PROCEEDINGS OF THE
ARCTIC SYSTEM SCIENCE PROGRAM
ALL–HANDS WORKSHOP

FEBRUARY 20–23 2002
SEATTLE, WASHINGTON

Proceedings of the

Arctic System Science Program All-Hands Workshop 2002

ARCUS

This material is based upon work supported by the National Science Foundation (NSF) under Cooperative Agreement # OPP 0101279. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the NSF.

NATIONAL SCIENCE FOUNDATION ARCTIC PROGRAM

In memory of Karoline Frey
30 March 1974 – 24 March 2002

Karo, an ARCSS-funded Geophysics graduate student at the University of Alaska Fairbanks, died in a climbing accident in the Alaska Range shortly after the ARCSS All-Hands Workshop.

This publication may be cited as:

ARCSS Program. 2003. *Proceedings of the Arctic System Science Program All-Hands Workshop 2002*. Fairbanks, Alaska: Arctic Research Consortium of the United States. 271 pp.

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Preface

ARCSS is at another critical point in its evolution. Behind us is a wealth of innovative research that has gone a long way to describe and understand how key parts of the arctic system work, and also how the arctic environment is changing in dramatic ways. We also have begun to heighten public awareness of arctic environmental change and its unprecedented nature. And we have concluded that there is now little doubt that arctic environmental variability and change will continue to affect people and societies more and more into the future. The impacts will be felt most at high latitudes, but the implications of arctic change will extend around the globe.

The challenge to ARCSS is to make the transition to a program that provides an ever more useful scientific basis for decision making. The target audience includes policy makers but also extends to all those who live or work in the Arctic, as well as to those who interact with some aspect of the global system that is influenced by the Arctic. To meet this challenge, ARCSS must continue to break down disciplinary boundaries, to understand the wealth of interconnected processes that underlie arctic system dynamics, and ultimately, to provide integrated knowledge that can be drawn on for decision support. ARCSS must also increasingly exploit international and programmatic linkages, and in doing so expand efforts to look at the interconnectivity of the entire arctic within the context of the whole earth system.

The arctic environment is changing as fast as any on Earth, and it could, though its myriad physical and biogeochemical feedbacks, be the harbinger of change for the entire planet. The researchers who are ARCSS, whether experienced veterans or hardworking students, will make the next phase of arctic research the most productive yet. This report highlights many of the most compelling ideas for this next phase, and augurs well for the future of an ARCSS that will continue to lead in the study of integrated environmental systems, variability and change, and also the development of knowledge that is readily of use to society.

Jonathan Overpeck

Chair, ARCSS Committee

Executive Summary

The Arctic is a complex, tightly coupled system. Research funded through the National Science Foundation's Arctic System Science (ARCSS) Program is diverse and has a thematic rather than disciplinary approach to scientific investigation. In our quest to understand the Arctic as a system, we face the challenging task of further integrating and coordinating research, both within the U.S. and across the global community. During the six years since the 1996 All-Hands Workshop, the ARCSS research community has moved toward a theme-based, integrated, and interdisciplinary approach to studying the arctic system. The 1998 ARCSS science plan, *Toward Prediction of the Arctic System*, introduced five broad thematic questions arising from the need for more integrative research. At the 2002 ARCSS All-Hands Workshop, there was a broad consensus to continue highly integrated research efforts and to coordinate ARCSS research around science-driven questions and research initiatives, rather than through the existing disciplinary components. This summary introduces three science questions based on the initial five, and a summary of the currently active or planned research initiatives.

ARCSS Questions

The following thematic questions, which have progressed from the questions presented in the 1998 ARCSS science plan, provide a scientific basis for organizing ARCSS Program research. These questions arose from ongoing arctic research and new findings, as well as planning discussions within the research community. An important assumption underlying these questions is that many changes in the global climate system affect the arctic system. Changes in the Arctic may, in turn, feed back on the globe, since we are dealing with an open system in many respects.

I. How do human activities interact with changes in the Arctic to affect the sustainability of ecosystems and societies?

A fundamental premise of the ARCSS Program is that global climate change creates changes in the arctic system. Since human activities in the Arctic depend closely upon the environment, arctic residents and resource developers are susceptible to arctic change and are capable of contributing significantly to it. Human activity within the region, such as large-scale oil development, alteration of fire regimes, or redirection of freshwater flow to the Arctic Basin, combined with natural variability in the system, are likely to have far-reaching and complex effects. For example, a reduction of permafrost, which can result from both human development and a warming climate, has significant implications for arctic engineering and development but also can have far-reaching affects on global biogeochemistry and hydrology. Warming temperatures also reduce the extent, thickness, and duration of sea ice, which, on a regional scale, can result in arctic coastal communities being more susceptible to powerful storms and erosion. On a global scale, reduced sea ice can result in rising sea levels, a freshening of the oceans, and changes to world ocean currents. Arctic communities and resource developers are confronted with the challenge of creating sustainable adaptations to these conditions that take into account not only current change, but projected future change. Research focused on human interactions with changes in the Arctic can contribute to an understanding of future arctic climate conditions and current ecosystem stressors and will help fulfill one of the fundamental missions of the ARCSS Program: to advance the scientific basis for formulating policy options in response to the anticipated impacts of global changes on human beings and societal support systems.

Research that will address this question includes the emerging Land-Shelf Initiative (LSI); Pan-Arctic Cycling, Transitions, and Sustainability (PACTS) initiative; and the existing Human Dimensions of the Arctic System (HARC) program. This is also an area where ARCSS-funded research interfaces with the NSF-wide Biocomplexity in the Environment program.

II. What are the limits of arctic system predictability?

Recent improvements in technology, support, and access to the Arctic have allowed scientists to collect data indicating changes to the arctic climate over the last half-century that have no precedent, at least over the previous three centuries. These detected changes have important repercussions to science and society, yet it is not clear whether they are the result of natural variability in the arctic system, of human actions, or of a coupling of anthropogenic and natural forcings. Predicting the extent and probable outcomes of these changes is a formidable challenge. Research that contributes to improved predictability includes paleoenvironmental studies, which use proxy indicators to reconstruct and understand past climate change; modern process studies, which use experiments and simulations to understand mechanisms affecting the operation and response of a system; and observational studies, which rely on extensive observational networks to gather large amounts of data that provide an essential foundation for arctic research. Climate models have been improved by all of these types of research. The extent to which changes can be predicted, however, remains unknown. For example, observational data suggest that warmer Atlantic waters are penetrating farther into the Arctic Ocean, which has significant ramifications for global weather and climate. To what degree can this trend be predicted? Can we develop enough of a predictive understanding of this and many other detected phenomena to be able to formulate policy responses that will allow societies to plan for or effectively adapt to changes in the climate? This question directly addresses a primary goal of the ARCSS Program: to understand the processes of the arctic system that interact with the earth system and contribute to, or are influenced by, global change in order to advance the scientific basis for predicting environmental change.

Research focused on this question includes aspects of long-term observational programs such as Paleoenvironmental Arctic Sciences (PARCS) and the International Tundra Experiment (ITEX), planned programs such as the Study of Environmental Arctic Change (SEARCH), and the modeling components of every aspect of ARCSS research. A possible initiative concerning modes of variability in the arctic system would directly focus on this thematic question.

III. How will changes in arctic cycles and feedbacks affect arctic and global systems?

The arctic system is linked to the global system through complex and dynamic physical and biogeochemical mechanisms. As the arctic climate changes, hydrologic and biogeochemical cycles will respond to these changes and feed back to the global system. Many of these changes to cycling and the associated feedbacks are still not clearly understood. Although freshwater outflows from the Arctic Basin have significant impacts on convection and thermohaline circulation of the world's oceans, the extent of these impacts is not fully known. Global climate models suggest that CO_2-induced warming is amplified by declining sea ice in the Arctic, but models return widely variable results on the degree of the amplification. Changes to arctic nutrient cycling have significant impacts on arctic and global ecosystems, but there is still a great deal to be learned about the mechanisms and probable outcomes of change. Understanding the contemporary and probable future states of the arctic hydrologic and biogeochemical systems is an imperative antecedent to understanding the associated impacts on ecosystems and societies. Without a better understanding of the nature of these cycles and feedbacks, sound policy and development decisions are nearly impossible to make. ARCSS research—through process studies, observational networks, paleoenvironmental studies, and the continued refinement of climate models—will continue to investigate the ways in which changes to arctic hydrologic and biogeochemical cycles feed back to both the arctic and global systems.

This question, particularly concerning feedbacks within the arctic system, has been the focus of much of ARCSS-funded research to date, including the Western Arctic Shelf-Basin Interactions Project (SBI), the Russian-American Initiative on Shelf-Land Environments in the Arctic (RAISE), Arctic Transitions in the Land-Atmosphere System (ATLAS), and Surface Heat Budget of the Arctic Ocean (SHEBA). The new Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) initiative also addresses this question.

ARCSS Initiatives

The development of community-driven, highly coordinated research initiatives has become a hallmark of ARCSS research. A recent development has been the way in which these science-driven initiatives transcend the disciplinary components that forged them. SEARCH and RAISE are vivid examples of this transition. Moreover, the interagency SEARCH program is a new type of partner for ARCSS, providing strong new scientific focus areas as well as new funding options. Although SEARCH is not a component of the ARCSS Program, it is expected that ARCSS research will make significant scientific contributions to SEARCH in coming years.

The working groups at the All-Hands Workshop focused on four themes: (1) arctic hydrology, (2) nearshore and coastal processes in the Arctic, (3) modes of variability in the arctic system, and (4) biophysical feedbacks and transitions in the arctic regional system. These themes represent current or potential initiatives that will develop further over the next few years. The discussions of each working group are detailed later in this document; a summary is provided here.

I. Arctic-CHAMP: Pan-Arctic Community-wide Hydrological Analysis and Monitoring Program

The primary aim of Arctic-CHAMP is to catalyze and coordinate interdisciplinary research and to construct a holistic understanding of arctic hydrology, through integration of routine observations, process-based field studies, and integrative modeling. At this workshop, maintaining long-term data series emerged as an important recurring theme, and emphasis was placed on the importance of including biogeochemical cycling and hydrological process studies.

The following key uncertainties were identified:

1. What is the role of lakes in arctic water, energy, and biogeochemical cycles?
2. What are the mechanisms for cloud formation and dissipation, and what role do arctic clouds play in the system?
3. What are the controls on the timing, magnitude, and quality of river inputs into the Arctic Ocean, and what is the fate of this input?
4. What are the impacts of changes in the hydrological cycle on humans?

Many improvements in the length and quality of data records will be required to address these uncertainties. Studies of many aspects of the system that influence these uncertainties, such as permafrost dynamics, aerosols, snow, and vegetation, require further study. Changes in these cycles affect vegetation, microbial processes, macrofauna, and humans.

II. Nearshore and Coastal Processes

The primary goal of the Land-Shelf Initiative (LSI) is to improve our understanding of the biogeochemical, physical, and hydrological processes that occur in the nearshore zone of the arctic shelf, with respect to changes in the global climate system, marine ecosystems, and resource use by humans. The zone of interest lies seaward of many Arctic-CHAMP research interests and landward of many SBI research priorities, serving to effectively integrate land and sea studies without ignoring the complexity of processes that occur uniquely in this zone.

The following key uncertainties were identified:

1. What are the bidirectional impacts of society and coastal environments?
2. Can we determine the evolution and landscape dynamics of the shelves and nearshore zone?
3. What are the mechanisms important to transport of materials in and through the coastal zone?
4. What is the importance of the structural and functional patchiness of the ecosystem in this zone?
5. How do processes in the coastal zone feed back with changes in the global system?

Various subthemes relate to these uncertainties, including biogeochemistry as a linking feature between land and sea, permafrost dynamics, atmospheric circulation and meteorological events; the effects of changes in the annual cycle of sea-ice cover; and the vulnerability of gas hydrates. Determining what kinds of information coastal communities of the Arctic need in order to adapt to rapid change is a major priority.

III. Modes of Variability

A central problem in detecting anthropogenically driven climate changes is the need for improved knowledge of the structure and evolution of, and the mechanisms responsible for, interannual and decadal variability in the arctic system. The system frequently adopts preferred states that are both persistent and recurrent: referred to as modes of variability. Vigorous debate over the past few years about anthropogenic and natural variability suggests that modes of variability is an important new research area that requires close study.

The following key uncertainties were identified:

1. Are recent arctic environmental changes remarkable? On what time and spatial scales? What connections can we make between the changes observed by science and those observed by or of greatest concern to arctic residents?
2. What do we know about thresholds, abrupt changes, high rates of change, and extreme events?
3. Can we define the extreme states of the arctic system?
4. How can we achieve useful scenarios about future change?
5. What are the interactions between global and arctic modes of variability? How might arctic environmental changes affect environments and societies "downstream" at lower latitudes? How do lower-latitude changes affect the Arctic?

Working group participants recommended that these uncertainties can best be addressed by a combination of longer observational time series, refinement and extension of available paleoenvironmental data, model development, and most important, renewed efforts in the development of appropriate conceptual models of variability.

IV. Cycles, Interactions, and Transitions in Arctic Biophysical, Biogeochemical, and Social Systems

Spatial and temporal heterogeneity is a fundamental characteristic of virtually all components of the arctic system, particularly the biotic ones. Understanding this complexity is an essential underpinning for characterizing arctic system predictability and is the basis on which understanding of rapid changes, transitions in state, and time-space heterogeneity must be based. This is precisely the understanding most needed to inform and advise arctic and global societies.

The following key uncertainties were identified:

1. What is the nature of biophysical and biogeochemical cycling within and between terrestrial, marine, and atmospheric components of the system?

2. What are the trajectories of change in biophysical systems?
3. What is the vulnerability and sustainability of biological systems in the face of cumulative industrial impacts and use of living resources?
4. How do we represent spatial and temporal heterogeneity in the arctic system?

The impact of the structure and composition of biological communities on the biogeochemistry and physical structure of the environment is an important focus of this initiative. Temporal state changes in these communities may be rapid, may possess transient elements, and, in some cases, may be irreversible. Food webs are a particularly attractive area where the study of biogeochemical cycles and cross-system linkages would yield results with direct bearing on the vulnerability of the arctic system to sustain human and other forms of life. To make progress in this research area, maintenance of observational networks over long periods of time will be crucial.

Next Steps

The current and planned ARCSS research initiatives that were the focus of the 2002 All-Hands Workshop, and that are described in this report, rely heavily on the fundamental premise that interdisciplinary research will be the most effective way to understand the arctic as a complex, tightly coupled system. The evolving thematic questions detailed above emphasize three concepts fundamental to arctic climate change research: predictability, sustainability, and feedbacks. As ARCSS moves into its next phase, these concepts will help provide a framework for integrating the diverse research that is being planned, is currently underway, and that has been completed through the efforts of ARCSS-funded investigations.

