increases in conditions of anthropogenic influence. The solution of ecological problems, optimization of preserved nature aquatories, creation and development of the unique international strictly reserved nature complexes are extremely important (Kukharenko L.A., 1999).

Russian Far East is a unique region on a joint of North-American, Euro-Asian and East-Asian provinces. It is notable for its specific geological history, various soil and climate circumstances and rich original flora and fauna. Although the area occupied by reserves is relatively small, the biotope and landscape diversity of their territories is so extraordinary to fairly represent the variety of flora and fauna of the entire Russian Far East.

The study of animals and plants took place in "Kedrovaya Pad", Ussuriysky, Bolshekhekhtsirsky, Lazovsky and other reserves, also science issues were published (Flora, 1972; Flora, 1978; Flora,1986; Flora, 1998; Flora, 1999; Flora 2002). The researchers of vascular plants, mosses, lichens, funguses and algae mark the wealth and multiplicity of the explored flora. The Southern regions of the Russian Far East bear great floristic similarities to the South-Eastern Asia, so as the Northern – to the North American flora. Many representatives of Far Eastern flora have wide areas. Most of them are met in Europe, North and South America and Asia. The reserved flora has abundance of rare, endemic and relict species, known in Russia only from a few whereabouts in the South of Far East.

It is impossible to imagine forest biogeocoenoses without the participation of algae. They are everywhere: on rocks and barks, in soil and water streams, in lakes and pools. And, as water-inhabiting algae, mainly of the Far East reserved territories are studied well, the soil algae, especially of the forest coenoses are scarcely touched by researches. Thereto, its studying is extremely important at theoretical, as well as practical aspect (Kukharenko L.A., 2001).

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Using Integrated Management and GIS Analysis to Understand Impacts and Adaptation to Climate Change for Fish and Marine Mammals in the Canadian Beaufort Sea

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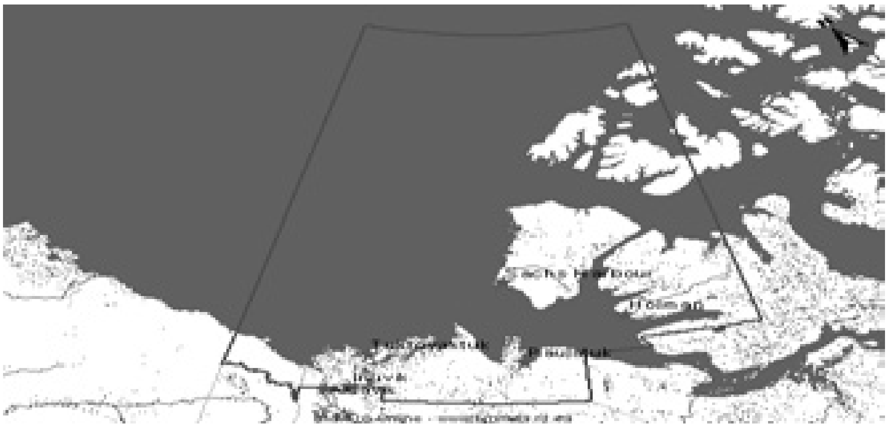
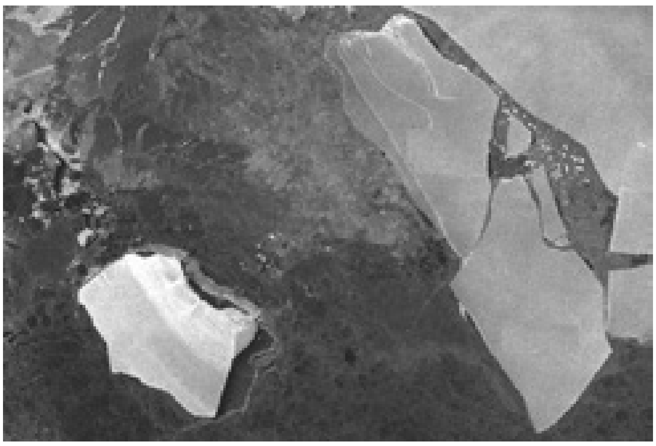
1. Introduction

Based on existing scientific research, the Beaufort Sea Project for Climate Change examines climate change and impacts on fish and marine mammals in the Canadian Beaufort Sea region, and the management of these species by the Fisheries Joint Management Committee and other government agencies and departments. The research identifies impacts of climate change and interactions with other environmental factors, tries to illustrate with GIS analysis some of these impacts and interactions, and begins the development of interactive web-based communications strategy to discuss results and recommend adaptive management strategies.



Inuvialuit Settlement Region. Original graphic taken from the BMMDA website. www.bmmda.nt.ca

2. Methodology



Climatic impacts for the Canadian Beaufort Sea include changes in ice cover and thickness, break-up and freeze up for the Mackenzie River, and atmospheric and ocean circulation; and potential interaction between climatic changes and air and marine contaminants. One focus for the research and GIS analysis is the inter-related topics of climate change, transboundary airborne and water borne contaminants, changing ocean circulatory patterns, and future hydrology changes for the Mackenzie River. Another focus is the relationship between ice cover, climate change, and marine species that are ice-dependent in the Beaufort Sea.

In the Beaufort Sea, seals and polar bears depend on ice cover for habitat. Ringed seals are the major food of polar bears, and important species for traditional and subsistence hunting. While the Beaufort Sea beluga whale population is large and healthy, climate change may affect their feeding patterns, if nutrient changes occur, and migratory routes, as they appear to travel along ice edges.

In the early stages of the project, a literature review was conducted, and there was a consideration of the use of GIS analysis to explore relationships between climate change and contaminants, and impacts upon fish and marine mammals. GIS analysis was also used to explore relationships between the Mackenzie River watershed, ice cover in the Beaufort Sea, and fish and marine mammals. This included a GIS analysis of relationships between sea ice cover and movements of beluga whales, with additional analysis being completed using subsequently acquired data sets.

A website for the Beaufort Sea Project for Climate Change is being developed to communicate existing and future results of the research project. This website will include web-based applications to communicate and exchange information and observations on existing and future climate change in the Canadian Beaufort Sea, relevant links to further information, data bases, and organizations; and information on future related research under the Project.

3. Discussion

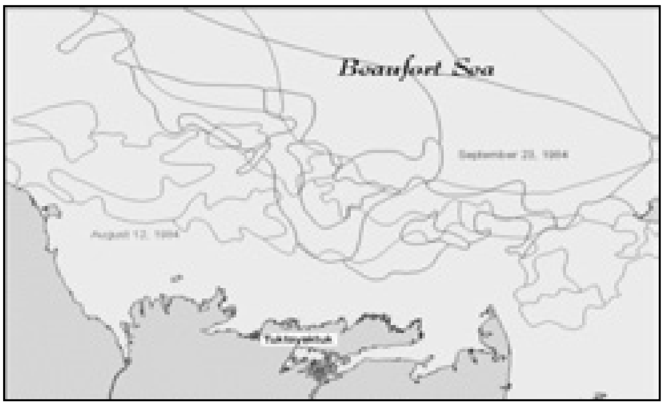
a) Integrated Management Approaches to Climate Change

For the Project, there is a general integrated management approach under the project, as well an examination of specific scientific and management issues. The general approach includes:

- An understanding of relevant laws and regulations, and the responsibilities of government departments and institutions, including the Fisheries Joint Management Committee.
- An understanding of the interests of major stakeholders, one of which is the Inuvialuit, with regard to understanding and responding to climate change in the Canadian Beaufort Sea.
- A discussion of integrated management and ecosystem-based approaches, and links to relevant documents and sites.

In addition to a more general approach, discussion is occurring under the Project for strategies to address specific scientific and management issues: introduction of alien species, sea ice edge and marine mammals, estuarine and coastal erosion, and climate change and contaminant interaction.

b) Application and Limitations of GIS Analysis



The GIS analysis explored the relationship between the retreat and advance of the sea ice edge and the movement of beluga whales. Aerial survey data for beluga whale movement collected from 1986 to 1997 was compared to digitized ice edge maps from the Beaufort Sea collected at the corresponding time period. An analysis of variance was performed on the data, accounting for within and between year variation by using year, month within year and day within month as independent variables. The effect of grouping (adults) versus (adults travelling with juveniles) was also tested. The results indicated that adults travelling with juveniles were generally observed closer to the ice edge than adults travelling alone. As well, it was observed that during years when the ice edge had retreat, the whales were generally farther from the land. Likewise, during years of advance, the whales were closer to the land.

These spatial trends have definite implications for climate change and its impact on the advance and retreat of the sea ice edge. The changing boundaries of the sea ice indicate parallel changes to movement patterns of fish and marine mammals. Due to a lack of detailed data, more research must be conducted to ensure a comprehensive evaluation of the relationship between ice edge changes and marine mammals. Using current satellite telemetry data, further analysis will be performed and results posted on the website. As data becomes available, both spatial and temporal patterns in the relationships between climate change, sea ice flux and marine mammal behaviour will become more apparent.

In the current stage of the Project (Stage 3), reports and GIS analysis will focus on important species that are disproportionately affected by climate change and contaminants - such as beluga whales, seals and polar bears- that are of interest to communities and interests. There will be the parallel development of interactive GIS frameworks and web applications to enhance and deepen the communication and consultation process.

c) Communicating Impacts and Responses to Climate Change

Community consultation is an integral part of the implementation of the Project. Integrated management approaches will be used, in conjunction with geographical information systems and web-based applications, to discuss and communicate the impacts of climate change for fish and marine mammals, and their management in the Canadian Beaufort Sea. An interactive web-based application will organize and manage community and international concerns as well, as provide an access point to information on climate change in the Canadian Beaufort Sea for interested parties.

Proposed communication actions include:

- Beginning dialogue with and between government agencies through electronic, oral and written communications and web applications.
- Beginning dialogue with communities and people, including communicating evolving state of knowledge, and facilitating feedback to government agencies through web applications.
- A research database is being created to organize pertinent information for parties interested in climate change issues in the Canadian Beaufort Sea. Scientific and traditional knowledge studies, local, federal and international initiatives, academic and professional projects, and relevant contacts will be included.
- A forum for community concerns will allow visitor to the website to contribute their knowledge and experience to the database, and to search the input of other visitors. Current plans for this community forum include digital forms which will be submitted to the Project. The information will then be entered into the database, and organized by spatial relevance through a map-based interface.

4. Conclusions

The Beaufort Sea Project for Climate Change is in early stages of implementation Further GIS analysis, web-based applications and communications, and integrated management approaches are required. However, it is hoped the Project will develop into a model project for the regional understanding of the impacts of climate change, and the development of adaptive responses.

Acknowledgements

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Website, Beaufort Sea Project for Climate Change: Impact and Adaptation to Climate Change for Fish and Marine Mammals in the Canadian Beaufort Sea, www.beaufortseaclimatechange.com. This site contains all reports, GIS analysis, and poster and slide presentations for the Project.

Using Migration Counts from Eastern Canada to Assess Productivity of Arctic-breeding Shorebirds in Relation to Climate

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Introduction

Shorebirds form one of the principal components of the Arctic avifauna, inhabiting all zones, including Low, Sub- and High Arctic regions. Climate change is expected to be particularly pronounced in the Arctic, and thus has the potential to affect shorebird populations in a variety of ways, not only through changes in the weather itself (e.g., temperature, wind, snow cover, radiation), but through associated effects on habitat types and availability, and on food resources (especially in relation to the phenology of the birds' breeding cycles).

Few studies have been carried out documenting the effect of climate on breeding success of shorebirds in the Arctic, especially on a long-term basis, apart from those describing catastrophic breeding failure in response to severe weather events. Measurement of breeding success, in terms of flying young produced, is also notoriously difficult to do, owing to problems in following highly mobile broods over large distances and in determining how many chicks may eventually achieve flight and depart successfully from the Arctic.

Measurement of the number or proportion of juvenile shorebirds that are able to reach migration or wintering areas in relation to the number of adults coming south provides a less direct, but potentially highly useful, method for assessing shorebird productivity during the previous breeding season. It also has the advantage of providing a measurement of how many juveniles not only survived in the Arctic but also successfully carried out a migration to more southerly areas. This index may then be related to climate variables from the breeding grounds. Several methods are available for estimating "juvenile proportions". While catching shorebirds on the wintering grounds enables the birds to be aged directly from plumage characteristics, there are concerns that differential habitat use by the two age groups may produce biases in estimates of juvenile proportions. Similar considerations apply to observational studies where the birds are aged through plumage characteristics using telescopes. This present study explores another method, involving the estimation of proportions of juveniles in shorebird species during southward migration on the east coast of Canada. In many shorebird species, adults migrate before juveniles, and where the migration periods of the two age groups are adequately separated, it may be possible to estimate the relative numbers, or proportion, of juveniles coming through the area from counts made at migration sites. These proportions may then be related to climate variables from those regions of the Arctic from which the birds have come.

Methods

Count data were taken from the Maritimes Shorebird Surveys (MSS), in which volunteer observers count shorebirds at two-weekly intervals at sites in the Atlantic Provinces of Canada (New Brunswick, Prince Edward Island, Nova Scotia, and Newfoundland) during the period of southward migration (mid July to November). Between 1974 and 1998, some 372 sites were surveyed, of which 157 were covered in 2 to 24 years. Six species were selected for preliminary analysis, based on the anticipation that young and adults migrated south at different times: Red Knot *Calidris canutus,* Sanderling *Calidris alba,* Semipalmated Sandpiper *Calidris pusilla,* Ruddy Turnstone *Arenaria interpres,* Black-bellied Plover *Pluvialis squatarola, and* White-rumped Sandpiper *Calidris fuscicollis*. Proportions of juveniles were estimated as follows. For each species, data from all years were combined and mean counts calculated for each Day of Year. A plot of mean count again Day of Year was inspected and used to define migration periods, or windows, of adults and juveniles in cases where two peaks were distinctly visible. For each year, mean counts were then determined for each window, and the juvenile proportion calculated as juvenile proportion = juvenile mean/(adult mean + juvenile mean).

Weather data for all Arctic stations were obtained from Environment Canada. For the preliminary study, temperature, precipitation, and snow cover (at end of month) data for the months of June and July were used, covering all years of the study (1974-1998). Data were analyzed separately for eastern, central and western regions. Mean monthly values were calculated for each region for each variable for each year and used in an exploratory analysis to relate to juvenile proportions for those years.

Results and conclusions

Climate trends were clearly detectable over the study period. Regression analyses showed mean June temperatures increasing significantly in eastern and western regions (and borderline significantly in the central region), and mean June snow depth decreased significantly in eastern and western regions: there was no trend in June precipitation in the three regions. In July, mean temperatures trended significantly upwards in all three regions, though there were no relationships for snow cover or precipitation.

Proportions of juvenile birds appearing in eastern Canada were significantly correlated with a variety of climate variables during June and July from different parts of the Arctic. Significant results ($p<0.05$) included : Red Knot: negatively with eastern June snow cover; Sanderling: positively with western June temperature, negatively with central July snow cover; Semipalmated Sandpiper: positively with central July temperature; Black-bellied Plover: positively with eastern and central June and central July temperatures, negatively with eastern June snow cover; and White-rumped Sandpiper: positively with western June and July snow, and negatively with western June and eastern July temperatures.

Although these studies are essentially correlational in nature, those relationships that were statistically significant were clearly biologically meaningful. Consideration of the breeding range of each species shows that the weather variables that are significantly correlated with juvenile proportions generally occur in Arctic regions which are the likely breeding origins for a particular species. Furthermore, climate variables that are significantly correlated are generally known to affect shorebird breeding schedules or success (e.g., June temperatures, snow depth) and occur in both nesting seasons (June) and brood rearing seasons (July). These parts of the season are where effects of climate are most likely to be felt by shorebirds, as they come at critical points of the reproductive effort, either during egg formation and incubation, or during brood rearing, when chicks are small and vulnerable to weather events. Significant correlations were found for five of the six species tested (and borderline relationships ($0.05<p<0.1$) were found for the Ruddy Turnstone), and all correlations were as predicted (e.g., positively related to temperature, negatively related to snow cover or precipitation), with the exception of White-rumped Sandpiper.

These results clearly indicate that climate has a demonstrable and measurable effect on the breeding success of shorebirds, and that methods to examine these effects can be developed at sites remote from the breeding grounds themselves.

Long-Term UV-B Exposure Study on Peatland Ecosystem in Northern Finland

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Effects of increasing UV-B radiation on the functioning of the peatland ecosystems have so far received little attention. Short-term microcosm experiments have shown that enhanced UV-B can alter pigment contents and membranes of the mosses (*Sphagnum* spp.), structure of the cotton grass (*Eriophorum vaginatum*) and the fluxes of CO_2 and CH_4 between the peat and the atmosphere. To verify the results in a more natural setting, we started a long-term experiment at a natural peatland site in Sodankylä.

In our UV-B experiment on an oligomesotrophic flark fen (Sodankylä 67º22'N, 26º38'E) study plots are exposed to enhanced UV-B radiation for several growing seasons, started in the beginning of June 2003. The UV-B exposure is applied with a modulated system in which the natural solar UV-B is continuously monitored and a constant proportional (46%) supplement of UV-B is provided by UV lamps. The UV-B experiment consists of a total of 30 plots (120 x 120 cm) randomly allocated to UV-B treatment, UV-A control and ambient control plots (n=10). Through the growing season methane dynamics is studied using a static chamber method and in the winter time we use so called snow gradient method. All gas samples are analysed in Kuopio by a gas chromatograph equipped with FID. Plant samples are taken for microscopic and pigment analysis. Also membrane permeability tests are made and growth parameters of sedges are monitored.

The results from the first study season under supplement UV-B radiation did not show drastic changes in the functions of the peatland ecosystem. UV-radiation did not significantly change typical methane fluxes. The highest fluxes 130 mg CH_4 m^2 d^{-1} were measured in the end of July. Snow gradient measurements taken from UV-exposed study plots indicate some changes on winter time methane fluxes. Number of *Eriophorum russeolum* leaves in study plots increased due to UV-B radiation, but no clear effects on stomatal density was observed. UV-B related pigments will be analysed from the plant samples. The analysis consists both soluble and cell wall related pigments. The results so far confirmed our hypotheses that possible changes on northern peatland ecosystem cannot be seen after single growing season.

The Influence of UVB Radiation on Lake Ecosystems of the Canadian High Arctic

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Introduction

The depletion of the ozone in the stratosphere raised strong concerns about the effects of increased ultraviolet-B radiation (UVB; 280 – 320 nm) levels on living organisms, including those inhabiting aquatic environments. Polar aquatic ecosystems, especially in Antarctica, have been of particular concern since ozone-related UVB increases have been the greatest in these regions. Unlike Antarctica, the Arctic region comprises many freshwater ecosystems (i.e. lakes, ponds, wetlands and rivers) that are of ecological importance to many organisms including migratory species. Over the Arctic, stratospheric ozone thinning has shown large interannual variability and UVB levels have been estimated to be 20-40% and 10-20% higher during spring and summer months respectively than those for the late 1970s. However, tropospheric warming due to climate change will cause decreasing stratospheric temperatures and a greater depletion of the stratospheric ozone is anticipated. Already, greater Arctic ozone losses than predicted have been observed over the last decade during record low stratospheric winters, which resulted in major increases in UVB levels during localized events of severe depletion.

The predicted climatic changes will also change underwater exposure to ultraviolet radiation (UVR) in Arctic freshwaters by decreasing snow and ice cover duration and altering levels of dissolved organic carbon (DOC), the principal attenuator of ultraviolet radiation in freshwaters. Although there has been an increase in research related to the effects of UVB on aquatic organisms, studies on the impacts of UVB in sub-Arctic and Arctic aquatic ecosystems have only recently begun in the late 1990s mainly on marine organisms, with very few studies on freshwater systems. This paper is presenting two studies on the effects of enhanced UVB levels on planktonic organisms of Canadian High Arctic lakes. In the first study, we assessed the long-term effects of a moderate increase in UVB levels on the planktonic community, including the microbial food web, of a Canadian High Arctic lake using *in situ* mesocoms. In the second study, we evaluated the sensitivity of phytoplankton productivity (quantity and quality) from clear (low-DOC) High Arctic lakes to enhanced UVB radiation after short-term exposure under different light intensities.

Methods

For the first study, square-shaped mesocosms (3 m wide, 3 m deep and open at both ends to allow natural exchanges with the overlying atmosphere and the littoral sediments) were placed in the nearshore part of Two Basin Lake that were exposed for 27 days to either ambient sunlight or artificially enhanced UVB levels. The UVB enhancement supplied when the lamps were on was about 50% higher than ambient levels, but the daily UVB dose (kJ m^{-2} d^{-1}) was only between 4 to 20% greater, depending on the weather conditions. TBL is a small (0.15 km^2), fishless, and oligotrophic lake located in the Fosheim peninsula on Ellesmere Island (79°55.5'N, 84°40'W, Nunavut, Canada). Due to the surrounding environment, lakes in that area have unusually high concentrations of colored dissolved organic materials, thus high

UV attenuation coefficients (e.g., depth of 1% surface UVB estimated to be only 0.7 m in Two Basin Lake).

For the second study, the sensitivity of phytoplankton productivity to high solar irradiance and enhanced UVB levels were assessed for nine lakes located in the Resolute Bay area (74°15'N, 94°50'W) on Cornwallis Island (Nunavut, Canada). These lakes have low DOC levels (< 4 mg L) with estimated UVB attenuation coefficients (K_dUVB) ranging from 0.2 to 2.5 m^{-1}. Phytoplankton productivity was measured using the ^{14}C-bicarbonate method. For each lake, the ^{14}C-inoculated water samples were placed in a waterproof incubator and were exposed to 6, 25, 50 and 100% of incoming solar radiation under ambient or enhanced UVB levels. UVB levels were enhanced by using UVB lamps that were erected above the incubator, which increased levels by 20% to 100% depending on the time of day, the presence of clouds, and on the level of incoming solar UVB radiation. After 2 to 24 hours of incubation, total phytoplankton productivity and the size distribution of phytoplankton productivity i.e. of picoplankton (0.2 - 2 µm), nanoplankton (2 - 20 µm) and netplankton (> 20 µm) were calculated. The incorporation of ^{14}C into low molecular weight (LMW) metabolites, lipids, polysaccharides and protein were also measured for five of the lakes.

Results

For the mesocosm experiment, the overall effects of enhanced UVB levels on all the variables measured are shown in Table 1. Although the productivity and biomass of phytoplankton were unaffected, the community size structure of phytoplankton changed significantly in the mesocoms exposed to enhanced UVB levels, with an overall reduction in small phytoplankton (i.e. picoplankton) and an increase in productivity by bigger cells. Generally, there was an increase in the abundance or activity of the heterotrophic microbial food web and zooplankton in the enhanced UVB treatment compared to the ambient UVB treatment. Within the zooplankton community, the cladocerans and rotifers were positively affected while the copepods were negatively affected in the enhanced UVB treatment.

For the second study, the overall effects of enhanced UVB levels on phytoplankton productivity, size distribution of phytoplankton productivity and the allocation of carbon into macromolecules of the nine lakes studied are summarized in Table 2. Results showed that phytoplankton performed poorly under high solar radiation and enhanced UVB levels further reduced their productivity. However, the negative effects of enhanced UVB generally decrease with decreasing levels of incoming irradiance, with usually no effects detected at 6% level of solar radiation. The contribution of the smallest size fraction (i.e. picoplankton) to productivity decreased or was unaffected after exposure to enhanced UVB levels while the contribution of the larger cells (i.e. netplankton) usually increased. For the allocation of newly fixed carbon into the major macromolecular classes, both the protein and polysaccharide fractions usually decreased with UVB exposure and photosynthate would remain or accumulate in the low molecular weight pool. The lipid fraction was in general unaffected (or slightly higher) after exposure to enhanced UVB levels and represented the most conservative and uniform class that accounted generally for about 20% of total carbon fixed.

Conclusion

With climate warming, stratospheric ozone depletion in the Arctic is expected to reach a peak between 2010 and 2020, about 10-20 years later than expected. Aside from influencing stratospheric ozone depletion, climate change is also projected to have an important impact in future levels of underwater UVR in freshwaters. Stratospheric ozone depletion only changes surface UVB levels while changes in DOC levels anticipated by climate warming will modify levels of both underwater UVA and UVB levels. Hence, it becomes important to learn more about the effects of UVR on aquatic organisms and the role of UVR in shaping freshwater ecosystems. From the mesocosm experiment, the high levels of DOC (which greatly reduce the penetration of UVB) combined with vertical mixing (which reduce the residence time of planktonic organisms in the surface layers) most likely protected the planktonic community from UVB damage. Furthermore, exposure to enhanced UVB levels may have resulted in an increase photodegradation of high molecular weight refractory dissolved organic matter into biologically available nutrients, which in turn could have stimulated heterotrophic processes and affected the abundance and species composition of zooplankton. Results from this experiment could be representative of many Arctic lakes in the future since lakes with higher DOC levels (similar to those from the Fosheim peninsula) are expected to become more common in parts of the Arctic region with climate warming. Meanwhile, from short-term assays on phytoplankton productivity, exposure to enhanced UVB levels could be detrimental to phytoplankton living in low-DOC waters and cause, for instance, an increase in photosynthetic inhibition, a shift towards more resistant species/cell sizes and change the biochemical composition/food quality of phytoplankton.

Table 1. Summary of the overall effects of enhanced UVB levels on all variables studied from the mesocosm experiment at Two Basin Lake. ns = no significant effect, + = positive effect, - = negative effect.

	Overall UVB effect
Chlorophyll *a*	ns
Total phytoplankton productivity	ns
Size fractionation of productivity:	
Picoplankton (0.2 – 2 µm)	-
Nanoplankton (2 – 20 µm)	+
Netplankton (> 20 µm)	+
Carbon allocation:	
Low molecular weight metabolites	ns
Lipid	ns
Polysaccharide	ns
Protein	ns
Heterotrophic bacterial abundance	ns
Heterotrophic bacterial activity	+
Picocyanobacteria (0.2 - 2 µm) abundance	-
Heterotrophic flagellate abundance	+
Total zooplankton (> 40 µm) abundance	+
Total zooplankton length	ns
Relative abundance of:	
Cyclop (adults)	-
Cyclop (nauplius)	ns
Daphnia	+
Diaphanasoma	+
Keratella	+

Table 2. Summary of the overall effects of enhanced UVB levels on total phytoplankton productivity (TOTAL), percent productivity of picoplankton (%PICO), nanoplankton (%NANO) and netplankton (%NET), and percent carbon allocated into low molecular weight metabolites (%LMW), lipid, polysaccharide (%POLY) and protein (%PRO) after short-term exposure in an incubator of water samples taken from nine lakes in the Resolute Bay area. ns = no significant effect, + = positive effect, - = negative effect, n/a = not available.

	TOTAL	%PICO	%NANO	%NET	%LMW	%LIPID	%POLY	%PRO
Barren	-	ns	ns	+	n/a	n/a	n/a	n/a
Black Char	-	ns	-	+	n/a	n/a	n/a	n/a
Char	-	-	+	+	n/a	n/a	n/a	n/a
Clear	-	ns	ns	+	+	ns	-	-
Meretta	-	-	ns	+	+	ns	-	-
North	-	-	+	+	ns	+	-	-
Resolute	-	ns	ns	-	n/a	n/a	n/a	n/a
Small	-	ns	ns	+	+	ns	ns	-
Tern	-	-	ns	+	+	+	-	-

Intense Feeding of *Calanus hyperboreus* on Arctic Autumn Bloom Propagated by a Record Minimum Sea Ice Extent in 2004

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Abstract

This study was initiated by the record northerly (82°N) location of the ice edge in autumn 2004, probably not observed since 1751. This opened up large areas normally ice covered for primary production, providing a luxus of food for large stocks of the Arctic herbivorous zooplankton. We studied the sea ice distribution, phytoplankton and ice-algae associations and zooplankton distribution using ice maps, photography, echo sounder, plankton nets, CTD - and fluorescence profiler. Over-wintering stages of *Calanus hyperboreus* were found in large numbers actively feeding on phytoplankton in the pack ice at 82°N, north of Svalbard. We conclude that the opening of large new areas for primary production above deep waters will increase the total production of this very energy rich copepod at the base of the Arctic food chain. This energy may be transferred further in the food chain increasing the stocks of higher trophic level animals such as fish, sea birds and mammals.

Introduction

This work was motivated by: 1) a record northward position of the ice edge in autumn 2004 2) high phytoplankton and ice algae biomass visible over large areas in the pack ice 3) the presence of large amounts of feeding *C. hyperboreus* in the surface waters. The extreme northerly location of the ice edge in autumn 2004 (Figure 1), with open water stretching from East Greenland to Franz Josef's Land, approximately along 82°N latitude has probably not been observed since 1751 (Figure 2). The period with reduced ice cover in this area lasted to approximately the 1780's and was followed by decades of heavy ice conditions with an autumn minimum ice edge at approximately 76-77°N. A marked retreat of the ice edge started in 1910, a trend that has continued until today. The ice edge has been recorded north of 81°N in the last century in the early 1960's, late 1980's as well as in 2002 (Vinje 1999, ACSYS, 2003, Serreze et al. 2003).

Results and Discussion

The yearly ice melt starts in the south west and blooms of phytoplankton propagate through the area, starting in the south western Barents Sea in April-May, continuing in the Laptev Sea in July-August, culminating in North Pole waters in August-September (Zenkevitch 1963).

The observation of large numbers of *Calanus hyperboreus* in net hauls (Figure 3) at Ice Station 1 and 2 was confirmed by echo sounding recordings. We suggest that this also is the case for the MIZ from East Greenland to Franz Josef's Land. We also observed large areas with high biomass of phytoplankton in leads with a chlorophyll maximum of 2-4 µg/l, and on the ice floes the sea water ponds had a brownish/ greenish coloration; infiltration layers of ice algae could be seen at sea surface and ice algae were observed under the sea ice (Figure 4). Such a situation presents to the large stocks of the Arctic herbivores an environment with a luxus of food over a vast area within a time span of weeks to months. The observation of green guts and well developed lipid sacks indicated active grazing and biosynthesis of lipid stores.

The carbon fixed through photosynthesis during the Arctic bloom is converted into large lipid stores by *Calanus hyperboreus* (Lee 1975). These high-energy lipids are then rapidly transferred further through the food chain in large amounts (Falk-Petersen et al. 1990, 2004), and the increase in lipid level from 10% of dry mass in phytoplankton to 50 - 70% in herbivorous zooplankton is probably one of the most fundamental specialisations in polar bioproduction. This lipid based energy flux is one of the primary reasons for the large stocks of fish and mammals in Arctic waters. We conclude that the opening of large new areas for primary production over deep waters which are core distribution areas for *C. hyperboreus,* will increase the total production of this very energy rich copepod. We further hypothesize that this increased production will be transferred throughout the food chain and increase the standing stock of marine animals on higher trophic levels.

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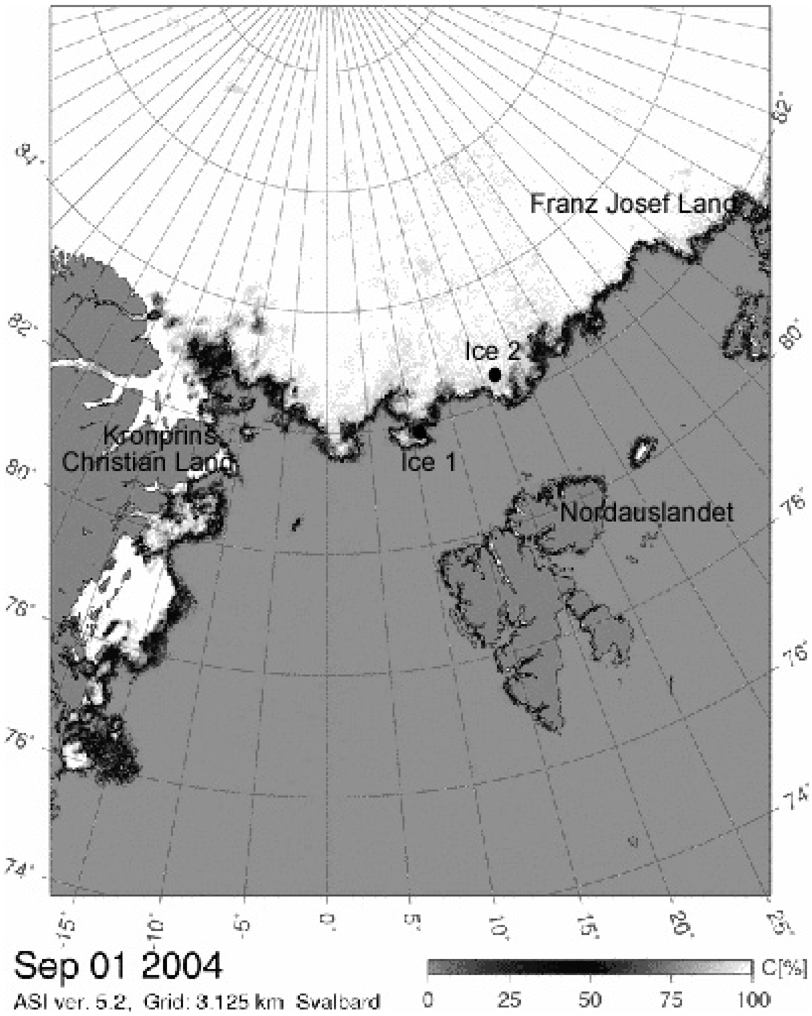

Figure 1. Map showing the ice edge and sampling stations in the Arctic Ocean north of Svalbard, August 2004. From ICEMON (Institute of Environmental Physics, University of Bremen).

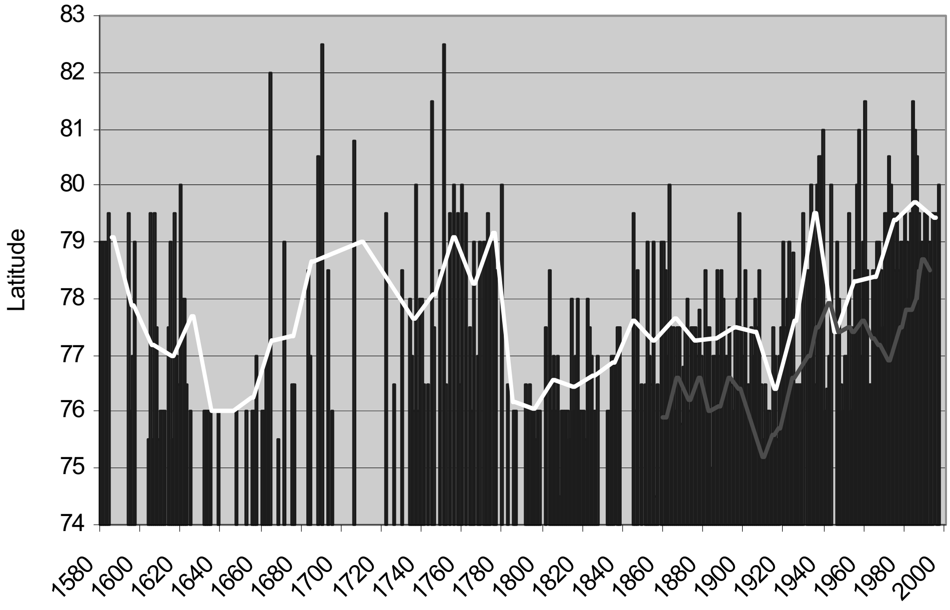

Figure 2. August ice edge between Svalbard and Franz Josef Land, 1580 to1998. From Vinje 1999.