Following this executive summary is a short overview of the current ARCSS Program structure. After the introduction, summaries of each of the working group discussions from the All-Hands Workshop follow, each focusing on the key uncertainties and readiness for research within those areas. Following the summaries are presentation and poster abstracts from the 2002 ARCSS All-Hands Workshop.

Introduction

The Current ARCSS Program

In 1989, the National Science Foundation (NSF) created the Arctic System Science (ARCSS) Program as part of its contribution to the U. S. Global Change Research Program. From the beginning, ARCSS researchers have used paleoenvironmental studies, contemporary process and observational studies, and modeling efforts to investigate the response of the Arctic to global climate change forcings and to elucidate processes unique to the Arctic that feed back to the global system. Three fundamental precepts have guided the ARCSS Program:

- research initiatives are community-driven,
- the research approach is system-centered, and
- projects are multidisciplinary or interdisciplinary.

The 2002 All-Hands Workshop offered the ARCSS research community the opportunity to mark progress in scientific knowledge, assess the current state of the program, and consider the future direction of the program. Over the thirteen years since its inception, the scientific goals of the ARCSS Program have evolved as comprehension of global change and the arctic system has expanded, and the programmatic structure has evolved accordingly. Below is a brief summary of the current state of the ARCSS Program structure and the proposed future structure that emerged from discussions before, during, and after the All-Hands Workshop.

Community-driven research initiatives have been an essential part of the ARCSS Program since it was established. The current ARCSS Program is built around components—Land-Atmosphere-Ice Interactions (LAII), Ocean-Atmosphere-Ice Interactions (OAII), Paleoenvironmental Arctic Sciences (PARCS), Human Dimensions of the Arctic System (HARC)—each of which has a science management office (SMO) that helps plan and coordinate projects. In addition to a science management office, LAII, OAII, and PARCS, as well as most of the major ARCSS projects and initiatives, have a science steering committee (SSC) that helps plan and coordinate research within these components. Each component, through the SMOs and SSCs, receives input and feedback from the ARCSS Committee. The science steering committees, ARCSS Committee, and science management offices are designed to represent and be responsive to the research community. This arrangement allows for investigator participation in the scientific direction of the program, which results in grassroots development of research initiatives. As the ARCSS Program continues to evolve, a management structure of science steering committees, science management offices, and the ARCSS Committee is likely to remain, although in a somewhat modified configuration.

OAII and LAII were developed with an emphasis on marine and terrestrial environments, respectively. PARCS, which has its roots in the first ARCSS components, Greenland Ice Sheet Project 2 (GISP2), and the Paleoclimates from Arctic Lakes and Estuaries (PALE) program, consistently contributes paleoenvironmental data and analysis to a wide variety of ARCSS initiatives as well as individual projects. Similarly, HARC contributes information about how societies are impacted by and impact arctic and global climate change to a broad range of ARCSS initiatives and projects. Each of the existing components have significantly expanded the knowledge base of their respective domains. As the ARCSS Program moves forward and the emphasis is placed more heavily upon integrating all the domains of the arctic system, reconfiguring these cooperative, multidisciplinary structures into more collaborative, interdisciplinary structures will be necessary. To effectively address questions necessary to understand a system as complex as the Arctic requires close collaboration among disciplinary scientists and integration of their knowledge and research at all levels of the science planning, implementation, and analysis process.

The Future of ARCSS

The ARCSS Program is currently at a crossroads, with a strong foundation of science, many achievements to its credit, and a productive future ahead. Much of this success is detailed in this All-Hands Workshop report. The next step for ARCSS, concurrent with the programmatic evolution, is the development of a fully integrated Arctic System Science Program. The ARCSS Committee will be responsible for articulating the goals and process for this evolution, as well as the implementation that will follow. Central in this effort will be input from the ARCSS community, and in this context, this All-Hands Workshop Report will serve as important input.

Workshop Report

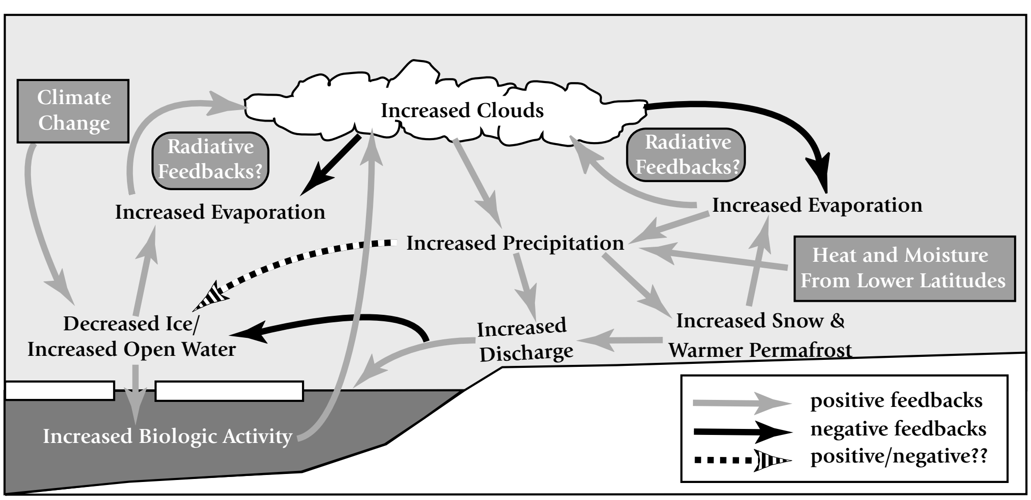
The remainder of this report is dedicated to summaries of the discussions from working groups that met at the 2002 All-Hands Workshop, key recommendations, and abstracts of oral and poster presentations.

Arctic-CHAMP

An Analysis of the Hydrologic Cycle and its Role in Arctic and Global Environmental Change

Changes in arctic hydrology resulting from climate change have major implications for the global system. The numerous elements and processes of the arctic hydrological system require close study to understand how changes to arctic hydrology impact the global system. These elements include biogeochemical cycling, vegetation dynamics, atmospheric dynamics, hydrological processes, marine interactions, snow hydrology, permafrost, and ice sheet and glacier dynamics. Each of these elements and processes of arctic hydrology have been the focus of research, but there are still significant gaps in our knowledge. For example, it is clear that atmospheric concentrations of carbon dioxide and methane may be affected by changes in the hydrology of high-latitude terrestrial ecosystems. With a warmer, dryer climate, there will be an increased flux of carbon dioxide in the Arctic. With a warmer, wetter climate, methane flux increases. What is unknown at this point is whether wetlands in the Arctic are expanding or receding, so it is difficult to predict how changes in arctic biogeochemical balances will feed back to the global system.

The feedback diagram below, taken from the Pan-Arctic Comunity-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) science plan, provides a useful graphic representation of a variety of feedbacks within the arctic system. Many of the arrows in this diagram, though, represent feedbacks that are not clearly understood. Whether a feedback is negative or positive is still unclear for many of these processes. One of the principal goals of the Arctic-CHAMP working group at the 2002 All-Hands Workshop was to gather



community input on the nature of the feedbacks and complex interaction of processes represented in this diagram.

Key Uncertainties

The three main categories of key uncertainties identified during the Arctic-CHAMP working group discussions were: (1) the role of lakes in the arctic system, (2) the role of the Arctic Ocean, aerosols, and fire in cloud formation and precipitation, and (3) watershed dynamics in the Arctic. Each of these three areas requires extensive research before there can be a clearer understanding of the important bidirectional feedbacks between the arctic and global systems.

Role of Lakes

There are many gaps in our current understanding of the roles arctic lakes play in both arctic and global systems. Lakes are a vital component of the water and energy balance of the Arctic, but we do not currently know enough about arctic lake dynamics to understand how lakes interact at the landscape scale. Arctic lakes are a considerable source of methane, which makes them central to understanding biogeochemical cycling in the Arctic, yet we do not have enough data to evaluate the extent to which arctic lakes drive and are driven by arctic biogeochemical cycles. Currently we do not have the ability to extrapolate our plot-level data to landscape, regional, or pan-arctic scales. As a result of these gaps in data and understanding, we lack a functional model that represents the important role that lakes play in the arctic hydrological system.

Understanding the role that lakes play in the arctic system has several broader implications to arctic and lower-latitude societies. For instance, lakes, and the ecosystems they support, are vital to the subsistence of many arctic people. Also, the natural system of expansion and contraction of arctic wetlands can provide insight into dammed and impounded waterways in lower latitudes. By better understanding the evolution of lakes, we may be better equipped to understand the impact that managed reservoirs and wetlands have on ecosystems.

Several questions related to the role lakes play in the arctic system emerged from the Arctic-CHAMP working group discussions at the All-Hands Workshop. Those questions, which represent some of the fundamental areas needing close study, include:

1. What are the drivers of arctic lake dynamics? What forces maintain arctic lake stability?
2. How sensitive are lakes to changes in permafrost and evaporation/precipitation dynamics?
3. How will modern studies of sedimentation and evaporation help us interpret paleoenvironmental data?
4. What impacts do changing lakes and wetlands in the Arctic have on arctic and lower-latitude societies?

Cloud Formation and Precipitation

Very little is known about arctic cloud formation. The role that the Arctic Ocean plays in cloud formation is unknown, as is the relationship among aerosols and cloud formation. In order to understand the impacts that climate change will have on arctic hydrology, it is critically important that we improve our understanding of arctic cloud formation and precipitation. It is assumed that the Arctic Ocean—and consequently changes to the surface temperature and sea-ice extent—plays a part in arctic cloud formation and precipitation. However, the paucity of data precludes any substantive analysis of this role, although it is seen as a highly important area for study. Aerosols also are presumed to contribute to arctic cloud formation, but we know very little about the way that aerosols may contribute to arctic cloud formation and precipitation.

A number of essential questions related to arctic cloud formation and precipitation were raised at the All-Hands Workshop, including:

1. What is the role of the Arctic Ocean for cloud formation?
2. What role do clouds play in the energy balance, evaporation, and precipitation in the Arctic?
3. Where does arctic precipitation come from?
4. What are the relationships among aerosols and cloud formation (from all sources, including fire)?

Watershed Dynamics

There are data suggesting that discharge into the Arctic Ocean from Eurasian rivers over the last half-century has increased, but the fate of that freshwater and the controls on timing, magnitude, and quality of the input are all unknown. The arctic watershed is vast and difficult to define. The headwaters of some of the rivers that ultimately drain into the Arctic Ocean originate outside the Arctic, making the development of a comprehensive understanding of the arctic watershed a formidable task. We know that snow, vegetation, and permafrost extent all play an important part in the dynamics of the arctic watershed, but we lack a clear understanding of how these components interact. For example, arctic ecosystems have changed notably over the last half-century, with increased shrub growth and decreased tussock tundra, but the bidirectional feedbacks of these changes on the watershed remain largely unknown. Understanding the dynamics of the arctic watershed will take extensive monitoring and integrated analyses to develop methods that will enable energy, trace gas, and water flux data to be usable across the vast arctic region.

Several questions related to the arctic watershed were identified at the All-Hands Workshop as critical to developing a functional understanding of the dynamics of this complex system, including:

1. What is the magnitude and timing of the input of freshwater into the Arctic Ocean?
2. What is the fate of that freshwater?
3. What are the impacts of a change in that input?
4. How can we scale our measurements of this flux?
5. What are the impacts on societies of changes in the arctic hydrological cycle, specifically the increasing input of freshwater into the Arctic Ocean?

Improved Technology and Techniques

The Arctic-CHAMP working group discussions also yielded a list of techniques and technologies that need to be improved before we can adequately address many of the questions above. Adequate methods for measuring temperature, precipitation, and runoff (particularly under ice) are necessary to develop a basic understanding of arctic hydrology in general and specifically precipitation, yet currently we lack these methods. We also lack adequate techniques for scaling and sampling strategies; we need to develop better instruments, particularly a reliable device to measure snowfall and sublimation; and generally we need to improve the consistency and quality of our data. The group emphasized maintaining long-term data series and developing more paleoenvironmental studies as fundamental needs in developing a basic awareness of the arctic hydrological cycle and the potential impact that changes to that cycle can have on the global system.

Modes of Variability in the Arctic System

One of the central problems in understanding and determining the predictability of arctic climate variations on decadal-to-century time scales is the need to distinguish natural variability from anthropogenic change. The *natural variability* is that which would be present in the absence of anthropogenic forcing. Addressing this problem is challenging because of the short duration of observational data series, the low temporal resolution and spatial extent of many paleoenvironmental data sets, and our limited theoretical understanding of mechanisms.

Although physical, chemical, and biological principles place constraints on the possible states of the arctic system, the number of states, or *ensemble of realizations*, that the system can assume is infinite. Yet it is a matter of common experience that there exist states that are both persistent and recurrent. Such states may be called *modes of variability* because they correspond to a mode (local peak) in the probability distribution of all states. The search for and analysis of such states is fundamental to understanding natural variability.

There is vigorous debate on the optimal approach to describe and understand the natural variability of the arctic system. This debate prompted a focus of the ARCSS community upon modes of variability. This section summarizes a discussion addressing the key uncertainties in this topical area that should receive priority attention in new ARCSS initiatives.

1. **Are recent arctic environmental changes remarkable? On what time and spatial scales? What connections can we make between the changes observed by science, and those observed by or of greatest concern to arctic residents?**

It will be important to better characterize low-frequency variability, and this requires consideration of the best mix of new observations, data rescue, and paleoclimatic data. The characterization must be linked to conceptual models, and at the most general level should span different disciplines and subsystems within the arctic system. The improved characterization is needed to provide a framework for distinguishing and understanding the contributions of natural and anthropogenic causes to the total variability. Participants noted a mismatch between the information required from models to address this problem and the accuracy or comprehensiveness of the models currently available.

Impact on our understanding: High

Level of confidence in assessment: High

Level of readiness: High in some areas and regions (such as the Barents Sea), but:

- we don't have a satisfactory theoretical understanding of the atmosphere-ocean circulation
- we possess insufficient long-term ecosystem time-series (e.g., Toolik Lake only ~25 years)

This focus area should be addressed through the SEARCH program and in collaboration with the Long-Term Ecological Research (LTER)/Long-Term Observatories (LTO) programs.