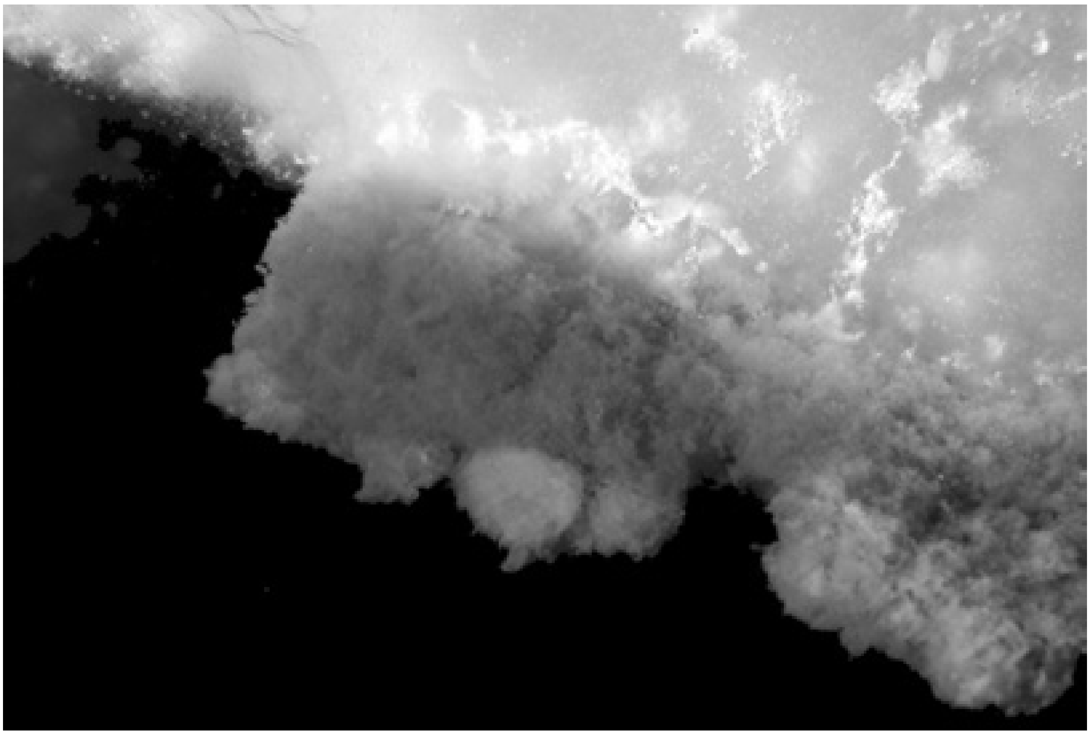

Figure 3. Photo showing ice algae attached to an ice floe.

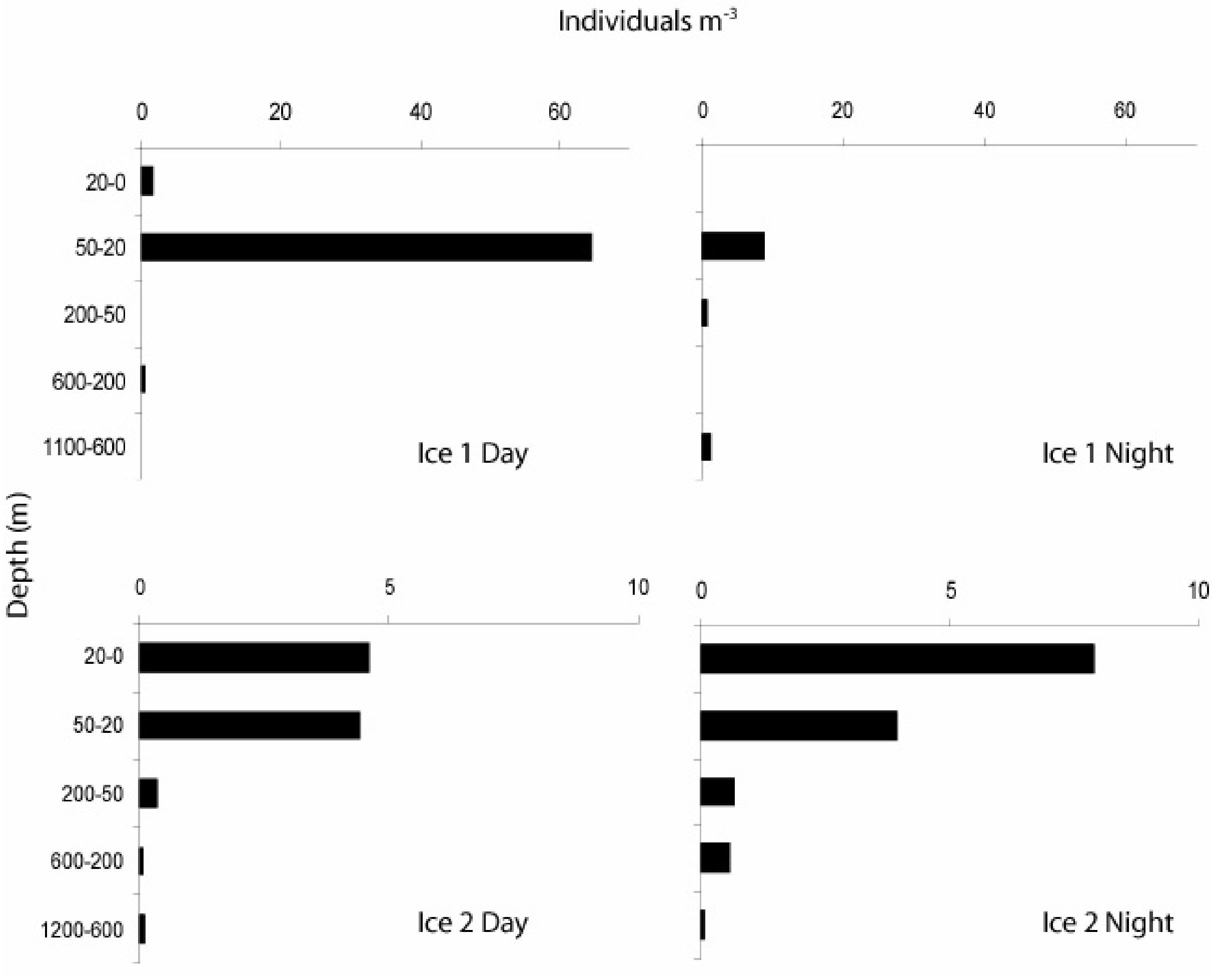

Figure 4. Depth distribution of *Calanus hyperboreus* in the upper 1200m.

Sustainable Use of Mountain Birch Forests in a Changed Climate

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Introduction

The mountain birch is a major constituent of the Fennoscandian subarctic forest ecotone with a large capacity for biomass production and CO2 binding. It has been investigated in many different ways, i.e. experimentally to find its temperature and light responses and its distribution and ecology has been thoroughly described. However, little is known about how much and in what ways human populations have used and intend to use the birch ecosystem culturally and economically. Large areas in northern Europe have been deforested by extensive cutting and grazing for centuries. Sheep, reindeer and red deer are important vertebrate herbivores in many upland areas, and their impact on birch has been significant. Pollen analysis show that many trees and shrubs like the mountain birch migrated to the coastal areas of northern Fennoscandia already about 6 000 B.C. Later the climate became colder, but the retreat of the birch forests is a result of many factors, both natural (climate, soil) and anthropogenic, such as overgrazing and cutting for fuel. Local populations, the aboriginal Sàmi and immigrant Scandinavian and Finnish settlers, have over long periods of time utilised this northern forests for hunting, fishing and herding as well as for agriculture, forestry, tourism and recreation.

One important objective is to obtain a better understanding on the interactions between humans and the birch forests, by focusing on the existing local knowledge of that environment, and document the historic and current use of birch forests by local residents and external users. There is a strong need for more basic knowledge of the system to predict the consequences of long-term climatic change for the interaction between insect outbreaks and mountain birch populations. These aims should be achieved in an interdisciplinary manner, combining productivity, herbivory and socio-economic studies, making it possible to formulate recommendations for future management schemes for sustainable development of the mountain birch forest ecosystem and improved quality of living in northern areas.

In order to investigate the objectives mentioned above, a 3-year (2000-03) EU-funded project "Human Interactions with the Mountain Birch Forest ECOsystem: Implications for Sustainable Development" (HIBECO) was initiated. The main outcome of the project was as follows:

Conclusions

1. Productivity of the birch forests.

Birch performance. The mountain birch forests are too low-productive to be of interest for traditional forestry. Tree biomass is about 10-30 tons per ha and the annual production 1.5 to 5 tons. About one third of the biomass production is wood (0.2 to 2.2 tons per ha and year).

Dry heath forests has a biomass and productivity roughly one third that of meadow forest types. Birch forests are usually dominated by relatively young trees, only a low proportion is older than 100 years. Different age classes dominate in different areas. The reason for this is recurrent outbreaks of various insects than can kill individual stems, local stands or in some cases even areas of several hundred hectars.

Soil and climate were found to be the most important factors determining the performance of northern *Betula pubescens* trees. Winter temperatures were also found to be the most important limiting factor for survival of the geometrid moth, *Epirrita autumnata.* Early leafing and monocormic birch provenances seemed to be preferred. Remote sensing studies and earlier investigations have shown substantial overgrazing by reindeer in northern Fennoscandia and by sheep in Scotland and Iceland.

Effects of climate change. In addition to the human impact due to overgrazing, logging and tourism, there has been a significant climatic shift during the last decades, resulting in warmer winters and a more humid climate. The removal of lichen cover by reindeer grazing has accelerated these vegetation changes. At Finnmarksvidda in northern Norway a change in vegetation over the last 40 years has been registered; blueberry (*Vaccinium myrtillus*) and the dwarf cornell (*Cornus suecica*) are currently more common than 40 years ago. In contrast, lichens preferred by reindeers have decreased in abundance. The reason for this change is believed to be a combination of a changed climate and changes in human use of these areas. Similarly, there has been an increase in the extent of the birch forests in some areas, for instance at Màze at Finnmarksvidda, Norway the coverage of mountain birch forests has increased by about 90% during the last 45 years, probably due to increased precipitation combined with higher temperatures and formation of ice crusts. Removal of lichen cover may cause more open soil, which in turn may result in better germination of many higher plants, for instance mountain birch.

Currently damages by extreme (winter and spring) temperatures are of relatively small and local importance only, but potentially this type of threat may be more important in the future with a changed climate. On the other hand, mountain birch show a large phenotypic plasticity regarding phenology and other characteristics. This may improve its ability to cope with a changed climate. In a transplant study the ability to adapt to different photoperiods and temperature changes was found to be higher in northern coastal birch provenances than in birch from more continental origin. These ecotypes seem to be more subjected to spring frost damages than before, because they lose their hardiness too early, leading to reduced growth during the following season.

2. Herbivory

Reindeer and sheep. The number of reindeer in northern Fennoscandia has undergone large spatial and temporal variation. Many recent studies indicate that pastures are overgrazed. However, some pastures are in good condition or only slightly damaged. The variability in numbers of reindeer and pasture conditions is resulting from variability in productivity and climatic conditions as well as different herding systems practised in different parts of northern Fennoscandia. A review of existing literature on experimental studies of reindeer grazing on different pasture components shows consistently reduction of lichen coverage in grazed areas However, the other pasture components exhibited highly variable responses to reindeer grazing. Birch tended to have lower coverage or biomass, lower height and lower seedling density in grazed areas. Grasses tended to have a higher coverage and biomass in grazed areas. In Iceland heavy grazing by sheep has even resulted in widespread erosion, not just vegetation damage, which can be very difficult to re-establish.

Experiments with simulated browsing as well as field studies during the HIBECO project showed that sheep grazing influenced all growth parameters, e.g. height, numbers of branches, leaves and shoots (long and short), canopy area and basal stem diameter. Strong browsing at late season was more detrimental to growth than winter browsing, but on the other hand induced growth of compensatory shoots.

Insects. Insects such as autumnal and winter moths rarely cause defoliation in southern latitudes. However, in some areas along the Scandinavian mountain chain they show rather regular cycles or outbreaks of varying amplitude. In the northernmost Finland *E. autumnata* defoliated birches in hundreds of square kilometres in 1965-66, The recovery of the birch forest has been very slow, partly due to overgrazing by reindeer, large areas remaining virtually treeless even about four decades after the damage. This has clearly decreased the possibilities for traditional livelihoods (reindeer herding, grouse hunting) in the area.

Cold winter temperatures (below –35°C) kill the eggs of autumnal moths and restrict outbreaks both geographically and locally. Higher winter temperatures would therefore increase the frequency of insect outbreaks in the continental areas but may not affect the defoliation risks in the oceanic areas. On the other hand, increasing summer temperatures may restrict the area and intensity of outbreaks due to increased pressure from the natural enemies of defoliating insects. Warmer summers would also enhance the capacity of birches to recover from damage. In addition to summer temperatures the recovery potential and regeneration rate of mountain birch forests depend on birch growth form and on grazing pressure.

3. Human interactions

Past and contemporary use of mountain birch resources. The research team completed more than 140 interviews with individual and institutional users of the mountain birch in northernmost Finland, Norway and Sweden in communities with Finnish, Norwegian, Sami and Swedish populations. The selection of interviews was left in the hands of local researchers and their counterparts in these communities. However, emphasis was put on including people representing the various economic activities such as reindeer herding, handicraft production, wage labourers as well as owners of recreational cabins and lodges in the regions. The interviews covered different aspects of mountain birch use, i.e. traditional use of birch for construction, firewood and handicraft, management practises and perception of birch forests.

In areas with recreational activities or heavy overgrazing by reindeer trampling damages may be a serious problem, in addition to the grazing impact. In a separate study long-term mechanical trampling, in combination with reindeer grazing was found to influence the structure and function of vegetation and soils.

4. Suggestions for a sustainable birch forest management.

In the Maze and Ohcejohka study areas the HIBECO project has revealed extensive overgrazing by reindeer, at the same time there has been an increase in the area and biomass of birch forests due to removal of lichen cover and climate change. Hence a less intensive grazing and a lower reindeer population should be achieved, to allow lichen growth.

However, more intensive cutting of birch for fuel should be possible, and this would tend to compensate for the loss of income on longer terms. In the Abisko study area the project and earlier studies have shown that tourism is an important source of income. However, the solution of existing conflicts between reindeer owners, tourism and environmentalists is a prerequisite for sustainable utilization of the birch forests in the region. In the Målselv area, however, there is still potential for more intensive use, due to lower grazing pressure. Sustainable reindeer herding indicates a carrying capacity varying from 2.5 reindeer/km^2 in northern Finland and Sweden where the animals graze also in summer, to 7.5 reindeer/km^2 in the winter grazing areas around Målselv. Although in most places tourism in the mountain birch forest today is the factor of strongest effect for man, also logging for an industrial purpose might be a factor for local income and employment. In Målselv in northern Norway industrial use of birch for particle board production per year during the last ten years has been 40 000 m^3, while birch used as fuel wood was 110 000m^3

Birch is also used for handicraft and furniture production, but in a small, although important scale.

Model results raises the question whether implementation of a so-called “scale-free” logging policy, which in the long run creates a forest mosaic with many small logging plots and fewer large ones, may be a better strategy to maintain or increase of the number of species (the biodiversity) of an area compared to traditional “scale-specific” logging where similar overall intensity of logging is constrained to a few larger plots totaling the same size. Modeling also indicates that a scale-free logging policy may favour the penetration of the forest by grazing animals. It is, however, too early to change the normally preferred policy today by taking out only single and scattered trees from the forest.

UV Radiation and Photoprotective Pigments in Scots Pine Saplings (*Pinus sylvestris* L.)

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Introduction

In the subarctic and Arctic ecosystems the plants may experience strong, but often short radiation stress at the start of their growing season due to ambient and reflected irradiance from the surrounding snow cover and can therefore be exposed to the direct effects of UV-B radiation (Ottander *et al.*, 1995; Gröbner *et al*. 2000). Many pigments play a significant photoprotective role in the plants. Carotenoids are long-chained compounds that include carotenes and xantophylls. They perform an essential photoprotective role in quenching triplet-state chlorophyll and scavenging singlet oxygen and other toxic oxygen species formed within the chloroplast. Xanthophyll cycle is a photoprotective mechanism involving two reversible reactions: light-dependent de-epoxidation of violaxanthin to zeaxanthin via antheraxanthin as an intermediate, and light-independent epoxidation of zeaxanthin to antheraxanthin and violaxanthin (Ottander *et al*., 1995). A unique characteristic of UV protecting pigments, flavonoids and related phenolic compounds, is that they absorb UV radiation, while simultaneously transmitting the visible PAR (photosynthetically active radiation) to the chloroplast-containing mesophyll cells within the leaf interior (Schnitzler *et al*., 1996; Jordan, 2002). The aim of this work was to study the effect of UV radiation on the photoprotective pigment metabolism in needles of Scots pine saplings at the subarctic.

Material and Methods

UV exclusion experiment was arranged with Scots pine (Pinus sylvestris L.) saplings during 2001-2002 on a randomized block design with four treatments, each replicated ten times, altogether 40 plots. The individual treatment exclosures (chambers) consisted of wooden frames with plastic covers adjusted over the whole sapling: (1) Control (a polyethene plastic filter) (2) UV-B-exclusion (a clear polyester filter) and (3) UV-B/UV-A exclusion (a clear acryl plate). The chamber structure, the daylight transmissions of all plastic filters and temperatures within the chambers were tested. The research also included (4) Ambient control plants that did not have plastic filter (Fig. 1) (Turunen *et al*., 2002). Soluble phenolics and xanthophyll cycle pigments were analysed by HPLC. The epoxidation stage (EPS) of xanthophyll cycle pigments was calculated as follows: EPS=0.5 antheraxanthin+violaxanthin/violaxanthin + antheraxanthin + zeaxanthin.

Results

Xanthophyll cycle pigments

There was a rapid increase in the concentration of violaxanthin and a decrease in zeaxanthin of Scots pine needles in April. The EPS (epoxidation stage) of xanthophylls (0.5A+V / V+A+Z) increased in April reflecting a conversion of zeaxanthin into violaxanthin. Significant, but transient changes in xanthophyll cycle pigments could be seen among the treatments (Fig. 2).

Soluble phenolics

Significant changes in soluble phenolics of Scots pine needles between the treatments could be observed. For example, the peak area of dicoumaroyl-astragalin is higher under UVB/UVA exclusion compared to the other treatments, but for unknown U2 compound it is smaller than in other treatments. Also, there is a trend for higher PMS (pinosylvin monomethylether) in UVB/UVA exclusion compared to the other treatments (Fig. 3).

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Fig. 1(a). UV exclusion experiment with Scots pine saplings in Sodankylä, Finland

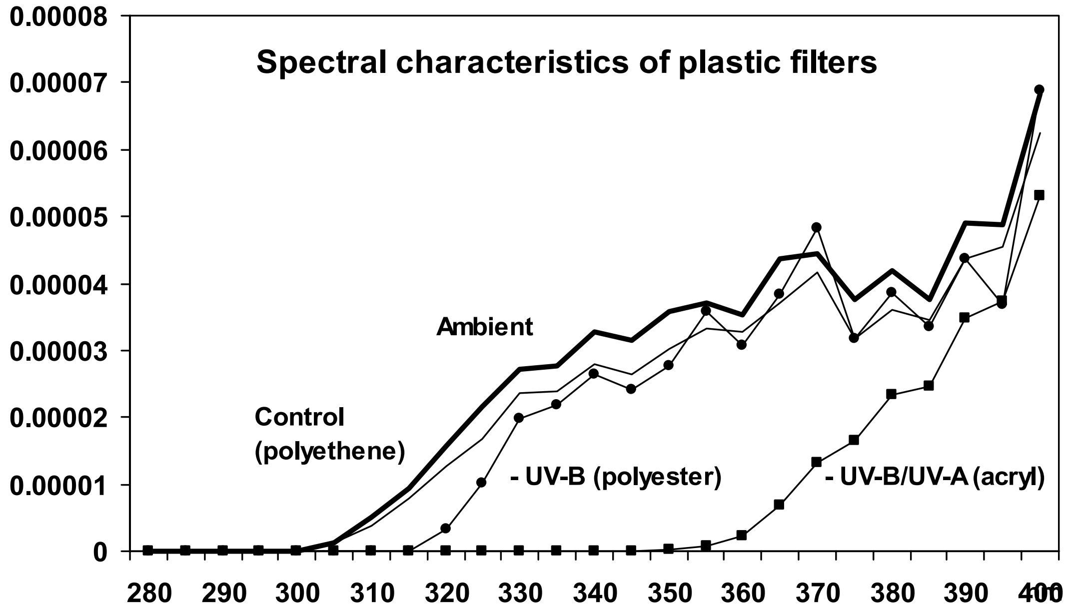

Fig. 1(b). Spectral characteristics of the plastic filters used in the experiment.

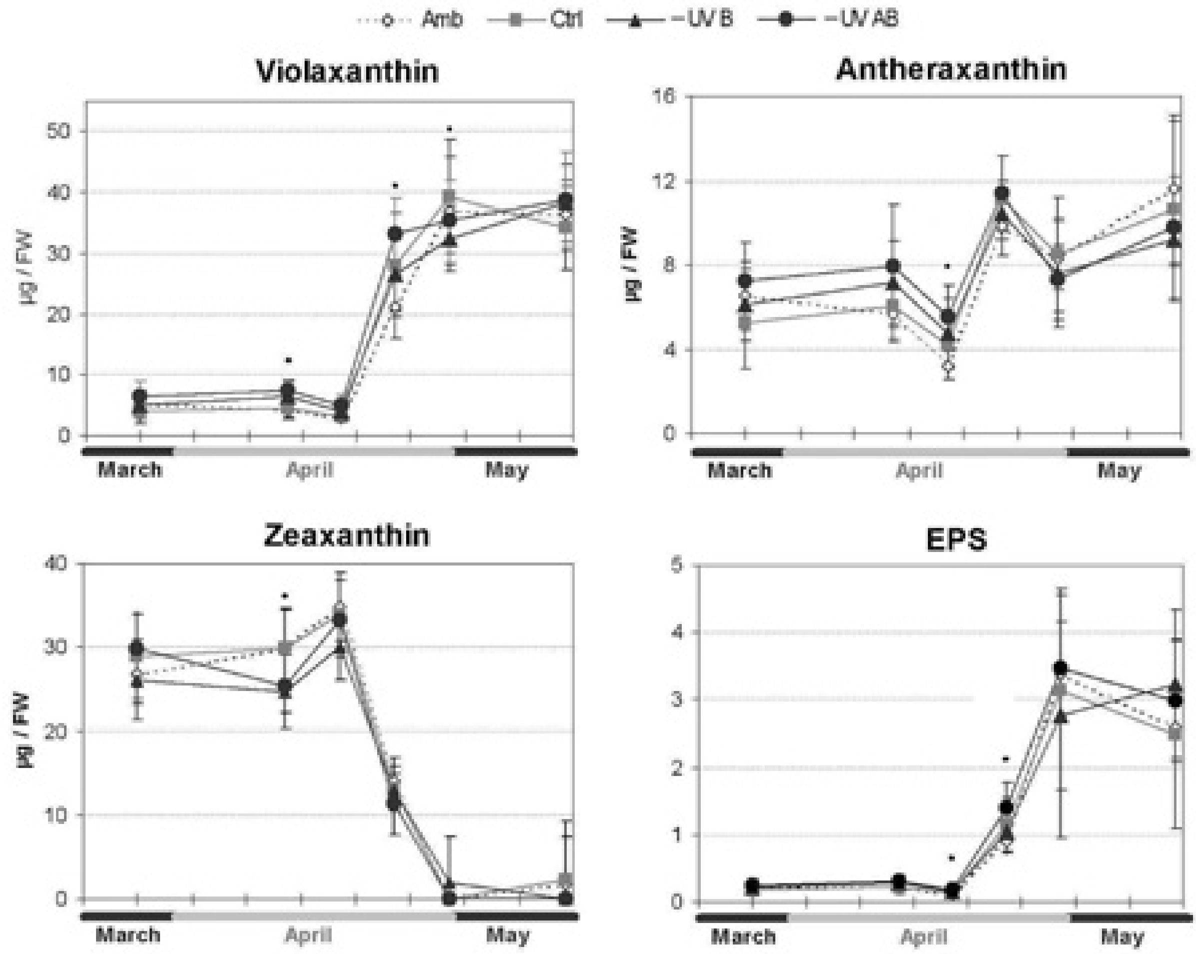

Fig. 2. Concentration of violaxanthin, antheraxanthin, zeaxanthin and the epoxidation status (EPS) of the xanthophylls of Scots pine needles in different UV exclusion treatments during spring 2002. Anova results shown among the treatments ($p<0.05$) are marked with black dot.

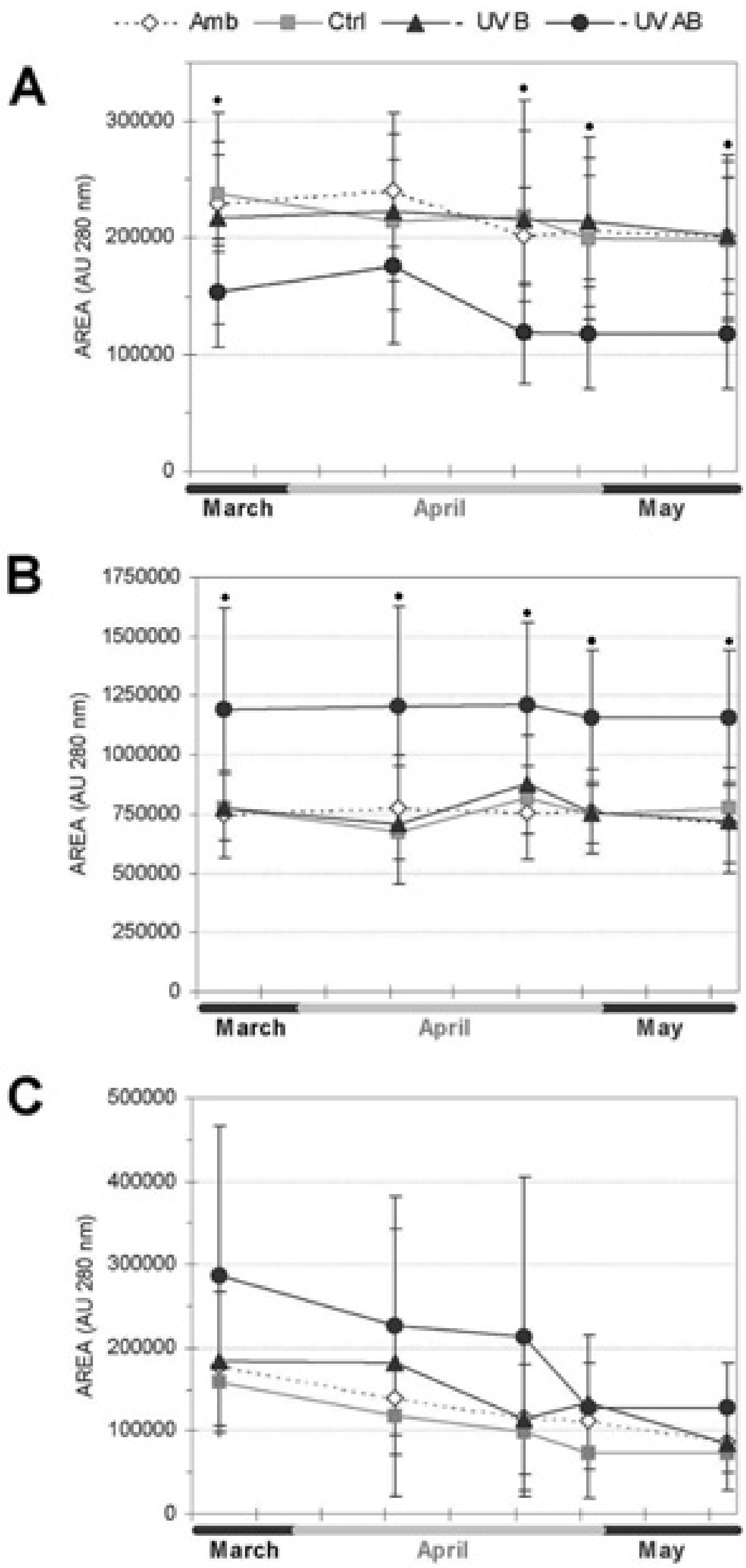

Fig. 3. Peak areas of unknown U2 (a), dicoumaroyl-astragalin (b) and pinosylvin monomethylether (PSM) (c) from the HPLC chromatogram of soluble phenolics of Scots pine needles in different UV exclusion treatments during spring 2002. Anova results shown among the treatments ($p<0.05$) are marked with black dot.

UV-B Radiation and Timberline Plants

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Abstract

Research has shown that some plants respond to enhanced UV-B radiation by producing smaller and thicker leaves, by increasing the thickness of epidermis and concentration of UV-B absorbing compounds of their surface layers and activation of the antioxidant defence system. The response of high-altitude plants to UV-B radiation in controlled conditions is often less pronounced compared to low-altitude plants, which shows that the alpine timberline plants are adapted to UV-B. These plants may have a simultaneous co-tolerance for several stress factors: acclimation or adaptation to the harsh climate can also increase tolerance to UV-B radiation, and vice versa. On the other hand, alpine timberline plants of northern latitudes may be less protected against increasing UV-B radiation than plants from more southern latitudes and higher elevations due to harsh conditions and weaker preadaptation resulting from lower UV-B radiation exposure. It is evident that more long-term experimental field research is needed in order to study the interaction of climate, soil and UV-B irradiance on the timberline plants.

Introduction

The timberline ecotone is a latitudinal or altitudinal transition zone between continuous forest and treeless terrain, where trees struggle to survive by trying to adapt their regeneration, growth forms, statures and physiological and genetic properties to the extreme conditions. The climatic and edaphic conditions of the alpine timberline vary depending on latitudinal location, topography, exposition and altitude but in general, low temperatures, rapid temperature changes, poor soil, increasing winds and extended periods of high irradiance levels are often characteristic for alpine timberline habitats (Tuhkanen, 1999; Gervais *et al.*, 2002).

The amount of UV-B irradiance (ultraviolet-B, 280-315 nm) reaching the earth's surface is influenced by latitudinal gradient in total atmospheric ozone column thickness, solar zenith angles, elevation above sea level, albedo (surface reflectivity) clouds and aerosols (Blumthaler *et al.*, 1997; Webb, 1997; Björn *et al.*, 1998; Gröbner *et al.*, 2000). Due to high altitude, unshaded environment with sparsely growing small trees and albedo from the long lasting snow cover and glaciers, irradiance levels on the alpine timberline during clear sky conditions can be high and stressful for plant life. The values for irradiance parameters, e.g. annual global net radiation, UV-B, UV-A (ultraviolet-A, 315-400 nm), visible and PAR (photosynthetically active radiation) rise on many alpine timberlines and are associated with the zonation of vegetation (Jokela *et al.*, 1993; Blumthaler *et al.*, 1997; Björn *et al.*, 1998; Gröbner *et al.*, 2000). The UV-B contribution to total solar radiation tends to increase with altitude because of a thinner, relatively unpolluted, more transparent atmosphere in many mountainous regions. For the first kilometre above sea level, the increase in biologically active radiation is 15-20% depending on how clean the air is and assuming there are no clouds below this elevation. The combination of latitudinal and altitudinal trends yields maximum UV-exposure in tropical-alpine and minimum in arctic lowland plants. In arctic regions, UV-B radiation levels are lower than at temperate latitudes, but the relative ozone depletion and the relative increase in UV-B anticipated in the Arctic are larger than at lower latitudes and this is probably more important for the timberline plant life than absolute radiation levels (Webb, 1997; Björn *et al.*, 1998).

Recent overviews have been published on the response of terrestrial ecosystems to UV-B radiation from various climatic and geographical zones including the Arctic and Subarctic (Gwynn-Jones *et al.*, 1999; Björn, 2002), grassland (Rozema *et al.*, 1999), Mediterranean (Manetas, 1999), South American (Ballare *et al.*, 2001) and Antarctic ecosystems (Huishes *et al.*, 1999). A number of reviews have discussed the effects of UV-B radiation on vascular plants (Laakso and Huttunen, 1998; Searles *et al.*, 2001; Day and Neale, 2002), some paying special attention to defence mechanisms against UV-B radiation (Bornman, 1999; Meijkamp *et al.,* 1999; Jordan, 2002). This work discusses the effects of UV-B radiation on the woody plants of the alpine timberlines, with special emphasis to the northern latitudes[1]. This presentation is an extended abstract of a review published in Environmental Pollution (Turunen and Latola, 2004).

Is UV-B radiation stressful to timberline plants?

Research has shown that some plants respond to enhanced UV-B radiation by smaller and thicker leaves, increased thickness of the cutin layer and the epidermal wall and increased concentration of UV-B absorbing compounds in the epidermal cells, waxes and leaf hairs and activation of the antioxidant defence system (Turunen *et al.*, 1999; Laakso *et al.*, 2000; 2001; Kinnunen *et al.*, 2001). Many of these defensive responses can be found in plants growing on the alpine timberline but it is difficult to identify whether they are caused by drought, high UV-B, UV-A, PAR or low temperatures. The response of high-altitude plants to UV-B radiation in controlled conditions is often less pronounced compared to low-altitude plants, which shows that the alpine timberline plants are adapted to UV-B (Sullivan *et a.l,* 1992; Van de Staaij *et al.*, 1997).

Probably the most stressful time for the timberline plants is the spring, when the solar radiation dose, and particularly the UV dose received by conifers and alpine plants emerging from the snow cover, may be particularly high. The plants may experience strong, but often short radiation stress at the start of their growing season due to reflectance of irradiance from the surrounding snow cover and are therefore exposed to the direct effects of UV-B radiation. On a clear day, new snow can reflect over 90% of all the incoming UV radiation on vertical surfaces, and thin cloud cover can cause the multiple reflections of UV rays between snow and clouds, increasing the UV dose in all directions (e.g. Björn *et al.,* 1998; Gröbner *et al.,* 2000). Within couple of days, or within few hours, when snow melts, plant tissue may become exposed to high intensities of solar radiation.

It has been suggested that alpine timberline plants of northern latitudes may be protected worse against increasing UV-B radiation than plants from more southern latitudes and higher elevations due to harsh conditions and weaker preadaptation resulting from naturally lower UV-B radiation. Depending on microclimatic and edaphic conditions, cuticle thickness, the amount of epicuticular waxes and wettability of alpine timberline plants, particularly conifer needles, either decrease, increase or remain unchanged with increasing altitude. Short and cool growing seasons may delay the development of protective epidermis, cuticles and the epicuticular wax of evergreen foliage, which may then contain less UV-B-absorbing compounds, and at the same time, low temperatures may slow down the enzymatic and non enzymatic UV-B-repair processes. This may predispose timberline plants to additional

1 Term "timberline" is used in a general sense to refer to the transition belt from forests to treeless vegetation, "northern timberline" referring to polar latitudinal timberline of the Northern Hemisphere and "alpine timberline" referring to timberline in accordance with increasing elevation.

stresses, such as photoinhibition due to high irradiance levels and winter desiccation (Turunen and Huttunen, 1990; 1991; Foyer *et al.,* 1994; Kinnunen *et al.,* 2001).

Co-tolerance for several stress factors?

It is interesting to speculate whether structural and physiological acclimation or adaptation to the harsh climate, particularly drought and low temperatures, and poor soil also provide protection against increasing UV-B radiation. Or are the plants in the northern timberline environment more sensitive to UV-B radiation due to harsh conditions and weaker preadaptation due to naturally lower UV-B radiation compared to plants from more southern latitudes and lower elevations? And vice versa: Does defence against increased UV-B radiation, such as thicker epidermal layer and cutin, increased concentration of UV-B absorbing compounds in the epidermal cells, and higher levels of glutathione (Turunen *et al.,* 1999; Laakso *et al.,* 2000; Kinnunen *et al.,* 2001) increase the plants tolerance against another environmental stresses such as drought and low temperatures? Most probably all these statements are true.

Many xerophytic plants with thick leaves and an epidermal cell layer are adapted to both water stress and high irradiance. It has been shown that many drought tolerators are generally resistant to UV-B damage and that enhanced UV-B radiation can induce xeromorphic characteristics, such as a thicker cutin layer, in northern conifers (Laakso *et al.,* 2000) or in Mediterranean species (Manetas, 1999). It has been reported that increased UV-B decreased the cross-sectional needle area of fully-grown fascicle needles of Scots pines. Since no decrease in needle length was seen, it was suggested that the smaller cross-sectional area was due to the more xeromorphic structure of UV-B-treated needles. In primary needles of Scots pine seedlings, UV-B increased the thickness of the cutin layer and the outer and inner periclinal walls and the anticlinal wall also thickened to fill cell lumen, which are common features in xeromorphic needles. Thus, the xeromorphic structure might give better protection also against UV-B radiation and on the other hand, the enhanced UV-B radiation may cause a more xeromorphic structure in evergreens (Laakso *et al.,* 2000; Latola *et al.,* 2001).