2. What do we know about thresholds, abrupt changes, high rates of change, and extreme events?

Threshold events, extreme events, and abrupt changes represent various manifestations of the nonlinearity of the arctic and global system. It is unclear how best to model these aspects, and without good models the limits to predictability are difficult to assess. Such events possess the greatest potential for deleterious impacts on ecosystems and human societies. Questions that need to be answered in order to address this topic include:

- What constitutes an extreme event (this is context sensitive)? Can we characterize their nature and frequency?
- How do nonlinearities in the system reorganize or synchronize components of the system? Do components of the system act as buffers to nonlinearities?
- What are the rates and reversibility of change?
- What threshold phenomena exist in human-environment interactions?
- How are arctic communities adapting to normal variations, and how might they be affected by more extreme changes?

Impact on our understanding: High

Level of confidence in assessment: High for the paleoenvironmental record, some limited co-varying data sets, and ecosystem models (depending on scale), but low for dynamic models and societal models.

Level of readiness: High for the reanalysis of already existing co-varying data; medium for new cross-disciplinary efforts. An important component to address this uncertainty will be stronger collaboration across natural science, social science, and mathematics communities.

This focus area is a good avenue for cross-directorate announcements of opportunity (Mathematics, LTER, Office of Polar Programs, Social, Behavioral, Economic Sciences, Geosciences).

3. Can we define the extreme states of the arctic system?

In order to understand the variability of the arctic system, we must identify and characterize special regions of the system state space, including steady and quasi-steady states, and limiting states that arise from constraints. We distinguish extreme states from extreme events by their persistence in the chosen time scale of interest. Examples of extreme states include an ice-free

Arctic Ocean, complete permafrost thaw, ecosystem collapse (return to a Cambrian ocean), and a phase lock of a natural oscillation. Addressing this uncertainty is a prime area for the integration of paleodata and modeling.

Impact on our understanding: Moderate to high with high relevance

Level of confidence in assessment: Low

Level of readiness: High

This focus area could be addressed by strong integration of the Paleoenvironental Arctic Sciences (PARCS) component of the ARCSS Program in the Study of Environmental Arctic Change (SEARCH) initiative.

4. How can we achieve useful scenarios about future change?

There are many possibilities for the global drivers of future scenarios of the arctic system, but not all of these choices are equally likely. The usefulness of scenarios will be measured by their relevance to stakeholder communities and policy decisions. Open problems include how to present information effectively (e.g., as probabilities or alternative scenarios), how to characterize uncertainty and confidence in the information, how to determine the path of change over time, and which models to use.

The Human Dimensions of the Arctic System (HARC) program provides an opportunity and starting point for articulating the social science research questions associated with these issues.

5. What are the interactions between global and arctic modes of variability? How might arctic environmental changes affect environments and societies downstream at lower latitudes? How do lower-latitude changes affect the Arctic?

This key uncertainty has thus far received limited attention from arctic scientists, due in large part to the complexity of the system under study. Because arctic science has made great strides in understanding components of the system, and many of the interactions between components, it is now possible to address the interactions between the arctic system and the rest of the globe. A central issue is the relative importance of internal and external modes of variability, and to what extent such demarcations can be defined. Components of the system which reflect these interactions include polynyas, river basins, animal migration, atmospheric circulation changes, generation and transport of radiatively active gases and contaminants, deep convection and salinity anomalies, changes in government policies, development of new technology, and stratospheric ozone.

Impact on our understanding: Very high

Level of confidence in assessment: Very high

Level of readiness: Different states of readiness exist according to the community. An example of high readiness is the area of contaminant transport. An example of low readiness that could be improved by entrainment of a different community is global climate modeling.

This focus area could be addressed by strong integration of SEARCH and the Arctic/Subarctic Ocean Fluxes (ASOF) program with global programs such as the international research program on Climate Variability and Predictability (CLIVAR), and joint announcements of opportunity.

Land-Shelf Initiative

The consensus of discussion at the Seattle meeting was that the overarching goal of the Land-Shelf Initiative (LSI) should be to improve our understanding of the biogeochemical, physical, and hydrological processes that occur in the nearshore zone of the arctic shelf with respect to changes in the global climate system, as well as alteration of marine ecosystems and societal resources. One of the primary challenges that will need to be resolved is defining operationally what constitutes the coastal zone of interest, including time and seasonal-scale variation. Within the ARCSS Program, the Land-Shelf Initiative is strategically located landward of the Shelf-Basin Interactions (SBI) research at the shelf-basin boundary, and seaward of hydrological studies that will be initiated as a part of the pan-Arctic Community-wide Hydrological Analysis and Monitoring (Arctic-CHAMP) program. It also will rest on the foundation of environmental insights provided by the Paleoenvironmental Arctic Sciences (PARCS) program and interlock with existing and developing international programs laterally and across the Arctic Basin. The strong historical linkage to the Russian-American Initiative on Shelf-land Environments in the Arctic (RAISE) and the importance of coastal zone processes to human communities, as promoted by the Human Dimensions of the Arctic System (HARC) component of ARCSS, were also acknowledged. As programs on biogeochemical and biophysical feedbacks develop, as does the Study of Environmental Arctic Change (SEARCH), it is expected that additional specific research opportunities in the coastal zone addressing those topics should also be apparent.

Among the important themes that grew out of two focused days of discussions on arctic coastal processes research were:

- the bidirectional impacts of society and coastal environments;
- the evolution and landscape dynamics of the shelves and nearshore zone;
- fate and transport of materials in and through the coastal zone, including lateral and vertical linkages;
- structural and functional patchiness in this ecosystem; and
- couplings and feedbacks to and from the global system.

Related subthemes that were discussed in the Land-Shelf Initiative breakout sessions included:

- the dynamic variability of the coastal zone;
- the importance of coastal zone processes to human communities;
- vertical stratification, advection, and forcing within the water column;

- biogeochemistry as a linking feature between land and sea;
- fate and transport of materials;
- river discharge connections to oceanic systems;
- foodweb transfers and dynamics; and
- permafrost status and related trace gas exchange.

Participants also stressed that gas hydrates, which are closer to the surface in the Arctic than at lower latitudes, may be vulnerable to change, consistent with the fact that cryospheric boundaries in the Arctic give the region many vulnerable characteristics with respect to environmental change.

A number of exemplary research questions were outlined for these themes and were organized in categories such as forcing functions, feedbacks, transformations and internal processes, and greater impacts. A few examples of these questions include:

1. How do changes in atmospheric circulation and meteorological events affect runoff, erosion, biogeochemistry, dispersal of contaminants, and societies in the arctic coastal zone? (forcing function)
2. How will change in the open water season change the distributions of inorganic and organic materials in the nearshore environment? (feedback)
3. How does transformation and fate of ancient organics affect nearshore food webs? (transformations and internal processes)
4. What kinds of information will coastal communities need in order to prepare to adapt to rapid change? (impacts)

The near-future plans for advancing the Land-Shelf Initiative are to revise an existing draft shell of a science plan posted on the RAISE web site (http://arctic.bio.utk.edu/#RAISE) so that the All-Hands Workshop contributions are incorporated and to provide additional opportunities for arctic research community input to goal development and implementation. These opportunities may take the form of additional workshops and/or an online forum at either the science plan or implementation plan stage, as well as opportunities to directly contribute to the written science plan. An e-mail list of people interested in being involved in future science plan development was expanded at the All-Hands Workshop by about thirty names, to a total of approximately 100 people, each of whom have indicated an interest over the past year in contributing to the development of a new science plan supporting Arctic System Science research in the arctic nearshore zone.

Pan-Arctic Cycles, Transitions and Sustainability

Biophysical, Biogeochemical, and Social Systems of the Arctic Terrestrial System

Introduction

The arctic terrestrial system supports a wide range of plants and animals. It is also where arctic residents live. The life and health of arctic peoples and living things are intimately coupled to the physical parts of the system—the atmosphere, water cycle, soil, and rocks—through a complex web of biophysical, biogeochemical, and social pathways. These living systems and pathways are constantly changing and interacting, but under a changing climate, it is possible that larger step-like changes could take place, and that these would affect life in a profound way. Sustainability is a measure of how resistant or resilient the ensemble system is to these larger changes. Pan-Arctic Cycling, Transitions, and Sustainability (PACTS) seeks to further our understanding of the interconnections of arctic living systems and their physical environment and more specifically to assess the ability of these systems to weather change.

Evolution of Theme During the Meeting

The basic concepts underpinning PACTS evolved out of multidisciplinary research done under the LAII program and reflect the "big" science questions that this group has identified as critical for future research. The title, and greater details concerning the concepts, began to evolve during an online forum held before the ARCSS All-Hands Meeting, continued to evolve throughout the meeting, and stabilized only after the meeting had ended. This process is evidence of how the broad collective thinking at the meeting was able to produce more extensive integration and a broader, interdisciplinary approach. Nonetheless, the core idea that biological systems, including humans, are a key in the arctic system has remained intact throughout the process, and in fact, emerged at the meeting as a central element of the next phase of ARCSS.

It also emerged at the meeting that living systems not only respond to change, but that they also feed back and induce change in a surprising number of important ways. Because one major way that humans interact with the Arctic is through biological and environmental resource use, PACTS appears to offer a natural and attractive way for ARCSS research to take on increased relevancy for human society, melding natural and human system science. At the meeting it also emerged that our original conception of pathways was too limited. For example, we had overlooked the transport of chemicals from the atmosphere to snow and ice surfaces, and to biological systems, as a pathway of some importance. But perhaps the most important implication of PACTS-type studies to emerge at the meeting was that understanding biophysical and biogeochemical cycles and transitions provides *the* key to increasing predictability of future states in a system that we increasingly recognize can undergo rapid changes, pass through irreversible transitions in state, and exhibit nonlinear and emergent behavior. Pressing questions of what the state of the Arctic will be like in the future can only be answered if we can understand and describe these complex biophysical and biogeochemical cycles on land, in the sea, and through the air.

Consensus Statement of Theme

The functioning of the arctic system can be thought of as the integration over time and space of its individual feedbacks and processes. Spatial and temporal heterogeneity is a fundamental characteristic of virtually all of these systems, and particularly the biotic ones, so prediction of the ensemble behavior is extremely complicated. It is clear that simple arithmetic summations over time-space domains will produce neither reliable spatial nor accurate temporal estimates for most system variables because of transport processes between elements, the existence of "hot spots," nonlinear effects, and the potential for multiple temporal trajectories. Understanding this complexity, however, is an essential underpinning for arctic system prediction and is the basis on which understanding of rapid changes, transitions in state, and time-space heterogeneity must be based. These are exactly the sorts of predictions that are most needed to inform and advise arctic and global societies. PACTS specifically addresses how these processes and feedbacks will impact living systems, including humans, with a strong focus on terrestrial systems because that is where humans live. Its scope spans that of the critical processes inherent in the pathways, from local to pan-arctic, and its goal is to understand which sets of changes will impact systems profoundly and which may not (sustainability).

Theme Subdivisions

For purposes of discussion at the workshop, the theme was divided into four topics, all of which were found to be interrelated. These were:

1. Biophysical and biogeochemical cycles (cycling)
2. Temporal state changes in biophysical systems (transitions)
3. Resiliency and vulnerability of biological systems (sustainability)
4. Heterogeneity, patchiness, and pattern in extrapolation and prediction

With the exception of topic 4, these topics mirrored exactly, and in fact anticipated, the three key themes that emerged from the ARCSS committee discussions that followed the All-Hands Workshop. As these key themes are likely to be the focus of ARCSS research over the next few years, it is clear that PACTS-type research will be an essential component of ARCSS. Topic 4 was initially thought of as a set of essential techniques, but as the meeting progressed, it was clear that considerable research would be necessary in this area as well, and that it comprised a set of real science questions in its own right. While not an explicit ARCSS theme, research on topic 4 is likely to be essential to facilitate progress of the three key ARCSS themes.

Topic 1: Biophysical and Biochemical Cycles *(Cycling)*

This topic could be restated as a focus on cycles of water, energy, nutrients, and contaminants. Building on the research from earlier phases of ARCSS, we are poised now to make progress in looking at biogeochemical transfers and linkages within *and* between system elements, whereas before within-element transfers tended to be the primary focus. This topic includes transfers between terrestrial, marine, and atmospheric components of the system, previously an area that was not ready for research. Likely to be the focus of much research is the role of the structure of the physical environment on biological and chemical cycling, and the conjugate of this, the impact of the structure and composition of biological communities on the biogeochemistry and physical structure of the environment. Food webs are a particularly attractive area where the study of biogeochemical cycles and cross-system linkages would yield results with direct bearing on the vulnerability of the arctic system to sustain human and other forms of life. Human impacts on food webs, and on biogeochemical cycling in general, can range from mild to profound, so these will necessarily form an important part of future studies. Our understanding and ability to attack biogeochemical cycling varies in different areas, so it is likely that in some cases sophisticated research will be possible, while in other areas, more basic reconnaissance investigations will be necessary.

Topic 2: Temporal State Changes in Biophysical Systems *(Transitions)*

This topic builds on the recognition that the arctic system is changing, that these changes can be rapid, and that thresholds potentially exist where the system state can change significantly with only a relatively small perturbation in external forcing. The fact that we do not know if such changes are reversible, or whether they mirror past changes, seriously impedes our ability to predict future states. We also recognize that trajectories of arctic change are most likely neither continuous nor linear, and as such, pose major challenges to prediction of future states. We can identify some of the likely triggers for state changes, but we don't necessarily know what the new states will look like, and more important, we have very poor understanding of the trajectories of change. This last point is coupled closely with issues related to observational networks and the maintenance of critical time series for monitoring change. Often the initial response of biological systems to changes in environment or climate is not the same as their long-term response. In some cases, it is even of opposite sign. While initial response is important, the long-term response (in which feedbacks play a greater role) may be a better basis for prediction. The need for both long and short time series is clear, as is the need for paleorecords that can suggest the nature of past state changes and rates of response.

Topic 3: Resiliency and Vulnerability of Biological Systems *(Sustainability)*

This topic directly addresses societal issues related to biophysical and biogeochemical cycles and transitions but takes an even wider view by asking, "How will the living systems of the Arctic adapt to the changes that are likely to take place? Will these changes produce small or large impacts?" At the meeting, a specific example that was discussed was the sustainability of food webs. It was recognized that these underpin many critical areas of arctic research affecting humans, and they have not been the focus of much previous ARCSS research. We have inadequate understanding of food web dynamics in both terrestrial and aquatic systems, yet they may be important in controlling the state of the system and form a core linkage to humans. Related in many ways to this area of research is the need for associated research into cumulative industrial impacts, use of living resources (forests, wildlife, fish), and how these affect the interaction of biotic and abiotic elements of the arctic system.