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Influence of Climatic Factors on the Nitrogen Fixation Activity in High Arctic Vegetation

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Introduction

There is a great agreement that ecosystems in the Subarctic and Arctic are vulnerable to environmental changes. Many research efforts in various scientific fields had been done in order to study and understand these unique environments. Climate models predict changes in climate patterns, which will become apparent especially in arctic regions (Maxwell 1995, ACIA 2001, IPCC 2001b, McKenzie et al. 2003). However, to be able to study possible effects of climate change the basic processes of the ecosystems and their interactions have to be understood. Microbial communities are important drivers of the biogeochemical cycles on the Earth including the cycles of the macronutrients carbon (C) and nitrogen (N) (Postgate 2000). Although N is a key-controlling factor for terrestrial primary production in the Arctic, the amount of available N in arctic soils is low. The annual uptake of N by the vegetation is in general much higher than the input of N by wet and dry deposition, and consequently, N becomes often the limiting nutrient for plant growth (Shaver and Chapin 1980, Henry et al. 1986). Biological fixation of atmospheric N by micro-organisms plays therefore an important role for the N economy of terrestrial arctic environments. Due to the absence of N-fixing legume-bacteria symbioses and low or absent N-fixation activity of heterotrophic soil bacteria, free-living, moss-associated or symbiotic (lichen) cyanobacteria become major contributor of N to terrestrial polar ecosystem (Henry and Svoboda 1986, Lennihan and Dickson 1989, Chapin and Bledsoe 1992, Liengen and Olsen 1997a). Nitrogen fixed by cyanobacteria is released relatively rapidly and can be taken up by plants subsequently (Mayland and McIntosh 1966, Alexander et al. 1978). Several studies (Solheim et al. 1996; Solheim and Zielke 2002, DeLuca et al. 2002) have previously examined biological N-fixation in subarctic and arctic environments and found that cyanobacteria in association with mosses were by far the most important source of N in vegetated areas. However, stress factors such as increased UV_B-radiation, desiccation and a change in temperature may have significant influence on the N-fixation activity in arctic vegetation. In our studies we investigated the influence of abiotic factors such as temperature, soil moisture and enhanced UVB-radiation on the cyanobacterial N-fixation activity.

Methods

The field sites for the UVB-experiment and the water and temperature experiment were located in the Sassen Valley (78°47'N, 16°19'E) and the Advent Valley (78°17'N, 16°00'E), respectively. In all experiments potential N-fixation activity was determined using the acetylene reduction assay. To study the long-term effect of enhanced UVB-radiation on N-fixation activity moss-dominated tundra vegetation was treated for six growing seasons with enhanced UVB-radiation corresponding a 15% depletion of the ozone layer. Soil-vegetation samples were collected from four treatment plots and four control plots, and assayed for N-fixation. Representative samples from three different types of high arctic vegetation were collected and used for a temperature gradient experiment (0 - 40°C) and an experiment to study the response of N-fixation activity on changes in moisture conditions.

Results

Nitrogenase activity measured as acetylene reduction was significantly decreased (P=0.02) in vegetation with long-term UVB-exposure compared to the controls. (Fig.1). The different in N-fixation activity corresponds to a 28% decrease.

Significant effects of temperature on N-fixation activity were found in the samples from all three types of vegetation (Fig. 2). Samples of all three types of vegetation showed low, but detectable nitrogenase activity at 0°C. In the range between 4 and 10°C the activity kept on a low level, before it increased to the maximum at a temperature between 20 and 28°C. Further increase of temperature led to a rapid decline of the activity, which reached values closed to zero at about 40°C.

Air-dried samples from all sites showed a significant increase of acetylene reduction activity when water was added gradually to the samples (Fig. 3). Already an increase of the water content by 0.2 ml cm^{-2} a significant increase in ethylene production could be detected. Adding of water to a final total amount of about 2 ml cm^{-2} led to a linear increase in nitrogenase activity in samples from all sites.

Discussion

The samples had optimum acetylene reduction activity around 25 to 30°C (Figs. 2, 3). Similar optimum temperatures of subpolar, polar, and alpine cyanobacteria have been reported by others (Kallio, 1974; Kallio and Kallio, 1978; Fritz-Sheridan, 1988; Chapin et al., 1991; Liengen and Olsen, 1997b). The temperature optimum for the cyanobacteria on Svalbard is typical for mesophilic microorganisms. However, the N-fixation rates were almost constant between 0 and 10°C, which is in contrast to studies done by Lennihan et al. (1994), Liengen and Olsen (1997b) and Dickson (2000). They reported an increasing N-fixation activity at this temperature range. The mean temperature at 1 cm depth in the vegetation layer in the experimental area during the growing season is between 0 and 12°C (data not shown). Thus, our results indicate that N-fixation is not significantly influenced by temperature during most of the growing season. This temperature-independent N-fixation activity make cyanobacteria, either free-living or moss-associated, well adapted to the temperature conditions in this area. An expected temperature increase of 3°C for the Svalbard region will increase the summer periods with temperatures above 10°C. If light and moisture are not limiting factors, the N-fixation in the studied vegetation will almost double with a temperature increase from 10 to 13°C.

The interior of Spitsbergen has an annual precipitation below 300 mm, and, except for the period of snowmelt, water often becomes a limiting factor for primary production in most terrestrial habitats. The significant interaction effects between the N-fixation activity in the different types of vegetation and the water content may be caused by differences in the capability and the capacity of the vegetation to store water and make it accessible for the cyanobacteria. However, the significant water-dependent increase of acetylene reduction activity of the samples from all sites shows the potential of the cyanobacteria in studied types of vegetation to fix nitrogen when water is not limiting. This corresponds with the results from other studies (Chapin et al., 1991 and Dickson, 2000).

The treatment of the vegetation with enhanced UVB did clearly affect the N-fixation activity of the cyanobacterial communities. The significant decrease of N-fixation activity by 28% in the vegetation exposed to increased UVB may be due to either a reduced physiological activity of the cyanobacteria or a shift in the cyanobacterial community structure to species with lower capability of fixing atmospheric nitrogen. These two possibilities, in turn, may be triggered by several direct or indirect mechanisms.

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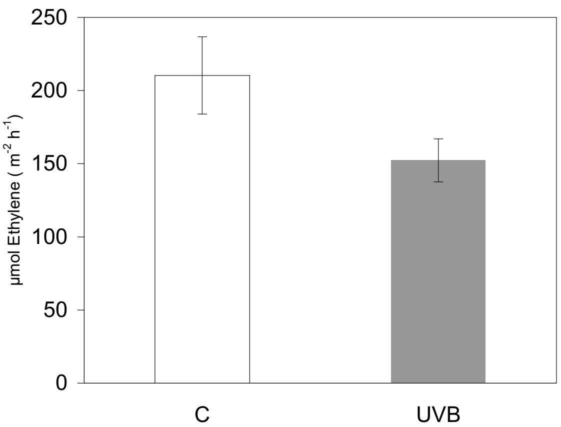

Fig. 1. Nitrogen fixation activity in vegetation samples (C: control, UVB: UVB treatment). Values are means (n=4). Whiskers indicate standard deviation.

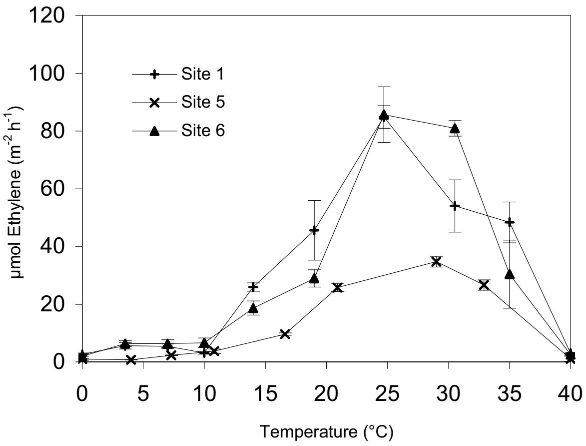

Fig. 2. Temperature response of acetylene reduction activity. Site 1: Salt-marsh, Site 2: Black crust, Site 3: Flush meadow. Values are means (n=3) ± SEM.

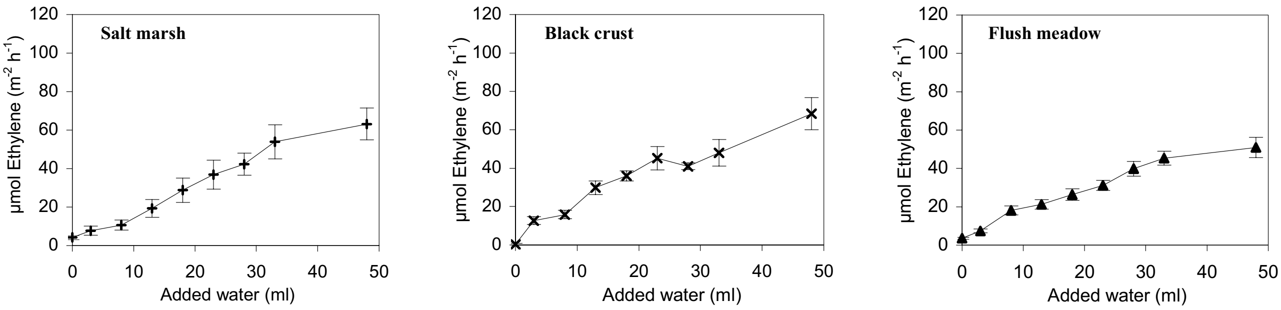

Fig. 3. Rehydration response of acetylene reduction activity in soil-vegetation samples from Salt-marsh, Wet marsh, Black crust and Flush meadow. Values are means (n=3) ± SEM.

Climate-Driven Regime Shifts in Arctic Lake Ecosystems

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Introduction

Polar amplification of anthropogenic warming is consistently predicted by general circulation models, largely because of positive feedback mechanisms involving cryospheric processes (Kattenberg et al. 1996). This heightened climatic sensitivity is supported, *inter alia*, by recent accelerations of glacier retreat (Dyurgerov and Meier, 2000), sea-ice thinning (Comiso, 2003), permafrost degradation (Oechel et al., 2000), and tree-line expansions (Kullman, 2001). However, the monitoring data of Arctic climate change and its impacts are brief and geographically sparse, which hamper a more holistic assessment.

In the absence of long-term climatic and environmental monitoring data, proxy data from the sediments of lakes and ponds, which are ubiquitous features of most arctic landscapes, can be used to provide a long-term perspective of environmental change (Douglas and Smol, 1999). Siliceous algal remains, specifically the valves of diatoms (Bacillariophyceae) and the stomatocysts and scales of chrysophytes (Chrysophyceae and Synurophyceae), as well as chitinous invertebrate remains (Chironomidae and Cladocera), are the primary palaeoindicators that reliably chronicle changes in water quality, habitat, and catchment processes. Here, we objectively synthesize a large number of palaeolimnological records from arctic lakes and ponds in Finnish Lapland and elsewhere in the Arctic, providing a circumpolar assessment of recent ecological changes.

Methods

Multiple regression methods were used to estimate seasonal and annual air-temperature anomalies (ºC) for NW Finnish Lapland using a suite of very long instrumental series (e.g., Trodheim, Uppsala and Leningrad to the south), historical records of ice-cover (e.g. River Tornionjoki since 1693), and tree-ring width and density series (at the Scandinavian timberline). Sediment cores were taken from five remote lakes in the region (Fig. 1) and analyzed for diatoms in fine intervals of 2 to 5 mm, equivalent to a temporal resolution of about 3 to 10 years. Diatom species diversity at constant sample counts was estimated using the index N_2 (Hill, 1973). Optimal partitioning was used to identify the periods of time of the most significant shifts in the diatom assemblages. Principal components analysis (PCA) was used to summarise the major trends in the diatom assemblages; Pearson correlation coefficients were calculated between the regularised PCA time series. The relationship between diatom assemblage and change in air temperature, since 1800, at the five lakes were studied quantitatively. The analysis was carried out for each of the four climatic seasons and for the complete year. For each sediment horizon, in each lake, the average air-temperature during the period of its accumulation was calculated. Finally, past pH was reconstructed from the relative abundance of fossil diatoms using weighted averaging partial least squares (WA-PLS) regression (ter Braak and Juggins 1993) and the modern calibration data set of surface-sediment diatom assemblages and associated water chemistry data collected from 64 lakes in the study region and (Weckström and Korhola, 2001).

The records from Finnish Lapland were compared with the Arctic wide palaeolimnological data series from lakes and ponds spanning the most climatically-sensitive latitudes of the Northern Hemisphere. To simplify our presentation of trends in the gathered 55 biostratigraphic profiles, detrended canonical correspondence analysis (DCCA) was used to develop robust estimates of compositional turnover as beta-diversity, scaled in standard deviation (SD) units. The greater the amount of species turnover along an environmental gradient, the greater the beta-diversity. We substituted an environmental gradient with a time scale to estimate the total amount of compositional change in each record within the last ~150 years. All time scales are based on excess ^{210}Pb activities and associated age-depth modeling. For each site, stratigraphic data were analyzed identically, with the general prerequisite for inclusion being an adequate geochronology and a sediment sequence spanning at least the last 200 years.

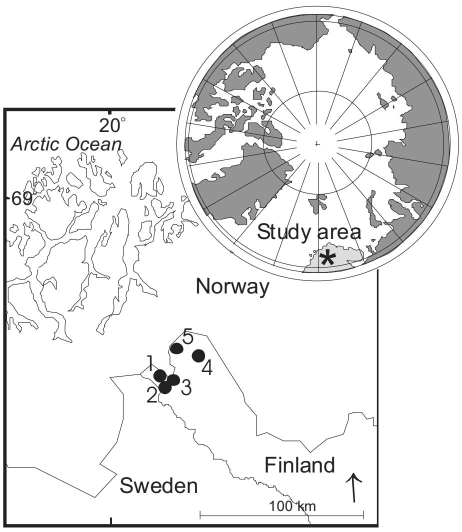

Fig. 1. Location of the study sites in Lapland.

Conclusions

Diatom assemblages in lakes of the Finnish Lapland showed clear changes in all study profiles. The changes were predominantly from benthos to plankton and affected the overall taxon richness. When the assemblage changes were summarised by principal components analysis (PCA), particularly strong relationship was found between spring temperatures and compositional structure of subfossil flora and fauna (Fig. 2.). When contrasted with 55 palaeolimnological records from the circumpolar Arctic, widespread ecological reorganizations were noted. New ecological states are characterized by high species turnover in algal assemblages since ~1850 A.D., and coeval changes in invertebrates. The remoteness of these sites, coupled with the ecological characteristics of taxa involved, indicate that such directional changes are primarily driven by lengthening of the summer growing season and related limnological changes. We postulate that the 19th century Arctic warming, rather than acidic or other anthropogenic deposition, is responsible for the recent ecological changes in these high latitude lakes. Our results demonstrate that the Holocene-Anthropocene boundary has a widespread biostratigraphic expression, and that the opportunity to monitor truly pristine arctic ecosystems may have disappeared.

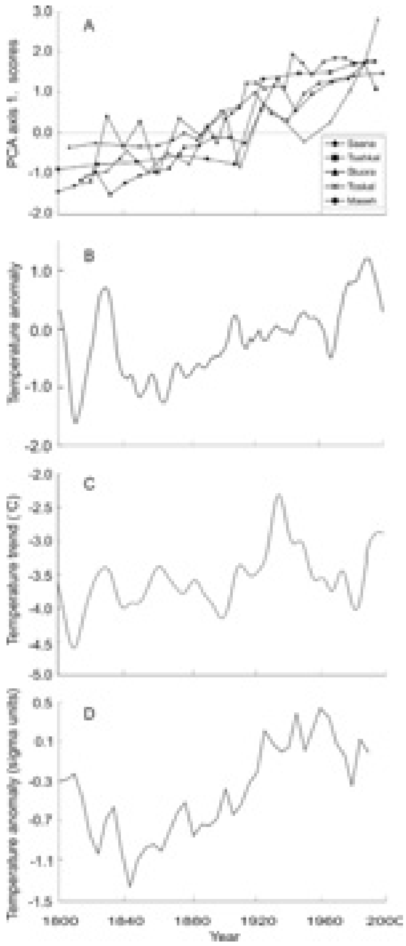

Fig. 2. Comparison of the diatom assemblage changes with the regional and Arctic-wide temperature anomalies (Sorvari *et al.,* 2003). PCA primary axis scores derived from the correlation matrices of the diatom percentage counts of the five study sites (**A**). Spring (MAM) temperature anomalies (ºC) for NW Finnish Lapland, smoothed using a 10-year low-pass filter (**B**). Annual air-temperature trend, smoothed using a 10-year low-pass filter (**C**). Standardised proxy Arctic-wide summer-weighted annual temperature, plotted as sigma units (**D**) (from Overpeck *et al*. 1997).

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Climate Change and Tree Line Dynamics in Northwest Siberia: Tree Ring Reconstruction for the Last 7000 Years

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Introduction

Tree rings as a proxy indicator of past environmental conditions are of special interest as they facilitate the reconstruction of climate change and of woody vegetation dynamics with very high resolution for many hundreds and even thousands of years. To develop multi-millennial tree-ring chronologies it is necessary to find special regions that meet specific requirements: well-preserved remains of trees that exhibit high sensitivity to climate changes. One such area is the Yamal Peninsula (northwest Siberia). Holocene deposits in the southern part of this peninsula (in the region located between 67°00′ and 67°50′N and 68°30′ and 71°00′E, near recent polar timberline) contain a large amount of subfossil remains of Siberian larch, Siberian spruce and Mountain birch.

Methods

At present, a total of 2700 sawn wood samples have been collected in order to create continuous tree-ring chronology for the past several thousand years. To date this work has resulted in constructing an absolute 7310-year chronology (from 5309 BC to 2000 AD) based on the data on individual series of 54 living and 452 subfossil larches (*Larix sibirica*).

In northwest Siberia tree ring width is increased in association with warm conditions during June and, more especially, during July. An average of June and July mean temperatures was therefore selected as the predictand to be reconstructed using ring width data. The reconstruction was carried out using regional curve standardization (RCS), which allows for long-term variability to be extracted from this annually resolved record.

The reconstruction of polar tree lines dynamics was based on the relative positions of more than 1200 subfossil trees, each of which has been precisely dated by cross-dating their ring patterns.

Results

The reconstruction is plotted in the form of temperature anomalies from the mean of the full reconstructed period (5200 BC-2000 AD) in Figure 1.

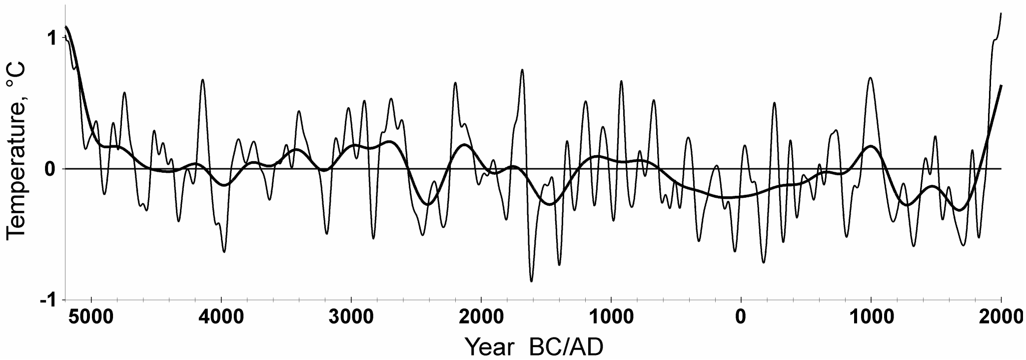

Fig. 1. The reconstructed summer temperatures after filtering with different band-pass filters: 100-year low-pass values (thin line) and 500-year low-pass values (thick line).

This long record shows that the amplitude of temperature variability has altered noticeably through time. Nevertheless recent warming is unusual. That argues that the most recent decades of this long summer record represent the most favorable climate conditions for tree growth within the last seven millennia.

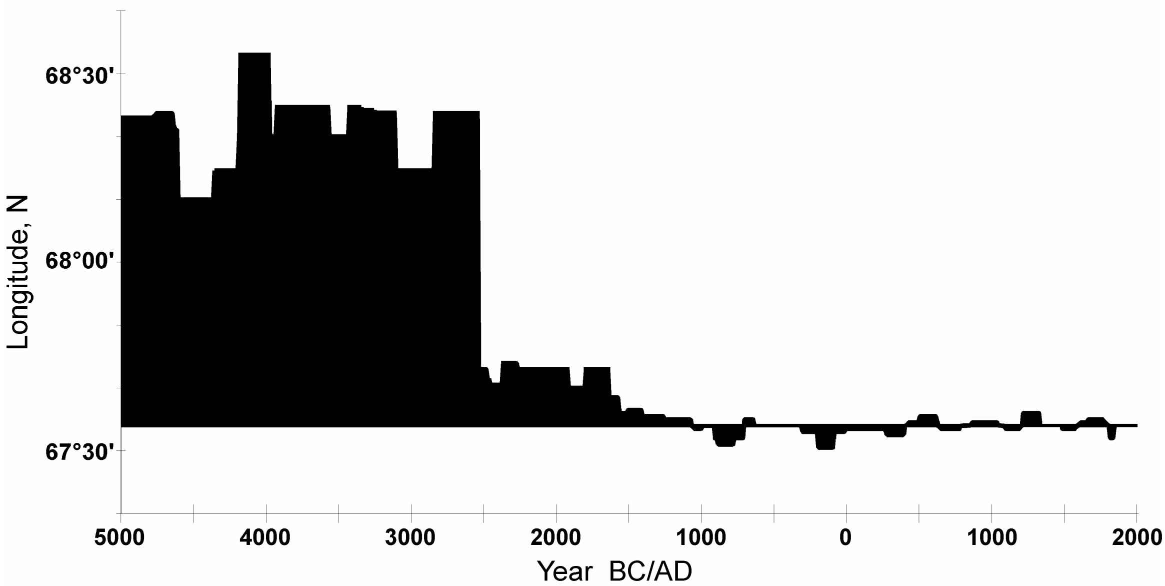

Fig.2. Reconstruction of polar tree-line dynamics since 5000 BC relative to recent position of northernmost trees.

Figure 2 shows a reconstruction of polar tree-line dynamics composited from evidence from the different river valleys in the Yamal Peninsula, expressed with respect to the present-day polar limits of larch. According to this reconstruction the most northern tree line position were 7000-4500 years ago. At that time polar timberline located in tens kilometres more to the north of its present-day position. Significant southward shift of tree-line forests was observed 4500 years ago. Second, less expressive, southward shift began 3650 years ago. During the last 3600 years insignificant shifts of tree-line position has occurred.
It is evident that there are not direct correlation between summer temperature changes and polar tree line dynamics. It may be explained by existing of different tree line forcing mechanisms or by sluggishness of tree line reaction to warming, while cooling can cause fast and large shift to the south. It is interesting also to note that the current position of the tree line in Yamal has not yet shifted fully in response to the warming of the last century.

Acknowledgement
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The Tundra-Taiga Interface

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What it is

The Tundra–Taiga Interface is a Project of the International Arctic Science Committee (IASC) dedicated to understanding the dynamics of the interface between the arctic tundra and the boreal forest in relation to global change. A working group has produced a Science Plan which provides the rationale, suggests a structure and recommends tools to guide individual task/projects to ensure that the results are useable in multiple contexts including helping the public and policy makers to make informed decisions.

Background

The circumpolar boreal forest and the treeless arctic tundra, meet in a transition zone of varying width up to hundreds of kilometers. The position of this zone has been found to change both on historical and geological time scales. Recent taiga advances onto tundra and taiga retreats have been observed. The fact that this boundary has moved in the past, at least partly in concert with climate change, implies that its position may be changing and has a potential for even greater change. The arctic and boreal regions of earth are expected to warm more than the rest of the globe and hence biome shifts across the present tundra-taiga interface can be expected to be more dramatic there than elsewhere. This could have drastic consequences for the biota and human societies.

The distribution of the boreal forest and the arctic tundra has global implications. The boreal forest and the arctic tundra have different carbon storage and radiation balance. Boreal forest advance would increase carbon dioxide drawdown from the atmosphere and reduce methane release slowing global warming. Conversely, release of this carbon brought about by forest removal would accelerate the rise in atmospheric greenhouse gases and the consequent climate warming.

The current state of knowledge about the tundra-taiga interface has recently been summarized in a Special Report in the journal Ambio in 2002. Specialists in different aspects of tundra-taiga interface research wrote articles dealing with its position and nature, its Pleistocene and Holocene history, its natural causes, human impacts, climatic feedbacks, and remote monitoring.

The need for an integrated circumpolar study

The complexity and great extent of the tundra-taiga interface, the uncertainties in its present location and characteristics, and our need to understand, predict and monitor changes in the interface require a circum-arctic approach.

In order to allow the greatest interpretative use of the data collected, it is important that the research be integrated and coordinated both in locations studied and by using generally agreed definitions and concepts, and standardized measuring and experimental techniques. This circum-arctic integrated approach suggests that both national operation logistic structures as well as international structures be identified or established.

The over-arching goals are to obtain an understanding of: 1. The controls on the location and pattern of the tundra-taiga interface. 2. The effect of global change on the location of the tundra-taiga interface. 3. The effect of the location of the tundra-taiga interface on the global climate

Implicit in the three items above is consideration of role of human societies inside and near the interface, both as local forces on the interface and as consequences of changes in its characteristics and location.

Objectives are:

- To develop effective techniques and carry out quantitative spatial and temporal analysis of the location and sensitivity of transitional ecosystems along the circumpolar tundra-taiga interface.
- To understand ecosystem controls in different tundra-taiga interfaces, both resilient and sensitive.
- To build realistic models of tundra-taiga interface dynamics.
- To validate the models by ground level observations, dependent on scale and land use history.
- To use them to implement a program of ecosystem and landscape analysis, examining the combined effects on ecosystem changes and survival in relation to biodiversity conservation.
- To model potential future changes in ecosystem structure and transitional vegetation types throughout the circum-arctic area, under conditions of potential climate change from the climatic sensitivity of each ecosystem type and a suitable set of climate change scenarios. These data should be used to evaluate the role of other drivers for future ecosystem changes in comparison to climate change, and to predict the combined effect of different drivers.
- To assess the socio-economic impacts of potential future changes in the transitional zones, incorporating its results into an expert information system, which will be utilized for estimating climate change responses in sensitive areas (e.g. with regards to tundra-taiga interface movements, biodiversity changes, disturbance and changed land use patterns), sustainable ecosystem management and landscape planning in support of policy decisions, e.g. reduced output of greenhouse gases.
- To exchange methods on climate change effects, biodiversity conservation strategy and science/policy issues, and use them as a tool in forecasting ecosystem changes and mitigation options.

Themes:

Terminology: A common set of criteria or definition must be adopted to allow global generalizations to be made.

Location: The location of the tundra-taiga interface depends not only on the choice of the concept definition but also on the scale of observation and method of presentation.

History of shifts: We know that tree species that are found within the present tundra-taiga interface have changed their distribution significantly in the last 20,000 years since the Last Glacial Maximum. We need to inter-calibrate the different techniques so that existing data can be reinterpreted better. We also need to better understand the way in which humans have affected the environment in the recent past, how they use and abuse it now, and what modifications or remedies could minimize future degradation.

Interface processes: In order to predict shifts in the future tundra-taiga interface locations, we must understand what controls its location now. Diseases, browsing, pests, fires and human activities also exert control in certain places and at certain times and these often large scale disturbances can be expected to increase under climatic warming. Both human impacts and climatic change in the tundra-taiga interface regions affect biodiversity which in turn affect ecosystem function.

Model realism: Models of vegetation redistribution resulting from global change operate on general mechanisms such as biogeography and biogeochemistry and thus lack the realistic complexities and feedbacks referred to above. We need a new models based on a wider range of processes in the North including land-use scenarios.

Effects of shifts: Changes in the surface cover of the tundra, taiga, and their interface zone will affect the feedbacks from the land surface to the atmosphere. We need to study the impacts of temporal land cover change as well as coupled comparison of spatial gradients to allow us to predict the regional and global effects of interface displacement on the hydrology and climate.

Monitoring shifts: Much of the extensive tundra-taiga boundary is remote and access is difficult. Remote sensing from space is, therefore, is likely to play a significant role in determining the dynamics of the tundra-taiga boundary. Greater use of high-quality circumpolar remote sensing data, the adoption of new platforms, and improved mathematical, statistical and computational techniques are needed.

Human societies and shifts: Human activities have impacts on the local climate, vegetation and all features of the landscape of the tundra-taiga interface. Conversely the location and nature of the interface affect human societies greatly. We need to understand how to minimize these effects.

Tasks

In order to realize our objectives the following tasks need to be pursued:

1. Standardize terminology
2. Determine current location and characteristics of the tundra-taiga interface using remote sensing data, aerial photographs, GPS, GIS, spatial mathematics as well as special methods of collecting local and indigenous knowledge.

3. Study past tree distribution patterns more comprehensively using multiple techniques such as tree-ring analysis, macrofossil, stomata, and pollen analyses coupled with molecular genetics and geographical information system.
4. Study environmental conditions across the tundra-taiga interface. These include, meteorological observations, geomorphology observations, hydrological measurements, and permafrost measurements.
5. Study the population ecology, biodiversity changes and the physiological ecology of present tundra taiga tree species and of the tundra-taiga interface.
6. Study the effect of tree cover on the ecosystem ecology and on the greenhouse gas fluxes and energy balance across the tundra-taiga interface (feedback effects).
7. Study the nature and effect of present and past disturbances such as fires, insect outbreaks, and human activities on the nature and location of the tundra-taiga interface and its sustainable use.
8. Study socio-economic and ecosystem management conditions across the tundra-taiga interface. This includes assessment of human impacts on the nature and location of the taiga-tundra interface. It also includes consequences for human health and activities, responses to negative impacts to prevent shifts, as well as strategies for sustainable development.
9. Build mathematical models that have greater degree of process realism than currently exists.
10. Carry out large-scale observations and conduct manipulation experiments to test the models.

Working Groups

We envisage that working groups be formed to elaborate a detailed implementation plan and conduct the research planned.

Russian Arctic Methane Fluxes Study: Measurements and Modelling

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Introduction

Atmospheric methane is one of strongest greenhouse gases. Russian Arctic and Siberian region is among the most intensive sources of natural and antropogenic methane. Very large gas fields are located and marshes occupy the most part of this area. At the same time direct measurements of atmospheric methane content as well as of methane fluxes are rare, unhomogeneously distributed in space and as a rule describe a small area. Therefore it seems reasonable to use the empirical relationships between local measurements of high precision and some external parameters of surroundings. Last time several investigations were devoted to study of methane emission from marshes depending on environmental parameters *(Nakano et al., 2000, Christensen et al., 2003)*. Due to warming conditions observed in Arctic especially important seems the influence of temperature change on the flux intensity. The warming of surface air is accompanied by warming in upper soil layer, with largest trends in permafrost regions *(Oelke and Zhang, 2003).* Under warming conditions the methane fluxes can be increased essentially not only due to surface temperature growth but also due to expansion of thawing areas and deepening of thawing layer. 3D regional model is used for verification of methane flux parameterisations and description of methane distribution over this region.

Methods

Numerical estimations of spatial distribution of natural methane fluxes from Greatest Siberian wetland area were executed using available local statistical dependence between methane fluxes value and wetland environment parameters (water table, temperature regime, marshes type). This parameterisation was input into specially developed 3D regional atmospheric transport model (Jagovkina et al., 2000). The next four types of boreal wetland ecosystems parameters were generalised for methane emission calculation: polygonal oligotroph wetland, hummock oligotroph wetland, Sphagnum bog, evtroph and mesotroph wetland (sedge bog) based on 30-years field expedition results and ECMWF meteorological data (Lagun et al., 2002).

The results of 3D regional transport model are verified by direct measurements of methane concentrations and methane fluxes in West Siberian region. It allows estimate spatial distribution of CH_4 fluxes with high resolution. Summer natural methane emission from Northern part of West Siberia (58-73^0 N, 62-82^0 E) is estimated as ~10.5 Mt CH_4/year. Regional natural emission and gas deposits leak was determined based on combination of field measurements data and numerical modelling results.

Data

Quasi-permanent greenhouse gases monitoring network is provided in Russian North. It includes the background station Teriberka (69^{o}12'N, 35^{o}6'E, located at Kola Peninsula), Voeikovo station (59°57'N, 30°42'E) located to the East from Saint-Petersburg, Cape Kamenny (68° 28' N, 73° 35' E) and Novy Port (67° 41' E, 72° 53' E) stations, both located on the West shore of Ob bay (Yamal Peninsula). This station set is a part of Russian Arctic greenhouse gases monitoring net. Original results of direct methane mixing ratio measurements during field expeditions in West Siberia, Arctic Sea and Northern Pole area give additional information of methane concentration distribution. Laboratory analysis of flasks air probes is carried out at the gas-chromatographic installation by the methodology recommended by WMO for measurements in Global Atmospheric Watch stations network.

Results

Methane concentration time-series for Russian Northern stations are shown in figures 1-2. These data provide the basis for study of seasonal and interannual variation of methane content formation mechanisms. The long continues set of data obtained in Voeikovo station allows study the diurnal course of methane concentrations in details (Zinchenko et al., 2002).

An example of regional modelled methane concentration distribution is presented in Fig.3. Modelled methane concentration values agree well with data in points of measurements for different seasons of modelling experiments.

Because the natural methane emission can be accelerated by atmospheric warming processes our further study will be aimed at numerical estimates of seasonal and multiyear variations of methane emission in West Siberia and other Russian Arctic regions and at quantitative estimates of possible future emission changes due to climate warming (based on IPCC scenarios). Some other methane sources such as winter methane emission from deep tundra lakes through ice cover holes, which role in forming of global atmospheric methane budget can be comparable with other well known methane sources in Arctic region will be studied also.

Acknowledgement

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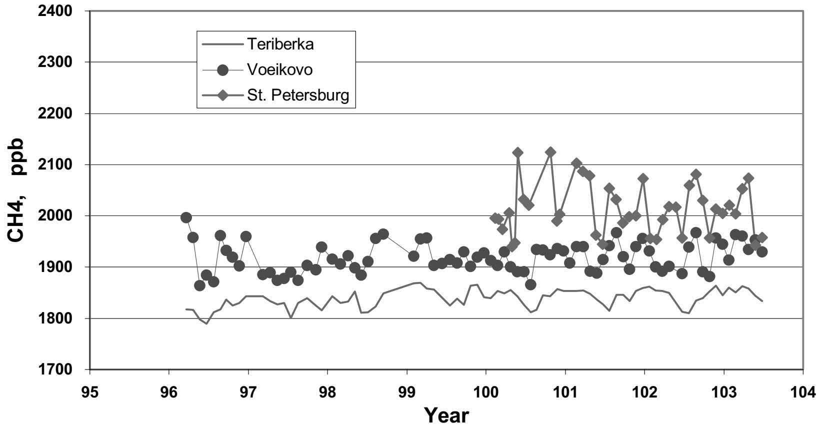

Fig.1. Monthly mean concentrations in ambient air in Voeikovo and Saint-Petersburg with concentration data at the Arctic coastal Teriberka station

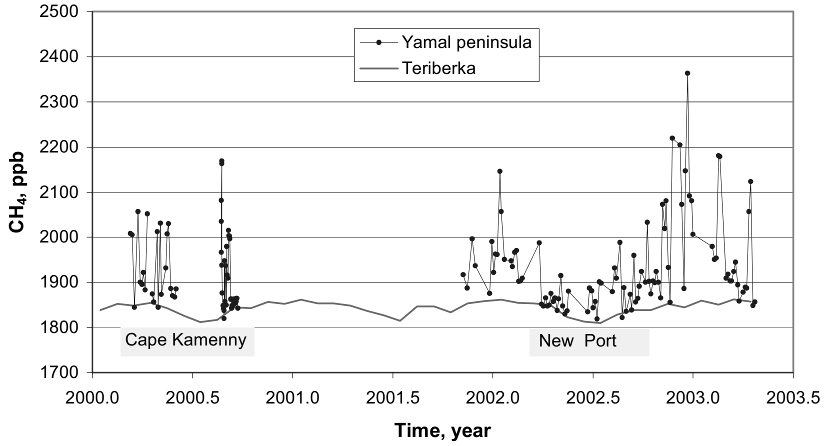

Fig.2. Results of CH4 concentration measurements at two stations located at Yamal Peninsula relative to the Teriberka background level

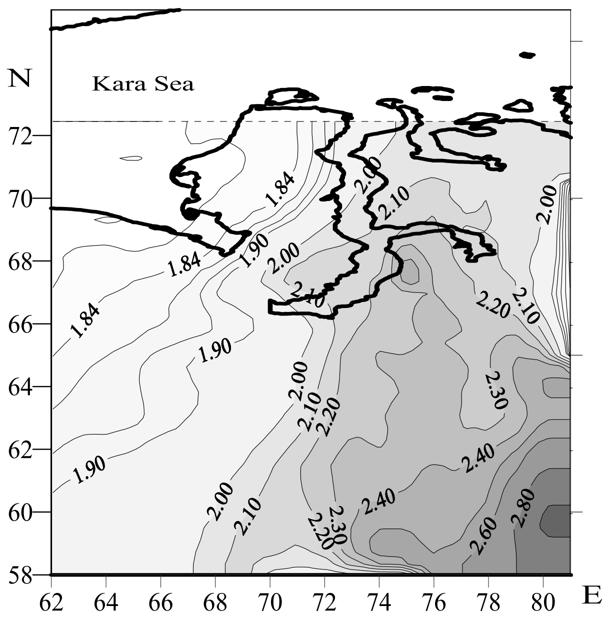

Fig.3. An example of methane content distribution (ppm) near the surface for July, 28, 1993.