Topic 4: Heterogeneity, Patchiness, and Pattern

There are parts of the arctic system that we are at risk of modeling and predicting incorrectly because we either cannot account for the spatial and temporal heterogeneity or cannot do so correctly. Many questions related to prediction (time) or extrapolation (space) hinge on correctly observing the heterogeneity and understanding how spatio-temporal patterns arise in order to correctly predict what form they may take in the future.

Relationship to Other ARCSS Themes

Because the main theme of PACTS, and the four subthemes (above), mirror two of the three key elements of the new ARCSS so closely, the connections to the larger ARCSS Program are myriad. At a programmatic level, many direct linkages between PACTS and Nearshore Processes and Arctic-CHAMP exist and became apparent at the meeting. The discussions showed that there were two common themes: (1) the fact that the arctic system seems to have thresholds in it and that distinct changes in system state are possible, and (2) that issues of heterogeneity in spatial and temporal extrapolation and scaling are common to all of the themes. These areas of commonality are not really a surprise since the group that developed Arctic-CHAMP includes a number of members in common with the group that has been developing PACTS. In contrast, the Nearshore Processes working group and PACTS group had not previously explored common areas, but when these were discussed at the meeting, a great many areas of commonality were found. Cycling of energy, water, nutrients, and contaminants from land to the nearshore environment, and transfers in the other direction, are all natural linkages between the two themes. In addition, food webs and the fact that many arctic residents (who subsist on both terrestrial and marine resources) live along the coast, naturally link the two programs. Less well explored were linkages to the Modes of Variability group. This group tended to think of modes in atmospheric cycles like the Arctic Oscillation (AO) and North Atlantic Oscillation (NAO), while the PACTS group tended to think of these more as changes in state and resources. However, the groups share a common theme in terms of prediction of future states and the impact of those states on people.

Recommendations from Student Working Group

Approximately eighty undergraduate and graduate students associated with the ARCSS Program attended the 2002 All-Hands Workshop. An ad hoc working group, consisting of approximately forty-five students, met to discuss ARCSS science and program issues. The students' discussions primarily focused on the current state of the ARCSS Program. The points outlined below were presented by seven representatives of the group in plenary, along with the other working group summaries.

Interdisciplinary Science

The student working group discussed the nature of interdisciplinary science as well as some of the challenges facing researchers involved in large interdisciplinary projects and made the following observations:

- Networking is especially important in the ARCSS Program, where large interdisciplinary projects are the norm. In order to develop interdisciplinary projects and to help ARCSS researchers incorporate each others' work and not duplicate it, ARCSS researchers need to understand what work is being done by whom within the ARCSS Program.
- Disciplinary science is fundamental to successful interdisciplinary programs. Specialists should not be neglected in the quest for more integrated, interdisciplinary projects. Since developing and implementing interdisciplinary projects can be challenging, graduate students in science should receive training in how to effectively work with colleagues in other fields.

Collaboration

The working group identified two major points related to collaboration in science. The group recognized the challenges of developing effective collaborations but emphasized the importance of overcoming these challenges in order to address important science questions.

- The limited amount of programmatic funds and proprietary nature of cutting-edge research were discussed as potential barriers to fruitful collaborations. Competition for limited funds cannot override the important science questions that need to be answered.
- Because of the enormous size of the Arctic, data is sparse. International collaborations could help fill some of these gaps. Since the major hindrances to this are nonscientific (e.g., international politics, foreign

logistics), scientists should look to successful international collaborations, both inside and outside the U.S., for models. Industries with interests in the Arctic, like oil companies, that have had to work through the hurdles of international collaborations may have helpful information for arctic logistics planning.

Human Impacts in the Arctic

The student working group recommended that the ARCSS Program emphasis on the interactions between humans and the arctic system is vital. The group identified two salient points related to humans and the Arctic.

- Scientists should always keep in mind that they are guests in arctic communities and that the science done there should be useful and pertinent not only to science, but to these communities. Arctic residents, through organizations like the Alaska Native Science Commission, should have a voice in arctic science not only as stakeholders, but as bearers of immense amounts of accumulated knowledge of the Arctic.
- Several important issues related to human impacts on the arctic—contaminants, bioaccumulation, oil spills, local development and resource use, erosion and permafrost—are complex or politically charged topics, but they are important in understanding the arctic system and should be more fully explored by ARCSS researchers.

Spatial and Temporal Scale in ARCSS Organization

The student group noted that issues of scale have emerged in all of the working group discussions. Useful identification of gaps and uncertainties is inherently linked to the scale of interest. An exclusive focus on the pan-arctic scale may misrepresent processes at regional and local scales that are intrinsic to the functioning of the arctic system. Since the scaling issue has the potential to confound many pan-arctic studies, local and regional scales should not be de-emphasized within ARCSS.

Paleoenvironmental Arctic Sciences

A common goal of all ARCSS research is to understand change in the arctic system. While arctic system scientists study changes manifested in different ways and driven by different forces, the time dimension is common to all of these endeavors. Working group discussions for the four emerging themes identified the basic need for time series of arctic system change that extend beyond those based on instrumental measurements. Records with decadal- to annual-scale resolution that extend 2000 years or longer provide the long-term perspective needed to place changes of the twentieth century in context of natural variability. Time series that extend to the early Holocene capture periods when the arctic system operated under warmer-than-present conditions. Studying the changes recorded in tree rings, glacier ice, peat lands, and lake and marine sediments enables a more complete understanding of the forces that lead to change and the consequences of that change. Paleoenviromental Arctic Sciences (PARCS) researchers recognize thresholds within the arctic system, develop scenarios for future conditions, establish baselines against which change can be measured, and evaluate the predicative capability of our models.

The centerpiece of PARCS research is its network of sites that record the spatial variability of the arctic system over long time scales. While the overall goal of PARCS is dedicated to expanding and improving this network, working group discussions at the All-Hands Workshop led to the identification of the most important processes and proxies that need to be studied to achieve the goals of the ARCSS themes and to provide the intellectual vehicles to cut across disciplinary goals.

Pan-Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP)

An improved understanding of modern hydrological processes is needed to better interpret and to calibrate the proxy records that are used to infer past hydrospheric changes. In turn, long-term records of all aspects of the hydrological cycle (lakes, rivers, glaciers, permafrost, etc.) are needed to understand the causes and consequences of the natural variability inherent in these systems. For example, lake sediments integrate a variety of hydrologic and biogeophysical processes on the watershed scale. Modern process studies are needed to better understand the linkages between these processes and the evidence they leave in the sedimentary record. Hydroclimatological data are needed to interpret quantitatively the extreme changes in distribution of atmospheric moisture known from lake-level records as young as the early Holocene. In contrast to deeper lakes, water level in lakes formed in permafrost may respond to geomorphic processes other than those driven by climate. The extent and dynamics of thaw lakes, in turn, has a major influence on the hydrologic budget and biogeochemical functions of coastal plains. The synergy between modern processes and paleorecords of the hydrologic cycle provides strong motivation for links between PARCS and Arctic-CHAMP.

Modes of Variability in the Arctic System

An expanded network of well-dated, high-resolution proxy records is needed to place the prominent twentieth-century warming in the context of longer-term variability and to identify the environmental consequences of this change in climate. Recent changes in the arctic system that may be related to a pronounced shift in the mode of the Arctic Oscillation (a shift that is unprecedented in the twentieth century) also need to be placed in the context of longer-term climate system variability. Paleorecords provide a temporal perspective on climatic, oceanographic, hydrological, and biogeophysical variability, rates of change, and the timing and magnitude of abrupt changes in the past, whether these are driven by forcing factors within or external to the arctic system.

Land-Shelf Initiative

An improved understanding of the recent geologic history of coastal zones is needed to better predict the environmental consequences of changes taking place on- and offshore. For example, the rate of sea-level rise during the Holocene controls the rate at which subsea permafrost warms and the consequent threat of methane and carbon dioxide release. Sea-level rise, combined with the local geomorphic and Quaternary geologic setting, control the rate of coastal erosion and the frequency of flooding. Records of changing sea-ice conditions, coastal-plain hydrology, and the history of deltas and estuaries are all preserved in coastal areas. Paleoenvironmental records from ancient beach deposits record oceanographic conditions of earlier warm periods, and coastal geomorphic features preserve evidence for the dynamics of beach processes and the human cultures that inhabited them.

Pan-Arctic Cycles, Transitions, and Sustainability

Defining future states of the arctic terrestrial system demands a longer temporal view than can be achieved with modern studies alone, and thus linkages with paleorecords are an essential component of the new biofeedbacks initiative. Of particular interest in predicting future states are the components in the arctic system that are likely to cause *switches*—rapid changes of state—and thus make nonlinear trajectories likely. For example, the invasion of woody plants and the melting of permafrost are both thresholds that seem to induce rapid changes in the behavior of the arctic, including shifts in biogeochemical feedbacks and energy exchange processes. Predicting future trajectories of nonlinear systems from process-based studies alone is difficult. Future scenarios of change must involve combined efforts that employ techniques focusing on a range of temporal scales, including long-term experiments and observational studies (0–10 year time frame), use of traditional ecological knowledge (10–50 year time frame), and high-resolution paleorecords (10–1000 year time frame). Similarly, paleorecords that define the past range of variability in the arctic system will be helpful in anticipating human adaptations and planning for sustainability.

Human Dimensions of the Arctic System

The arctic system determines the environmental conditions in which arctic residents live, and changes to the system will have many and complex impacts on those residents. At the same time, arctic people modify their environment locally and regionally, with consequent effects on the arctic system. Understanding these links and their physical, biological, and social implications is critical to an understanding of the overall function of the arctic system. The Human Dimensions of the Arctic System (HARC) program provides an opportunity to investigate these aspects of the arctic system.

HARC is broadly defined, allowing prospective investigators to develop their own understanding of human dimensions of the arctic system and to propose appropriate research. At present, several innovative and illuminating studies are underway, examining a range of topics, including policy responses to sea-ice change in Barrow, Alaska; the impacts of climate and caribou on reindeer herders on the Seward Peninsula, Alaska; models of possible futures facing indigenous communities in the northern Yukon Territory, Canada; and the implications of economic and political change in Russia on Kola Peninsula watersheds.

However, there has been relatively little interaction among these projects, nor between HARC projects overall and other research within ARCSS. To address these gaps and to try to stimulate more interest in HARC, a Science Management Office (SMO) was created in 2001. This office has organized online discussions of potential HARC topics and worked with other parts of the ARCSS Program to determine how best to integrate HARC research. The All-Hands Workshop was a great help in many respects, and significant progress was made in two areas in particular.

First, the All-Hands Workshop was one of the first opportunities for HARC investigators to meet, as they did in two breakfast meetings. These meetings helped establish a community of HARC researchers. Based on discussions at the meetings, the SMO is looking into having a research journal publish a special issue on HARC research, and is also making plans for the first HARC all-hands workshop. In addition, the SMO has set up a web site (http://www.arcus.org/HARC) and e-mail list for HARC researchers and others interested in human-dimensions research.

Second, an impromptu set of HARC presentations showed examples of HARC research to the entire ARCSS community, demonstrating what could be done and how and leading the way to better integration in the future ARCSS Program. The discussions in the breakout groups of the All-Hands Workshop reflected the influence of human dimensions ideas and the many human links in each of the new ARCSS themes. Some specific research areas were identified, for example:

Arctic-CHAMP

Identify and characterize the interactions of people and the hydrological cycle (e.g., as outlined in the table below from Vörösmarty et al. 2001), including human influences on and responses to change.

CHANGING PHYSICAL ENVIRONMENT	HUMAN DIMENSION IMPACTS				
	Infrastructure	**Transportation**	**Other Economic Activities**	**Subsistence, Traditional Activities**	**Health**
Permafrost	Building, water & power systems	Roads, runways	Pipelines	Overland travel, subsistence resources	Water supplies, waste disposal
Precipitation, runoff	Riverbank erosion, flooding, water supplies	Roads, navigable waters	Mining & industrial wastes	Overland travel, subsistence resources	Water-borne illness
Storms, fog	Coastal wave erosion	Sea, air	Fire prevention	Subsistence hunting & fishing	Accidents
Snow Cover	Snow removal	Winter travel avalanches	Water supply	Overland travel, subsistence resources	Water supply
River & sea ice	Coastal/riverside erosion	Shipping routes & season	Hydropower	Subsistence hunting, travel	Accidents
Summer temperature	Foundation instability	Permafrost and ice-road degradation	Tourism	Changes in species and migration routes	Insects, vector-borne illness
Sea level	Coastal flooding, erosion	Shipping facilities	Village relocation	Coastal cemeteries or artifacts	Freshwater salinization
Ocean circulation	Harbor siting	Shipping	Commercial fisheries	Subsistence hunting & fishing	Contaminant transport
Contaminants	Water supply/ treatment	Spill prevention remediation	Commercial fisheries	Subsistence hunting & fishing	Human exposure

Table 5-2: Points of contact, and areas of needed research, where changing physical environment parameters are likely to affect human activities in the Arctic.

Land-Shelf Initiative

Examine the many feedbacks in this key area for human activity such as hunting, settlement, development, and transportation.

Modes of Variability

Identify and examine long-term records of human activity to establish connections to environmental and social causes.

Feedbacks

Include human influences in the feedbacks that shape ecosystems, recognizing that humans have long modified certain aspects of the arctic system, especially on local and regional levels.

As a first step in promoting the development of these and the many other ways in which human-dimensions research connects to ARCSS as a whole, the

HARC SMO will hold online workshops focusing on Arctic-CHAMP and the Land-Shelf Initiative, with the goal of identifying project-level ideas by which HARC can contribute to each of these themes. As the other themes develop, the SMO will seek similar opportunities. The goal in each case is to establish human-dimensions research as an integral part of the theme.

Reference

Vörösmarty, C.J., L.D. Hinzman, B.J. Peterson, D.H. Bromwich, L.C. Hamilton, J. Morison, V.E. Romanovsky, M. Sturm, and R.S. Webb. 2001. *The hydrologic cycle and its role in arctic and global environmental change.* Fairbanks, Alaska: Arctic Research Consortium of the United States, p. 47.

Invited Presentation Abstracts

Land-Atmosphere-Ice Interactions

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The objectives of the LAII program have been the detection and analysis of change in the land-atmosphere system at regional and pan-arctic scales, projections of these changes into the future, and implications of these changes in terms of the sustainability of the arctic system under global change. Our approach has been to measure key processes over a range of temporal and spatial scales, to develop process-based models, to use these models to extrapolate in time and space, and to test these predictions in new locations.

The land-atmosphere system of the Arctic is changing. Temperatures are warming more rapidly than at lower latitudes. This has implications for thaw depth, which correlates closely with air temperature, and for permafrost, which has warmed significantly in the last decade. In zones of discontinuous permafrost, this is causing thermokarst and the shrinkage of lakes for example in the Seward Peninsula. These changes are mediated by interactions among air temperature, snow, and vegetation. The consequences of these changes could be profound and may have contributed to the large increases in discharge of the major arctic rivers over the past seventy years.

Arctic vegetation is also changing dramatically. The arctic treeline is extending into tundra, and the density of trees in this transition zone is increasing. Within treeless tundra, repeat photography demonstrates that the density and extent of shrubs is increasing. Replicated experiments conducted throughout the circumpolar Arctic by ITEX (International Tundra Experiment) demonstrate that warming leads to increased shrub growth within five to eight years. The resulting changes in community composition result from interactive changes in environment, physiological processes, and population processes. The increased shrub abundance observed in the field is consistent with satellite measures of increased NDVI (normalized difference vegetation index), a measure of plant greenness. The observations demonstrate that the transitions in the land surface have been highly nonlinear and are leading to new community assemblages.

The vegetation changes have pronounced effects on the arctic system. Some of the most important changes involve winter processes. Shrubs lead to increased depth and insulative capacity of the winter snow, which warms the soil, leading to more mineralization of carbon and nutrients and greater nutrient availability to plants the following spring, a factor that promotes the growth of shrubs. The stimulation of winter decomposition also contributes to high rates of winter respiration observed in shrublands. The positive feedback between shrubs, snow, temperature, and nutrients provides one potential explanation for the large magnitude of vegetation change that has occurred in the last half-century.

The vegetation change also feeds back to climate. Shrub tundra absorbs more radiation than moist tundra and transfers more of this energy to the atmosphere as sensible heat, creating a positive feedback to regional warming. The warming has also had substantial affects on carbon budgets, initially increasing carbon efflux and subsequently bringing carbon uptake and loss more nearly into balance. It has become increasingly clear that carbon exchange during winter plays a large role in determining whether the tundra is a net source or sink of radiatively active trace gases.

We have scaled our observations of land-atmosphere exchange to large areas in several ways. By making measurements at multiple scales (chambers, towers, aircraft), we can determine the important sources of variability at different scales. Based on these observations, maps of vegetation and soils, and models derived from them, we have extrapolated carbon fluxes to the Kuparuk Basin in northeast Alaska, the North Slope of Alaska, and the circumpolar Arctic.

The development of the LAII program has changed the way terrestrial ecologists and climatologists do science in the Arctic. Through the LAII program, the science has become increasingly interdisciplinary and has placed greater emphasis on integrating processes across temporal and spatial scales through modeling and through interactions with paleoecologists. There has also been greater emphasis on data archival in electronically accessible forms and an increased emphasis on synthesis at all phases of the research. The program has placed substantial emphasis on outreach, for example, involving local residents and providing real-time climate data to remote communities. These advances lay the groundwork for a more integrated approach to study of the entire arctic system and its interaction with the rest of the globe.

Investigating the Arctic Marine Environment During a Period of Rapid Change: Development, Accomplishments and Outlook for OAII

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The Ocean-Atmosphere-Ice Interactions (OAII) component of the National Science Foundation's Arctic System Science Program (ARCSS) began in 1991 as a response to the need to study the arctic system's role in and response to global change. Prior to the development of this program, most U.S. studies of the marine system of the Arctic were small "pure science" projects or were underpinned by the requirements of national defense, the petroleum industry, environmental quality, or management of living resources. OAII represents an attempt to study the marine system of the Arctic in a long-term and interdisciplinary way, with the focus on global change. We are interested in both how this system responds to change and in how it contributes to global change. The development of this program was timely because the arctic system began to undergo major changes at about the time of OAII's inception. These included changes in the atmosphere, the ice regime, the hydrographic structure of the Arctic Ocean, and the ecosystem.

There has always been room within OAII for medium- and smaller-scale projects and modeling studies. For example, OAII helped to maintain time-series moorings under the aegis of IWA (Investigations of the Western Arctic), supported several modeling activities and supported a program to investigate summer and wintertime denitrification rates in western arctic shelf sediments. Because of the emphasis on interdisciplinary system-oriented research, however, a great deal of the OAII effort has been under the aegis of large projects with greater than five-year durations and several-million-dollar budgets. Although OAII was a major (usually the major) contributor to each of these projects, all involved interagency and international collaboration. The first major OAII project, the Northeast Water Study (NEW), examined a high-latitude polynya that could be considered a surrogate for ecosystems that might exist more generally if there is a significant decrease in the ice cover of the Arctic Ocean. The second major project was SHEBA (Surface Heat and Radiation Budget of the Arctic), a program designed to help provide more appropriate data for incorporating arctic processes in global circulation models. The third project involved a significant contribution to the Canada Basin Section, an exploration of the least explored portion of the Arctic Ocean. The next major project was the Shelf-Basins Interaction Project (SBI), a study of biological processes over the shelves that generate products and signals that are transmitted to the interior of the Arctic Ocean. SHEBA and SBI were executed in three phases, an initial phase that included retrospective data analysis and modeling and pilot or *ad hoc* field studies, a second phase that included the major field program, and a third phase devoted to synthesis and modeling of the new results. SEARCH (Study of Environmental Arctic Change) is an outgrowth of OAII activities and discoveries and is in the initial stages of becoming an major interagency and international effort that will transcend OAII and help to foster a new, more holistic ARCSS structure.

Because data from the Arctic Ocean are relatively sparse and because OAII activities occurred during a period of rapid change, many exciting results arose from our efforts. These include:

- Helping to document the massive changes in the temperature-salinity regime of the Arctic Ocean that occurred in the 1990s, including increased penetration of warm Atlantic waters and erosion of the cold halocline. During the SHEBA

experiment, these changes were also associated with dramatic changes in the ice-associated ecosystem.
- Providing further evidence for the remarkable decrease in the volume of ice in the Arctic.
- Demonstrating that canonical estimates of primary production in the interior of the Arctic Ocean were too low.
- Demonstrating that wintertime conditions in sediments do not necessarily cause a significant decrease in the globally significant denitrification rates that occur in arctic shelf sediments.
- Documenting a recent freshening and warming of the Pacific waters entering the Arctic Ocean via Bering Strait.
- Providing paleoceanographic data showing that the western Arctic has a record of rapid climate change that is not reflected in the records from Greenland ice cores.
- Adding considerably to the body of knowledge that suggests that much of the variability observed in the arctic system can be related to increases and decreases in the cyclonicity of the atmospheric and oceanic circulation associated with the Arctic Oscillation, and hence providing evidence that arctic climate is intrinsically linked to climate variability throughout much of the Northern Hemisphere.
- Showing that Arctic-Oscillation-like variability can occur over a wide variety of time scales.

We believe that the results of OAII research demonstrate a compelling societal need for intensified investigations of change in the arctic system. At present, our studies are inhibited by a lack of adequate time-series data for most processes. In many cases, we do not even possess a first-order description of the seasonal cycle of biological processes such as primary production and associated carbon sequestration. The limited suite of observations, in turn, impacts our ability to produce models that allow us to generalize and make predictions. OAII investigators have identified critical gaps in our understanding of nearshore processes, deep convection, the hydrologic cycle, paleoceanography, the fate of arctic clathrate deposits, and ocean-surface layer–lower troposphere chemical exchanges. The resource base to support these studies is, at present, uncertain. OAII investigators plan to vigorously pursue these research aims and to work towards a more interdisciplinary ARCSS structure.

The RAISE Component of ARCSS: Where We Have Been and Where We Might Go

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The Russian-American Initiative for Shelf-Land Environments in the Arctic (RAISE) is unique among ARCSS programs. It is the only ARCSS component that is by definition international in implementation, since it promotes a partnership between the NSF and the Russian Foundation for Basic Research. RAISE also explicitly promotes interdisciplinary arctic research across the land-sea boundary with both present-day and paleoclimatic approaches for the scientific challenges of environmental change in human and biological communities and related physical and chemical systems. Many important results have come out of individual RAISE projects, including documentation of the age and accumulation dynamics of peat deposits in the west Siberian lowlands, development of networks for assessing coastal erosion, and an improved understanding of the chemical constituents contributed to the Arctic Ocean by Russian river runoff. Despite this progress, the original and continuing vision of the RAISE program is to couple studies of processes that occur on land (e.g., fluxes of organic materials into rivers and from eroding shorelines) with impacts and feedbacks that occur in the marine environment (e.g., productivity) of the Arctic Ocean. It is clear, however, that the coastal marine research component of RAISE has been only very incompletely implemented. Based upon discussions within the RAISE PI and Steering Committee Meeting in Seattle, Washington, in December 2000, the LAII/OAII/RAISE joint meetings in Salt Lake City, Utah, in November 2001, an on-line discussion held in February 2002, and work to be completed at the Seattle All-Hands Meeting, the International Science Steering Committee of RAISE has concluded that a new focused research opportunity for supporting research at and near the arctic land-sea boundary is a critical goal. A draft science plan to support this effort has been posted on the RAISE web site (http://arctic.bio.utk.edu/#RAISE), and scientific community involvement is invited to flesh out the scientific justifications and bases for new coordinated research that will focus on the important biogeochemical, physical, biological, and related human dimensions of environmental change at the arctic land-sea margin.

Arctic Nearshore Processes: A Proposed Land-Shelf Initiative

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The Land-Shelf Initiative (LSI) is a research planning effort centered on the land-sea margin in the Arctic that focuses on environmental change in human and biological communities and related physical and chemical systems. The land-sea boundary is a dynamic geomorphic boundary between arctic coastal plain watersheds and the arctic shelf and basin. Freshwater runoff, the rate of coastal erosion or accretion, sea ice formation and melt, atmospheric gas exchange, and biological communities all change in significant ways across the land-sea boundary. It is also the site of most human activity, especially subsistence hunting, intense petroleum development, both onshore and offshore, and migrations of anadromous fishes, migratory waterfowl, and large mammals.

The Land-Shelf Initiative has grown out of efforts within the Russian-American Initiative for Shelf-Land Environments in the Arctic (RAISE) and from a recognition that coastal processes have not been adequately addressed in recent Arctic System Science (ARCSS) research. Our goal is to lay the groundwork for a coordinated, interdisciplinary research opportunity in the Arctic that would focus on the coastal zone and would support land, river, and sea-based researchers who would take advantage of coordinated logistical capabilities that would otherwise be unavailable. The overarching goal of the Land-Shelf Initiative is to improve our understanding of the biogeochemical, physical, and hydrological processes that occur in the nearshore zone of the arctic shelf and its adjoining shoreline, with respect to changes in the global climate system. The LSI focus on biogeochemical and hydrological cycling are two major thematic approaches in the Ocean-Atmosphere-Ice (OAII) science plan. Understanding these processes in the context of local alteration of marine and terrestrial ecosystems and related societal resources is crucial.

Many scientific issues requiring complex, interdisciplinary research approaches have been identified at the land-sea margin in the Arctic. A nonexhaustive list includes the impacts of changes in precipitation and runoff patterns on Arctic Ocean circulation and coastal climate, ice formation and distribution, the biogeochemical fate of materials transported in rivers and from eroding coastlines, the impacts of climate warming on nearshore and offshore permafrost, and the social stresses on human communities in the North as a result of recent political and environmental change.

Another important focus is the role of food chains and the efficiency of transfers of carbon, nitrogen, contaminants, and other constituents from the environment to marine and terrestrial organisms. Because of the relatively high density of human communities in arctic coastal zones, these foci provide an opportunity to address the linkages between marine and terrestrial ecosystems in ways that have direct relevance to society. This initiative could also examine the role of people in the arctic system as an important mediator of interactions between marine and terrestrial food webs, which in turn affect the productivity of these systems. It is also worth noting that many uncertainties concerning environmental change in the Arctic can be approached through the study of past changes in biological communities in response to environmental change. A science research plan outlining the major issues outlined here is in preparation and community input is invited.

Western Arctic Shelf-Basin Interactions: Project Overview and Phase II Field Implementation

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The Western Arctic Shelf-Basin Interactions (SBI) project—a contribution of the Ocean-Atmosphere-Ice Interactions (OAII) component of the National Science Foundation (NSF) Arctic System Science (ARCSS) Program, in coordination with the U.S. Office of Naval Research—is investigating the arctic marine ecosystem in an effort to improve our capacity to predict environmental change. The overarching hypothesis underlying the Western Arctic SBI project is that climate change will significantly and preferentially impact the physical and biological linkages between arctic shelves and the adjacent ocean basins. SBI will therefore focus on the outer shelf, shelf break, and upper slope, where it is believed that key processes control water-mass exchange and biogeochemical cycles, and where the greatest responses to climate change are expected to occur. The geographical focus is on the Chukchi and Beaufort Seas and adjacent slopes.

The SBI Phase II field project is centered around three research foci in the core study area in the Chukchi and Beaufort Seas: (1) northward fluxes of water and bioactive elements through the Bering Strait input region; (2) seasonal and spatial variability in the production and recycling of biogenic matter on the shelf-slope area; and (3) temporal and spatial variability of exchanges across the shelf/slope region into the Canada Basin.

The SBI project is going forward in three phases. Phase I has been completed (1998–2001) and included regional historical data analysis, opportunistic field investigations, and modeling. Currently the SBI project is in Phase II (2002–2006), which constitutes the core regional field investigations in the Chukchi and Beaufort Seas, along with continued regional modeling efforts. The SBI Phase II Field Implementation Plan (Grebmeier et al. 2001) outlines a combination of moorings, seasonal survey and process studies, and modeling efforts at various time and space scales. A special concern is that physical and biogeochemical process studies be well-coordinated. Moored arrays will allow investigations of the flow into the study area through Bering Strait, as well as the exchanges at the shelf-slope interface to document the influence of this highly productive region on the arctic ecosystem. Mesoscale, interdisciplinary survey and process studies conducted across the outer shelf and slope regions during various seasons will be critical to understand biogeochemical processes occurriung over time and space scales relevant to interpreting annual and interannual change in the system. The Phase II sampling program (with required platforms) includes integration with both national and international programs. Current plans include May/June and July/August cruises from 2002 through 2004 in the SBI study region.

Further information on the SBI project and updated (February 2001) SBI Phase II Implementation Plan can be found on the SBI web site at http://utk-biogw.bio.utk.edu/SBI.nsf.