Arctic Sea Ice, Climate Change and Related Climate Feedback Mechanisms

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Sea ice in the Arctic plays a central role in the context of climate change: both in its role when influencing the surface energy balance and the freshwater transport, and acting as an indicator for climate changes (see e.g. IPCC 2001). It is well established that the ice extent in the Arctic is currently significantly decreasing. While there is evidence that the ice thickness is also decreasing (e.g. Haas 2004; Yu et al. 2004, see also Fig. 1), the record is not as comprehensive as that for ice extent.

At an ACIA workshop on climate feedback mechanisms (Gerland & Njåstad 2004), held in Tromsø/Norway in 2003, a working group collated key sea ice parameters for climate change and feedbacks, including information on how they are changing, corresponding confidence levels related to measured or modeled changes, and what the group would recommend for future work (Perovich & Wadhams 2004; Tab. 1). Among parameters listed were ice extent, ice thickness distribution and mean ice thickness (Haas et al. 2004; Hansen et al. in press; Perovich et al. 2003), ice types, albedo (Eicken et al. 2004; Perovich et al. 2002; Perovich & Grenfell 2004), length of ice-free period, melt pond fraction, snow depth and snow properties. As one example, the surface albedo and optical properties of sea ice (Hamre et al. in press) are crucial for the ice-albedo-feedback mechanism, being a key to summer melting. Among other relevant parameters were leads and polynyas, surface energy balance (Ivanov et al. 2003) and ice motion. Process studies on sea ice properties and their changes with specialised *in situ* observations provide data (along with remote sensing information) for large scale atmosphere-ice-ocean modelling (Haapala 2004; Karcher & Harms 2004; Kauker et al. 2003; Magnusdottir et al. 2004a,b). In return, the models enable the identification of key areas, e.g. sensitive regions in respect to climate feedbacks, and they give the possibility for the calculation of future scenarios.

Our recent research and monitoring activities with *in situ* and remote sensing studies aim at addressing and understanding the processes that are responsible for observed changes include observations and measurements undertaken at Svalbard, Fram Strait and Greenland Sea, the Barents and Kara seas, Alaska, the Beaufort Sea, and the central Arctic Ocean. Detailed long-term process studies are performed at Barrow (Alaska) and Ny-Ålesund (Svalbard), and on mooring profiles (Fram Strait, Hansen et al. in press), and are supplemented by studies on drifting ice stations (SHEBA, Perovich et al. 2003).

Here, physical parameters and related feedback processes are considered. The effects for the environment including habitats, biota etc. are not discussed. However, recent work indicates that biota itself can also be an active component in feedback processes (Leck et al. 2004).

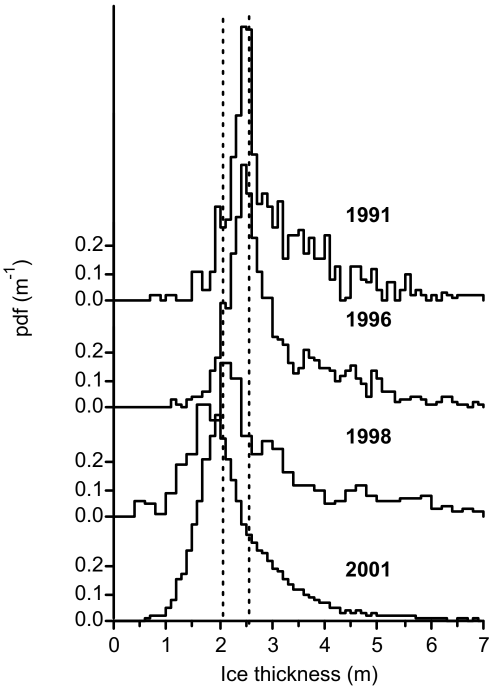

Fig. 1 (*left*): Ice thickness distributions (pdfs: probability density functions) of ice floes in the Transpolar Drift in 1991, 1996, 1998 and 2001. Dashed lines at 2 and 2.5 m are shown as a reference. From Haas et al. (2004). The modal ice thickness was reduced by 20% within 1991 and 2001.

Table 1 (*below*): Key sea ice parameters for climate change and feedbacks. Also listed are changes in the parameters, whether the changes were detected by observation or theory, our confidence in the results, future work recommendations, and comments. Abbreviations: MY=multi-year sea ice, FY= first-year sea ice, ULS= upward looking sonar, AUV= autonomous underwater vehicle, RS=remote sensing, cal-val=calibration-validation, RGPS=RADARSAT geophysical processor system.

Parameter	Change	Obs./ Theory	Confidence	Recommendations	Comment
Ice extent & ice concentration	Decreasing	O	High	Continue time series, improve spatial resolution	Automatic camera monitoring from ships
Thickness distribution	Shifting			ULS-time series, submarine surveys, ship obs.	Key climate parameter
Ice type	Shifting	O	High	Continue time series, improve spatial resolution	Automatic camera monitoring from ships
Mean thickness	Decreasing	O	High	Increase satellite cal-val	Since 1950's
Ridges	Decreasing	O	Medium	Submarine (or AUV) & aircraft campaigns	
Rafting	Increasing	T	Low	Process studies, thickness surveys, models	Difficult to determine what is rafted
Thin ice	Unknown		Low	Process studies	Important for ice prod., inferred from RGPS
Leads and polynyas	Unknown		Low	Process studies	Important for ice prod.
Energy balance	Increasing	O	Medium		
Ice mass balance	Decreasing	O	Medium	Field campaigns, autonomous buoys, Particular ice types	Demand of separation dynamics/ thermo-dynamics impact
Albedo	Decreasing	T	Low	Process studies (FY and special surfaces), RS input	Key to summer melt; important for climate models
Length of ice free period	Increasing	O	Medium	Satellite analysis	Important for mass bal., biology, shipping
Melt pond fraction	Increasing	T	Low	Field campaigns	Major impact on albedo
Ice motion	Different regimes	O	High (large scale), low (small scale)	High time resolution (hourly), coastal radars	Atmosphere driven, influences thickness distribution
Snow depth and properties	Unknown		Low	Satellite snow depth maps, field campaigns	Superimposed & snow ice formation; important for albedo

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Estimation of the Carbon Cycle in Forest Ecosystems of the Pechora River Basin (Northeast European Russia)

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Northern forest ecosystems play an important role in the global terrestrial carbon cycle. The forest area in the Pechora river basin occupies 17 mill ha, 85% from this value belongs to coniferous forests and 15% to deciduous ones. Spruce communities prevail. The forests of the area consist mainly of old-aged tree stands, which account for 80% of the total area in coniferous forests and 44% in deciduous ones.

It was established that the Pechora region forest phytocenoses yearly accumulate 58 mill t phytomass or 27 mill t carbon, 63.5% of which are deposited in tree stands. In phytomass accumulation and carbon flow, the coniferous forest communities are of highest importance. Annually, they deposit 85% of the total carbon flow to forest phytocenoses of the basin. Deciduous forest dominated by birch annually deposit 35 mill t carbon or 14% of the total carbon flow to the Pechora basin.

The old-aged bilberry spruce forests in the northern taiga subzone of the Pechora region were revealed to be a reservoir for CO_2-flow. The net primary production (NPP) value of phytomass here is equal to 7-8 t/ha or 3.5-4 t/ha carbon. As a part of tree waste, 2.5-3.0 tC/ha comes back to the soil yearly. Annual carbon fixation in net ecosystem production (NEP) is 1.0 tC/ha. During a year, 24-26 % of tree waste undergoes decomposition. The main part (60-70%) of carbon loss is formed by a mineral flow. Carbon return index to the atmosphere from the soil accounts for 0.6-0.8 tC/ha per year. Correlation between carbon in- and outflow shows that spruce tree stands serve as a carbon sink of 0.2-0.3 tC/ha annually. Chlorophyll content counting on 1 ha for the studied spruce phytocenoses comprises 10 and 13 kg. These figures correspond to values of carbon flow between 1.3 and 1.7 t/ha yearly being a little higher than the NEP data but quite comparable with the data on bioproductivity. According to the ecophysiological method, the old-aged spruce woods have typically a positive carbon balance (0.3-0.5 tC/ha annually), as well.

This research was conducted in the framework of the SPICE (Sustainable development of the Pechora region In a Changing society and Environment) project, funded by the INCO-COPERNICUS 2 Programme of the EC (Contract ICA2-CT-2000-10018).

Carbon Sequestration of East European Tundra Landscape

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Introduction

The tundra landscape mosaic consists of uplands, wetlands, lakes and rivers. The atmospheric impact of wetlands results from their carbon dioxide (CO_2) and methane (CH_4) dynamics. Northern wetlands have withdrawn CO_2 from the atmosphere since the last deglaciation and stored the carbon as organic matter in the soil. The wetland area of Russia is 150-165 Mha with a carbon stock of 200 – 215 Pg (Botch et al. 1995). The annual carbon accumulation of wetlands is not constant, it highly varies depending on weather conditions. Furthermore, a wetland is not a homogenous unit in terms of its carbon dynamics because the microhabitats of wetlands differ in their CO_2 and CH_4 dynamics and sensitivity for climatic variability (Alm et al. 1999). Knowledge on the carbon dynamics of various microsites is needed to understand the processes determining the carbon balance of wetlands.

In northern landscapes the aquatic ecosystems can not be neglected in estimates for the regional carbon balance. The northern lakes and rivers are generally CO_2 saturated reflecting leaching of organic matter from terrestrial ecosystems to aquatic ecosystems (Cole et al. 1994, Kling et al. 1991, Hamilton et al. 1994).

We studied the CO_2 and CH_4 fluxes in the East European discontinuous permafrost zone including both the terrestrial and aquatic ecosystems. Chamber techniques were used to measure CO_2 and CH_4 fluxes of various functional microsites. The fluxes of the terrestrial and aquatic habitats were then upscaled using satellite images. Here we present a short summary of the study (Heikkinen et al. 2004) conducted in the framework of the TUNDRA project.

Materials and Methods

The study sites were close to the Lek Vorkuta permafrost monitoring station (67°23´N, 63°22´E). The mean annual air temperature is -5.9 °C and mean annual precipitation 548 mm. The terrestrial microsites were grouped to five main groups (Fig. 1), in addition there were three aquatic environments. The study plots of 60 x 60 cm were measured in 2001 from June 6 to September 10. Net ecosystem exchange (NEE) and respiration (R_{tot}) were measured twice a week with a static chamber system using a portable infrared gas analyzer (LI-6200) for CO_2 (Nykänen et al. 2003). The seasonal CO_2 balance was then modelled from the measured fluxes using temperature and photosynthetic active radiation (continuous data) as the independent variables. Methane dynamics were measured on a weekly basis using a static chamber method (Nykänen et al. 1998). The gas balance for the whole Lek Vorkuta catchment was estimated using a landcover/vegetation classification scheme based on Landsat TM 5 images and ground truth data from the vegetation.

Results and Discussion

The wet peaty tundra withdrew 109 g C m^{-2} (NEE) during summer from the atmosphere, all the other measured terrestrial classes showed carbon loss from -5 to – 123 g C m^{-2} (Fig.1). The willow dominated sites could not be measured by the chamber method, and their carbon balance was estimated to be zero. Methane was included to the C fluxes. Methane-C fluxes varied from low uptake of 0.2 g C m^{-2} to emission of 13.6 g C m^{-2}. The lichen dominated dry peat plateaus had CH_4 uptake, and the wet peaty soils had the highest CH_4 emission, i.e. the wet soils with vascular plants had the highest CO_2 uptake and the highest CH_4 release. Thermokarst lake profundals, lake margins and rivers were sources of CO_2 (Fig. 1) and CH_4. There CH_4-C fluxes varied from -1 to -5.4 g m^{-2}.

The coverage of wet peaty tundra was about 13 %, and corresponded to a net carbon uptake of 1.6 Gg C for the whole (114 km^2) Lek Vorkuta catchment. Tundra heath had the highest coverage (47 %) and showed the highest carbon loss (4.7 Gg) from the catchment. The losses from dry peat tundra and peat plateau (palsa) were 0.45 and 0.38 Gg, respectively. The carbon losses from the other soil classes as well as from the aquatic ecosystems were negligible at the catchment scale when compared to the losses above.

The photosynthesis and respiration potentials were controlled by the vegetation. Soil temperature further controlled respiration. Some of the soil classes were studied also in summer 1999 when soil mean temperature at the depth of 5 cm was 1-2 °C lower than in summer 2001 (Heikkinen et al. 2002). The increase of 2 °C in temperature doubled the CH_4 emissions from the wet surfaces. These results support the conclusion by Christensen et al. (2003) on the importance of temperature on CH_4 emissions from wetlands.

The various functional terrestrial surfaces have different carbon dynamics, and the tundra carbon balance is a sum of the carbon dynamics of the various functional surfaces. The results suggest that the dry soils in the East European tundra landscape are units releasing the stored carbon to the atmosphere. The wet terrestrial surfaces in the region can not compensate the carbon loss from the dry soil classes. In the region the coverage of aquatic ecosystems is not high enough to give an important contribution to the regional carbon balance. The change in temperature and hydrology obviously had different effects on the carbon gas dynamics of the various functional surfaces.

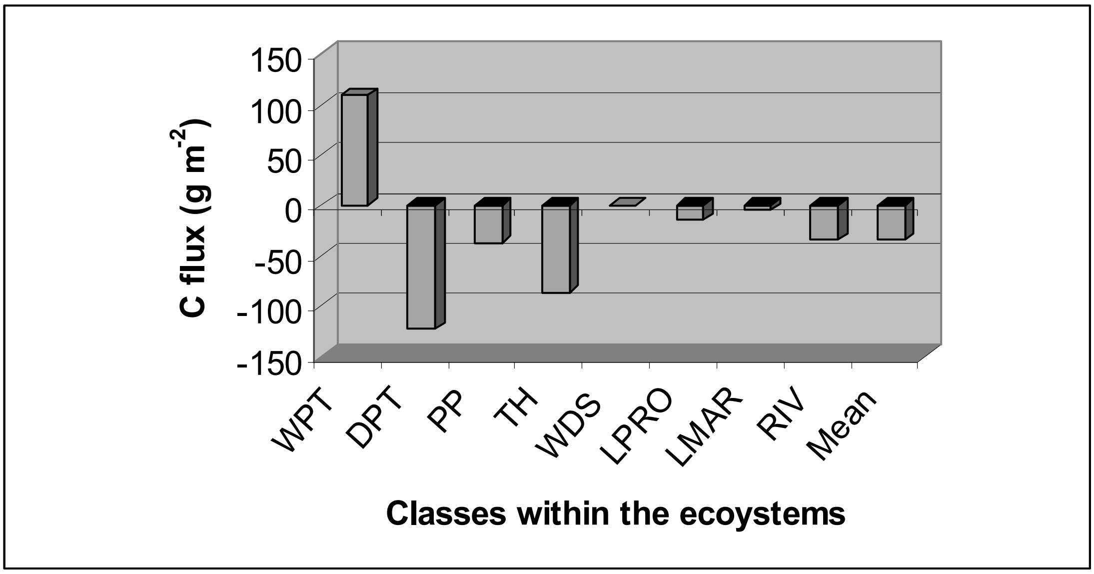

Figure 1. Carbon gas (CO_2 + CH_4) exchange between the atmosphere and various terrestrial and aquatic ecosystems in the Lek Vorkuta catchment in summer 2001. Positive flux is carbon uptake, negative flux means carbon loss.

WPT= Wet peaty tundra (12.9), DPT= Dry peaty tundra (3.2), PP= Peat plateau (9.0). TH= Tundra heath (46.8), WDS= Willow dominated stands (24.3) , LPRO= Thermokarst lakes, profundal (3.3), LMAR= Lake and pond margin (0.1), RIV= Rivers (0.3), Mean = carbon dynamics weighted by area. Number in parenthesis is the percentage coverage of the classes.

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The Runoff and Concentrations of Nutrients in the Rivers Utsjoki (N. Finland) and Khosedayu (N.E. European Russia)

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Introduction

River runoff, nutrient and TOC concentrations were studied at two locations in the European Arctic, i.e. the rivers Utsjoki in northern Finland and Khosedayu in northeastern European Russia (Fig. 1). The study was carried out during the years 2000-2002 with the most complete dataset obtained during the summer 2001. The results are discussed in relation to catchment properties.

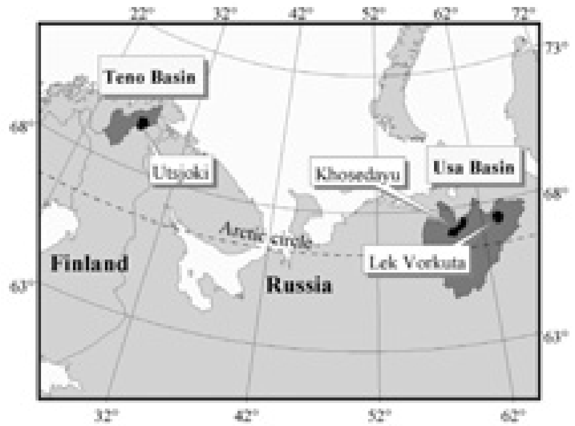

Figure 1. Location of the study sites

Material and methods

Average annual temperature (average of years 1971-2000) is -5,0 ^{o}C in Khosedayu and -1,7 ^{o}C in Utsjoki. Annual precipitation (average of the same years) is 452 mm in Khosedayu and 415 mm in Utsjoki. The catchment areas above the sampling points are for Khosedayu River 2280 km^2 and Utsjoki River 1520 km^2. The proportion of area covered by forests is clearly higher in the Utsjoki catchment than in the Russian study site, where peatlands dominate. Unlike in the Khosedayu catchment, the area of permafrost is minimal in the Utsjoki catchment.

Sampling for water chemistry was done weekly during the open water period at both study sites. During the winter time, samples were taken usually once a month. Discharge measurements were performed at the same frequency as sampling in Khosedayu River while daily discharge values were available for Utsjoki River. Samples from Khosedayu were analyzed in the Ecoanalytical Laboratory of the Komi Institute of Biology, Russian Academy of Sciences, while Utsjoki samples were analyzed at Lammi Biological Station, University of Helsinki, Finland, both according to the standard methods.

Results and discussion

The spring flood formed a considerable proportion of annual runoff in both rivers, but even more so at Khosedayu (Fig. 2). Nutrient concentrations were much more variable in the Russian study site and usually higher than in Utsjoki (Fig. 3). The Khosedayu water samples analyzed at Lammi Biological Station for calibration purposes indicated the same properties. Contrary to Khosedayu River, there were clear increases of phosphorus concentrations only during the spring flood in Utsjoki River.

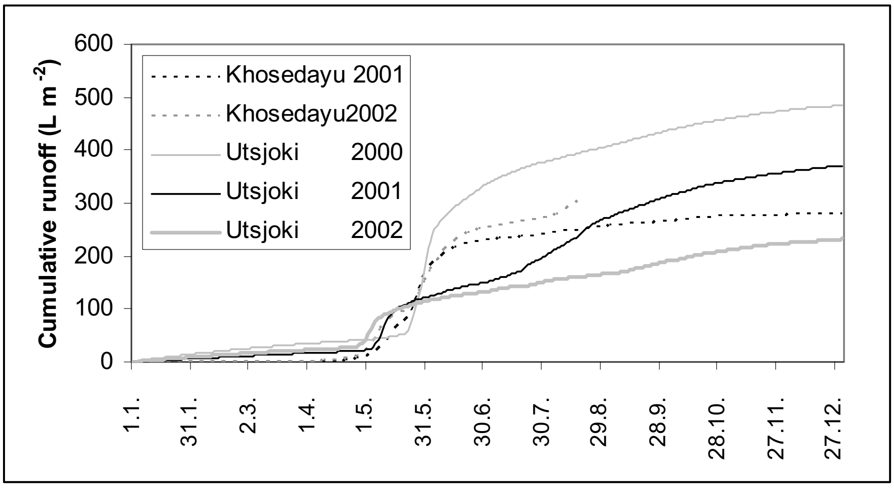

Figure 2. Cumulative runoff at the two study sites.

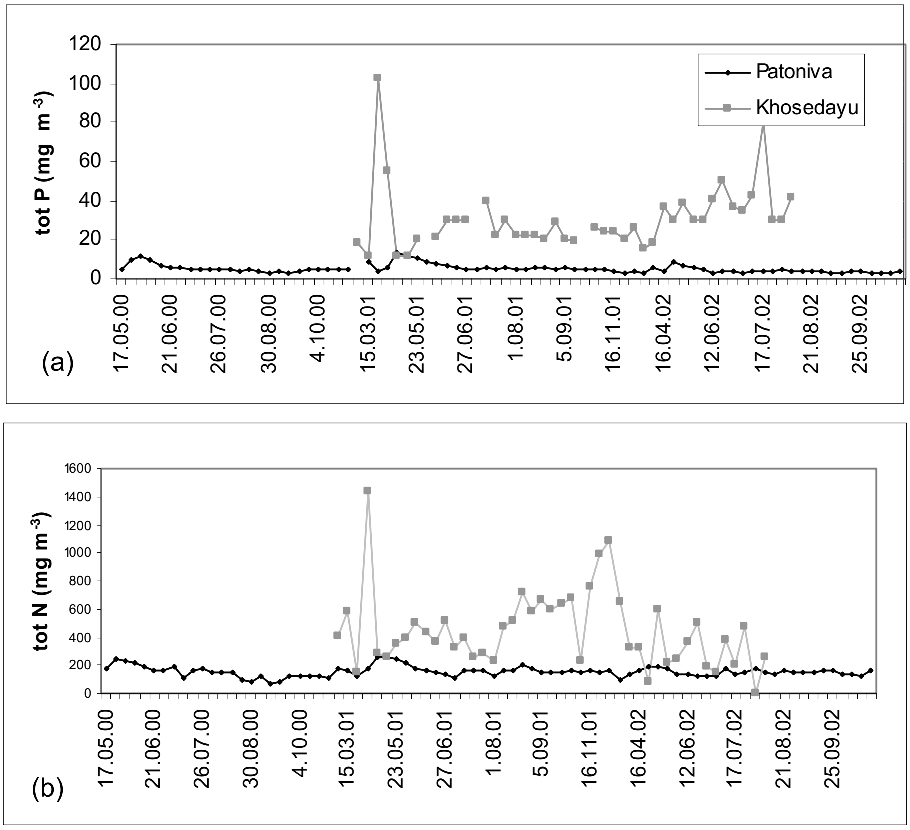

Figure 3. The concentrations of (a) total phosphorus and (b) total nitrogen during the study.

The flux of total organic carbon (TOC) was 3,11 g C $m^{-2}a^{-1}$ in Khosedayu in 2001. In the middle of August, the end of the sampling period of the year 2002, the flux was already 3,13 g C m^{-2}, indicating differences between the years but also highlighting the importance of the spring flood for carbon transfer in runoff (Fig. 4). For Utsjoki, the TOC flux was 1,93 g C $m^{-2}a^{-1}$ in 2000 and 0,82 g C $m^{-2}a^{-1}$ in the year 2002.

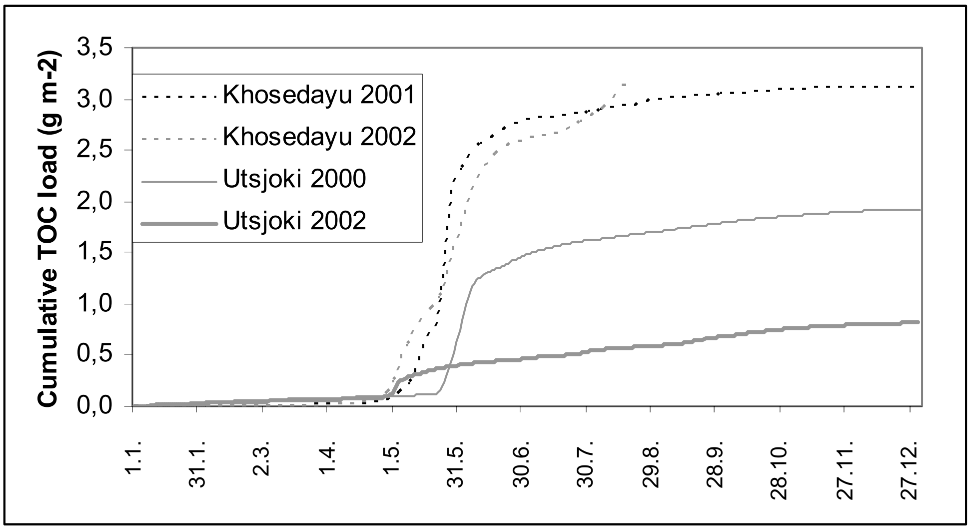

Figure 4. Cumulative TOC load from the study sites.

The higher flux of TOC in Khosedayu was probably due to the high proportion of peatlands compared to the Utsjoki catchment. Heikkinen (1989) found TOC loads in a humic river in northern boreal Finland to be 6.75-7.91 g C $m^{-2}a^{-1}$ and Arvola (1999) calculated TOC loads of 0,88-8,00 g C $m^{-2}a^{-1}$ from two large drainage basins in northern Finland. In their study of 16 Finnish rivers, Arvola et al. (2004) found carbon outflow from the terrestrial ecosystems to be highly dependent on the amount of peatlands in the drainage basin.

Acknowledgments

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Soil Carbon Database for the Usa River Basin, Northeast European Russia

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Introduction

Soil organic carbon estimates crucial for assessments of the carbon balance in terrestrial ecosystems are mostly scaled-up using coarse-scaled landscape or vegetation maps. Meanwhile, sensitivity of these estimates to data source, scale and upscaling method remains poorly known. In this study we obtained soil organic carbon estimates for major soil and vegetation classes in the subarctic Usa River basin (ca. 93,000 km^2; Fig. 1) based on two independent datasets and using two independent upscaling methods (Kuhry et al., 2002; Mazhitova et al., 2003). Pedon density per area unit and map resolution are higher than in similar studies from the Russian North.

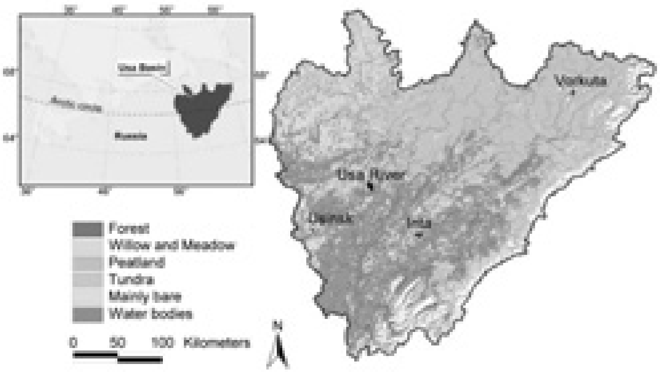

Figure 1. Location of the Usa River Basin

Methods

For soil classes, 93 pedons (soil sections) were used collected under the EC-funded TUNDRA project and 272 pedons previously available in a Russian database. For vegetation classes, all TUNDRA and most Russian pedons were used. Carbon pools were calculated for the upper 30- and 100-cm layers and for the actual soil depth (BC and C horizons excluded). For the TUNDRA database internationally adopted laboratory methods were applied, whereas laboratory methods varied greatly in the Russian database. For mineral horizons in which carbon content had been determined by wet digestion the coefficient 1.28 was used to convert data to dry digestion. For organic horizons carbon was either determined by wet acid-chromium (III) oxide digestion, or calculated from Loss-of-Ignition using the coefficient 0.57. To obtain missing bulk density values, a regression of carbon by bulk density was utilized with R^2 equal to 0.83. To upscale ground measurements to the entire Usa Basin vegetation/landscape and soil classification schemes were used, both implemented in GIS format. The former is based on Landsat 5 TM images with a pixel size 30 m x 30 m. The main source for the latter was the National Soil Map of the USSR. For the basin area 653 polygons were recognized averaging circa 144 Km^2.

Results and Conclusions

Based on soil classes, highest carbon contents within a 1-meter soil depth (59-67 KgC/m^2) are found in different Histosols (peat deposits), among which Cryic Histosols dominate in the Usa

Table 1. Amount of organic carbon in soil classes that occupy >3% of the Usa Basin

Soil class	Mean carbon, Kg C m^{-2}		n	Mean carbon, Kg C m^{-2}		n
	30 cm	SD		100 cm	SD	
Silti-Stagnic Albeluvisols	5.9	2.5	10	9.8	3.3	8
Stagni-Histic Albeluvisols (Siltic)	10.7	3.4	7	14.1	5.6	6
Turbi-Histic Cryosols (Gleyic)	14.4	5.8	15	24.4	2.6	6
Stangic Cambisols	6.8	3.1	63	12.4	5.2	63
Gelic Cambisols	7.1	4.1	10	12.0	7.4	9
Stagni-Gelic Cambisols	9.2	5.1	23	16.1	7.2	21
Dystri-Leptic/Dystri-Sceletic Camb.	5.5	2.0	30	7.9	2.7	19
Dystric Leptosols	2.8	1.8	8	4.2	0.6	3
Dystric and Rhei-Fibric Histosols	17.6	no value	15	58.7	no value	15
All Cryic Histosols	19.9	no value	11	66.3	no value	11

Basin having permafrost within a 1-meter depth (Table 1). High values (23-25 KgC/m^2) are also reported for Histic Cryosols (mineral tundra soils with permafrost within 1 m depth). Besides storing carbon in Histic horizons, Cryosols have mineral horizons enriched with organic matter by cryoturbation. Lowest values of 4.2 KgC/m^2 are in Leptosols (shallow mountain soils). Thus, the soils shallow over permafrost and, therefore, most dynamic under climate change, contain the highest amounts of carbon in the active layer. Besides, carbon content is high in the upper layers of permafrost underlying these soils. Estimates based on vegetation (Table 2) show the highest carbon contents (53 KgC/m^2) in peatland-associated vegetation classes. Classes associated with mineral tundra soils have values similar to spruce and mixed coniferous forest classes (9-16 kgC/m^2). Standard deviations in carbon estimates based on soils are lower than those based on vegetation, though soil classification is not based directly on carbon content. Attempts to additionally subdivide soil classes by texture further reduced standard deviations.

Table 2.Amount of organic carbon in vegetation classes that occupy >3% of the Usa Basin

Vegetation/landsacpe class	Carbon, Kg C m^{-2}				n
	Mean 30 cm	SD	Mean 100 cm	SD	
Spruce forest	9.2	3.2	16.0	8.6	23
Mixed forest	9.3	4.7	15.1	7.5	31
Young stands	4.2	1.4	6.8	2.1	4
Willow complex	12.2	6.3	23.2	11.1	15
All peatlands	18.1	no value	53.0	no value	33
Shrub-moss tundra	7.5	3.4	14.3	5.9	39
Dwarfbirch heath	7.9	4.1	15.5	7.8	30
Lichen-moss tundra	8.1	5.7	11.4	6.7	13
Natural barelands	0.4	0.0	1.2	1.2	2

Results of upscaling the obtained estimates to the entire basin are shown in Table 3 (generalized). Upscaling using soils has as advantages the larger sample numbers and low standard deviations. On the other hand, the resolution of the soil map is much lower than that of the vegetation map. Despite the differences in datasets and upscaling tools, the average soil carbon content obtained for the Usa Basin is similar, i.e. for actual soil depth 24 kgC/m^2 using soils and 28 kgC/m^2 using vegetation, and for a 1-meter depth 25.6 kgC/m^2 and 29.0 kgC/m^2, respectively. These values are higher than those mentioned in most previous estimates for tundra and northern taiga, 10-27 kgC/m^2 (Table 4). Most of these estimates employed much coarser scales compared to our study. Of the total carbon in the Usa Basin, 67% to 75% is allocated in peatlands that occupy only 27 to 30% of the basin area.

Based on the vegetation map we delineated subregions in the Usa Basin. Vegetation-based average carbon pools calculated for actual soil depth were 27 kgC/m^2 for forest, 35 kgC/m^2 for tundra and 1 kgC/m^2 for the Ural mountains. These averages include the upland-, wetland- and lake

Table 3. Upscaling soil carbon estimates for the Usa Basin using vegetation/landscape and soil classification schemes (water bodies excluded)

Vegetation/soil class	Area, % in the basin	Total carbon, TgC	
		30 cm	100 cm
Forests	24.1	190.7	295.2
Azonal (peatlands included)	42.6	298.0	1667.8
Tundra	25.7	163.7	333.6
Alpine	7.6	3.4	8.8
TOTAL	100.0	979.6	2329.3
Cryosols	16.8	220.2	364.5
Non-Cryosolic mineral soils	57.9	396.3	759.3
Dystric and Rhei-Fibric Histosols	6.6	107.5	358.3
All Cryic Histosols	18.7	347.7	1159.0
TOTAL	100.0	1071.7	2640.1

Table 4. Estimates of average total soil carbon content in northern soils

Original reference	Kg C m^{-2}	Region
Kononova, 1976	20.0	Russian tundra
Schlesinger, 1977	21.6	World Arctic and alpine tundra
Schlesinger, 1977	14.9	World boreal forest
Ajtay et al., 1979	12.7	World Arctic and alpine tundra
Post et al., 1982	21.8	World tundra
Orlov & Birukova, 1995	16.8	Russian forest-tundra and northern taiga
Kolchugina et al., 1995	21.4	Russian tundra
Kolchugina et al., 1995	20.0	Russian forest-tundra
Kolchugina et al., 1995	27.0	Russian taiga
Rozhkov et al., 1996	10.6	Russian Polar and Tundra zones
Chestnykh et al., 1999	17.8	East-European Russian tundra
This study	31.2	Usa Basin, Russia

components of the landscape. The difference between the northernmost taiga and southern tundra carbon pools is much lower than usually reported for taiga (13-16 kgC/m^2) and tundra (20-24 kgC/m^2). Soil-based pools were 28 kgC/m^2 for forest, 32 kgC/m^2 for tundra and 5 kgC/m^2 for the Ural mountains. Based on C/N ratio and other indexes, tundra soil organic matter, however, is less decomposed than in the taiga. Hence, the potential of large-scale carbon emissions from southern tundra soils under conditions of global warming (and permafrost thawing) is not only related to the greater carbon pool compared to northern taiga but also to its susceptibility for more rapid decay.

Acknowledgments

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Modelling Treeline and Phytomass Changes in European Arctic Catchments

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Introduction

Transitional zones in the Arctic may be especially sensitive to climate change, which in turn may have several impacts on their various functional roles in these areas. When the potential responses of tundra and taiga ecosystems and their border zone to predicted climate changes are modelled, detailed basic information about the local vegetation structure and its carbon allocation are needed. In remote and largely pristine regions, satellite image based inventory and modelling of the vegetation patterns with GIS (Geographical Information System) can produce spatially detailed information about the effects of climate change on vegetation. For this purpose, we compiled GIS-databases about major landscape/vegetation units and associated phytomass and carbon in two study areas in the European Arctic. Furthermore, we established models describing the relation between present climate and vegetation by combining GIS-based vegetation data and regional climate data. With these models and some additional information we present predictions about the vegetation distribution and carbon in phytomass under climate change scenarios.

Material and Methods

We compiled data sets for two study areas, the Usa-river basin, 93500 km^2, located in NW European Russia, and the Teno-river basin, 16800 km^2, extending from Finnish Lapland to Finnmark in Norway (Fig. 1). Vegetation zones in both study areas range from northern taiga forests to treeless tundra vegetation types and the transition is caused by northerness and/or altitude.

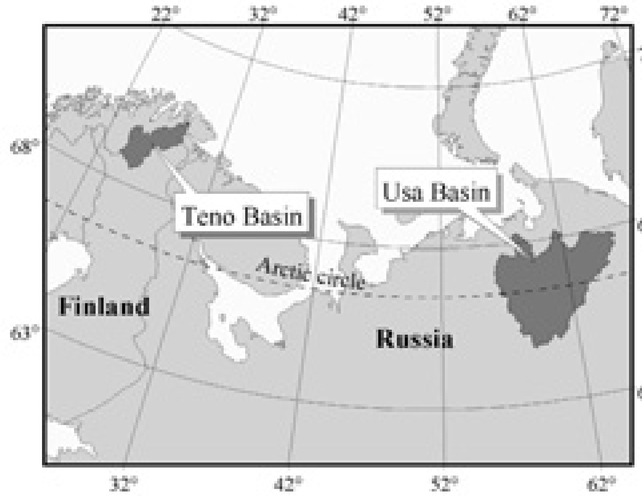

Figure 1. Location of the study areas.