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Human Dimensions of the Arctic System Initiative

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Humans have long been part of the Arctic system. In recent decades, their influence on the Arctic has increased greatly. Many of the ways in which the Arctic affects humans have also changed, some significantly and some subtly or not at all. To examine these and related aspects of the Arctic system, NSF started the Human Dimensions of the Arctic System (HARC) initiative in 1997, with the issuance of the HARC Prospectus. Unfortunately, response to the initiative has been lower than anticipated. In 2000, the ARCSS Committee recommended establishing a Science Management Office for HARC, as has been done for other ARCSS components. In 2001, the HARC SMO began operation. Although there are several HARC and HARC-like projects underway, examining a range of topics, the initiative is still in its formative stages. It is thus too early to give a summary of its achievements or to attempt to identify key gaps or questions. Instead, this presentation outlines the significance of HARC research, gives examples from recent and current projects, and encourages investigators to create research partnerships in the social and natural sciences in order to develop this initiative further.

The Paleoenvironmental Arctic Sciences Program

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Development of PARCS

The Paleoenvironmental Arctic Sciences (PARCS) program was founded in 1999 to coordinate research efforts on paleoenvironmental changes in the Arctic and how they relate to the arctic and earth systems (PARCS 1999). The program evolved from the Paleoclimates from Arctic Lakes and Estuaries (PALE) Program, which focused on records from lakes and marginal seas (Andrews and Brubaker 1993), and from the Greenland Ice Sheet Project (GISP II), which yielded a suite of annually resolved proxy data from the Greenland ice that forms a cornerstone of arctic and global paleoclimate research. The more broadly defined PARCS program was developed to expand the efforts of the arctic paleoscience community by drawing upon other proxy sources of information. PARCS research has focused mainly in the western Arctic, extending from eastern Siberia through Alaska (i.e., Beringia), and in the eastern Canadian Arctic and Iceland (i.e., northwestern North Atlantic), but it has not been limited to those areas. PARCS researchers initiated and share the leadership of the Circumarctic Paleoenvironments (CAPE) initiative, an IGBP-PAGES project that fosters international cooperation and integration of paleoenvironmental records from around the Arctic.

PARCS studies of past ecological, hydrological, biogeochemical, oceanographic, glaciological, and climatological changes are conducted in collaboration with other ARCSS initiatives and with other allied programs in NSF and internationally. PARCS paleoenvironmental studies use "natural experiments" of the past, coupled with modeling, to provide an understanding of the causes and consequences of climate change in the Arctic. They provide an indication of what to expect as the climate changes, including the potential magnitude, cyclically, and rapidity of such changes. Paleoenvironmental studies also provide a baseline for detecting changes in the arctic system.

Near-Term Goals

The PARCS community has recently identified two priorities for research during the next three to five years. They are:

***Research priority 1*: High-frequency climatic variability**

A major focus of ARCSS is to understand the natural variability of the arctic system. While the instrumental record of climate is restricted to short-term changes over the past century, paleoclimate proxy data capture longer-term climatic processes. Thus, paleoclimate proxy records are needed to understand the prominent twentieth-century warming in the context of longer-term variability driven by oscillations intrinsic to the climate system. PARCS researchers intend to recover and analyze data from the highest-resolution multiproxy paleoclimate records possible (including ice cores, tree rings, and lake and marine sediment cores) with temporal resolution ranging from annual to decadal. Patterns of climatic change will be reconstructed at a variety of temporal scales and will be compared to the known patterns of historically documented oscillations (e.g., AO, NAO, ENSO) to elucidate possible driving mechanisms and longer-term behavior of the arctic climate system. These records will span at least 1,000 years and will extend through the twentieth century. PARCS will also encourage the development of longer annually to decadally resolved records from earlier intervals of the Holocene to gauge the long-term persistence of climatic oscillations.

***Research priority 2*: Warm climates and their consequences for the arctic system**

One of the ARCSS Program's (1998) primary goals is to predict how the arctic environment will change in the near future. Because the effects of greenhouse forcing are likely to be amplified at high latitudes, the principal concern focuses on a warmer-than-present Arctic: What will be the extent, rapidity, and spatial pattern of warming, and what will be its environmental impact? PARCS will contribute to an understanding of a warmer arctic by describing the state of marine, terrestrial, and biological systems during periods when the Arctic shifted toward, and experienced, warmer conditions in the past. PARCS will focus on the response to warming of key elements within the arctic system (e.g., sea ice, surface hydrology, and vegetation cover) and their nonlinear feedbacks within the Earth system. Paleoclimate proxy data for key intervals of arctic warmth will be compared with model simulations with the goal of understanding the sensitivity of the arctic system to global warming and its feedback to the Earth system. These "natural experiments" will be used in data-model comparisons to assess the sensitivity of the arctic system to various forcings and to address possible mechanisms of climate change. PARCS will focus on three well-known periods when the arctic system operated under warmer-than-present conditions: (1) warm intervals during the last two millennia (e.g., the Medieval anomaly); (2) other warm intervals of the current interglacial period (generally during the early to middle Holocene; ca. 10,000 to 5,000 years ago), and (3) the last interglaciation (ca. 130,000 to 120,000 years ago). Together these intervals provide realistic constraints on scenarios of future conditions and insights into the dynamics of a warm arctic system.

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Update on the Study of Environmental Arctic Change

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A complex suite of significant, interrelated atmospheric, oceanic, and terrestrial changes has occurred in the Arctic in recent decades. This event is affecting every part of the arctic environment and is having repercussions on society. There is evidence that these changes are connected with the rising trend in the Arctic Oscillation (AO), a mode of atmospheric variability that is potentially active over a broad range of time scales, including climatic time scales, and that involves changes in the strength of the atmospheric polar vortex. There is theoretical evidence that the positive trend observed in the AO index might be indicative of greenhouse warming. It is unclear what feedback processes on climate or ecosystems may be involved in the recent changes, or what the long-term impacts may be. However, observations suggest the impact at high latitudes is substantial and the impact at middle latitudes is significant. Because the observed changes have made it harder for those who live in the North to predict what the future may bring, we have given the name *unaami* (the Yup'ik word for "tomorrow") to the complex of intertwined, pan-arctic changes. The Study of Environmental Arctic Change (SEARCH) has been conceived as a broad, interdisciplinary, multiscale program with a core aim of understanding *unaami*.

Part of gaining this understanding will be to determine the full scope of *unaami*. As a working definition based on present knowledge, we define *unaami* as the recent and ongoing, decadal (e.g., three to fifty year), complex of interrelated changes in the Arctic. These changes include, among other things, a decline in sea level atmospheric pressure, an increase in surface air temperature, cyclonic ocean circulation, and a decrease in sea ice cover. The physical changes are producing changes in the ecosystem and living resources and affecting the human population. The changes are affecting local and hemispheric economic activities such as shipping and fisheries totaling billions of dollars. These biological and societal consequences may be considered part of *unaami*. Although the dynamics are different, the situation is similar to the El Niño-Southern Oscillation (ENSO) phenomenon.

Activities undertaken as part of SEARCH are guided by a series of hypotheses:

- *Unaami* is related to or involves the Arctic Oscillation.
- *Unaami* is a component of climate change.
- Feedbacks among the ocean, the land, and the atmosphere are critical to *unaami*.
- The physical changes of *unaami* have large impacts on the Arctic ecosystems and society.

The SEARCH strategy is conditioned in part by the knowledge that a number of long-term, large-scale observing systems have disappeared or are in danger of disappearing. The strategy includes four major activities:

- Long-term observations to detect and track the environmental changes
- Modeling to synthesize observations, to test ideas about the coupling between different components of *unaami*, and to predict *unaami's* future course
- Process studies to understand potentially important feedbacks
- Application of what we learn to understanding the ultimate impact of the physical changes on the ecosystems and societies and to distinguish between climate-related changes and those due to other factors such as resource utilization, pollution, economic development, and population growth

In 2001 the SEARCH science plan was published (available at http://psc.apl.washington.edu/search/) and in 2002 the first announcement of opportunity for research funds that address some of the scientific questions raised in the SEARCH science plan was issued. The SEARCH science steering committee and the interagency working group are currently working toward developing a Bridging Implementation Strategy.

An Overview of Surface Heat Budget of the Arctic Ocean Project

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The Surface Heat Budget of the Arctic Ocean (SHEBA) is an interdisciplinary, interagency research project designed to enhance understanding of the thermodynamic coupling between the atmosphere, the sea ice, and the ocean. SHEBA is motivated by the large discrepancies among simulations by global climate models (GCMs) of the present and future climate in the Arctic and by uncertainty about the impact of the Arctic on climate change. These problems arise from an incomplete understanding of the physics of vertical energy exchange within the ocean-ice-atmosphere system. To address this problem, the SHEBA project is focused on enhancing understanding of the key processes that determine ice albedo feedback in the Arctic pack ice and on applying this knowledge to improve climate modeling.

The project has five strategic objectives:

1. To develop accurate physical and mathematical relationships between the state of the ice cover and albedo, for any given incident shortwave radiation
2. To determine how the state of the ice cover changes in response to forcing from the atmosphere and the ocean
3. To relate the surface forcing to conditions within the atmospheric and oceanic boundary layers
4. To extend the relationships determined in Objectives 1–3 from local scales to the aggregate scales suitable to climate models
5. To establish a basic data set suitable for developing and testing climate models that incorporate the processes SHEBA is proposing to study.

To achieve these objectives, the SHEBA project conducted a multiseason field experiment starting in the autumn of 1997 in the pack ice of the Arctic Ocean. This field experiment was complemented by remote sensing and modeling analyses. The field observations emphasized the physical processes associated with interactions among the radiation balance, mass changes of the sea ice, the storage and retrieval of heat in the mixed layer of the ocean, and the influence of clouds on the surface energy balance. The modeling effort is designed to provide insight into the mechanisms that affect climate change and to improve the parameterizations of crucial air-sea-ice interactive processes in GCMs. Geophysical data products derived from satellite-borne sensors and analyses derived from operational assimilation models will be used to provide the large-scale context for the SHEBA field experiment.

The SHEBA project is divided into three phases. Phase I included the analysis of existing data, preliminary modeling studies, technology development, and planning to develop and refine the experimental design. Phase II, 1997–1999, included the field experiment, initial analysis of the new observations, and initial development of detailed process models. Phase III, currently underway (2000–2003), includes further analysis and process modeling, the development of models of the surface heat budget on aggregate scales, and development of GCM parameterizations for application in simulating the Arctic and global climate.

Pan-Arctic Cycles, Transitions, and Sustainability: Biophysical, Biogeochemical and Social Systems as Engines of Change in the Arctic

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The pan-arctic region plays a crucial role in global change through three major pathways: fluxes of trace gases (CO_2 and CH_4), energy exchange between the land surface and the atmosphere, and the freshwater input to the Arctic Ocean. In each of these pathways, living organisms—plants, microbes, and animals (including humans) play important, complex, and incompletely understood roles. The proposed PACTS research program focuses on biophysical feedbacks and biogeochemical cycling between biotic and abiotic components of the arctic system. Understanding these interactions is critical to successful prediction of change.

Two thematic questions motivate and guide PACTS:

- How vulnerable are current arctic terrestrial ecosystems and food webs, and how sustainable are arctic societies?
- How will changes in arctic biogeochemical cycles and biophysical feedback processes affect both arctic and global systems?

These questions evolved out of, and are consistent with, the research objectives of ARCSS, yet no other ARCSS program or initiative focuses specifically on living systems and their physical, chemical, and thermal environment.

PACTS will employ the concepts of *vulnerability* and *sustainability* to link the research directly to issues with societal importance. Strong evidence suggests that some components of the arctic system are highly vulnerable because: (a) the arctic system exists in a thermal state centered on the freezing point of water (0ºC); and changes in the balance of time the system spends above and below this threshold can dramatically alter biotic function; (b) much of the Arctic is underlain by permafrost, which, when thawed, can lead to profound consequences; and (c) there is a high dependence of many arctic peoples on keystone subsistence species like caribou. Research will be directed towards understanding what governs the vulnerability of ecological and human communities and the food webs that link them and determining to what degree human activities and natural perturbations might change the basic state or framework of the system.

In order to develop the ability to predict future states, PACTS research will also focus on biophysical interactions and biogeochemical cycles and transitions. These are inextricably linked at a myriad of scales, so by necessity, the Arctic will be treated as a regional complex system under PACTS with the goal of understanding the ensemble functioning of the whole system. This scale of understanding, while essential, is going to require greatly improved knowledge of the relationship between controls over short-term vs. long-term changes in ecosystems, landscapes, and regions, as well as controls on landscape-scale spatial variability. In particular, three challenges will warrant specific attention: (a) developing the ability to separate *important* heterogeneity (that which will affect prediction) from that which is *unimportant*, (b) determining which feedback mechanisms will stabilize (vs. destabilize) the system when multiple mechanisms are operating, and (c) differentiating primary from secondary or tertiary system responses so as to ensure that response time scales are appropriate to the questions and predictions of interest.

PACTS research will be pursued using (though not limited to) the following approaches:

1. Process studies that permit the development of parameterizations for regional and global models linking biotic and abiotic systems
2. Manipulations or comparison experiments conducted at spatial scales sufficient to incorporate landscape heterogeneity
3. Observations that contribute to spatial and temporal scaling
4. Modeling and observations that identify parameters to which the arctic system is most sensitive
5. Vulnerability assessment to determine consequences of the coupled interactions between the arctic system and human activities
6. Space-for-time and time series comparisons; integration of paleorecords with modern time series and process studies

The program will also have a strong community outreach through education and mentoring in the scientific community, through the news media to the general public, and most important, through researcher-to-arctic resident contacts.

ARCTIC CHAMP: An Analysis of the Hydrologic Cycle and its Role in Arctic and Global Environmental Change

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There is accumulating evidence that the hydrologic cycle of the Arctic is changing. The productivity, carbon balance, energy balance, and runoff of arctic terrestrial ecosystems will be affected by the combined changes in temperature and precipitation. Over decadal time scales the stature and relative abundance of plants may be changing, producing new patterns of feedback to regional and global energy and carbon balances. Increases in freshwater transport to the Arctic Ocean may at some point reduce the formation of North Atlantic Deep Water, resulting in a cooling in the North Atlantic region. Because of these changes, we need to have a better understanding of arctic hydrology and the natural linkages of related atmospheric, terrestrial, and oceanic processes and cycles.

In September 2000, scientists met for a National Science Foundation-sponsored workshop to determine research priorities for arctic hydrology and how it can contribute to the goals of the National Science Foundation Arctic System Science Program. There are several notable gaps in our current level of understanding of arctic hydrological systems. At the same time, rapidly emerging data sets, technologies, and modeling resources provide us with an unprecedented opportunity to move substantially forward. Workshop participants defined the following important unresolved questions:

- What are the major features (i.e., stocks and fluxes) of the pan-arctic water balance and how do they vary over time and space?
- How will the arctic hydrologic cycle respond to global change?
- What are the direct impacts of arctic hydrology changes on nutrient biogeochemistry, and ecosystem structure and function?
- What are the hydrologic-cycle feedbacks to the oceans and atmosphere in the face of global change? How will these feedbacks influence human systems?

Key challenges were associated with (a) a sparse and declining observational network, (b) lack of understanding of the basic hydrological processes operating across the pan-arctic, and (c) absences of cross-disciplinary synthesis. These gaps demonstrate an urgent need to reformulate the manner in which arctic hydrological research is funded and executed. Implementation of the recommended actions requires a dedicated research program to support arctic hydrological synthesis studies. To support this new science, members of the scientific community recommended that NSF invest in the development of a pan-Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) to provide a framework for integration studies of the pan-arctic water cycle and to articulate the role of freshwater in terrestrial ecosystem, biogeochemical, biogeophysical, ocean, climate, and human dynamics. The primary aim of Arctic-CHAMP is to catalyze and coordinate interdisciplinary research with the goal of constructing a holistic understanding of arctic hydrology through integration of routine observations, process-based field studies, and integrative modeling. The contributions of an Arctic-CHAMP toward articulating the diverse physical, biological, and human vulnerabilities to a changing climate provide an important impetus for international cooperation in wisely managing this critical part of the earth system.

Poster Abstracts

Growth Rate of Lichen, *Cetraria cucullata,* Under Lengthened Growing Season and Soil Warming: A Climate Change Scenario

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In the Arctic, lichens contribute a large part of the total biomass and productivity. Lichens with cyanobacteria symbionts contribute significantly to nitrogen fixation and nutrient cycling. Lichens occur in food chains of a variety of invertebrates and some vertebrates. For example, lichens are an essential food for caribou, *Rangifer tarandus*. Because they are notably sensitive to small changes in the environment, lichens can provide early warnings of forthcoming climate changes. As part of the ITEX program, we used *Cetraria cucullata*, a dominant lichen species, as an indicator of lichen response to an extended growing season and soil warming. Our hypothesis was that there would be a negative response associated with these treatments. We measured changes in lichen biomass in wire mesh baskets every three weeks throughout the growing season from 1997 to 2001. The results demonstrated a consistent decrease in growth of treatment lichens relative to that of the controls, most likely as a result of desiccation. This study is differentiated from greenhouse warming studies in which lichen biomass has decreased as a result of shading by vascular plants. The results of our study indicate that as season length and soil temperature increases due to arctic warming, the desiccation sensitivity of lichens will result in a decrease in lichen biomass and the potential food supply to caribou.

Snow-Air Transfer: Investigating a Missing Link in a Paradigm of Atmospheric Chemistry

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Understanding the atmosphere-snow-firn-ice-ocean/land system is imperative for predicting the effects of future environmental change on the atmospheric composition of the Earth. Understanding the system is also necessary for interpreting the ice-core record; chemical signatures in ice cores are used to infer ancient chemistry of the atmosphere. Recent exciting findings in polar regions indicate that photochemical processes in the snow have a great impact on atmospheric composition; sunlit snow has very recently been shown to be one of the most photochemically and oxidatively active regions of the entire troposphere. This discovery is changing the paradigm in the field of atmospheric chemistry. In this poster we show recent results on air-snow exchange in the Arctic. Measurements of snow properties, inert tracer gas measurements, and interstitial ozone measurements are described along with model results that show the impact of physiochemical processes in snow on air-snow chemical exchange.

Holocene Climate from Arctic Lake Sediment, Yukon Territory, Canada

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High-frequency climate variability in the northwest Arctic is a mystery relative to our understanding of the region's climate on millennial time scales. This hinders our ability to evaluate recent and predicted warming within a context of natural variability. This research seeks evidence for sub-millennial-scale climate change and its spatial pattern in Canada's interior Yukon Territory over the last ~10,000 years. High-resolution sedimentological and geochemical data from three widely spaced, but similar, closed-basin lakes are used to estimate the regional climate history during the Holocene. The three study sites are located between 63° and 60° N in the semiarid Yukon Plateau (<400 mm annual precipitation); Marcella Lake (60.074° N, 133.808° W), Seven Mile Lake (62.179° N, 136.376° W), and Jackfish Lake (63.020° N, 136.469° W). Each of the three study sites is a small (<3 km^2), hydrologically closed, depressed kettle basin. Sediments are organic and carbonate rich and AMS radiocarbon ages indicate that they are complete Holocene sequences. The lakes are basic with high calcium concentrations, and bio-induced carbonate precipitation was evident. First, evidence that sediment-calcite oxygen isotope ratios are a proxy for aridity has been collected from a region-wide study of modern water and calcite. Second, sediment-core isotope data from three lakes are evaluated within the context of lake-level reconstructions and other climatic and limnologic proxy data. Lastly, the climate proxy data from a regional series of different lakes are compared. Results from this research have broad implications for understanding oxygen isotopes in lakes, natural climate variability, and climate forcing mechanisms for the northwest Arctic.

Dramatic Climatic and Vegetation Fluctuations in Northeast Siberia During the Last Glacial Cycle

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One of the most startling and exciting findings in late Quaternary studies is that the climatic system is capable of changing radically and rapidly. These dramatic temperature oscillations were originally defined from Greenland ice cores and show ranges of variations up to 15–20°C. Over the last ~11.8 to 110 cal kyr BP (calibrated yr before present x 103), 24 glacial interstades (warm events within a glacial epoch) have occurred. They persisted between ~0.2 to 2.5 cal kyr, have a dominant periodicity of ~1.5 cal kyr, and are becoming the focus of increased interest for the study of abrupt climate changes. The importance of these events is underscored by methane records from both Greenland and Antarctica, which suggest that these interstadial temperature shifts can cause fluctuations in atmospheric trace-gas concentrations through their effect on the distribution and/or productivity of terrestrial ecosystems. While the response of terrestrial biomes to these warm-cool fluctuations has been recorded in the North Atlantic sector, it is uncertain to what extent they are registered in other areas of the Arctic. Previous work by Soviet scientists indicated that a significant portion of northern Siberia varied from forest to tundra several times during the last glacial cycle. The Siberian climate-stratigraphic scheme was built from a suite of discontinuous sections and relied on liquid scintillation for radiocarbon (^{14}C) dating of bulk sediments. Thus, the chronological control is somewhat suspect, and some researchers have suggested that warm palynological assemblages more correctly are of last interglacial age. However, more recent PALE-supported studies of continuous lake records from northeast Siberia support the initial conclusions of marked climatic fluctuations during the last glacial period, although the exact timing and numbers of these events require clarification (e.g., Anderson and Lozhkin, 2001).

Newly funded PARCS research will concentrate on a sediment core from Elikchan Lake (to be collected in spring 2002). Previous palynological analysis indicates the lake is at least 60 kyr old, with marked fluctuations between forest and tundra during the Karginski interstade (MIS3 equivalent), although the precise timing of these events is uncertain. AMS dating of pollen and luminescence dating will provide an improved chronology. Variations in past temperature and moisture indices will be based on pollen, diatom, and geochemical data. In such areas as northeast Siberia, where carbonate is not preserved in sediments, δD measurements on algal sterols may provide the best opportunity for reconstructing air temperature from geochemical proxies. In addition-al, $\delta^{13}C$ measurements on algal lipids and lipids derived from higher plant leaf waxes, when combined with the detailed pollen and diatom analyses, will add valuable information on within-basin changes in carbon cycling that can be correlated to climatic change. Preliminary geochemical results show great promise for detailed geochemical analyses for the new Elikchan core, to be collected in 2002. Organic carbon preservation for 5, 18, 30, and 60 ka year old samples range between 7 and 0.5%, and adequate lipid concentrations exist for both $\delta^{13}C$ and δD compound-specific isotope ratio analysis (CSIRA) of the glacial interstades. The $\delta^{13}C$ values of long chain n-alkanoic acids (C24, C26, C28) range between –34 and –38%, indicating that C3 plants dominated the terrestrial plant component of the drainage area 5, 18, 30, and 60 ka ago. Future CSIRA of lipid biomarkers extracted from plankton tows, and plants and the δD of lake waters will be used to interpret the CSIRA of algal biomarkers down-core (after Sauer et al. 2001).]

The new data, when combined with other paleorecords and conceptual or numerical climate models, will allow us to evaluate: (1) whether some or all of the climatic variations in northeast Siberia correspond to changes in the North Atlantic sector; (2) the reasonableness of different climatic simulations of temperature responses in northern Asia to perturbations in the North Atlantic; (3) the role of Siberia as a "mechanistic bridge" for transmitting North Atlantic temperature perturbations to the North Pacific; and (4) the relationship of changing distributions of boreal forest, a major methane source, to variations in atmospheric methane as suggested by analyses of ice-core records.

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A Very High-Resolution Sediment Record from Húnaflòaáll: Holocene Century-Scale Variability along the Northern Iceland Margin

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MD99-2269 is a 25 m-long core from Húnaflòaáll, a deep trough that runs toward the shelf break off northern Iceland from the narrow neck of land that joins the northwest peninsula of Iceland with the "mainland." The seismic architecture of the trough was surveyed in 1997 as part of the B997 Bjarni Saemundsson cruise. Sediments in the main trough appear to be 20–30 m thick. Seismically they are transparent to laminated; there are one or two regional reflectors that can be tracked over hundreds of km. MD99-2269 was collected as part of the IMAGES V Leg 3 cruise and was chosen to retrieve sediments from the thickest part of the section. On board, the core was run through an MST system that recorded several aspects of the sediment (wet density, velocity, magnetic susceptibility). In addition, color was measured with a spectrophotometer. The core was split on board; a basaltic tephra was located at 21 m below the surface and the core cutter was rich in silica-rich ash shards. Geochemical microprobing indicated that these units were correlative with the Saksunarvatn and Vedde tephras, respectively. The date at the core top is contaminated by bomb carbon, hence we recovered sediments post-1960 AD. The date at the base of the core is 10.9 ka (uncorrected). The depth/^{14}C age plot of the nine mollusc samples indicate that the rate of sediment accumulation is virtually linear at ca 5 yrs/cm! The core was sampled on board by U-channels and these have been subjected to sediment magnetic measurements at the UC-Davis Cryogenic Magnetometer Facility at a resolution of one measurement per cm (5 yrs/sample). Samples for sediment analysis were taken every 5 cm (25 yr/sample); our sampling resolution is such that we can search for multidecadal to millenial periodicities. This core is thus a superb archive of changes in the outer part of Húnaflòaáll, an area where significant hydrographic variability has been detected over the last fifty years by the Iceland Marine Institute. This variability is associated with the interaction between warm Atlantic water in the North Iceland Irminger Current and Polar/Arctic waters of the East Iceland Current. The sediment magnetic record shows considerable variability. The Saksunarvatn tephra caused a major decrease in both mass-specific magnetic susceptibility and in ARM_{susc}. A plot of ARM/ARM20, a measure of magnetic coercivity, indicates that the eruption produced fine-grained, high-coercivity materials. The carbonate content shows a steady ramping up of values to reach maximum values at the start of the Neoglacial. An initial increase in carbonate at the base of the core is followed by a distinct low in carbonate that might be coeval with the 11.3 cal ka Pre-Boreal cold event. There is no obvious evidence for the 8.2 cal ka cold event but there is a striking decrease in carbonate around 6.5 cal ka. Color changes in the three CIE* parameters (L, a*, and b*) indicate an increase in variability during the Neoglacial. The bulk of the sediment is silt but sand-size particles increase from ~7% to 15% over the interval 7–9 cal ka. Wavelet analysis will be used to describe the variability in the sediment properties and will provide a test for the presence/absence of the 1.47± ky periodicity off northern Iceland. Preliminary analysis detected significant periodicities in the 300-to-2,500 yr range. Studies on the flora, fauna, and isotopes are being undertaken by Nalan Koc, J. Giradeau, Anne Jennings, and Greta B. Kristjansdottir.

Investigation into the Relationship Between Climate Change and Sedimentary Processes from Core PG 1351 from El'gygytgyn Crater Lake, Northeast Siberia

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Sedimentological analyses completed so far at UMass from the upper 300 cm of the 1998 pilot core show that Lake El'gygytgyn records large climate shifts for the last ~65 ka. The established chronology is based on magnetic susceptibility and OSL correlated to the GISP2 ^{18}O curve (Nowaczyk et al. 2002). Magnetic susceptibility varies by nearly two orders of magnitude and reflects the climatic and environmental history of northeastern Siberia over most of the last glacial/interglacial cycles. In general, high susceptibility in the sediments correlates with warm conditions (interglacial-like) with more oxygenated bottom waters. Low susceptibility correlates to cold (glacial) periods when perennial ice-cover causes anoxia and the dissolution of magnetic carrier materials. Oxygen-deficient conditions preserved laminated sequences of the core. A bioturbation index (c.f., Behl and Kennet 1996) correlates well to the susceptibility and TOC (Melles, in prep) curves.

The clay mineral assemblages in the sediment include illite, highly inter-stratified illite-smectite (I-S), and chlorite. Clay mineralogy is sensitive to changes in climate and can be used as a proxy for paleoclimate reconstruction. Under warm or hydrolyzing conditions, chlorite weathers more easily and I-S abundance increases, producing an inverse relationship in the relative abundance of these clays. Trends in relative abundance show distinct downcore changes that correlate with susceptibility and other proxies. These trends can be divided into eight climate-related zones, beginning with isotopic stage 3. Fluctuations in zones 6–4 suggest a change in climate that may be correlative with the transition from the Bølling-Allerød (13–11 ka) into the Younger Dryas (11–10 ka).

Measurement of particle size in the core indicates that magnetic susceptibility does not correlate to changes in grain size. The mean grain size is in the silt fraction, with few grains larger then 60 μm. Terrigenous input to the lake comes from over fifty streams that are filtered through storm berms, limiting clastic deposition into the lake system.

Bleb structures, from the laminated segments of the core, were analyzed in thin-section using scanning electron microscope (SEM) in backscatter mode (BSE). The bleb composition suggests modes of deposition different from the surrounding laminae.

Using the BSE imaging technique, we hope to improve our understanding of the climate-controlled sedimentary processes operating in this lake system through quantification of the detital input and redox conditions that control diatom abundance, vivianite diagenesis, and bioturbation (c.f., Francus, 2001, Francus and Karabanov 2000, 1998) for Lake El'gygytgyn.