We produced vegetation classification schemes using Landsat TM satellite image mosaics. The Usa basin classification is presented in Virtanen et al. (2004a); the Teno basin data is not yet finalised. For every vegetation class we estimated mean phytomass and related carbon of the living aboveground vegetation. Phytomass estimates are based on tree volume measurements and laboratory analysis of ground layer samples. Tree volumes were converted to whole tree phytomass estimates using equations found in the literature (Alexeyev et al., 1995; Shvidenko et al., 1998). Phytomass values were converted to carbon using a coefficient of 0.5. More details will be presented in Virtanen et al. (in preparation).

We modelled the relation between present climate and vegetation by using different GIS-based data sets and logistic regression. As the forest line is the most important vegetation and related phytomass border zone in the area that potentially responds quickly to climate change, we concentrated our modelling efforts to model its location (for details see Virtanen et al., 2004b and Mikkola & Virtanen, submitted).

Results and Discussion

The average carbon content of the different vegetation communities vary in the Usa basin from about 4 kg C m^{-2} in spruce-dominated northern taiga forests to about 1.5 kg C m^{-2} in the sparse tree-line forests, and to about 0.4 kg C m^{-2} or even less in the shrub tundra (Table 1 and Fig. 2a). In the Teno basin, the average values vary correspondingly from almost 4 kg C m^{-2} in pine-dominated forests to over 2 kg C m^{-2} in mountain birch forests, and to about 0.5 kg C m^{-2} in the treeless heath vegetation. Our values correspond relatively well with some regional inventories made in nearby or corresponding regions, but gradients are not so steep as typically used in global vegetation models. As not all Teno basin calculations are finalised, we will focus only on the Usa basin results further in this paper.

	Present C	C in 2080	C in stab. climate
The whole Usa Basin	**0.84**	**1.28**	**2.54**
Boreal Northern taiga	2.04	3.27	4.44
Extreme Northern Taiga	1.70	2.33	3.36
Forest-Tundra	0.62	0.98	2.17
Tundra	0.35	0.56	2.09
Mountains	0.25	0.31	0.91

Table 1. Present mean carbon stock in living aboveground vegetation (kg/m^2) and predicted stocks for future climate for different vegetation zones within the Usa basin.

We made scenarios about the future vegetation distribution and allocated aboveground carbon in phytomass for the Usa basin under climate change scenarios produced by the HadCM2S750 integration (Hadley Centre, UK). When compared to climate in 1960-1990, this scenario predicts an increase in the July mean temperatures of 2.8 ºC by 2080, and 3.9 ºC for a stabilized climate after 2230. When the climate warming scenario for the year 2080 is applied, almost the whole Usa basin lowland would be potentially forested (Virtanen et al., 2004b), and only some mountainous areas would be outside of the range where climate would allow the growth of forest. Thus, if predicted climate warming will happen, in the year 2080 temperature will not anymore be the limiting factor for the forest expansion to all soils suitable for forest growth within the Usa basin.

We made two different aboveground phytomass change scenarios, for the year 2080 and for a stabilized climate after 2230. In both scenarios we assumed that peatland phytomass will not change, as they are mainly controlled by hydrologic conditions. Phytomass of the presently mainly bare areas were assumed not to change due to the lack of suitable soil and/or disturbance conditions. It was also assumed that there will be no forest cuttings and that the amount of any kind of disturbances will not change. Even though our treeline-distribution model already showed that temperature will not anymore be the limiting factor for forest growth in the Usa basin by the year 2080 (Virtanen et al., 2004b), it is not reasonable to assume that the whole Usa basin would already be occupied by mature forests at that time due to time lags caused by seed dispersal and forest growth. Historical treeline expansion values from 1 to 10 km per decade have typically been presented in literature, but in process-based models lower expansion rates have often been used (Clark, 1998; Rupp et al., 2000). Thus, we assumed that the treeline will have expanded 30 km northwards in the 2080 scenario, and phytomass of these new forests will be 50% of the phytomass of the present forest line forests. Furthermore, we assumed that the mean phytomass of the forests and shrub tundra vegetation communities will increase by a factor of 1.5. For the stabilized climate scenario, we assumed that all nowadays shrub tundra-vegetation will be occupied by forests with corresponding phytomass values to the present forests in the Usa basin. For the present forests in taiga and forest-tundra we assumed that their mean phytomass will be corresponding to forests found in the headwaters of the Pechora basin nowadays (Bobkova, 1999). Field data and literature based increase values used in these calculations are optimistic, probably the greatest possible increase. In the whole Usa basin, the amount of the carbon in living aboveground phytomass might be 1.5 times higher in the year 2080 than present, and in a new stabilized climate 3 times higher (Table 1, Fig. 2b and c). Our scenario is not taking into account any potential increase in disturbance factors (fires, insect outbreaks, etc.) that could affect negatively the carbon stock.

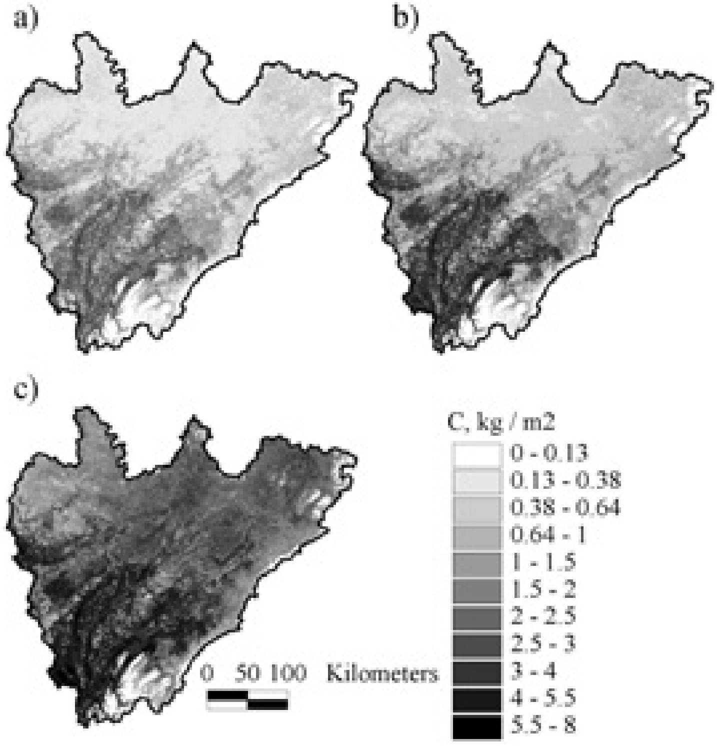

Figure 2. Carbon in the living aboveground vegetation in the Usa basin. a) Present situation, b) Scenario for 2080, and c) for stabilised climate.

Concluding remarks

We produced spatially detailed vegetation classifications and related carbon stock estimates for relatively large and remote study areas with fairly small amounts of fieldwork. These data sets have already been used successfully in many different studies. This kind of regional studies can aid the global vegetation and climate modellers to adjust parameters of their models to be more realistic, as there are significant discrepancies in different generally used land cover and vegetation carbon content data sets.

Acknowledgments

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Spatial Variability of Atmospheric DMS and its Implication of Cloud Formation in the High Arctic - A Model Study

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Introduction

The high Arctic region (north of 80°N) is a suitable region for studies of climate change since the anthropogenic influence is limited. The results from different climate models show different scenarios, but all indicate that climate changes would appear earlier and more pronounced in the high Arctic (IPCC, 2001).

Clouds are important for the Earth-atmosphere radiation budget since for instance, they reflect incoming short-wave radiation. The amount of radiation reflected back to space depends on the concentration of cloud droplets in the cloud. This, in turn, depends on the available concentration of soluble particles (larger than 70nm). They are called cloud condensation nuclei, CCN (Twomey, 1974).

Atmospheric dimethyl sulfide (DMS(g)) is a gas with biological origin, produced in the surface oceans. It is transported into the atmosphere where it is transformed by photo-oxidation into gas-phase sulfur components i.e. sulfuric acid, sulfur dioxide and methane sulfonic acid (Leck and Persson, 1996a).

The sulfur components condense on pre-existing aerosols to, subsequently, be able to act as CCN (Leck et al., 2004). As a result they contribute to the cloud formation and thereby influence the radiative balance (Charlson et al., 1987).

In the high Arctic region, the major source of DMS(g) is found along the marginal ice zone (MIZ). Local sources of DMS(g) over the pack ice have been found to be negligible compared to DMS(g) that is advected from the MIZ (Leck and Persson, 1996a; Leck and Persson, 1996b).

The production of CCN by condensation of DMS(g) oxidation products advecting over the pack ice region is potentially important in controlling the available sulfur and consequently the cloud formation north of 80°N.

2. Observations from the Arctic Ocean expedition 2001

The Arctic Ocean expedition 2001 (AOE01), is an interdisciplinary and multinational research program, divided into five sub programmes: marine biology, gas and aerosol chemistry, aerosol physics and meteorology. The field experiment took place in the summer 2001 where the icebreaker Oden cruised over the Arctic Ocean for two month. More information about the expedition is found at:

http://www.fysik.lu.se/eriksw/aoe2001/aoe2001main.htm.

Figure 1 shows the spatial variability of DMS(g) from AOE01. The concentrations are highest over the open water in the MIZ while the concentrations found over the pack ice are lower.

Atmospheric DMS(g) concentrations decline by oxidation during transport over the pack ice from the open water south of and within the MIZ (Leck and Persson, 1996b and Nilsson and Leck, 2002). The estimated turnover time for DMS(g) is about 1.6 days for AOE01.

Past observations over the pack ice area have shown changes in gas phase DMS near the surface exceeding the entire seasonal variability, occurring on time scales of minutes to hours (Bigg el al., 2001).

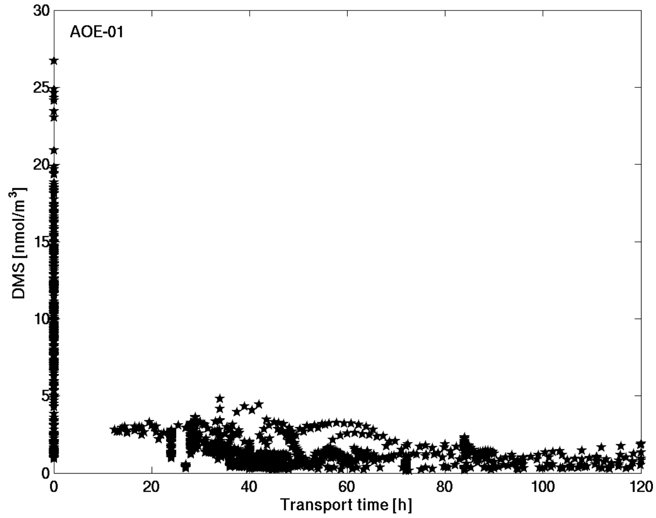

Figure 1. DMS(g) in nmol m^{-3} plotted against transport time in hours, i.e. the time since last contact with open water. From AOE01 (4 July to 25 August, 2001).

3. Model setup and the case study

This study has been undertaken to see the extent to which chemical or meteorological processes could be the cause of the observed variability. It is based on a real case scenario using ECMWF-analyze fields, provided by ECMWF data server, as initial and boundary conditions to a simulation using COAMPS^{TM} (Coupled Ocean Atmosphere Mesoscale Prediction System, Hodur, 1996). The source of DMS(g) is given by a dynamical DMS-flux and a chemical decay rate is applied based on field observations from AOE-01.

The dynamical flux is based on a transfer velocity (Liss and Merlivat, 1986) using a constant value of the Henry law constant of 0.0399 (Dacey et al., 1984). This velocity is a function of the wind speed, sea surface temperature and surface-water concentration of aqueous DMS (DMS(aq)).

The DMS(aq) value is assumed to be constant in the model domain with a value based on 15 samples of DMS(aq) from AOE01 at depths from 1 to 10m. Since the samples of DMS(aq) show a large variability and they do not have normal distribution, the calculated median value was used in the model.

Actual satellite based ice cover data (Kaleschke et al., 2001) was used in the model instead of a climatological average ice cover.

A 5-day simulation (19-24 of August, 2001) was chosen since it was a clear case of DMS(g) advected straight to the observational site from the MIZ in the Greenland Sea (Figure 2).

4. Conclusions

Our model results show that DMS(g) is advected in narrow plumes from the source region at the open ocean and MIZ. Concentrations within the pack ice region will therefore depend heavily on the location of observation and could at least partly explain the observed variability at any given location.

Figure 3 shows model results of DMS(g) from the location of observation and the surrounding grid points, plotted against time from 24 to 120h. The concentration is higher (about 3 to 5 nmol m^{-3}) around 60-80h and 110 to 120h, probably due to the plumes of DMS(g).

Acknowledgements

We thank Patricia Matrai for providing the DMS(aq) data.

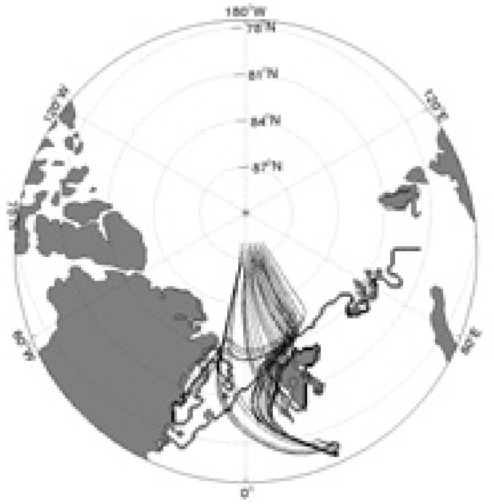

Figure 2. Trajectories following an air parcel within the boundary layer from a region around the location of observation. Results from the model.

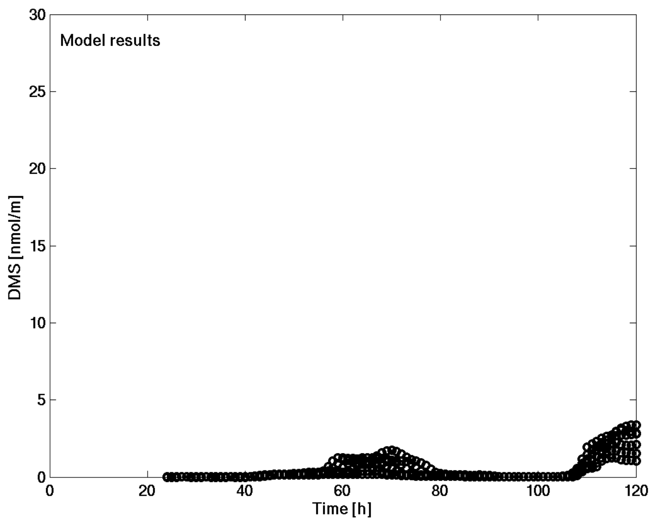

Figure 3. DMS(g) in nmol m^{-3} plotted against time in hours. Model results from the location of observation and the surrounding grid points, 20-24 of August 2001.

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The Combined Effects of Climate Change, Acid Rain and Ultraviolet Radiation (UVR) on Mercury Contamination of Arctic Ecosystems

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Introduction

Too often environmental problems are considered independently of each other. Here we illustrate that the combined influence of climate change, acid rain and UVR can profoundly influence mercury contamination of Arctic ecosystems leading to man. It is known that the subsistence lifestyle of some northern residents has resulted in high levels of mercury in their blood and hair (Wheatley and Wheatley, 1998). While there are still many unanswered questions, we identify areas where progress is important for future management decisions. Aspects of the complex interplay is given below:

1. Sources of mercury to the environment are related to carbon dioxide emissions

Budgets for anthropogenic mercury released to the environment remain incomplete but the contribution due to coal combustion, particularly by power generation stations, is clear. New data for natural gas and crude oil suggest that these sources cannot be ignored. In general, the release of carbon dioxide is thought to be related to climate change and is intimately linked to the release of mercury. Reducing fossil fuel consumption will reduce mercury emissions.

2. Climate warming and long-range transport of mercury linked to acid rain

Mercury transport to the Arctic is in part due to transport from warmer regions and deposition in colder regions (Wania and Mackay 1996). Volatilization from soils does increase with temperature (Schroeder, 2004) but the return to the ground via wet deposition requires an oxidation step that is controlled in part by the concentration of sulfur dioxide or sulfurous acid. In air highly polluted with sulfur dioxide, the rate of conversion to Hg(II) is slower. Conversion of elemental mercury Hg(0) to Hg(II) will occur further from the source increasing deposition where the air is lower in sulfur dioxide and where it is cold (Van Loon et al, 2000; 2001).

3. Mercury depletion events following polar sunrise

Based on research at Alert, concurrent depletions of atmospheric Hg(0) and tropospheric ozone occur over a 3-month period following polar sunrise (Schroeder et al., 1998). UVR initiates photochemical reactions involving halogens such as Br and BrO derived from sea-salt aerosols. The oxidation of atmospheric Hg(0) vapour enhances the wet and dry depositional flux of less volatile Hg(II) forms (Lu et al., 2001). Ariya et al. (in press) have performed a modeling study that showed that Arctic deposition was about 325 tonnes per year. Lindberg et al. (2002) concluded that 30-40% of the depleted Hg(0) is converted to an oxidized form of mercury and the remainder scavenged by aerosols then deposited as fine particulate mercury. Both are biologically available for formation of methyl mercury.

Lahoutifard et al. (in press) monitored Hg(0) at two heights above the snow surface (20 and 150 cm) in May 2003 at Resolute. At this time there was continuous daylight (long past polar sunrise). Nevertheless, there was still a noticeable diel pattern in solar radiation. Our focus was to follow the detailed patterns between solar radiation and mercury gradients above the snow pack. In this way, we identified the direction and magnitude of mercury flux between the atmosphere and the snow. We concluded that much of the mercury deposited in mercury depletion events moved back into the atmosphere either from the snow directly or volatilization from water formed when the snow melted.

4. Influence of UVR on volatilization of mercury from snow and water

Fortunately, Hg(II) in the snow can also be converted to Hg(0) through photolytic reduction. It is then emitted to the atmosphere as Hg(0) (Lalonde et al., 2002). These investigators observed that about half of the Hg is lost to the atmosphere within 24h after deposition in fresh snowfall. Earlier work on lakes showed that exposure to UVR was necessary for the conversion of Hg(II) to Hg(0) that can volatilize from Arctic lakes to the atmosphere (Amyot et al., 1997).

5. Role of pH and hydrogen peroxide formation from UVR exposure

Diel patterns of hydrogen peroxide (H_2O_2) in snow were also measured at Resolute during May 2003 (Lahoutifard et al., submitted). At this time of the season, snowmelt had not started and there was continuous 24 hour daylight. Daily surface snow concentrations of H_2O_2 increased from early morning to maximum levels in the afternoon following solar irradiance by about 2 hours. H_2O_2 can be both an oxidant and a reducing agent depending on the pH of the snow or water. The pH in snow at Resolute was higher due in part to particulate material (containing carbonate, SiO_2, Ca^{++} and NH_4^+) from natural origins blowing in the Arctic winds. It was shown that here hydrogen peroxide was a reducing agent that increased the rate of mercury flux from snow to air. In a previous experiment at Kujjuarapik, PQ where the pH was lower, hydrogen peroxide increased the opposite flux from air to snow due to its ability to act as an oxidizing agent (Lahoutifard et al., 2003). This illustrates the link between UVR, pH and mercury transport.

6. Direct deposition of methyl mercury as a source for the Arctic food web

Only two papers provide any data for methyl mercury in the Arctic snow or fresh water (Loseto et al., 2004a; b). Methyl mercury is by far the most toxic form of mercury and the only form that accumulates in food chains leading to man. They showed that although methyl mercury can be formed in wetland soils even at the cold summer temperatures of 4-6 ^{o}C direct input from the snowpack was the major source to downstream rivers and lakes.

It other work it was hypothesized that the source of methyl mercury in snow is from volatilization of dimethyl mercury from the North Atlantic followed by photodegradation by UVR to monomethyl mercury and subsequent deposition (St. Louis et al., 2004). Alternatively, sources of dimethyl mercury must exist from industrial activities as we have also identified high levels of methyl mercury in newly fallen snow in the Ottawa/Montreal region of Canada.

7. Photodegradation of methyl mercury

With the first spring thaw in the Arctic, methyl mercury is lost from the snowpack and appears in the meltwater of the small streams (Loseto et al., 2004). Fortunately, some of it is degraded by exposure to UV radiation. New data will be provided showing this process.

8. Role of pH in methyl mercury accumulation in food chains

The variable that best predicts the mercury in small fish in temperate regions is pH (Hickey et al., in press). It is reasonable to conclude that a reduction in sulfur dioxide emissions will not only increase the atmospheric transport of mercury (see above) but reduce the binding of methyl mercury to ligands increasing uptake of methyl mercury at the base of the aquatic food web.

Conclusions

Reducing fossil fuel consumption will reduce mercury emissions. Climate warming will increase mercury transport to the Arctic. Sulfur dioxide emissions extend patterns of mercury deposition. Acidity increases accumulation of mercury in food chains. Although mercury depletion events do occur with polar sunrise in the Arctic, much of the mercury is volatilized back to the atmosphere. UVR initiates the formation of hydrogen peroxide in snow that can increase the transport of mercury from the snow to the air if the pH is >6 but the reverse if the pH is <4.5. The principal source of methyl mercury to the Arctic food web is direct deposition rather than conversion of Hg(II).

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Lead-210 Concentration in Ground-Level Air in Finland – Correlation with the State of the North Atlantic Ocean

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Introduction

Lead-210 (^{210}Pb) is a decay product of radon-222. The sources of atmospheric radon-222 are the continental areas of the Earth. Oceans are a negligible source. Thus ^{210}Pb concentrations are lower in maritime than in continental air masses (Baskaran et al., 1993). ^{210}Pb has a radioactive half-life of 22 years, but in the atmosphere its concentration is determined by the residence time of the aerosol particle carrying it. Based on the activity ratio of ^{210}Pb and its progeny, mean aerosol residence times of one to two weeks have been obtained in Finland (Mattsson 1975) and in eastern USA (Papastefanou & Bondietti 1991). In Alaska Baskaran and Shaw (2001) observed residence times varying between 0 and 39 days. Samuelsson et al. (1986) reported values between 4 and 7 days during summer over the Arctic Ocean around Svalbard. Finnish Meteorological Institute (FMI) has collected aerosol samples for radioactivity monitoring purposes at several stations in Finland since the 1960s'. Some of these samples have been analysed for ^{210}Pb by alpha-counting of the in-grown daughter nuclide polonium-210.

Experimental

Daily aerosol samples with an air volume of ca 3500 m^3/day from Nurmijärvi have been collected with glass fibre filters (Whatman GF/A or Munktell MGA). Nurmijärvi (60°30'N, 24°39'E, h = 105 m above sea level [a.s.l.]) is in southern Finland 40 km north of the Baltic sea coast (Fig. 1). The ^{210}Pb contents of the samples have been assayed six months after the sampling, first with ZnS(Ag) scintillation detectors and later with gas-flow proportional counters (Mattsson et., 1996).

Results and discussion

The phenomenon called North Atlantic Oscillation (NAO) is a periodic variation of the temperature and salinity conditions in the North Atlantic Ocean (Rodwell et al., 1999). The NAO variations cause also periodic climatic differences in e.g. air temperature and wind direction and speed distributions leading further to even biological variations (Weyhenmeyer et., 1999). A commonly used measure for NAO is the sea-level barometric pressure difference between Portugal and Iceland. A negative correlation exists between the winter-time NAO index and the average winter-time (December-March) ^{210}Pb activity concentration in the ground-level air in Finland (Fig.2). The correlation coefficient between the NAO index and the ^{210}Pb activity concentration is –0.67. When the NAO index is high, the westerly winds become more dominant bringing maritime air masses with low ^{210}Pb concentrations in Finland. When the NAO index is low the continental air masses with a high ^{210}Pb content become more frequent. Similar relations can be found also with ^{210}Pb concentrations and, for example, the surface water temperature of the eastern Atlantic Ocean and the North Sea

(Paatero et al., 1998). A nonparametric Mann-Kendall test and Sen's method show that the ^{210}Pb activity concentration values have decreased on average 6±2 μBq/m^3 per year during the study period 1968-2002 (Salmi et al., 2002). The trend, which is assumed to be linear, is significant with a 99 % confidence. A corresponding trend of NAO Index was not found with this confidence level. This indicates that, in addition to annual and 5-7 years variations, the origin of air masses, and thus ^{210}Pb activity concentrations observed in Finland, are affected by decadal changes in atmospheric circulation patterns.

The results of this study suggest that the atmospheric transport to Finland of substances with a diffuse continental source similar to ^{210}Pb, for example methane, can be affected by the long-term variations in the state of the North Atlantic Ocean.

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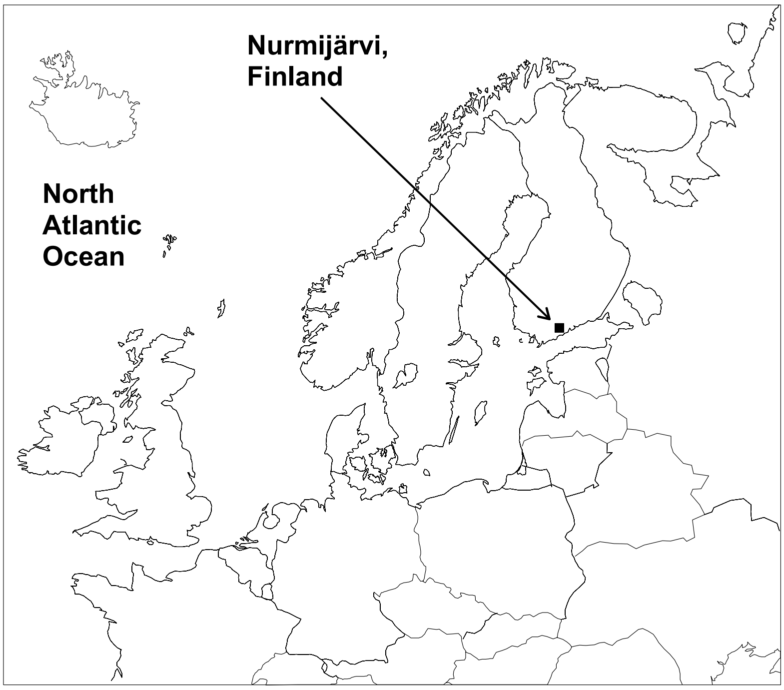

Figure 1. Location of the sampling site.

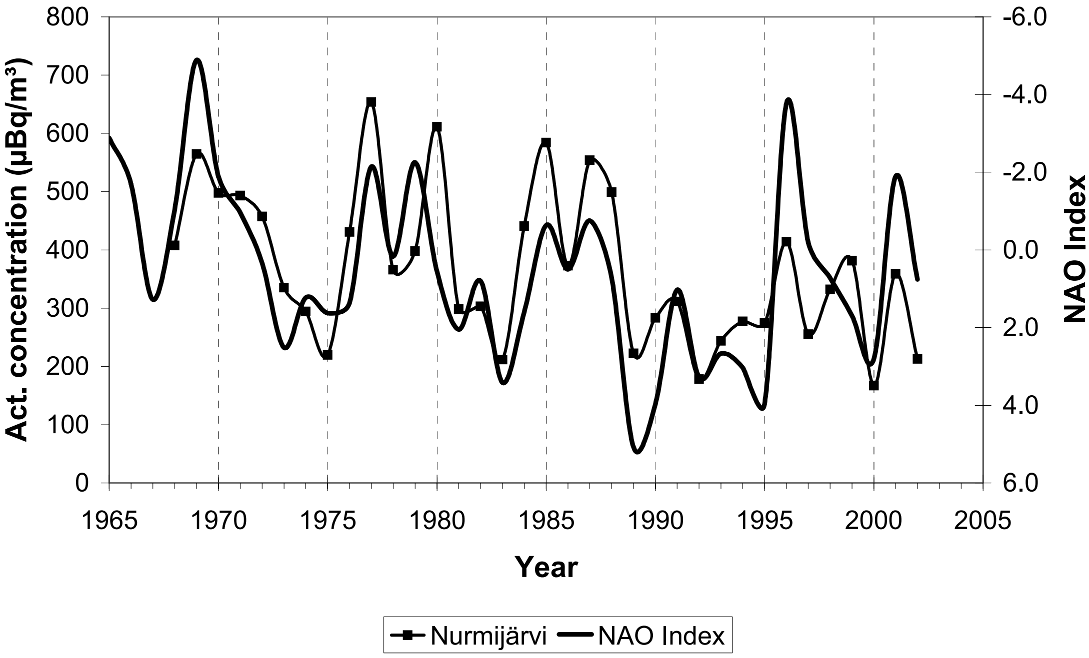

Figure 2. Wintertime (December…March) NAO Index values and average wintertime ^{210}Pb activity concentrations in the ground-level air at Nurmijärvi, Finland. Note the inverted NAO Index scale. The NAO Index values were obtained from National Center for Atmospheric Research, USA, via http://www.cgd.ucar.edu/~jhurrell/nao.html.

Evidence and Implications of Dangerous Climate Change in the Arctic

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Several recent studies have shown that global warming is altering the distribution and abundance of plant and animal species worldwide (e.g. Parmesan & Yohe 2003; Root et al. 2003). A primary concern for wild species and the people dependent on them is the rapid rate of both the observed and projected changes (Malcolm et al. 2002; Overpeck et al. 1992). Arctic ecosystems, which are strongly constrained by temperature, are expected to be markedly influenced by global warming. In many cases, threshold changes will occur in physical systems shifting from permanently frozen to periodically thawed, thereby propagating ecosystem-wide effects (Anisimov & Fitzharris 2001).

While the goal of the United Nations Framework Convention on Climate Change (UNFCCC) is to stabilize the concentration of greenhouse gases in the atmosphere at a level that would prevent “dangerous anthropogenic interference with the climate system,” it remains a crucial task for policymakers to agree on the level of warming that can be called “dangerous”. Scientists have used various threshold levels of warming (e.g. 1.5, 2, 3, 4°C) to examine what constitutes dangerous climate change from the perspective of catastrophic events (Hansen 2004), national sovereignty (Barnett & Adger 2003), and ecological impacts (O'Neill & Oppenheimer 2002). Here we examine biophysical changes in the Arctic associated with a global increase in temperature of 2°C which is considered by some NGOs to be the critical level beyond which dangerous climate change occurs.

An inter-comparison of global climate models (GCMs) was made with two objectives: (1) to provide an estimate of the time-range within which global mean temperature might increase to 2°C above its pre-industrial level, and (2) to describe the possible changes in arctic climate that will accompany such an increase. Results from six coupled ocean-atmosphere GCMs, each driven by four separate forcing scenarios, indicate that the Earth will have warmed by 2°C relative to pre-industrial temperatures by between 2026 and 2060. The geography of the Arctic, with its land-sea distribution and snow/ice albedo feedbacks, along with subtle changes in cloud and heat transport, produce an amplified regional warming for latitudes above 60°N that ranges between 3.2 and 6.6°C. In each of the GCMs that were evaluated the amplification is similar for fast and slow warming scenarios. In other words, changes in the Arctic will be similar regardless of when a global change of +2°C occurs. However, a faster global warming will necessarily produce more rapid warming in the Arctic. This amplification of arctic temperature changes means that the rates of warming are likely to be between 0.45 to 0.75°C per decade, but possibly even as large as 1.55°C per decade.

Results from the GCM study were then used to simulate future vegetation in the Arctic using the biogeochemistry-biogeography model BIOME4. The effect of a 2°C global warming suggests a potential for greater changes in terrestrial arctic ecosystems during the 21st century than have occurred since the end of the last major glacial epoch. Forest extent increases in the

Arctic on the order of $3x10^6$ km^2 or 55% with a corresponding reduction of 42% in tundra area. Tundra types generally shift north with the largest reductions in the prostrate dwarf-shrub tundra where nearly 60% of habitat is lost. Modeled shifts in the northern limit of trees reach up to 400 km from the present tree line, but may be limited by dispersion rates.

The rapid changes to the terrestrial environment projected here will bring wide-ranging, and often negative consequences. Changes to habitats may lead to a loss of biodiversity in the Arctic as the distribution, range, and diversity of wildlife species are altered under the new conditions. Further impacts will stem from changes to food availability and changes in predator-prey relationships.

Historical satellite records of surface temperatures from the late 1970s to 2003 were also analyzed to assess the magnitude of recent warming. This record shows that the Arctic has been warming at a rate of 0.46°C per decade. Since this falls within the range of projected changes from our GCM exercise we took this as a reasonable conservative estimate of future warming in order to investigate associated changes in sea ice cover.

Regression analysis of the satellite record indicates that for every 1°C increase in temperature, the perennial ice in the Arctic Ocean decreases by about $1.48x10^6$ km^2, however the correlation of the two variables is not particularly strong (r=-0.57). Still, since surface temperature has been shown to be highly correlated with sea ice concentrations, we used this trend to project how the perennial ice cover may look in the years 2025, 2035 and 2060 when temperatures are expected to reach the 2°C global increase. Maps indicate considerable decline (9.2% per decade) with changes basically around the periphery as the ice edge moves progressively to the north with time. While our assumption of a linear negative trend is likely not valid, a similar technique used in Comiso (2002) accurately predicted the perennial ice cover during the last 3 years.

Since ice is an important habitat to many life forms from micro-organisms to mammals, the impact of retreating ice to the arctic marine ecosystem can be substantial. Of particular concern are the deleterious effects on ice-living seals, polar bears, walrus, and some species of marine birds, thus leading to profound cultural and economic impacts for Inuit and other northern indigenous peoples. Observations by Inuit lend credence to the designation dangerous climate change: environmental indicators for when and where to go hunting, and when and when not to travel are no longer reliable; melting permafrost is altering the physical landscape, increasing rates of shore erosion and beach slumping, and prompting some coastal communities to plan for relocation; and in some regions traditional ice cellars used to store country food have lost their preservative value (Fenge 2001). In short, climate change is already threatening traditional ways of life among arctic peoples, leaving very little time for Inuit and other northern indigenous people to adapt.

Understanding what constitutes dangerous climate change is of increasing importance for scientific analysis and policy debate. Peaking at less than 2°C will not prevent major damages, but the option of avoiding a >2°C increase will disappear within the next decade unless immediate action is taken. Arctic countries, which account for 58% of the carbon dioxide (CO_2) emissions of Annex I Parties to the Kyoto Protocol, should as a matter of urgency mitigate the causes of climate change by reducing greenhouse gas emissions, especially CO_2 from fossil fuel combustion.

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Heavy Metals and Persistent Organic Pollutants in Air and Precipitation in Iceland

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Persistent organic pollutants in air and precipitation have been measured in Vestman Islands, off the south coast of Iceland, since 1995. Due to a change in processing values below detection limit in year 2000, the last four years of data are presented here. Results compare well to those of other stations in the North Atlantic but are relatively low for HCB and sum HCH.

Considering each halfmonthly period 2000-2003, results for POPs in air give a maximum of 94 ng/m3 and a minimum of 14 ng/m3, summing up all twentyfive species, with an average of 25 ng/m3 and a median of 24 ng/m3 to which about half is contributed by the HCH's but only 1-2 ng/m3 by the PCB's. As for POPs in precipitation, the total range is 3.1-0.2 ng/l, summing twentyfive species, with an average of 0.7 ng/l and a median of 0.5 ng/l. Almost half of the values are below detection limit which explains these low sums. HCH's account for two thirds but the PCB's only amount to about 0.1 ng/l on average.

Heavy metals in aerosol have been measured since 1995 in Vestman Islands off the south coast of Iceland. Analysis and processing improved in 1999, hence five years of data are presented. Interelement correlation suggests at least two regional sources, probably dominated by the coarser fration, but other elements may represent long range transport of the finer particles.

Fe and Mn, as well as Al and V, probably only reflect local dust. Average and median values are, respectively, 605 and 196 ng/m3 for Fe and 423 and 160 ng/m3 for Al. Same may be the case for Cr and Ni, where the average and median values range between 4 and 7 ng/m3. Possibly Cu concentrations, about 1 ng/m3, originate mainly from terrestrial sources as well. Seaspray affects the samples also, with Cl concentrations reaching a maximum of 80 ug/m3 in one instance. On the other hand Pb, averaging 0.5 ng/m3, Cd averaging 0.02-0.08 ng/m3, and Zn averaging 4-8 ng/m3, may have undergone long range transport. The values of As are generally very low, about 0.1 ng/m3, but Hg concentrations are more variable, ranging 0.1 - 108.8 pg/m3. Locally originating elements show seasonal variations, low in summer, whereas Cd and As do not. Mercury shows high winter values while Pb shows low values in summer.

Heavy metals have been measured in precipitation at two stations in Iceland since 1991, one rural station and one urban. In 1999 the sampling and analytical methods improved, providing five years of reliable data. The rural site was moved to the seashore from an inland location in 2001 although presented here as one series.

For most elements the median values are lower at the rural site than the urban one but the average values are higher, indicating more fluctuations in the rural data series. Difference in Pb and Cd concentrations between the two sites is little, median values are 0.47 and 0.62 ng/ml for Pb and 0.013 and 0.005 for Cd, at Vestman islands and Reykjavik respectively. Difference in Zn concentrations is significant between the sites, with higher values at the rural one. Median values for As are lower at the rural site.

Global Emission Estimates for GHG within the EU EVERGREEN project (EnVisat for Environmental Regulation of GREENhouse gases)

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As part of the EVERGREEN (EnVisat for Environmental Regulation of GREENhouse gases) project, work is being undertaken on inventories of baseline 1990 and 2003 greenhouse gas (GHG) emissions. The main objective of this part of the EVERGREEN work is to review available information pertaining to global emissions inventories of CO_2, CH_4 and CO for the years 1990 and 2003 (or the nearest available year), corresponding to 12 months of the ENVISAT mission, and to compile datasets on GHG emissions that can be used by other groups involved with project components concerning modeling, etc.

A number of currently available global databases have been considered, including relevant IGBP GEIA (Global Emission Inventory Activities) datasets, the EDGAR 3.2 database on anthropogenic emissions produced by a group at RIVM in the Netherlands, datasets published by the UNFCCC/IPCC, and those compiled within the EU POET project. Most of these databases deal with emissions from anthropogenic activities and/or emissions from biomass burning associated with agriculture. In addition, recent work on emissions from biomass burning (e.g. Generoso *et al.*, 2003; Hoelzemann *et al.*, 2004), and CO_2 fluxes from oceans (Takahashi *et al.*, 2002.) has been incorporated.

Data on anthropogenic emissions are typically compiled at the national level, using appropriate emission factors for various sectoral activities and source types. With respect to recent years in particular, the available databases are incomplete, and work has been undertaken within EVERGREEN to evaluate and in some cases fill the gaps.

National emission totals may be adequate for some purposes, however for inverse modelling applications, spatially distributed (gridded) emissions datasets are required. These are produced by distributing sectoral emissions according to spatial patterns of 'proxy' or 'surrogate' variables that can represent a specific source sector or activity. Surrogate datasets such as population distribution for example are used to represent source sectors associated with certain human activities (waste disposal, industrial activities, etc.); similarly agricultural/land-use maps are used to represent the spatial distribution of emissions associated with agricultural sources (rice cultivation, emissions from cattle, etc.).

Under the EVERGREEN work, as a first estimate of anthropogenic emissions for 2000, a series of projected datasets for emissions of CO_2, CO and CH_4 were derived by extrapolating the trends in the 1990-1995 EDGAR gridded datasets - Figure 1 shows the results for CO_2. A clearer picture of the changes in the estimated emissions between 1990 and 2000 is shown in Figure 2, where differences between cell estimates for 1990 and 2000 emissions of CO_2, CO and CH_4 are calculated. GIS tools have also been employed to compare dataset derived from different sources (e.g. EDGAR vs. UNFCCC datasets).

Fire and burnt areas distributions, obtained from satellite remote sensing, have been used by various groups (e.g., Generoso *et al.*, (2003) and Hoelzemann *et al.* (2004)) to develop spatially distributed datasets for emissions from biomass burning sources. These are also temporally resolved (to yield monthly gridded datasets). In this context, biomass burning includes emissions from deforestation, savanna burning, agricultural waste burning, and (temperate) vegetation fires, and *not* biomass fuel consumption (e.g., wood, straw burning in ovens and boilers).

Inaccuracies in emission estimates and differences in global emission datasets need to be considered taking into account availability and completeness of global emissions datasets for the years 1990 and 2000/2003, the fact that global emission inventories are mostly based on models rather than measurements, uncertainties in (economic) activity data and emission factors for GHGs, and the fact that spatial distributions of source sectors/activities use 'proxy' or 'surrogate' datasets for development of gridded emission maps.

Evaluation of the uncertainties associated with emissions data is important:

- So that emissions data are credible and national inventories and data are comparable;
- So that guidelines for improvements of national inventories, measurements and methodologies can be further developed;
- To allow international agreements such as the Kyoto process to set robust targets for the future;
- To ensure that compliance obligations are met.

In addition, sound uncertainty estimates will be a market demand, and support better prices in emission trading.

Considering methodological issues related to the calculation of emission inventory uncertainty, satellite data and inverse modeling provide useful tools for calculation of uncertainties. Questions remain however about appropriate ways to treat/report uncertainties with respect to national inventories, emission trading, international arrangements, and communication with policy makers and general public, and these should be included when agendas for future research are set.

Acknowledgement

The EVERGREEN project is funded under the European Commission – 5th framework programme EESD-ESD-3: Earth Observation Technologies

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UNFCCC GHG emissions http://ghg.unfccc.int/

EDGAR 3.2 http://www.rivm.nl/env/int/coredata/edgar/

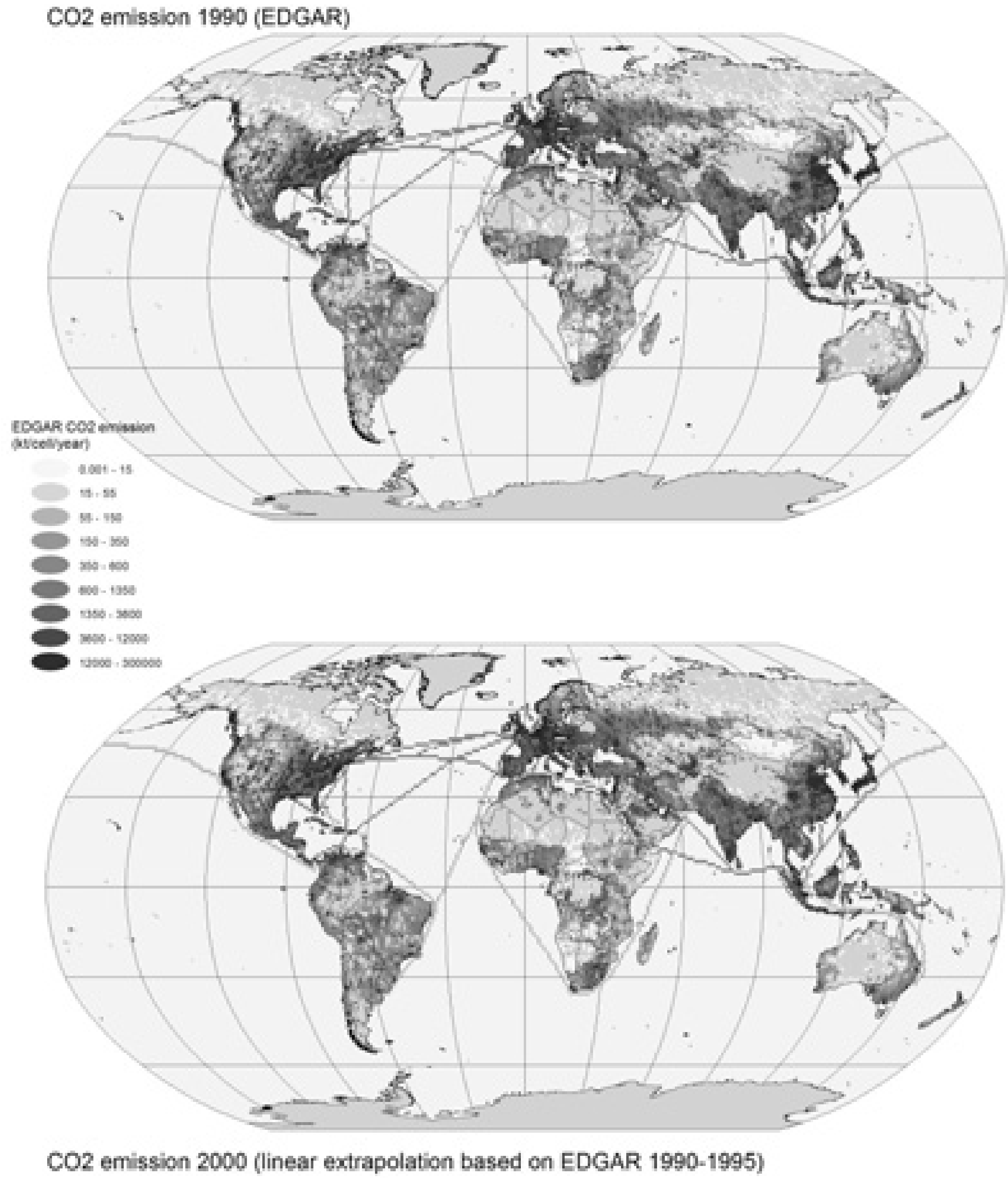

Figure 1. Spatially distributed CO_2 emission estimates for 1990 (EDGAR 3.2) and 2000 (EVERGREEN - based on projection of EDGAR 1990-1995 trends) – for all sectors combined.

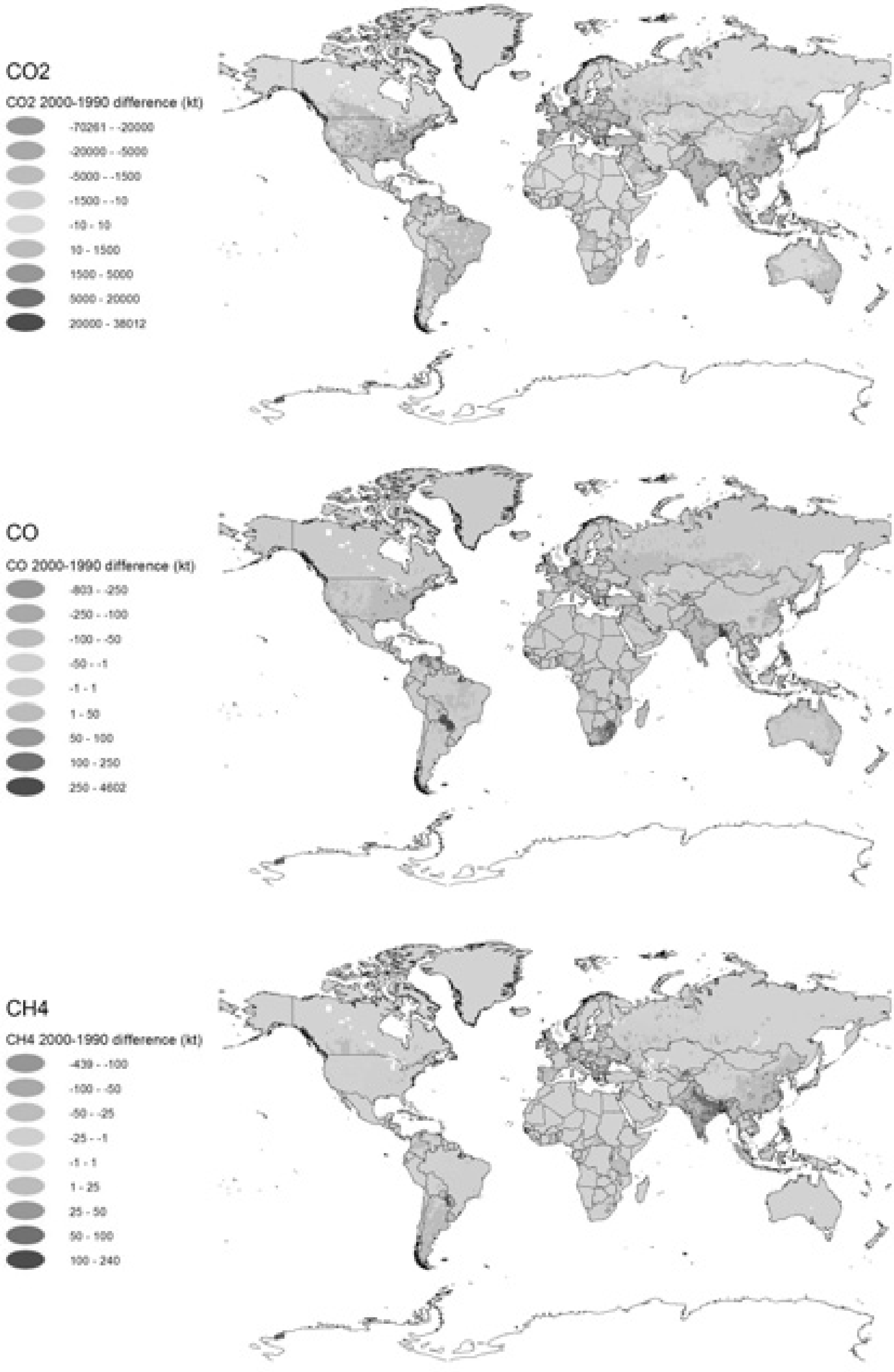

Figure 2. Changes in estimated emissions of CO_2, CO and CH_4, 1990 to 2000 (green shades imply reductions, red shades imply increased emissions).

Storms and Coastal Impacts in the Mackenzie Delta Region of the Beaufort Sea, Northwest Territories and Yukon, Canada

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Introduction

The Mackenzie Delta coastal region of the Beaufort Sea, in northwestern Canada is characterized by modest levels of human activity and increasing amounts of industrial activity related to oil and gas development. The most important community in this region, the Hamlet of Tuktoyaktuk, has been threatened by coastal erosion virtually since its founding in the 1930s. Coastal change (dominated by erosion) in this region is a product of the interaction of local geological/geomorphological conditions with waves and storm surges. Strong winds during the open water season are responsible for wave and storm surge development. The presence of sea ice mediates the atmosphere-ocean interaction and therefore controls the oceanographic conditions. Sea ice may play an additional role in the modification of the coast through ice-keel scouring and its role in the entrainment and export of sediment from the shoreface. All of there processes are superimposed, over the longer-term, on rising relative sea level. Predictions of coastal impacts of climate change depend on an understanding of the relations between the environmental forcing (e.g. storm frequency and intensity, sea ice, sea surface temperature, sea level, etc.) and coastal responses operating over a range of time scales from days to decades. To date no clear trends in forcing or coastal response have been recognized; decadal scale variability remains the dominant attribute over the study period (1958 to 2001).

Trends in Storm Frequency and Severity

For assessing the impacts of storms on the coast, analyses are restricted to the open water season (between June and October) during which waves can be generated. An analysis of winds for the region was undertaken using a wind record from Tuktoyaktuk (from three different stations since 1958). Since the Tuktoyaktuk wind speeds are low relative to shorter records from other stations along the Beaufort Sea coast, they were modified using data from a station on the outer coast (Pelly Island). The modified record indicates that prominent storms causing daily mean wind speeds up to 79 km h^{-1} (22 m s^{-1}) and maximum sustained winds speeds of nearly 100 km h^{-1} (28 m s^{-1}) have occurred with variable frequency since 1958. Storm wind events are defined by 6 or more consecutive hours of winds of at least 50 km h^{-1} (14 m s^{-1}). From the historical combined wind record, a list of 354 events was constructed. This list was sampled to include only those events with mean northwesterly wind directions occurring in the open water season (n=85), referred to hereafter as northwesterly open water (NWOW) wind events.

Annual average frequency and intensity (defined as the sum of wind speeds over its duration) of NWOW winds show significant interannual and decadal variability with no detectable unidirectional trend (Figure 2). Stormier intervals are recognized in the early 1960s and early 1980s. Analysis of moving sums of frequency and intensity (not shown) reveal a period of low storm activity during the late 1970s. A similar lull in wind events was observed in the

Barrow, Alaska region (Lynch et al, 2004). The 1960s stormy period was characterized by frequent storms with rare high magnitude events. However, since the 1970s, the rare events are not necessarily embedded in stormy periods. In fact the most damaging storm in recent memory occurred in 1970 (Department of Public Works, 1971), a year not otherwise notable for storminess. Isolated high magnitude events also occurred in 1993 and 2000.

Trends in coastal change

In a recent study of coastal hazards and hydrocarbon development, aerial photographs from 1972, 1985 and 2000 were analyzed to obtain measurements of coastal change in the Mackenzie Delta region of the Beaufort Sea (Solomon, in press). Changes from 1972-1985 and from 1985 to 2000 are dominated by retreat of the shoreline. Average annual retreat rates are 0.6 m a^{-1}, but range as high as 22.5 m a^{-1}. Rates vary significantly both between and within zones of similar exposure, morphology and coastal geology with the highest average rates located in areas that are most exposed to northwest winds. Differences were noted between the behaviour of exposed (e.g. westward facing) and protected (e.g. eastward facing in the lee of storm-driven waves) sites during the 2 time intervals of the study. In general, along the most rapidly retreating shores, average rates of change have remained constant (1.5 to 2 m a^{-1}) during the 28 year interval. However, there is a slight (and in some cases statistically significant) tendency towards decreased (20-50%) shoreline retreat rates along the more slowly retreating shorelines during the 1985-2000 period. These shorelines are located in the morphologically more protected locations.

More detailed temporal analysis of retreat has been undertaken at sites where high resolution air photography and/or ground measurements are available. A time series of cliff retreat near the hamlet of Tuktoyaktuk reveals dramatic variations that coincide with specific large storm events. During time intervals with only a few low wind speed events retreat rates are less than 0.5 m a^{-1}. In contrast, a single severe event in 2000 resulted in retreat of 7-10 m in a matter of days, largely through the mechanism of undercutting and associated block failures (Figure 3). Similar impacts were also note resulting from storms in 1993 (Solomon and Covill, 1995) and 1987 (Dallimore et al. 1996).

Discussion

In general, annual storminess, expressed in terms of frequency and total intensity, show significant interannual and decadal scale variability. Rates of shoreline change and coastal retreat averaged over longer time periods (> 10 years) show less temporal variability although the rates are highly variable spatially. Retreat rates from some locations (i.e. slowly retreating shores) over the intervals 1972-1985 and 1985-2000 have declined along with total annual storm intensity, although storm frequency has increased slightly. The inconsistency between the response of protected and exposed shores may signify some limiting process to shoreline retreat whereby increased storminess does not necessarily produce a concomitant increase in retreat rate along more exposed and rapidly retreating coasts, but does so along less exposed coasts.

The more detailed study of retreat rate at Tuktoyaktuk Island illustrates the impact of a single, relatively rare storm event that occurred in 2000. Analysis of that storm indicated wind and water level return intervals of 10 and 15 years, respectively. The mode of failure of the coastal bluffs, in the form of undercutting and block failures, implies that large volumes of eroded material may persist on the beach and shoreface for some time following an event (cf. Dallimore et al, 1996). Armouring of the bluff faces by sloughed material following a storm may limit the ability of subsequent storms to reach the base of the bluffs until that material is removed. This suggests that sequencing of storms may be an important factor in predicting coastal impacts of climate variability and change. More detailed data collection and analysis of individual storm impacts versus a series of storms are required to quantify the role of storm sequencing on retreat rates.

Acknowledgements

The Canadian Climate Action Fund and the International Center for Arctic Research provided funding for studies of wind climatology. The Government of the Northwest Territories and the Earth Science Sector of Natural Resources Canada supported analysis of coastal retreat rates. Tekmap Consulting undertook georeferencing of air photography.

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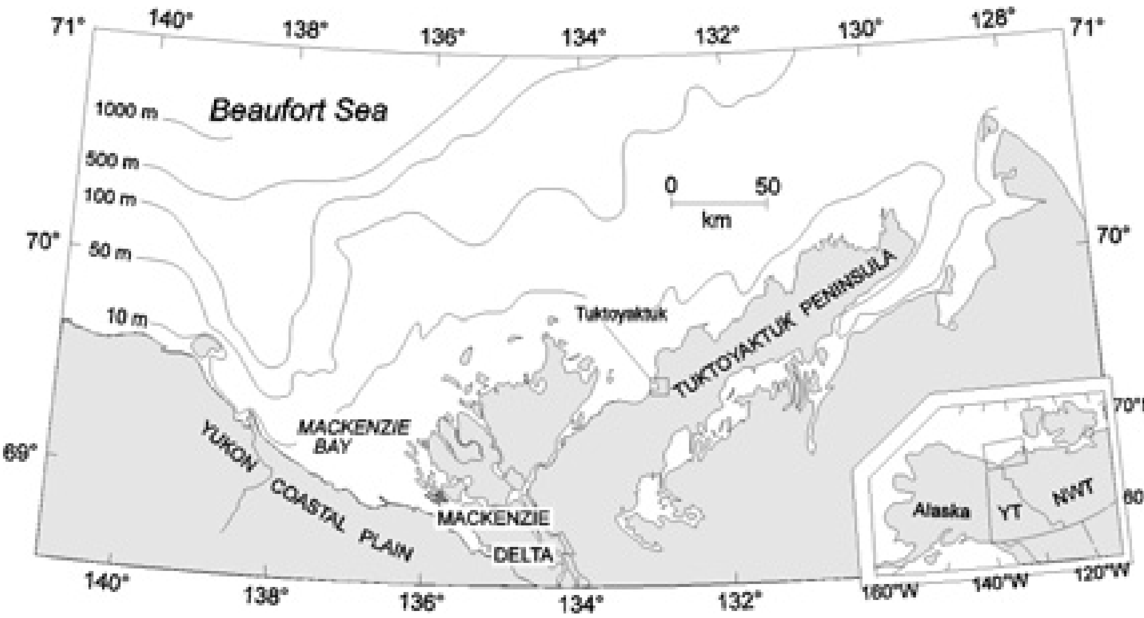

Figure 1 Study area location.

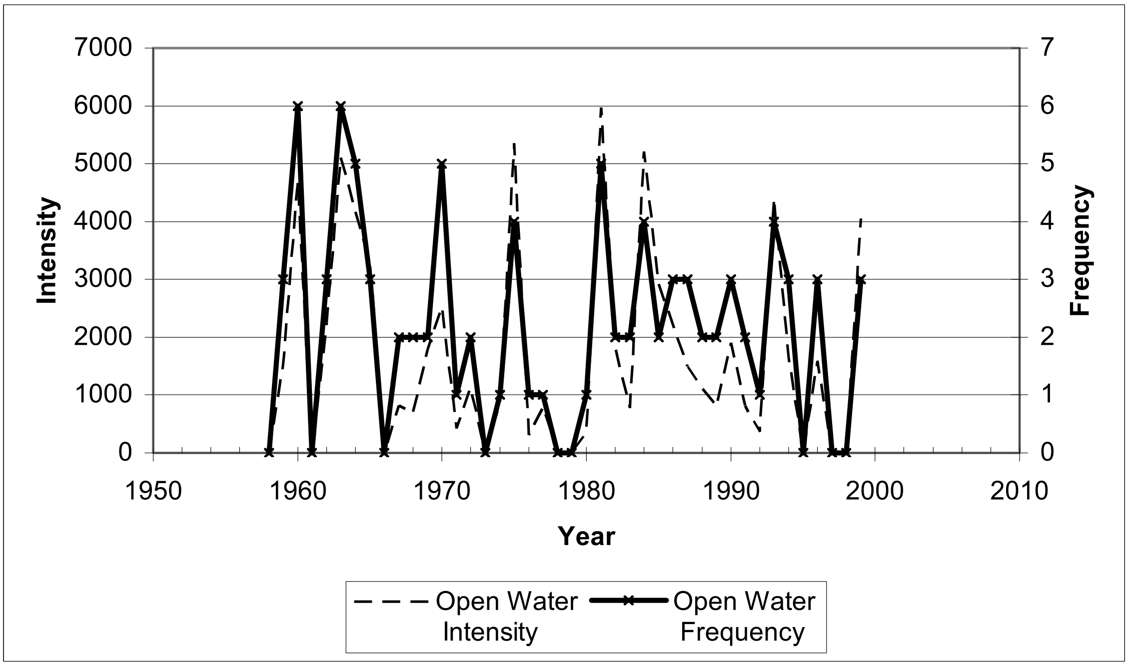

Figure 2 Annual NWOW storm frequency and intensity are based on wind records from Tuktoyaktuk and nearby stations. Storm intensity is defined as the sum of wind speeds throughout an event. Stormy periods occurred in the 1960s and 1980s. Infrequent high magnitude storms occurred in 1970, 1993 and 2000

Figure 3 Tuktoyaktuk Island (part of the Hamlet of Tuktoyaktuk) experienced significant coastal erosion, undercutting and block failure following a severe storm in August 2000.

The Economic Implications of a Shortened Winter Exploration Season on the North Slope of Alaska

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Introduction

Over the last 30 years, the length of the winter tundra travel season allowing oil exploration on Alaska's North Slope has declined 100 days (Figure 1). The narrowing operating window, attributed to climate change, poses a threat to the fiscal stability of the State of Alaska and the energy security of the United States. The implications to Alaska's economy from declining oil revenues are profound since oil royalties and taxes account for 84 percent of the State's general fund revenues. Furthermore, with 19 percent of U.S. production, Alaska's oil reduces the nation's dependency on unstable foreign oil sources. The Department of Natural Resources (DNR) is responsible for making the yearly determination if conditions are suitable to declare a "general tundra opening" for winter exploration. A review of DNR's management history in conjunction with a statistical analysis of available scientific data implies that a large percentage of the declining season has been due to management choice rather than climate change.

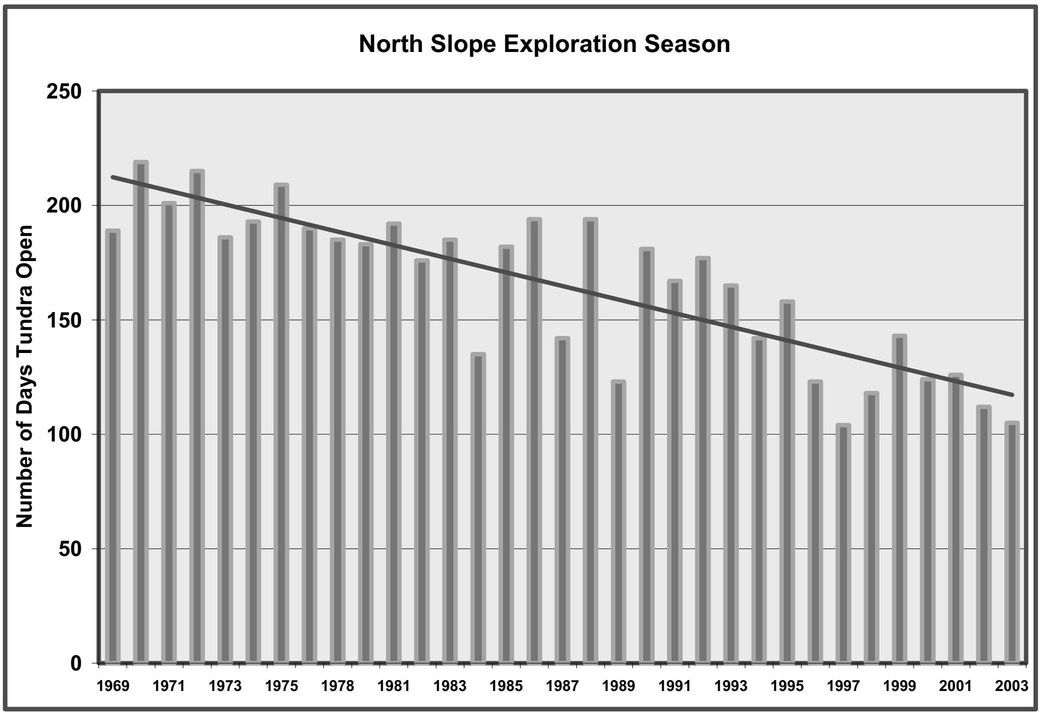

Figure 1: A graphical depiction of the declining trend in number of days open for winter tundra travel.

To reduce impacts to the tundra on the North Slope[1], oil companies conduct most of their exploration from ice roads and ice pads which are time-consuming and costly to build. The shortened season has significantly impacted the ability of companies to conduct their exploration activities since many of the leased areas are at distances that require the

[1] An increase in damage to vegetative mat leading to thermokarsting from exploratory activities has not been documented. Technological advances have drastically reduced vehicular pressure on the tundra.

construction of longer ice roads to reach prospective drilling sites.[2] A 200-day work season provided oil companies with the opportunity to drill four wells from one ice road. The shortened season has resulted in fewer wells being drilled from each ice road and therefore overall costs for exploration have drastically increased. ConocoPhillips, the North Slope's major explorer stated: "We have more projects than money and we must consider where we can most efficiently spend our money. Alaska is in a disadvantaged position to compete, given the seasonal operations. Exploration is teetering on the brink of extinction."[3]

The State of Alaska mandates that DNR maximizes North Slope oil revenues while preventing damage to the vegetative mat in compliance with GC-19[4]. DNR managers have generally followed a heuristic standard requiring 12 inches of frost in the active layer and an accumulation of 6 inches of snow in making their decision to "open the tundra" for exploratory travel. The standard can be traced back to 1975 when Dr. Max Brewer incorporated the 12 inches of frozen ground and 6 inches of snow standard into the environmental impact statement (EIS) he wrote for the Navy's exploration of Naval Petroleum Reserve No. 4 (now NPR-A).

While it is not possible to fully ascertain how much of the decrease in the North Slope exploration season can be attributed to DNR management decisions as compared to the impact of climate change, analysis of recent climate data from the North Slope reveals statistically significant estimates. A review of DNR's North Slope trip files reveals that other than 1989 when insufficient snow was present, general tundra opening was delayed for winter travel due to measurement techniques that led managers to believe frost was inadequate. What stands out from analysis of DNR's field reports is that in an attempt to become more accurate, they actually became less accurate in their assessment of the hardness of the tundra. Figure 2 shows that from 1986 to 1995, before the adoption of a slide hammer when DNR simply measured for 12 inches of frost, DNR's opening data was much closer to actual final freeze-up of the tundra.

The adoption of a slide hammer and the perception by managers that observations of dirt, mud, and ice crystals on the probe tip indicated inadequate frost[5] resulted in the tundra opening becoming progressively later as depicted in Figure 2. A statistical chow test on the data reveals a structural break in 1996 which signifies that the difference is so extreme, it can't be explained by what's happening within the data, but is determined outside of the system. In this case, it is the methodology of determining adequate frost. DNR used "drops per inch" (DPI) of a slide hammer as an indication of whether the active layer was sufficiently hard, when the drops per inch were not correlated with actual load-bearing strength. In addition, until the standardization of methods occurred in the 2003 season, variability was induced as operators applied various forces to drive the probe into the ground. Lastly, DNR's trip reports indicate that managers vacillated year-to-year in their interpretation of how many DPI were necessary to allow tundra travel.

Figure 2 depicts the day of the year when the Deadhorse (DH) active layer was frozen hard to 12.6 inches at -1 Celcius.[6] The p-value associated with the DH regression implies that with

[2] Exploration has extended into the National Petroleum Reserve-Alaska (NPR-A).
[3] Personal Communication with Dick Gerrard, July 23, 2004.
[4] The standard contained in the Alaska Coastal Zone Management Program's General Concurrence 19 for Cross-Country Movement of Equipment (GC-19) requires that vehicles can only be operated on tundra areas that have "adequate ground frost and snow cover." It also requires that "vehicles shall be operated without disturbing the vegetative mat."
[5] The tip conditions are caused by liquid water that is present in the solidly frozen active layer.
[6] Data Source: Dr. Vladimir Romanovsky, University of Alaska Fairbanks. 2002 DH data not available due to equipment malfunction. The data was collected on loggers from thermistors placed in the active layer.

83% certainty the slope of the regression equation is significant while the low r-squared suggests that the linear trend, and strength of the linear relationship is poor. On average, DNR opened the tundra 3.94 days a year later, while the active layer in Deadhorse was frozen to 12.6 on average of .75 days-a-year later. Given these two slopes, it can be said that 19% of DNR's later tundra opening dates can be attributed to climate change, while 81% was due to management choice. If the 1989 data is not included[7], the slope of DNR's line is 4.54, while the slope of the DH data is .72. This would mean that 16% of DNR's decision to open the tundra later can be attributed to a warming trend, while 84% has been management driven.

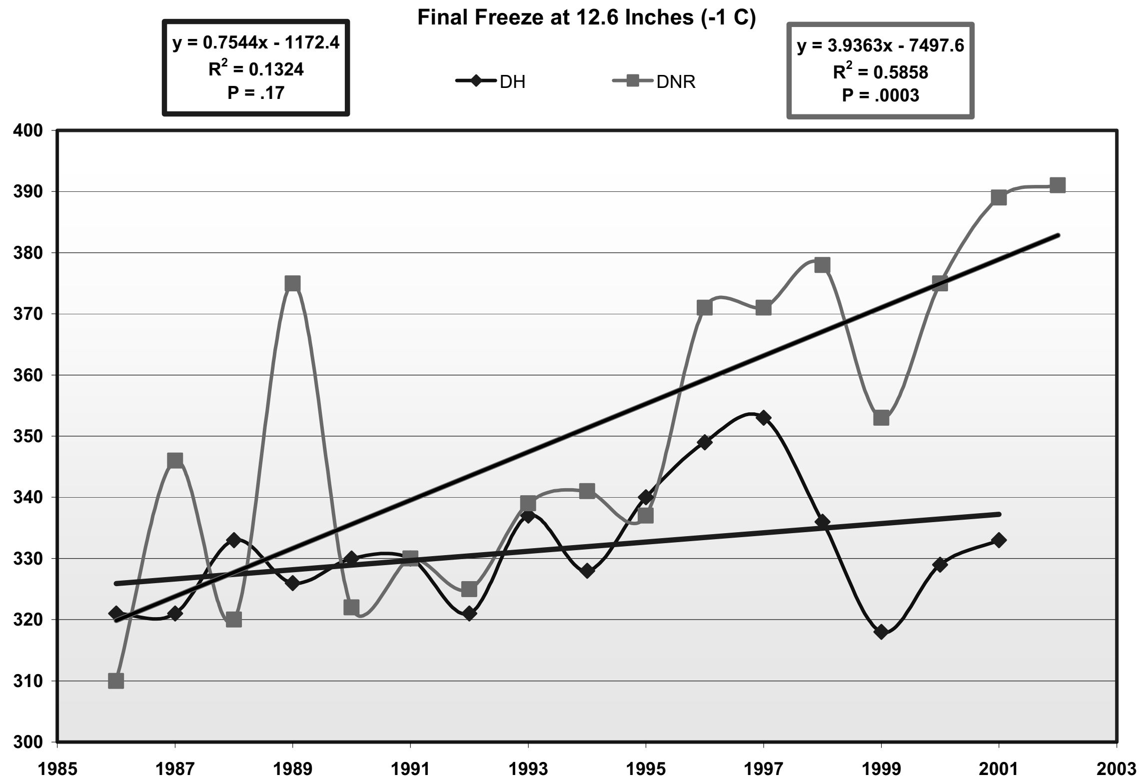

Figure 2. Day of year DNR opened tundra compared to final freeze-up at 12.6 inches at Deadhorse, AK

Acknowledgements

I am extremely grateful to 1) my Ph.D. supervisor, Dr. F. Stuart Chapin, III, Professor of Ecology, Institute of Arctic Biology, University of Alaska Fairbanks; 2) Dr. Mark Herrmann, Professor of Economics, UAF, for his review of my statistical analysis; and 3) Harry Bader, Regional Director, DNR, Northern Region Office, for my 2004 summer internship opportunity; 4) ACIA for facilitating my attendance to this symposium.

[7] Opening was delayed due to insufficient snow depth.

Climate Change Research at the Royal Swedish Academy of Sciences Abisko Scientific Research Station, Northernmost Sweden

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Abstract

The Abisko Station has been monitoring climate and the environment in general for 100 years. The information it possesses is probably unique for its high latitude – 68^{o} N 18^{0} E, 200 km north of the Arctic Circle. The Station has also carried out, and hosted, research into ecology, geomorphology and meteorology. Currently, over 2,700 publications are listed in the Station' bibliography. Since the mid 1980's, climate change and its impacts on ecosystems have become a major aspect of research. The varied biodiversity and ecosytems of coniferous forest, subalpine birch forest, mires, lakes, alpine and nival areas offers considerable potential for investigating relationships between current climate and ecosystems, and for projecting impacts of future climates on the structure and function of varied ecosystems.

The Station has a small staff, it hosts an in-house research group, the Climate Impacts Research Centre (CIRC), and it hosts about 700 Swedish and international scientists per year together spending about 9,000 days there. While the focus of research is placed on the subarctic environment surrounding Abisko, the Station contributes to many international activities such as the Arctic Climate Impacts Assessment (ACIA), Intergovernmental Panel on Climate Change (IPCC) and the United Nations Environment Programme's assessment of impacts of stratospheric ozone depletion. In addition, the Abisko Station co-ordinates SCANNET, a network of 14 research stations/field sites in northern Europe and is contributing to the establishment of a circumpolar environmental monitoring network, CEON. The current main focal point for climate impacts research at Abisko are listed below.

Environmental monitoring, observation and reconstruction

Proxies for annual temperatures have been established from pine tree rings for a continuous period of 7,500 years (Grudd et al., 2002). Observations from the Station extend back to 1913 and show two periods of warming. Regional climate scenarios summarised within SCANNET suggest future warming of 2.5 to 4.5 ^{o}C by 2080. A current challenge is to downscale temperature and precipitation to the complex topographical surface of the Abisko area.

Changes in vegetation

Various projects have measured treeline extension during the twentieth century. This varies over small distances but rates of upward displacement have reached 0.5 m per year and 40 m per degree C. However, deconvoluting a climate signal from changes in other factors such as nitrogen deposition and browsing by reindeer is difficult.

Changes in fauna

Some animals are becoming scarce, e.g. voles at peak population levels, arctic foxes, snowy owls. Other species are becoming more abundant, e.g., moose. Moose browse pine shoots in winter and constrain the response of pine-limit advance in a warming climate. However, the ecosystems of the area below tree-line are dominated by periodic outbreaks of the autumn moth *Epirrita autumnata*. The year 2004 has seen a massive outbreak with large areas of birch forest and ground vegetation defoliated. The specificity of the caterpillar opens the birch forest up to a step change to pine or aspen in a warming climate. The autumn moth abundance and browsing is determined to some extent by winter temperatures and UV-B radiation effects on behaviour and physiology.

Simulation of future environments

Experiments that manipulate soil temperature, air temperature, atmospheric CO2 concentrations, UV-B radiation levels, soil nutrient levels, summer rainfall and winter snow depth and duration are making major contributions to our projections of responses of ecosystems to environmental change. Rapid changes in dominance and loss of species have been demonstrated and there is an increased recognition of the importance of episodic and extreme events and winter environments, particularly on soil microbe activity.

Carbon balance

Numerous small scale chamber measurements of ecosystem gas exchange and a growing network of eddy covariance towers in the birch forest, lake, mires, at treeline and in the alpine region, show the considerable variation from year-to-year, the importance of warm episodes in winter, the importance of the "Shoulder" periods in the year, and a fine balance between current carbon sink and possible carbon source status in a mire. In addition, observations of permafrost thawing, vegetation change and models of resulting methane emissions have estimated a considerable increase in methane emissions from a mire over the last 30 years (Christensen et al., 2004).

Effects of increasing UV-B radiation

Researchers based at the Abisko Station have pioneered investigations on effects of elevated UV-B on in-tact natural ecosystems, and also on biogeochemical cycling. The world's first and longest running experiments are based there. They show that plants are surprisingly well adapted to withstand forecasted future levels of UV-B but that herbivory, nutrient cycling and microbial communities are affected with potential ecosystem-level consequences.

Modelling and Integration

A major challenge for the Abisko Station is to integrate results from experiments performed by different groups of researchers from around the world, working in different areas and at scales from cms and meters to the landscape. In particular, the Station is using downscaled climate and climate projections to model changes in biodiversity and ecosystem function.

Key publications

Callaghan, T.V. (ed.) 2002. Dynamics of the tundra-taiga interface Ambio Special Report 12, 63 pp.

Callaghan, T.V. (ed.) (2004). Climate Change and UV-B impacts on Arctic Tundra and Polar Desert Ecosystems. Ambio 33 (in press).

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Grudd, H., Briffa, K.R., Karlen, W., Bartholin, T.S., Jones, P.D. and Kromer, B. (2002). A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales. The Holocene 12: 657-666.

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ITEX in Iceland: Responses of Two Contrasting Plant Communities to Experimental Warming

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Introduction

The International Tundra Experiment (ITEX) is a scientific network of experiments focusing on the impact of climate change on selected plant species in tundra and alpine vegetation. The network was initiated in 1990. Currently, research teams at more than two dozen circumpolar sites carry out similar, multi-year plant manipulation experiments that allow them to compare annual variation in plant performance with respect to phenological and longer term plant community responses to climate conditions (Henry & Molau 1997).

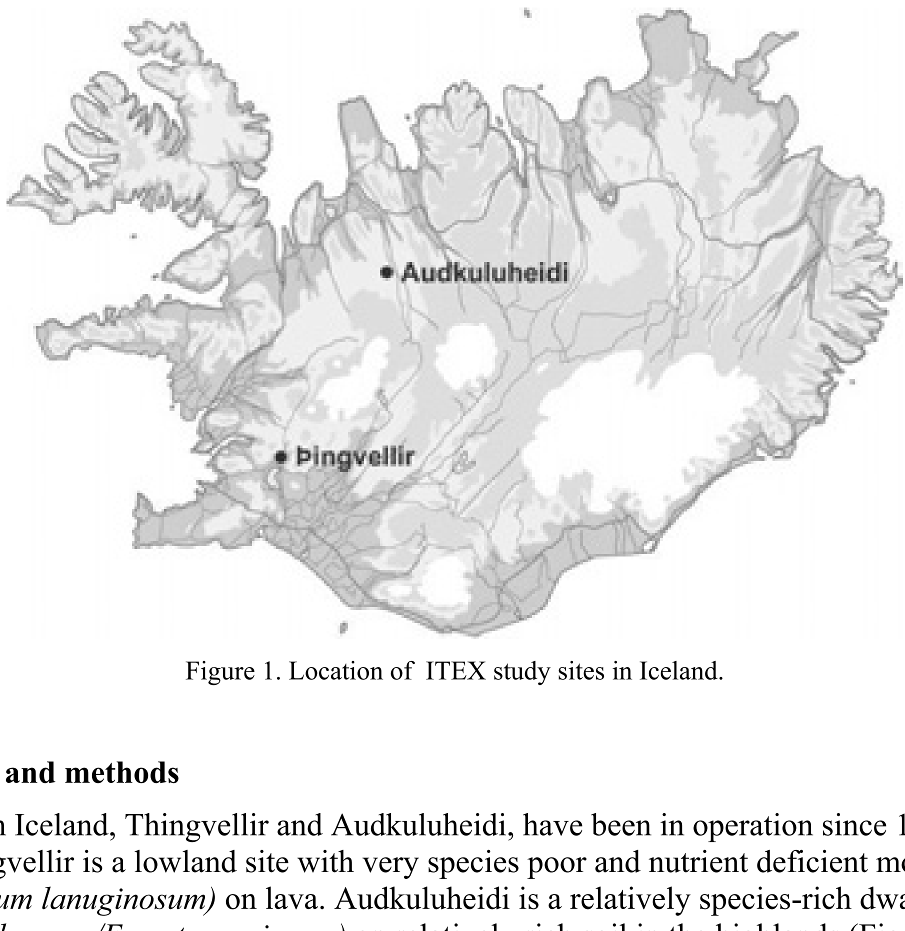

Figure 1. Location of ITEX study sites in Iceland.

Study sites and methods

Two sites in Iceland, Thingvellir and Audkuluheidi, have been in operation since 1995 and 1996. Thingvellir is a lowland site with very species poor and nutrient deficient moss heath (*Racometrium lanuginosum)* on lava. Audkuluheidi is a relatively species-rich dwarf shrub heath (*Betula nana/Empetrum nigrum)* on relatively rich soil in the highlands (Fig. 1, Table 1). Open top chambers (OTCs) were used to manipulate temperature. At both sites air and soil temperature were monitored over the growing season. Flowering phenology of selected species was studied as well as plant community composition (Jónsdóttir *et. al.*, in press).

Table 1. Comparison of climate, floral richness and soil conditions at study sites.

	Thingvellir	Audkuluheidi
Height above s.l. - m	120	490
Mean annual temp. - °C	3.7	0.3
Mean annual precip. - mm	1196	397
Species richness	12	49
Soil pH	5.12	6.48
C%	11.80	4.89
N%	0.47	0.37
C/N ratio	22.9	13.4

Results

Surface air temperature was raised over the growing season by 0,7 – 2,0 °C within the OTC chambers compared to controls. Warming treatment accelerated flowering phenology of most species studied, the changes were more pronounced at the highland shrub heath site (Fig. 2).

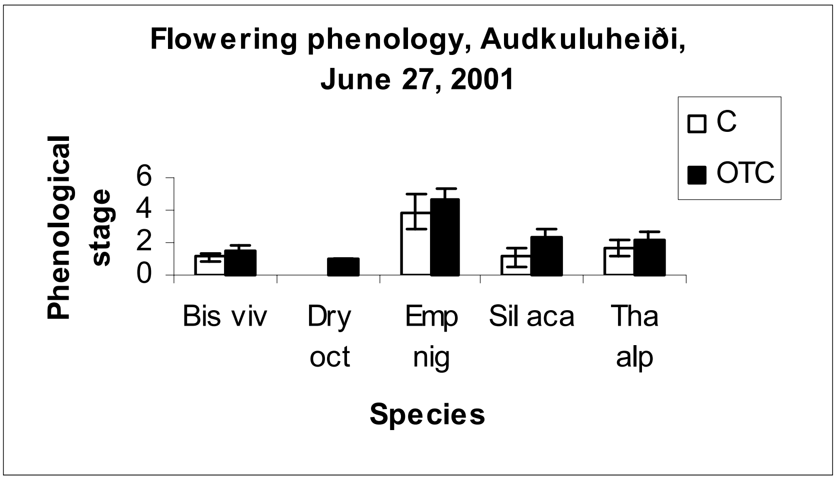

Figure 2. Results for flowering phenology of *Bistorta vivipara*, *Dryas octopetala*, *Empetrum nigrum*, *Silene acaulis* and *Thalictrum alpinum* in control and warmed plots (OTC) at Audkuluheidi site in 2001.

DCA-ordination of the community data revealed that after 5 years at the Thingvellir moss heath site, definite changes in vegetation composition could neither be detected within control nor warmed plots. At the Audkuluheidi shrub heath site, on the other hand, a change in vegetation composition had occurred within warmed plots following 3 – 4 years of treatment, mainly due to an increase in cover of shrubs and decline of bryophytes (Fig. 3).

Conclusions

The results of this short time study indicate that ecosystem responses to climatic warming will depend on initial community composition and soil nutrient status. Communities of high species richness, on relatively rich soils will show stronger responses than species poor communities on infertile soils. In areas where climatic warming will occur shrub cover will increase while there will be a decrease in cryptogam cover in the ground layer. Flowering and seed formation will be hastened and less limited by growing season temperature (Jónsdóttir *et. al*., in press).

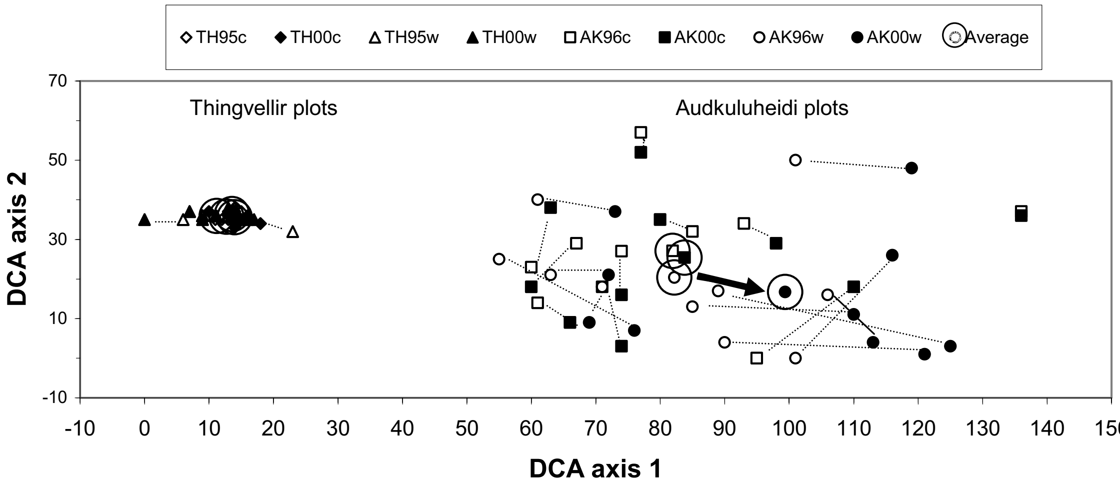

Figure 3. Decorana ordination results for control (c) and warmed (w) plots at the Thingvellir (TH) and Auduluheidi (AK) sites. Dotted lines connect the same plots and indicate relative vegetation changes between between first (in '95 or '96) and second (in '00) sampling. Average scores for the 10 plots in each treatment are also shown within large circles; the arrow indicates the direction of vegetation change occurring in the warmed plots on Audkuluheidi.

Acknowledgements:

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Freshwater Ecosystems and Global Change: A Brief Introduction to EURO-LIMPACS

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Freshwater ecosystems, already under stress from land-use change and pollution, now face additional pressures from climate change, directly and through interaction with other drivers. Euro-limpacs; (European Project to Evaluate Impacts of Global Change on Freshwater Ecosystems) is concerned with the science required to understand and manage the ecological consequences of these interactions. The project, which involves 38 institutes from the EU, wider Europe, Russia and Canada, started in February 2004 and will finish in 2009. The project will bring together a consortium of leading scientists aiming to integrate river, lake and wetland ecosystem science at the catchment scale. It focuses on the key drivers of aquatic ecosystem change such as land-use, nutrients, acid deposition and toxic substances. The project is aimed to examine their interactions with global, especially climate, change in using time series analysis, space-for time substitution, palaeolimnology, experiments and modelling. Iceland's role in this project will mainly be on climate - eutrophication interactions, based on experiments and palaeolimnological analysis. In the presentation I will give an introduction to the project.

Zackenberg Basic: Monitoring of Ecosystem Dynamics in High-Arctic Northeast Greenland

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Long-term monitoring of ecosystem dynamics is identified by Arctic Climate Impact Assessment as an important development area for future research in the Arctic. At present, long time series of parameters describing the dynamics of Arctic ecosystems are very limited and normally focused on a very specific scientific question or originally sampled for purposes other than monitoring.

In the past ten years a number of different circum-Arctic monitoring networks have emerged. Common to most of these networks (e.g. Arctic Coastal Dynamics, Circumpolar Active Layer Monitoring, International Tundra Experiment) is that they monitor single parameters at several locations in the Arctic. In time, this type of monitoring will provide good insight of how single parameters are affected by Climate Change, but it will not allow us to quantify the interactions between ecosystem parameters and how interactions are affected by and will affect climate. To do this, extensive monitoring quantifying all important ecosystem parameters in a well-defined landscape system is needed.

Since 1995, Danish and Greenland institutions have been operating an extensive cross-disciplinary ecosystem monitoring programme, Zackenberg Basic, at the Zackenberg Research Station in High Arctic Northeast Greenland. This abstract describes the concept of Zackenberg Basic. The abstract focuses on the Zackenberg experiences in relation to implementing and maintaining a long-term ecosystem observatory. Focus is more on structure, management and coordination issues than on the actual research carried out.

Zackenberg Research Station

Zackenberg Research Station is situated in central Northeast Greenland (74°28'N, 20°34'W). The station can accommodate and support 20 scientists at a time. Climate models for High-Arctic Northeast Greenland indicate a temperature increase of up to 6-8°C over the next 100 years (Rysgaard et al., 2003). The anticipated climate change will probably cause the High-Arctic zone to move northwards and it may disappear completely from Northeast Greenland.

Zackenberg Ecological Research Operations

During the planning of Zackenberg Research Station it was considered important to establish a coordination body to ensure cooperation between the visiting research projects and the permanent monitoring programme, thereby avoiding being just another logistics base for individual research projects in the High-Arctic. By facilitating this cooperation it was the hope to establish a shared interest among the various users of the station to work towards a common goal of describing the entire dynamics of a High-Arctic ecosystem and to ensure a better-than-normal usage of sampled data. Furthermore, it was considered important to carry out the necessary logistics with the largest possible concern to the fragile High-Arctic ecosystem and to the investigations carried out. For these purposes the framework

"Zackenberg Ecological Research Operations" (ZERO) was conceived and implemented. ZERO encompasses research, monitoring and logistics at the station and facilitates cooperation between these components. ZERO is personalized by ZERO Working Group with representatives from the research, monitoring and logistics components at Zackenberg. ZERO Working Group evaluates all applications for use of the Zackenberg Research Station, it suggests cooperation between various research projects (including more untraditional interdisciplinary cooperation), and it takes decisions about new activities that might affect the ecosystem (e.g. manipulative research projects, new logistic solutions). Although the coordination of activities does affect the degree of freedom for the individual interest groups, it has been accepted as a shared overall benefit.

Zackenberg Basic

Zackenberg Basic is the monitoring component of ZERO and a Danish contribution to AMAP's Climate Change Effects Monitoring Programme. It comprises four fully integrated sub-programmes: ClimateBasic (monitoring of climate), GeoBasic (monitoring of abiotic processes in the terrestrial ecosystem), BioBasic (monitoring of biotic processes in the terrestrial ecosystem) and MarineBasic (monitoring of abiotic and biotic processes in the marine ecosystem). The monitored area is the entire drainage basin to the river Zackenbergelven (500 km^2) and the adjacent fjord system, Young Sund - Tyrolerfjord (400 km^2).

The primary purpose of Zackenberg Basic is to sample data addressing the questions:

1. How does climate variability influence the dynamics of High-Arctic ecosystems?
2. How do High-Arctic ecosystems affect climate?

The first question is related mainly to quantification of the effects of climate variability and change on trophic interactions in the ecosystem, while the second question is related mainly to quantification of potential ecosystem feedbacks to climate change. To address the questions, Zackenberg Basic monitors more than 2000 parameters each year. These data are reported annually in the "ZERO Annual Report", and more thorough scientific syntheses of the work will be published every ten years (the 1995-2004 synthesis is in preparation).

As a secondary purpose, Zackenberg Basic provides basic ecosystem data to any scientist, institution or international organisation / network interested in using the data. Zackenberg Basic data can be downloaded free of charge through the Internet immediately after quality assurance (typically one year after sampling). This service has proved to be an important contribution to ZERO. With basic data being provided by Zackenberg Basic, guest scientists working at Zackenberg Research Station can concentrate on their more project specific data collection, and they can easily relate the results from their short-term investigations to the variability in e.g. climate. Furthermore, Ph.D. students can use Zackenberg Basic data extensively in their studies and thereby avoid expensive data collection.

Due to the specialised expertise needed to provide the inputs required from different scientific disciplines, the four sub-programmes of Zackenberg Basic are maintained by different institutions. Integration and coordination of the monitoring activities is accomplished by the Zackenberg Basic Working Group with participation of the managers of the different sub-programmes and with supervision from an advisory group of university scientists. Zackenberg Basic Working Group secures the coordination and integration of the sub-programmes by clearly defining:

1. The major questions to be answered in cooperation between the sub-programmes.

2. Who should monitor which parameters.
3. The flow of information / data between the sub-programmes.

It is still too early to conclude on the efficiency of Zackenberg Basic, as the first synthesis of the work has not yet been published. However, the following side effects of the monitoring have already proved to be successful:

1. Data from Zackenberg Basic have been used extensively by almost all of the research projects working at Zackenberg.
2. Zackenberg Basic data have already been included in numerous publications (10-20 peer reviewed papers per year).
3. Coordinated biotic and abiotic marine and terrestrial monitoring at the same facility has proved to facilitate interdisciplinary cooperation not only among the monitoring researchers but also among visiting scientists at the facility.
4. In recent years several Ph.D. students have based their theses more or less completely on existing data from Zackenberg Basic. Currently six Ph.D. students use Zackenberg Basic data for their theses.
5. Zackenberg Research Station provides data to almost all circum-Arctic monitoring networks.

Perspectives for future ecosystem monitoring in the Arctic

In the future Zackenberg Basic would like to see itself as one among a series of Arctic ecosystem observatories with extensive monitoring programmes. We find it important that monitoring of Climate Change effects in the Arctic focuses not only on single ecosystem parameters but also on effects, interactions and feedbacks in ecosystems as a whole. This is only possible at observatories with long-term monitoring, and we would therefore like to see more observatories like Zackenberg established in different climatic settings (e.g. Low Arctic and Sub-arctic) to supplement the existing and relatively fine-meshed network of single parameter monitoring.

Acknowledgement

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Recent Progress towards Establishing an Arctic Ocean Observing System: A NOAA Contribution to the Study of Environmental Arctic Change (SEARCH)

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Introduction

The Arctic plays several important roles in the global climate system, including effects on the surface heat budget and on the global thermohaline circulation. The atmosphere and oceans transport heat toward the poles, where it is radiated back out to space. The surface heat budget is further influenced by the large areas of highly reflective ice and snow, which reduce the amount of solar energy absorbed by the ice- and snow-covered areas. The global thermohaline circulation is affected by the volume of freshwater exported from the Arctic Ocean, which is thought to regulate the intensity of the large-scale ocean overturning.

SEARCH is a coordinated, US interagency program established in recognition of the important role of the Arctic region in global climate (SEARCH SSC, 2001). SEARCH is focused on understanding the full scope of changes taking place in the Arctic and to determine if the changes indicate the start of a major climate shift in this region. NOAA has initiated its contribution to the SEARCH program with seed activities that address high priority issues relating to the atmosphere and the cryosphere. One element of the NOAA SEARCH program is an Arctic Ocean Observing System.

The SEARCH Arctic Ocean Observing System is envisioned to include 6 categories of in situ observations: Ocean Pathway Moorings, Cross Shelf Exchange Moorings, Basin Moorings, Gateway Moorings, Repeated Hydrographic Sections, Automated Drifting Stations, and drifting buoys. Enhancement of the International Arctic Buoy Program (IABP: http://iabp.apl.washington.edu/) and the Automated Drifting Stations (ADS), like the one at the North Pole Environmental Observatory (NPEO: http://psc.apl.washington.edu/northpole/), have been identified as two of the key components of the SEARCH Arctic Ocean Observing System. These enhancements and the deployment of drifting buoy have been the initial focus of NOAA's efforts. More specifically, the focus has been on establishing a network of instrumentation to monitor and understand changes in the thickness of the ice cover.

Method

Central to the progress that has been made in establishing a network to monitor changes in the thickness of the ice cover has been the development and employment of autonomous ice mass balance (IMB) buoys. An IMB buoy is equipped with thermistor strings, which extend through the thickness of the ice cover, acoustic sensors monitoring the position of the top and bottom surfaces of the ice, a barometer, a GPS, and a satellite transmitter. These buoys provide a time series of sea level pressure (SLP), surface air temperature (SAT), snow accumulation and ablation, ice mass balance, internal ice temperature fields, and temporally averaged estimates of ocean heat flux (Perovich et al., 1997; Perovich et al., 2003). Together, these data not only provide a record of changes in the ice thickness, but equally important they provide the information necessary to understand the source of these changes. This is critical to extending the results from these individual sites to other regions of the Arctic. The buoys are installed in the ice cover and, hence, drift with the ice cover. Monitoring the drift of the buoys also provides information on the circulation pattern of the sea ice cover.

The current and planned deployment of IMB buoys for 2004 is shown in Figure 1. By the end of this season, 8 IMB buoys will be installed in two major regions of the Arctic Ocean: the Beaufort Sea and the Central Basin. These locations enhance and complement the drifting buoys deployed as part of the IABP, which are more basically instrumented to measure position, SLP and SAT.

Whenever possible, the deployment of an IMB buoy is coordinated with other programs to provide a more comprehensive set of data. During 2004, 3 of the IMB buoys will be collocated with other ocean and radiometer buoys to form clusters of Automated Drifting Stations. These sites have been achieved through collaboration with the NPEO, the Japan Agency for Marine-Earth Science and Technology (JAMSTEC) and Woods Hole Oceanographic Institution's (WHOI) Arctic Group. These stations provide critical atmospheric, ice and upper ocean hydrographic measurements that cannot be obtained by other means.

In addition to drifting buoys, in August 2003 we also established a new mooring site in the northern Chukchi Sea (Figure 1). The mooring is equipped with an ice profiling sonar (IPS) to measure the ice draft and velocity as the ice drifts overhead, providing a measure of the ice thickness distribution (Melling, 1996). This site was located using the results from a coupled ice/ocean sea ice dynamics model (Zhang et al., 2003). The model was used to generate estimates of the basin-wide mean annual thickness using a 52-year window, 1948 through 1999. Using these estimates, a correlation analysis was applied to investigate the effectiveness of establishing a second seafloor-moored IPS to monitor changes in the annual mean thickness of the Arctic sea ice cover. The analysis recognized and was dependent on the existence of the IPS at the NPEO. The results of the analysis indicated that a moored IPS located in the northern Chukchi Sea, coupled with the results from the established NPEO site could explain 86% of the variance of the basin-wide, annual mean ice thickness. The location of a second mooring significantly improves the data collected from a single moored IPS at the North Pole, where the explained variance is estimated to be 65%. Data from the mooring sites are only available after mooring is recovered. The first recovery of the mooring in the Chukchi Sea is scheduled for September 2004.

Conclusion

Recent progress has been made in establishing components of an Arctic Ocean Observing System. The initial focus is on a network of instruments to monitor and understand changes in the thickness of the ice cover and in near surface ocean characteristics. Central to the success of this network is the coordination of our efforts with other national and international programs. The use of sea ice dynamics models has also been important, helping to optimize the location of instrumentation and the allocation of limited resources.

We have only just begun to receive the data from the recently deployed sites, but we can already observe regional and interannual variability in the changes in the thickness of the ice cover and upper ocean. This observation is consistent with our assessment of other historical observations. It is our objective to make these data generally available to the scientific community for use in validating satellite-derived products; for forcing, calibration and assimilation into numerical models; and for forecasting weather and ice conditions. By maintaining and further developing this network, it is our intention to provide a more consistent record of change, necessary for improving our understanding of this complex and important component of the global climate system.

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Our appreciation goes to the scientific and crew members onboard the Russian ice breaker *Kapitan Dranitsin*, Canadian ice breakers *Louis S. St. Laurent and Sir Wilfred Laurier*, United States of America ice breaker *Healy*, Swedish ice breaker *Oden*, and the Japanese ice breaker *Mirai* who have shown great support and ability in the deployment of our equipment.

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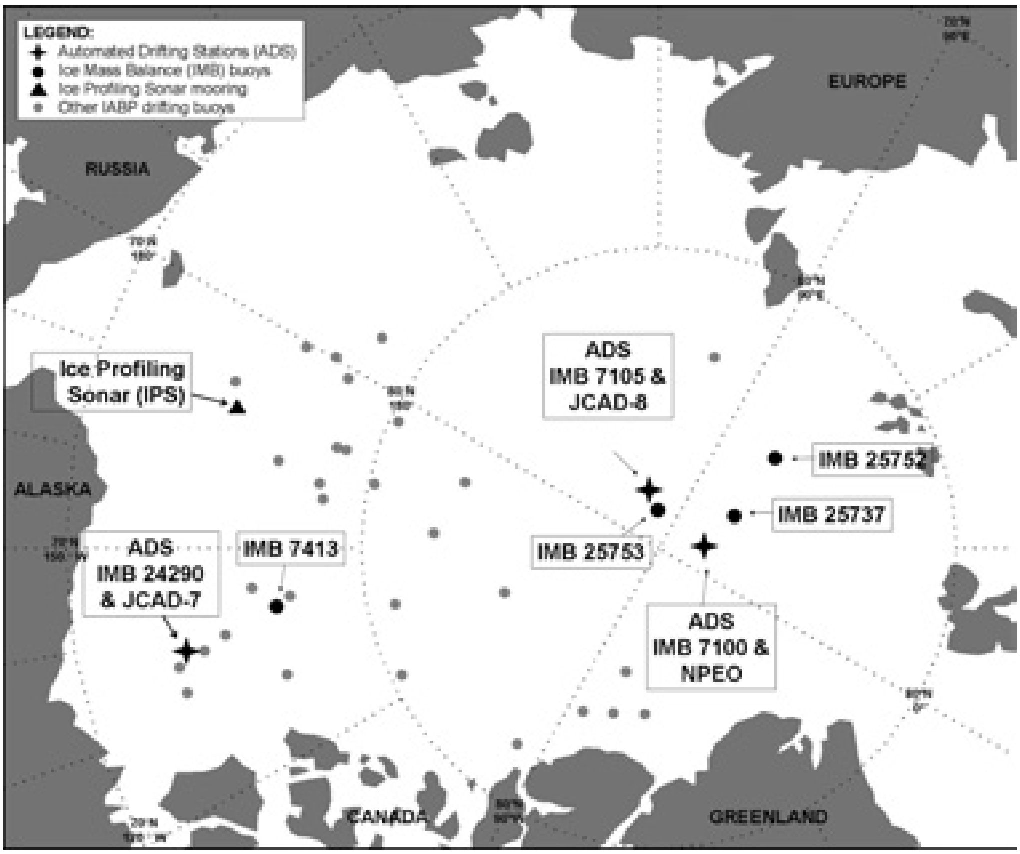

Figure 1. The 2004 deployment of instrumentation to monitor changes in the thickness of the Arctic sea ice cover and the upper ocean surface.

Global Terrestrial Network for Permafrost (GTN-P) – A Contribution to Improved Understanding of the Arctic Climate System

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Introduction

Permafrost regions of the Northern Hemisphere occupy about 24% of the exposed land area. Climate warming associated with increased concentration of atmospheric greenhouse gases is expected to be greatest over high latitudes and the permafrost regions will be among those significantly affected. Variations in permafrost conditions can be a sensitive indicator of climate change and variability. Warming and thawing of perennially frozen ground can lead to landscape instability, and changes in surface and subsurface hydrology and vegetation which can have impacts on ecosystems, infrastructure, northern development and lifestyles. Changes to near surface moisture and gas fluxes may also occur, resulting in changes to carbon sources and sinks associated with permafrost-affected soils and important feedbacks to the climate system.

Active layer and permafrost thermal state have been identified as key cryospheric variables for monitoring through the World Meteorological Organization's Global Climate Observing System (GCOS) and the Food and Agriculture Organization's Global Terrestrial Observing System (GTOS). The Global Terrestrial Network for Permafrost (GTN-P) was established in 1999, under GCOS/GTOS, by the International Permafrost Association (IPA), to provide long-term field observations of active layer and permafrost temperature essential for understanding present permafrost conditions and detecting and characterizing changes (Burgess et al. 2000). The information supplied by the GTN-P improves understanding of the cryosphere-climate system and enhances our ability to predict the consequences of permafrost degradation associated with climate warming and to develop adaptation strategies to respond to these changes. This report describes the GTN-P, and presents recent North American results from the thermal monitoring component.

The Global Terrestrial Network for Permafrost

The GTN-P consists of two components: the Circumpolar Active Layer Monitoring (CALM) Network that has been in operation for the last decade, and the recently established borehole thermal monitoring component. Active layer thickness is measured at approximately 125 monitoring sites that contribute to CALM. Data from the CALM network are submitted annually and disseminated through the CALM web site. Further details on CALM and recent results can be found in Brown et al. (2000).

The permafrost thermal monitoring program consists of a globally comprehensive network of boreholes for ground temperature measurements. Over 350 boreholes have been identified from 16 countries for inclusion in the network (Figure 1). Most of the boreholes are located in the Northern Hemisphere, but a few are located in Antarctica and Argentina. Regional

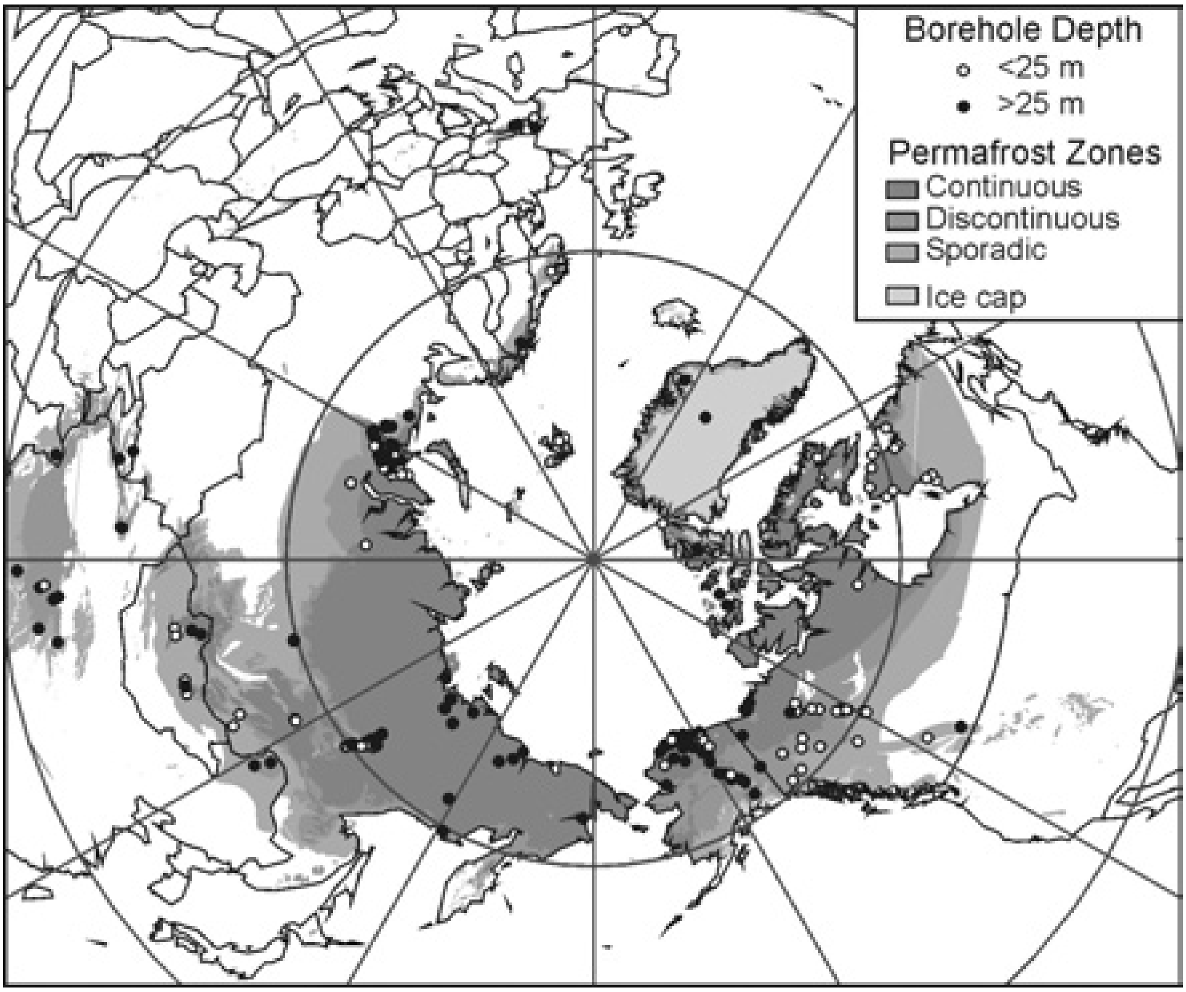

Figure 1. Permafrost distribution in the Northern Hemisphere and location of candidate boreholes for permafrost thermal monitoring.

networks include the Geological Survey of Canada's (GSC) boreholes in the Mackenzie region, the University of Alaska's Alaskan transect, the United States Geological Survey's (USGS) deep boreholes in northern Alaska and the European Community's Permafrost and Climate in Europe (PACE) program of boreholes largely in alpine permafrost. Site descriptions and summary data are disseminated through the GTN-P web site (www.gtnp.org). Plans are being developed for an IPA contribution to the International Polar Year that will involve collection of data from as many GTN-P sites as possible in 2007/2008.

Recent North American Results from the Thermal Monitoring Component

Preliminary results from GTN-P sites are discussed and presented in Romanovsky et al. (2002). This report focuses on results from across the North American Arctic.

Analysis of permafrost temperatures in the upper 20m from a network of boreholes in Alaska maintained by the University of Alaska, Fairbanks, indicates that permafrost has warmed over the last 20 to 50 years. Temperatures at a depth of 15 m at Barrow, increased 0.02°C per year between 1950 and 2001. Along the Trans-Alaska pipeline route increases of permafrost temperature ranging from 0.03 to 0.09°C per year between 1983 and 2000 have been observed at a depth of 20 m, with the larger increase occurring in the colder permafrost. Warming of permafrost has also been observed along the Alaskan Arctic coast and on the Arctic coastal plain in the USGS's network of deep boreholes. Increases in surface temperature between 1980 and 2003 range from 0.04 to 0.09°C per year along the Arctic coast to 0.13 to 0.17 °C per year on the coastal plain with most of the warming occurring since about 1989.

The GSC has operated a network of thermal monitoring sites in the Mackenzie region, Northwest Territories since 1985. In the central Mackenzie valley, at a depth of 15 m, increases in temperature of about 0.03°C per year were observed between 1986 and 2001 in permafrost with temperatures of approximately –1°C. In colder (-7°C) and thicker permafrost in the northern Mackenzie region, temperatures at a depth of 28 m increased by about 0.1°C per year in the 1990s. In warm (-0.3°C) thin permafrost in the southern Mackenzie valley no significant trend in permafrost temperature since 1985 has been observed.

At the northern-most permafrost observatory, the GSC's high Arctic observatory at Alert, Nunavut, warming of permafrost occurred in the late 1990s of 0.15°C per year at a depth of 15 m. Cooling of permafrost was observed from the late 1980s to the early 1990s in the eastern Canadian Arctic at a depth of 5 m at Environment Canada's borehole at Iqaluit, Nunavut. This cooling was followed by an increase in permafrost temperature of about 0.4°C per year beginning in 1993 and continuing through the 1990s.

Summary

The GTN-P has been established to provide long-term observations of permafrost conditions that will provide information to scientists studying the cryosphere and also to stakeholders, politicians and other decision makers. This information is essential for improved evaluation of the impacts of climate change as well as the development of adaptation strategies.

Initial results from the North America network sites show that although recent warming of permafrost has been observed across the North American permafrost zone, the magnitude and timing of this warming varies. For example, warming has been observed since the early to late 1980s in the western North American Arctic. Warming however in the Canadian eastern and high Arctic occurred in the late 1990s with cooler permafrost temperature generally occurring in the 1980s and early 1990s. This pattern of change in permafrost temperatures is consistent with regional variations in air temperature trends although the magnitude of change may be different.

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Arctic Change Detection in the Post-ACIA Period

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The ACIA Assessment Report documents changes in Arctic climate and the impacts of these changes, and forms the basis for a longer term emphasis by the Arctic Council on the role of climate change on the people, environment and economy of the northern high latitudes. The Council and their Working Groups will rely on member countries for increased data and information and updates on climate indicators as they consider responses to the future scenarios that the Report describes. A next step in the post-ACIA period is to apply proven procedures to produce an easily understood but comprehensive Arctic Change Detection Product in near real time.

The US/NOAA Arctic Research Office has built on the 10 key findings, 19 climate trends and 10 society impacts enumerated in the ACIA Report. Current data, for comparison to historical analyses, is being obtained from throughout the Arctic region. The project benefits from close liaison with scientists from the Arctic Council Working Groups. The following four-part procedural framework is used to refine a suite of indicators of Arctic change:

- **Objective** – Identify relevant issues or impacts from those listed in the ACIA Report, such as shifts in vegetation, shifts in animal diversity and range, increased shipping and impacts of thawing ground.
- **Measured indicators** - Select a subset of indicators for each Objective. Criteria for selection include concreteness, public awareness, availability, sensitivity and specificity. The 19 indicators of the ACIA Report and 86 from previous work of the authors will serve as the initial basis of the selection process.
- **Reference points** – Indicators are evaluated on the basis of historical information or critical values relevant to a given issue or impact.
- **Communication** - Highlight major changes in quantitative indicators and qualitative information from news reports, updated several times a year.

Credibility of the process is based on multiple lines of evidence; using such a procedure balances problems caused by having too many indicators which lack specificity, or too few indicators which do not consider the complexity of the process nor provide a robust result.

The NOAA Arctic Change Detection website provides information from near-real time indicators and their potential impacts for the state of the Arctic in an accessible, understandable, and credible format. The Arctic Change Detection website (Figure 1), at http://www.arctic.noaa.gov/detect/, addresses core Arctic issues identified in the key findings of the ACIA report. Users entering the website see these core issues at a glance. More detailed pan-Arctic information, spanning multiple scientific disciplines, is available with a single mouse click. Information provided for each core issue includes recent news headlines and scientific articles, photographs, narrative descriptions and time series of selected indicator variables. Updated information is provided as it becomes available, so that the Arctic Change Detection website serves as a near-realtime continuation of the ACIA report.

Figure 1. Screen snapshot of the Arctic Change Detection website.

The NOAA Arctic Change Detection website is presented in the context of the very successful NOAA Arctic Theme Page, located at www.arctic.noaa.gov, and all background information is available to the reader/user. More information on historical indices is in Overland, et. al. 2004. Results from this project will be updated and tailored for the Arctic Council to aid its members in their effort to understand the rate and extent of change and make informed decisions concerning the impacts which result.

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The Swedish Icebreaker *Oden* as a Research Platform: THE ARCTIC OCEAN EXPERIMENT 2001

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1. Introduction

Recently, scientists and scientific organizations have identified the significance of the Arctic in the global climate system. The past decade has seen changes in the Arctic system suggesting that anthropogenic climate change has begun to affect the region. The Arctic is often assumed to have large climate sensitivity. Anthropogenic warming is projected to be largest in the Arctic, at ~ 2.5 times the global average in CMIP (Coupled Model Intercomparison Project, Meehl et al. 2000) simulations (Räisänen 2001). However, the global models used for these projections have problems reproducing the current Arctic climate. Consequently, the inter-model spread in the CMIP scenarios is larger in the Arctic than elsewhere (Räisänen 2001).

Difficulties in simulating the Arctic climate relate directly to insufficient understanding of several strong feedback processes. The Arctic is one of a few remaining areas on Earth where relatively little is know both about the current climate and about important climate processes. An important reason is a lack of direct observations. Consequently the ensemble of observations forming the empirical basis for description of many climate processes in models of the Arctic may be too small.

2. 'ARCTIC OCEAN 2001'

The Swedish Secretariat for Polar Research (http://www.polar.se) has a tradition of icebreaker based research in the Arctic. The Arctic Ocean Experiment 2001 (Leck et al., 2004; Tjernström et al. 2004; http:// www.fysik.lu.se/eriksw/aoe2001/aoe2001.html) followed a series of expeditions in 1999 and 1996, with the aim to identify and quantify key processes controlling sources, fate and properties of aerosols relevant to formation of Arctic low-level clouds (Leck et al. 1996 and 2001). A conclusion from these was that atmospheric dynamics play an important role in the Arctic, such that interpreting atmospheric chemistry and aerosol measurements without understanding of the concurrent boundary-layer dynamics is difficult. Another conclusion was that biologic activity in open leads might play a more direct role in aerosol production, besides that of DMS production. AOE-2001 thus carried significant atmospheric boundary layer and ocean/ice biology programs.

AOE-2001 took place between 29 June and 26 August 2001, on the Swedish icebreaker *Oden*; the expedition track is shown in Fig. 1. Some atmospheric measurements were carried out continuously. Somewhat more intensive measurements were taken during a few research stations around Svalbard and in transit north when *Oden* was lying still for limited periods. The main atmospheric event was an ice-drift experiment 2 - 21 August.

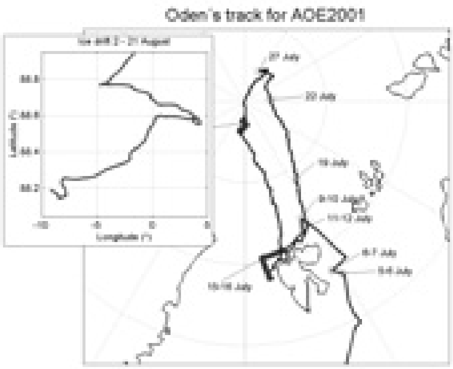

Figure 1. Map of the northern North Atlantic and Arctic with the track of the AOE2001. The insert shows the track during the ice-drift.

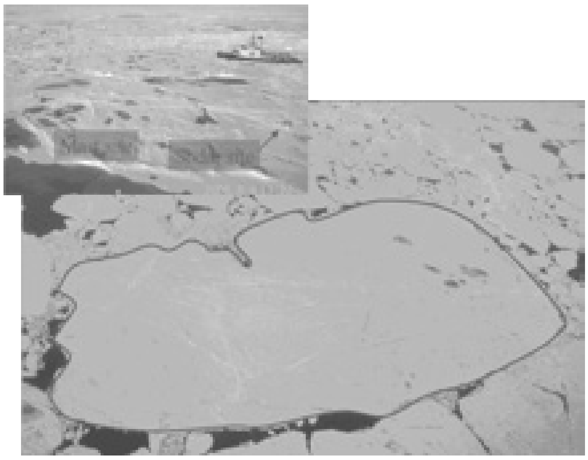

Figure 2. Photo of the ice floe for the AOE-2001 ice drift. The lower portion shows the floe; the experiment was mostly conducted in upper left quadrant. The insert shows *Oden* from across the floe with the measurement site in the foreground.

3. The Ice-Drift

The ice-drift was conceived to minimize effects of the icebreaker on the measurements.

A large ice floe (1.5 - by - 3 km) was selected close to N89° E00°. Fig. 2 shows a birds-eye view of the ice floe from the helicopter, that was part of the expedition. The ice was fairly level with melt-ponds of varying size. The ice thickness varied from ~1.5m to >6 m.

Almost all atmospheric chemistry and aerosol measurements were taken onboard *Oden* in container-housed laboratories located forward on Oden's 4th deck. Fig. 3 shows a view of *Oden* with the row on containers on the 4th deck and the masts with pollution controlled air inlets for trace gases, among others SO_2, NH_3, DMS and O_3, and aerosols. Aerosol size distributions were also sampled, between 3nm – 10 µm in diameter and by mass between 40nm – 10µm. Aerosols were also collected on filter packs for chemical analysis. Additionally, aerosol profiles were also taken with the helicopter, and with a tethered sounding system, see below. Seawater was regularly sampled and analyzed, from CTD casts and from the ocean surface micro-layer, using a remote controlled boat, Fig. 4.

Figure 3. Side view of *Oden* showing the 4th deck row of laboratory containers with the masts for air intakes.

Figure 4. The remote controlled miniature boat used to sample the ocean surface micro-layer.

Most meteorological remote sensing instruments also remained onboard: a wind profiler and a cloud radar located on the foredeck (Fig. 5), and a scanning microwave radiometer mounted on the 7th deck (Fig. 6), with a 270° free view in the vertical plane.

Figure 5. View of the *Oden* foredeck from the 7th deck, showing the square-shaped NOAA/ETL 915MHz Wind Profiler antenna and the round S-band cloud radar antenna, also from NOAA/ETL, partly hidden aft of the forward container housing electronics for both systems.

Figure 6. Scanning microwave radiometer mounted on the starboard side of the 7th deck, with a free view over the ocean.

Several instrument systems were deployed on the ice during the ice-drift (Figs. 7-9). The sodars, disturbed by noise on *Oden*, were moved to the ice (Fig. 7). Combining winds from the wind-profiler and the sodar resolve the boundary-layer winds continuously. A continuous record of the temperature profile < 1 km is available from the scanning radiometer. Additionally, radio soundings for wind, temperature and humidity profiles were launched every six hours during the ice drift.

Alongside the sodars, the CIRES tethered profile system was deployed, using an airfoil or an aerodynamic balloon (Fig. 8). This system was used for different payloads: A basic met-payload for meteorological profiles, a turbulence package and an aerosol package.

Figure 7. Ice-camp view from *Oden*, with the sodar and tethered sounding site in the foreground and the tower site farther back.

Figure 8. View of the tethered sounding system.

A main system deployed on the ice was an 18-m mast with temperature and wind speed profiles, and turbulence instruments at two levels (Figs. 7). Wind direction, atmospheric moisture, radiation and pressure were also measured at this site. To better characterize horizontal variability and to track propagating mesoscale systems, two additional meteorological stations were deployed on nearby ice floes, within ~ 10 km, by helicopter (Fig. 9).

Figure 9. Deployment of a remote weather station. Batteries charged by solar panels and a wind generator, seen in the foreground, powered the instruments.

4. Summary

Nothing can replace *in-situ* observations and process studies as a means to improve climate models. In the Arctic this becomes critical for two reasons. First, there is a general lack of relevant observations. This directly impacts the understanding of feedback processes particular to the Arctic and our ability to model the Arctic climate. Second, acquiring this type of data in the Arctic is extremely difficult and demands significant logistical efforts. The dynamics of the sea ice inhibits deployment of unmanned equipment for long periods, thus much knowledge must be gained from field experiment data. Additionally, the Arctic environment is very harsh and unfriendly, with very cold conditions in winter and very moist conditions in summer.

Having access to an experimental platform such as the *Oden* greatly facilitated the the AOE-2001.

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Development of the Archive of Historical Ice Charts of the Arctic Region for the XX Century and Statistical Parameters Describing Variability of Ice Conditions

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In the present report an attempt is undertaken to give a possibly fuller description of historical ice charts of the XX century submitted in a digital form by national ice services, and to show special features of applying various statistical parameters to assess long-term and large-scale variability of ice conditions of the Arctic region.

The historical sea ice information used in climatic researches, may be differentiated

a) by the nature as direct and indirect or proxy,

b) by dimensions as pointal, linear and fields of characteristics, and lastly,

c) reception means as surface (visually and/or instrumentally) and remotely sensed.

We estimate ice charts as an information product, optimal and self-sufficient for an assessment of the variability of an ice cover of XX century from aspects of temporal duration, accuracy, harmony (i.e. presence of insignificant changes in compilation technique), as well as spatial coverage of Arctic regions. Other types of the ice information under condition of their individual use - satellite data (for example SSMR-SSM/I), coastal station, shipborne, proxy from fauna/flora, folklore, etc. concede on a number of parameters – either in duration, or accuracy, or in spatial coverage.

The largest archive of 5-10 days ice charts of XX century in standard digital WMO format SIGRID presently is available within the framework of WMO project “Global Digital Sea Ice Data Bank” - GDSIDB (http://www.aari.nw.ru/gdsidb). The project includes charts from Canada (since 1962), Russia (since 1933), the USA (since 1972), the Baltic services (since 1961), Japan (since 1970), etc., giving the information on distribution of the sea ice total and partial concentrations and stages of development of the Arctic seas and Basin, total number of archived units being of 10,000 order.

Climatic processing may be carried out on separate charts collection to obtain sea ice characteristics for a single area. However, for large-scale phenomena those data are more optimal, where natural information from all possible sources is fused. Such a blended GDSIDB dataset, developed recently, integrated on a monthly basis and on a 15x15 geographical minutes grid the data of sea ice total concentration from various ice services since 1950 up to 1998. Elimination of gaps equal to ~1/2 in the first version was provided by means of monthly climatology, further planned to be replaced with more sophisticated means likely by values typical for each year from the point of atmospheric processes. Such a blended file, planned to be extended to year 2005-2006, is proposed to be used as a source of WMO climatic normals for the planned International Polar Year – IPY 2007/2008.

Climatic characteristics can be differentiated as 1-dimensional (1-D) (ice index), 2-D (fields of statistics) or 3-4-D if such transformations as Furie, wavelet, Hilbert, etc. are applied. Further, from statistical point of view characteristics may be unstable or robust, the first one sometimes corresponding to artificial cases, the least probable in the nature (e.g. average concentration 4-6/10 in the vicinity of the ice edge with binary 0 or 10/10 state). Analysis of relationship between statistics, assessed on a basis of GDSIDB data, and special features of ice conditions provides possibility to choose optimal statistical parameters for describing ice variability within certain areas of the Arctic Ocean in seasonal cycle, e.g. choose between r.m.s., range and entropy. For temporal variability, estimations of such classical parameters as ice index on a basis of GDSIDB historical charts give a typical picture of a negative trend from 1950 to ~2000; however transition to 2D or 3D patterns (wavelet-transform) gives a more sophisticated picture varying in space and season. Typical features are alternation of -/+ signs of linear trend and heterogeneity for the fields of amplitudes and phases of 20-40-year fluctuations of ice concentration for the Eurasian Arctic regions.

The AARI Oceanographic Database and Its Use in Investigations of the Arctic Ocean

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The Oceanographic Database of the Arctic Ocean and the adjoining water areas has been generated at the AARI for 15 years. It is based on the observations of Russian oceanographic expeditions that operated in the Arctic onboard the research vessels from 1920 up to present, in the high-latitudinal airborne "Sever" expeditions during the period 1937-1993, at the drifting "North Pole" stations from 1937 to 1991, data of coastal stations and drifting buoys and also on the available information from other sources. In general, the materials included to the database cover the late 19th century - present time period.

The database structure is comprised of the blocks of thermohaline characteristics, hydrochemical characteristics, calculated fields, vertical profiles and transects. The database numbers more than 400 thousands of primary and non-duplicated oceanographic stations.

For generation of the database, a multi-level control was carried out both by the statistical methods and the expert checking performed by a group of experts for each specific region

An important aspect in creation of any database is elimination of backup information provided different sources are used for the database construction. In our case, the control for duplicates was made by the equality of dates, time, coordinates and codes of ships. Preference was given to the stations with the largest number of observations on temperature and salinity or at the equal number of observations, to the stations with more complete information on ships.

The statistical control of temperature and salinity values was conducted in each standard horizon. For calculation of mean temperature and salinity values and standard RMS deviations, the Arctic Ocean area was divided into squares in the following way:

- squares with 1000x1000 km sides of the initial grid were subdivided into four squares;
- the number of measurements of thermohaline characteristics and the number of years when these observations were made were calculated;
- if in each of four new squares the number of measurements were more than 31, and the number of years was more than 5, each of them was also subdivided into four squares;
- the subdivision into smaller squares continued until the prescribed criterion by the number of observations and the number of years in which these observations were fulfilled (31 observations and 5 years) was not met in one of the new squares.

The values of mean multiyear thermohaline characteristic (X) and the RMS deviation (S) were calculated in the obtained squares. The values of the characteristic beyond the $X \pm S$ bound were marked and were not used in further work.

In addition, the statistical characteristics (number of observations, number of years in which observations were made, mean, dispersion, RMS deviation, asymmetry coefficient, excess coefficient and coefficient of regression plane equation were calculated.

Calculation of statistical characteristics in the squares was performed by means of the scripts developed for this purpose using the Visual FoxPro DBMS.

For creating the database, the software and scripts were developed and improved in order to provide oceanographic database management at different stages of its generation, supplement, administration, maintenance and also to provide operational calculations meeting various requirements of users and to create different analytical, calculated and graphical materials for reference-books and atlases.

The software products and scripts were created by means of programming languages: xBASE and SQL (in the MS Visual FoxPro v3.0 environment), C++ (in the MS VisualC v4.0 environment), JavaScript (in the Macromedia DreamWeaver v3 environment), GS Scripter32 (GS Surfer v6.04, v7.0 and GS Grapher v2.0 environments). The work was carried out in the following directions:

- elaboration and improvement of software packages for data loading and conversion;
- software for data control;
- scripts (software) for visualization and analysis of thermohaline measurement data.

The following software packages for visualization and analysis of thermohaline measurement data were devised:

Software for generation of a by-voyage (by-expedition) catalogue for a prescribed period of time with a subsequent display of the layout of stations at the chart of the selected voyage (expedition), software MatSklon for the analysis and classification of the vertical temperature and salinity profiles, which allows us to:

- create a catalogue of the expeditions;
- depict the location of oceanographic stations at the chart of the Arctic Ocean (with seabed relief) with indication of the types identified at the formal stage for the chosen expedition;
- visualize the temperature and salinity profiles for the chosen station (both at logarithmic and linear depth scale) taking into account the types identified at the formal stage;
- visualize the T, S-diagram for the chosen station;
- look through the numerical characteristics of temperature, salinity and density values and their gradients for the chosen station;
- identify finally the type of thermohaline structure for the chosen station and make record of the type to the file created for this purpose.

The database materials have been used for generating the oceanographic atlases on the basin and the seas of the Arctic Ocean and for conducting a series of research studies. On the database basis, climatic and annual seasonal fields for the ocean water area were constructed.

The proposed presentation contains information on the DBMS developed on the basis of the VISUAL FoxPro DBMS and the quality and quantity of available oceanographic information in the database as well as the results (atlases, climatic estimates and reconstructions) and the components of the products derived using the database in the framework of the projects carried out on its basis.

The following was made based on the Oceanographic database**:**

- Studies of the active layer of the Arctic Basin were carried out, estimates of variability of the active layer thickness and mean temperature and salinity were obtained for the seasonal and interannual variability scales.
- Estimates of the contributions of different factors to the variability of the active layer characteristics were derived.
- Assessments of the freshwater balance components of the seas of the Siberian shelf and the Arctic Basin were performed. The Russian-US electronic climatic atlas "Oceanographic Atlas of the Arctic Ocean" (winter period – 1997, summer period – 1998) and the Russian –US electronic "Hydrochemical Atlas of the Arctic Ocean" were published.

For the first time for the Arctic Basin region, fields of mean salinity of the upper 100-m layer, freshwater content in the 100 and 200-m surface layer, upper and lower boundaries of Atlantic water for the years with a low number of observations were reconstructed and continuous series of the fields of these characteristics for the last 45 years were derived.

Using modern processing procedures for observation data that were used by the Russian and western partners in preparation of the Russian-US "Oceanographic Atlas of the Arctic Ocean", water temperature fields of the Arctic Basin and the Arctic Seas in standard horizons from the surface to the bottom were reconstructed for the winter season over the last 45 years.

The variability of thermohaline characteristics in the area of the Arctic Seas in the 20th century was evaluated.

The AARI oceanographic database of the Arctic Ocean База is a basis for climatic studies in the Arctic region and for undertaking experimental programs and expedition studies of the Institute for the future.

The AARI Arctic Oceanography Database can be used during the next phase of the Arctic Climate Impact Assessment (ACIA) Program.

Climate Change in the Arctic: Information Support of the Problem

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Global climate change due to growth of greenhouse gas content in atmosphere will impact not only the Earth natural conditions, but also the world economy and human life quality. As a result of climate change there will be global environmental changes, which appear in the rise in the world ocean level, changing limits of natural zones and their northward shift, reducing the territory available for human and biota life. The most significant on scales transformation of ecosystem under anthropogenic climate warming will take place in arctic and subarctic regions, where climatic changes lead to irreversible processes in cryolithozone: permafrost degradation, thawing and heaving frozen grounds, which cause construction accidents. That's why the problems of climate change are key for elaborating scientific forecasts in a sphere of environmental protection. A special attention must be paid to the Arctic as "a kitchen of the world weather and climate".

To study global environmental changes under anthropogenic impact International and national research programs "Global Change" are created in all development countries of the world (USA, Canada, Germany, Russia). State Scientific-Technical Program of the Russian Federation "Global change of environment and climate" is aimed to solve this problem.

Leading Russian and foreign scientists join their efforts in studying global changes. They cumulate a great amount of materials, create various models and databases, exchange views at workshops, conferences and symposia. To search, summarize, analyze and systematize all materials devoted to ecological problems and global environmental changes is the objective of activity of the Department of Scientific Bibliography of the State Public Scientific-Technological Library of the Siberian Branch of the Russian Academy of Sciences (SPSTL SB RAS). A wide spectrum of retrospective and current indices of literature and problem-oriented databases were created for informational support of ecological scientific projects and programs of SB RAS: "Sustainable development of nature and society in Siberia and the Far East", "Nature and natural resources of Siberia and the Far East, their protection and rational use", "Ecology and natural complexes conservation in West Siberia", "Problems of the North". All DBS generated by the Department are web-oriented bases of a documentary type. The total volume of electronic resources compiled by SPSTL SB RAS on ecological topics is about 300,000 bibliographic records, which are represented in Internet and available at the library site www.spsl.nsc.ru/win/onb.html.

To improve information service of researches and specialists the activity on informational massives creation are accompanied by their logical-statistical analysis. Based on the DB of integrated subjects "Problems of the North", dealing with multiple problems of the Far North development, the information massif touching investigation of arctic climate and its changes was selected. It includes more than 1000 documents and contains books, articles from journals and collections, summaries of dissertations, papers of conferences, congresses and symposia, deposited manuscripts, preprints published in 1988-2003 in Russian and foreign languages. A geographical range of the DB is rather wide: arctic and subarctic regions of Northern Europe (Sweden, Norway, Finland, Denmark [Greenland]), Alaska (USA), northern regions of Canada, European Russia, Siberia, the Urals and Far East.

Problems related to climate are separated in a special section. The thematic structure of the information massif covers researches on climate monitoring and climatic fluctuations and changes in the Arctic, content of greenhouse gases (especially CO_2, CH_4) in atmosphere, air pollution and ozone depletion, weather phenomena and forecasts, arctic ice–atmosphere relations. Thereto the DB contains materials on effect of climate changes on biota and permafrost, prediction of possible consequences in the Arctic of global warming, knowledge of indigenous peoples of the North on the Arctic climate and its change, which are massed in conforming sections devoted to biota, permafrost, aboriginals and others.

Climate Change and Health among Women of Labrador

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This exploratory research project used a qualitative approach to identify environmental and climate changes in the Nain, Labrador (Canada) region and the effects of these changes to the health of the local population. Research was carried out during September and October, 2002 in the community via semi-structured interviews and participant observation. The Informants were a group of 18 Inuit women ranging from 32 to 78 years of age at the time of interview who had lived in the Nain area for at least 30 years and who had extensive experience with land based activities.

Projects based on local knowledge to better understand environmental and/or climate changes carried out in the Canadian North have predominantly sought the male hunter's perspective given their extensive experience in travelling on the land and water and skills required to hunt and fish successfully in an extreme clime. Women's perspectives on the other hand have been largely overlooked, despite their experience on the land and with traditional land based activities. As well, women hold a particular relationship to questions of health making them a key group to seek input from in trying to understand the current and potential health effects of climate changes.

Interviews were carried out in the community of Nain, Labador in English and Inuktitut, were translated, transcribed and verified. Content analysis followed three major themes: 1) climate and environmental changes; 2) impacts of those changes to the women and their community and; 3) the local concept of health.

Climate and environmental changes

Recent climate patterns in comparison with those of the past, where the past commonly refers to an average of thirty years for the younger group of women and up to seventy years for the oldest of the informants, have changed in the following ways:

For the following there was a high level of consistency across data: There is less snow and the period with ground cover is shorter; winters are warmer and characterized by increased variability and humidity and the later onset of ice; there is increased frequency and strength of winds particularly in but not restricted to winter, and some reported changed wind direction from West to East; thunder is less strong, loud (and possibly less frequent); and the in-land water bodies (ponds, brooks, glaciers) are lowering/receding.

For the following there was a good level of consistency across data: Tides rise higher and fall lower possibly explained by increased erosion causing a shallowing of interstitial waters. The increased erosion is associated with less freezing of soils. Variability of climate has increased in comparison with four to seven decades ago but not in comparison with one to three decades ago. Unpredictability of climate behaviour was found to be linked to social as well as environmental shifts.

Trends for humidity versus dryness are unclear. It would seem that humidity in winter has increased with the reported increased in "damp" conditions among the older informants, perhaps consistent with warmer temperatures. On the other hand we have dryer land conditions associated with less snow precipitation and the drying of fresh water sources.

For animals and plants marked declines in populations over the lifetime of informants were consistently observed. Sporadic but interesting observations indicate that biological responses within the ecosystem may be in flux. Observations include new and resurging species seen in the area, the seasonality of transient species shifting, the behavior and health of individuals from well known indigenous wildlife populations as being abnormal, and the loss of indigenous plant species due to changing climatic conditions. As well, aesthetic attributes of taste and smell of common species such as the Spruce grouse (Spruce partridge) were reported as changing.

Effects as they pertain to the women and others in their community

Climate changes were reported to contribute to: illness and loss of vitality; in some cases impeding access to basic needs of food and heat and potentially affecting shelter in the future; increasing risks associated with injury and material loss for some while for others to taking a more conservative approach to participating in land-based activities. Changes were also found to have altered some of the ways in which informants interact with their environment through opportunities for play, the sensory experience of interacting with the land and in daily routines such as with clothing and apparel, meals, and hanging laundry to dry.

Local concept of health

Eating wild foods and knowing that they are safe and healthy to eat, going-off onto the land, and not suffering from having been relocated are important threads in defining a local concept of health according to the women interviewed. The older Inuktitut speaking women spoke of health in terms of what may be called more traditional Inuit values of sharing, helping, obeying and taking responsibility for one's self.

Going-off onto the land as a major need to being healthy – it is an activity that would be very difficult to replace with any other that would produce the same effect among these women. It is the means through which health is found, maintained, captured and replenished. It is a fountain of wellness and healing needed to counterbalance other more negative influences present in community life in Nain today.

Discussion

Both the population health model and its related determinants as adopted by Health Canada and the local determinants of health derived from the interviews formed the basis against which the results regarding the effects of climate change were interpreted. Currently, climate change was found to be adversely influencing health among this population through three general determinants, namely through changes to the physical environment, income and social status and culture. The two local determinants of health that were seen as being influenced by the effects of climate change were traditional food security and going-off onto the land.

Conclusion

The qualitative approach taken in this study enabled an exploration of the modes of action between reported climate and environmental changes and influences to health status with reference to the population health model. The local knowledge of 18 women with extensive experience with land based activities provided information that led to a better understanding of the specific ways that observed changes in climate are adversely influencing health in this population. The strategy of focussing on women provided insight into a number of interactions between climate change and this Labradorian population.

Interactive Poster – "When the Weather is Uggianaqtuq: Inuit Observations of Environmental Change"

Shari Fox Gearheard and Inuit from the communities of Baker Lake and Clyde River, Nunavut

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Uggianaqtuq (pronounced OOG-gi-a-nak-took) is a North Baffin Inuktitut word that means to behave unexpectedly, or in an unfamiliar way. From the perspective of many hunters and elders in the Arctic, the weather has been uggianaqtuq in recent years.

In the interactive multi-media CD-ROM, "When the Weather is Uggianaqtuq", Inuit from two communities in Nunavut, Canada (Baker Lake and Clyde River), share their observations and perspectives on recent environmental changes. Many topics are discussed including sea ice, snow, wind, weather variability, changes in seasons, changes in activities, and animals. Maps, text, photos, video and music are integrated to help illustrate the changes Inuit have observed and the impacts on their livelihoods. The integrated components of the CD-ROM allow the user to:

- search by topic or person
- view interview clips in Inuktitut with English interpretations
- view and print maps about environmental changes drawn by Inuit elders and hunters
- view short videos with scenes from the communities
- view summaries and photos of environmental changes and their impacts to the landscape and community life

"When the Weather is Uggianaqtuq" stems from research carried out by Shari Fox in collaboration with the communities of Baker Lake and Clyde River, Nunavut (2000-2004). The CD-ROM was created as a pilot project to address two challenges faced by the research, 1) to find an alternative to written reports that could document and communicate Inuit observations and knowledge in a creative and engaging way, and 2) to find a more useful and interesting way to report research findings to the community, creating a research product that could be accessed by community members, especially youth.

In 2003, elders involved in the making of the CD-ROM approved it for educational use. To read more about the CD-ROM, or order copies free of charge, please see the CD-ROM website at the National Snow and Ice Data Center (NSIDC):

http://www.nsidc.org/data/arcss122.html

or Contact NSIDC at:

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We hope the CD-ROM is of interest to students, researchers, educators, decision-makers, and others in Nunavut and beyond who are interested in issues around Arctic environmental change.

Climatic Changes Associated with Societal Changes Produce New Combination of their Direct Impacts on Health

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A special feature of the future climatic change is the variability, especially the occurrence of extreme conditions. Even under the circumstances of climate warming, extreme cold spells will persist and cause damage. A predicted increased occurrence of heat waves is also a new recognisable risk factor relevant to the future of arctic regions. The impact limits of cold spells and heat waves are, as far as health is concerned, dependent on the average living temperatures. In the Arctic, these limits are much lower than in the South.

If the temperature of the circumpolar climate increases by 5-10 °C, the climate would still be cool, or cold; and cold temperatures still have more impact on human physiology and health than heat.

In contrast to healthy people capable of a physically active lifestyle, strong decreases, or increases, in ambient temperature, may constitute a serious threat for sick and/or elderly people, especially if the change is rapid and lasts for several days.

Urbanisation, with living in city-dwellings and a reduction of our readiness to manage environmental thermal loads by traditional practices, represents an increased health risk to the growing elderly population of the Arctic.

Mortality

Environmental temperatures are associated with increased daily mortality. The relationship is generally a non-linear J, or V shaped. The lowest daily mortality in circumpolar regions is present in the much lower temperatures than in the countries having warmer climate. . This in circumpolar regions is related also to warm related increased mortality already in the mild summer climate.

The lowest mortality related to daily environmental temperature is seen at higher environmental temperatures in countries with the warm summers. This suggests that different populations adapt to their environmental temperatures. This also means that populations have ability to adapt their health behaviour to environmental temperatures.

Epidemiological evidence has accumulated indicating a causal relationship between mortality and cold weather. The most important diseases associated with cold related excess mortality are ischaemic heart disease, cerebro-vascular disease and respiratory disease, especially influenza Cardiovascular diseases due to cold are estimated to contribute 5-20% of the annual mortality, depending on the country. Mortality figures based on monthly, rather than daily, mortality statistics under-estimate the problem .Body cooling may offer a better explanation for the cold related excess mortality than environmental temperature does. Deaths from excessive cold are epidemiologically quantified

The incidence of frostbite requiring hospital treatment increases at temperatures at and below -15 °C, and the risk of suffering frostbite increases with age. This more severe frostbite has been reported to be more common in metropolitan areas than in other types of living resorts in Finland.

Injuries and Frostbites

The total injury rate may change as a consequence of the direct or indirect effects of cold. Causal relationships between different injury sources and accident types, the nature of the injury and the degree of the disability sustained from injury, may also have different pathways.

Unintentional injury occurs least frequently at a temperature of about +20ºC and increases at lower and higher ambient temperatures. The cold environmental temperature is usually a secondary source of injury, rather than a primary one. Cold exposure injuries are reported with much higher frequencies in questionnaire studies than in records, which tend to underestimate this type of injury.

The majority of the occupational outdoor cold exposure injuries occur during the few coldest winter days in USA.. Wind speed strongly increases the injury rate. Freezing, strains and sprains are commonly represented among the cold exposure injuries. Cold exposure injuries display a strong negative relationship with temperature. Occupational slips and falls exhibit such a negative correlation with temperature. The higher rates are linked to about 0ºC and even colder environmental temperatures in the US mining industry.

The onset of air-related frostbite appears at an environmental temperature of -6°C. Wind, high altitude and wet clothing lead to onset of injury at higher environmental temperatures. The incidence of more serious frostbite requiring hospital treatment increases at temperatures of -15°C and less. The risk of suffering frostbite increases with age. This more severe frostbite has been reported to be more common in metropolitan areas than in other types of living resorts in Finland. The self reported frostbite in second or higher grade, occurred 12% of the Finnish young men having the age 18-30 years, sometime in their lifetime. The risk for frostbite in different body parts were increased among the subjects with cold provoked white finger (CPWF) (confidence interval, CI: 1.66 – 3.87), regular smoking (CI: 1.02 - 3.15) and vibration exposure (CI: 1.07 – 4.03). Synergistic increase of frostbite was reported between CPWF and regularly smoking,, also between CPWF and hand arm vibration.

Frostbites are comparable to burns with respect to their immediate consequences. In the case of frostbite, the latter can be a mild or more severe functional limitation of the injured area, sick leave, or, in some cases, hospitalization. The latent symptoms of frostbite are common, the most often of them is local hypersensitivity to cold and pain in the injured area, cold-induced sensations and disturbances of muscular function, and excessive sweating may also occur. These latent symptoms may have negative impacts on occupational activities in 13-43 % cases.

Cold related symptoms

Environmental cold may provoke cardio-pulmonary, respiratory, peripheral vasoneural, musculoskeletal and skin symptoms. They are reported in 41% of Finns by population questionnaire.

Preventing Actions for Cold Related Health Impacts

The goals of public health activities related to the impacts of cold extremes on health are to reduce premature deaths, the amount of disease and injuries, disease-induced discomfort, sickness and disability in the population. In order to evaluate the prevention of cold or heat exposure-related excess mortality, there is a requirement for collaboration between health care, weather broadcasting and other officials, to produce usable preventive action models. The definition of public health programmes aimed at preventing extreme weather-related mortality needs further research in the Arctic to define the the importance of cold and heat related mortality: 1) the populations at risk, 2) the lag time of the effect, 3) the effect of cardio-vascular and respiratory morbidity, 4) the role of respiratory mortality, and 5) the significance of other meteorological variables]The prevention of cold injuries and illnesses is usually the responsibility of health care providers and it requires both practical information and professional support.

Literature list is available form the Author