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The Role of Arctic Freshwater Export in a Model of the Arctic-North Atlantic Oceans

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The export of freshwater from the Arctic is believed to play a significant role in determining the strength of the meridional overturning circulation (MOC) in the North Atlantic. In some ocean general circulation models, a complete shutdown of the MOC is possible given a sufficient input of freshwater in the right locations. A key issue for these models, however, is that the deepest convection often occurs south of the Denmark Strait and the dense overflows from the Greenland-Iceland-Norwegian Seas are poorly simulated. This leads to a simple relationship between the single convection site and the MOC that is easily shut down by an excess of freshwater. In reality, the downward portion of the MOC is comprised of several branches and it is highly unlikely that all branches would be shut down simultaneously through an input of freshwater. From observations, the multiple sinking branches lead to water masses of intermediate depth (Labrador Sea water), deep ocean (North Atlantic deep water) and bottom water (Denmark Strait overflow water) characteristics. In the downstream evolution of the MOC and the deep western boundary current, the distinct water masses are well separated in density (by at least 0.1 kg/m^3) while models tend to mix these waters in the western subpolar gyre. Here we discuss simulations from an ocean circulation model in which Labrador Sea water production is particularly active, and strongly correlated with the MOC and surface heat flux. This model shows a strong sensitivity to surface freshwater availability and its propagation out of the Arctic. Our goal in this research is to diagnose the relative roles of the different downward branches of the MOC and how they are influenced by freshwater from the Arctic. The existence of multiple branches of the overturning could stabilize the circulation compared with single-branch models. We will continue to investigate these ideas using a range of ocean general circulation models, including a global isopycnal coordinate model.

The Sea-Ice Dynamic in the Coastal Zone of the White Sea

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It has become recently well known that sea ice is an important component of the global climate system, controlling miscellaneous natural processes in the polar oceans. However, little is known about the sea-ice impact on the sea floor, the coastline and its inhabitants, and especially in the coastal environment with its tidal dynamic. The annual advance and retreat of sea ice may be considered a major physical determinant of spatial and temporal changes in the structure and function of marine coastal ecosystems.

In this presentation we will demonstrate some of the data obtained in the tidal zone of Kandalaksha Gulf (White Sea) during the 1996–2001 period. Previous observations in this area were mainly obtained during the ice-free summer season, however, there was not any information on the ice-covered winter season (seven months duration), and especially on the sea ice itself. During three expeditions in the winter season a series of standard transects were conducted along the coastline with sea-ice samplings including under-ice observations of the sea-ice/bottom floor interactions. Interannual cycles or trends in the annual extent of the sea ice during the period of observations have shown significant effects at all levels of the food web—from the winter production of the sea-ice algae to breeding success among seabirds in the summer. It was concluded that to understand all spectra of the ecological problems caused by pollution in the coastal zone, as well as the problems of the sea ice melting caused by global warming, needs an urgent integrated long-term study of the physical, chemical, and biological processes occurring in the coastal-shelf zone in the Russian Arctic.

Effects of Extended Growing Season on Flower Production of Seven Alaskan Tundra Species at Toolik, Alaska

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As climate warming occurs in northern latitudes, season length is expected to change. As a result of this change, plant phenology will shift, changing the temporal expression of flowering and other phenological traits with important consequences at the community and ecosystem levels. The purpose of this study was to determine the effect of a shift in growing season on the expression of reproductive phenology in several important tundra plants. We studied the timing of specific phenological events, as well as the quantitative production of flowers for seven species over the course of two growing seasons in an arctic tussock tundra community. Flowering abundances and status were measured in an experimental manipulation consisting of increased season length by snow removal coupled with soil warming. There was a strong yearly variation in the quantities of flowers produced, but the number of flowers were not significantly affected by the treatment in either year for any of the species. However, early snow removal slightly accelerated flower development in most species. The dominant plant, *Eriophorum vaginatum*, showed an early progression of flowering status in treatment plots, but control plots fruited at similar times to treatments as a result of accelerated development during flowering. These results indicate that changes in season length may be more important for timing of flowering than for the absolute amount of flowering.

Toolik GIS: Spatial Data and Products for a Diversity of Clients

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Toolik Field Station, located on Alaska's North Slope in the Brooks Range foothills, has been a center of multidisciplinary scientific research for over twenty-five years. From small beginnings in the 1970s, Toolik has grown to support up to 100 researchers and staff at peak capacity. Science at Toolik includes all components of the ecosystem: soil, rocks, vegetation, lakes, streams, vertebrates, and invertebrates, from mountain peak to valley bottom. Virtually all disciplines have a spatial component, and linking processes that comprise the ecosystem is greatly aided by well-organized spatial components in concert with the tools to maximize its use. At the same time, Toolik Field Station is located in a region with various natural resource interests and various custodial agencies assigned to manage the landscape. Spatial data and products help ensure that managers have the best tools at their disposal in decision-making processes. Toolik GIS is designed to meet the following goals: a) augment analysis capabilities for research scientists; b) facilitate collaboration and help integrate scientific results, extending the benefits of the rich scientific legacy of Toolik research, and c) aid in facility and landscape management for the benefit of science as well as the broader community.

Benthic Community Composition and Biomass Distribution: Viral, Bacterial, and Infaunal Associations from the Gulf of Alaska to the Canadian Archipelago

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As part of a U.S.-Canada scientific collaboration during the *St. Roch II* Voyage of Rediscovery in 2000, benthic sediment and water column samples were taken along the continental shelf from the Gulf of Alaska, the Bering, Chukchi, and Beaufort Seas, and within the Canadian Archipelago (C.A.) as east as Spence Bay, Nunavut.

Bivalves in the southern stations dominated infaunal biomass: *Yoldia* sp. in the Gulf of Alaska, *Nuculana radiata*, *Nucula bellot*, and *Macoma calcarea* in the Bering Strait regions. Ampeliscid amphipods dominated northern Bering Strait stations. Sternaspid polychaetes and ampeliscid amphipods were dominant in the Beaufort Sea samples and entering the C.A. At Hat Island in the C.A., bivalves again dominated, particularly the families *Astartidae* and *Hiatellidae*. A siliceous sponge dominated the most northeasterly station, near Spence Bay. Benthic biomass ranged from 57.80 gC/m^2 in the southern Chukchi Sea to 0.16 gC/m^2 in the C.A. Infaunal “hot spots” were observed at Hat Island (43.77 gC/m^2) and Whale Bluff (21.76 gC/m^2) in the C.A., comparable to many of the Bering Strait biomass measurements.

Water column virus-like particles (VLP) ranged from 2.25×10^{11} L^{-1} in the Gulf of Alaska to 5.64×10^{9} L^{-1} in the C.A.; bacterial counts ranged from 1.32×10^{9} L^{-1} in the Gulf of Alaska to 4.57×10^{7} L^{-1} in the C.A. Integrated water column VLP and bacterial distributions correlated most significantly with integrated chlorophyll *a*; discrete water column VLP and bacterial distribution correlated most significantly with chlorophyll *a* and temperature, but also with other water-column characteristics.

Sediment bacterial counts ranged from 3.18×10^{8} per gram dry weight in the Bering Sea to 1.74×10^{6} per gram dry weight in the C.A. VLP counts ranged from 1.08×10^{9} per gram dry weight in the St. Lawrence Island region of the Bering Sea to 2.12×10^{7} in the archipelago. However, at one C.A. station the VLP was observed at 1.22×10^{9} per gram dry weight.

The high VLP and bacterial abundances in sediments associated with water column abundances and high infaunal benthic biomass suggest that biomass accumulation in the sediments may be more influenced by potential sediment microbial reprocessing than previously discussed.

Reconstruction of Summer Temperatures in Interior Alaska from Tree-Ring Proxies: Evidence for Changing Synoptic Climate Regimes

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Maximum latewood density and $\delta^{13}C$ discrimination of interior Alaska white spruce were used to reconstruct summer (May through August) temperature at Fairbanks for the period 1800–1996, one of the first high-resolution reconstructions for this region. This combination of latewood density and $\delta^{13}C$ discrimination explains 59.9% of the variance in summer temperature during the period of record 1906–1996. The 200-year reconstruction is characterized by seven decadal-scale regimes. Regime changes are indicated at 1816, 1834, 1879, 1916, 1937, and 1974; they are abrupt and appear to be the result of synoptic-scale climate changes. The overall mean summer temperature for the period of reconstruction was 13.49°C while the recorded was 13.31°C; the coldest interval was 1916–1937 (12.62°C) and the warmest was 1974–1996 (14.23°C) for the recorded data. The reconstruction is anomalous compared to other Northern Hemisphere records, especially because of interior Alaska warm periods reconstructed from 1834 to 1851 (14.24°C) and from 1862 to 1879 (14.19°C). Autogenic effect of tree growth on the site, altered tree sensitivity, or novel combinations of temperature and precipitation cannot be ruled out as contributors to the anomalously warm nineteenth century reconstruction, but do not appear to be likely. White spruce radial growth is highly correlated with reconstructed summer temperature, and temperature appears to be a reliable index of carbon uptake in this system.

The Spatial Distribution of Vegetation at a High-Arctic Oasis

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The relationships among plant community structure, diversity, phenology, and abiotic factors, including snowmelt pattern, temperature, soil moisture, and soil nutrients, were studied at the Alexandra Fiord lowland, a high-arctic oasis on the east coast of Ellesmere Island. At each of twenty-eight sampling points, vegetation was surveyed, soil was sampled, temperature was recorded by data loggers, and phenological observations were made on four plant species throughout one growing season. A geographic information system is being used to analyze the data from the discrete sampling points and relate it to the observed distribution of plant communities. From these data are anticipated insights on the spatial interrelationships between vegetation and the abiotic environment with a view to improving predictions of vegetation response to climate change in this region.

Adjustment of Daily Precipitation Data at Barrow, Alaska, for 1995–2000

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It has been recognized that systematic errors in precipitation measurements caused by wind-induced undercatch, wetting, and evaporation losses affect all types of precipitation gauges. These errors are more sensitive for solid precipitation than for rain. In arctic regions, these systematic errors become significantly more pronounced than for other regions due to the relatively slow precipitation rates (frequent occurrences of "trace" precipitation days), low temperatures, high winds, and low annual precipitation measurements that are characteristic of the arctic climate. This study performed daily adjustments to measured precipitation data for a six-year period, from 1995 through 2000, for the National Weather Service station in Barrow, Alaska. The study indicated that the adjustments resulted in increases of 14 to 272% to the average monthly gauge-measured precipitation and 58% to the total precipitation for the six years. It is expected that these increases will impact climate monitoring, the understanding of the arctic freshwater balance, and the assessment of atmospheric model performance in the Arctic.

Limiting Extent of Ice Sheets in the Russian High Arctic During Isotope Stages 2–3 from IRSL Dating of Lake Sediments, Taymyr Peninsula

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The reconstruction of MIS 2-3 ice-sheet dimensions and ice-flow directions for the Eurasian Arctic remains controversial, with the maximalist view (Denton and Hughes, 1981; Grosswald, 1998) perhaps now (2001) being out-balanced by the minimalist view (Brigham-Grette et al. 2001; Möller et al. 1999; Svendsen et al. 1999; Velichko et al. 1997). For accurate reconstruction of global ice volumes at least during the last glacial maximum (LGM), it is essential to resolve this controversy. Changeable Lake, in the Severnaya Zemlya Archipelago (79° N, 96° E) at the northern end of the Taymyr Peninsula, contains consolidated till at the base of a 10.5 m core. This represents the last time glacier ice overran this area. Younger core deposits represent nonglacial conditions. A minimum date for this till would place a clear temporal limit on the last presence of an ice sheet here.

Application of ^{14}C AMS dating to humic acids, pollen grains, insects, and undetermined organics give some age reversals and scatter, with the youngest ages near 10 ka (upper 4 m) and the oldest at 22–28 ka in the 8.5–9.8 m zone. AMS ages for two samples of benthic foraminifera in the marine facies directly over the bottom till are "infinite" (>48 ka). Fine-silt infrared-stimulated luminescence (IRSL) dating yields a clear age-depth trend, from 4.0 ± 0.4 ka in the upper 2 m to 33 ± 2 ka at 9.6 m. A sample from the marine facies (9.95 m) immediately overlying the till gives an age of 53 ± 3 ka. Thus, an ice sheet was last present in this area before 50 ka, probably in MIS 4 or even before MIS 5. This improved chronology supports the minimalists' view of the Eurasian Arctic ice sheets, and the "precipitation-shadow" view of Möller et al. (1999) for the LGM at the Taymyr Peninsula.

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What Happened to the Yukon River Chums? Climate Variation and Management of Western Alaska Salmon Fisheries

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Since 1998, low returns of chum salmon (*Onchorhynchus keta*) to western Alaska rivers have caused serious hardship to communities in the region whose subsistence and commercial fisheries rely on this resource. The cause of the run failures is unknown. However, fishery managers, research biologists, and fishery participants have advanced a number of competing hypotheses. The hypothesized causes include inadequate spawning escapement, climate-driven variation in freshwater and/or marine survival, competition with hatchery fish, incidental harvest at sea, and intercept harvests in mixed-stock commercial fisheries. Recent stock assessment studies conducted by Alaska Department of Fish and Game (ADF&G) biologists provide estimates of escapement, total return, and age distribution of returning Yukon River fall and summer chums that enable us to conduct preliminary tests of some of these hypotheses.

Multiple regression analysis of the ADF&G data shows a negative association of brood year return per spawner with number of spawners ($p<.01$) and a positive association with the Pacific Decadal Oscillation (PDO) two years after the brood year ($p<.02$) for both summer and fall chum stocks. Age at return positively correlates with Pacific Basin chum hatchery releases ($p<.03$) and with the Arctic Oscillation (AO) three years after brood year ($p<.03$). We find no statistical support for the other hypotheses. The observed statistical associations are consistent with the life cycle of Yukon chum salmon and with research on other chum stocks. They suggest that climate variation interacts with fisheries management in complex ways to affect run sizes. The two-equation model for brood-year return and age-at-return appears to explain much of the large swings in Yukon River chum returns from the 1970s through 1997. However, the model fails to predict the 1998–1999 run crash, leaving its cause yet a mystery.

Effects of Ice on Arctic River Channel Morphology: Ground Penetrating Radar Investigations

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Ground-penetrating radar (GPR) can be used to detect spatial changes in ice characteristics on an arctic river as a potential cause of anomalous downstream trends in channel morphology. In this study, GPR was employed as a method to investigate a shift in the typically log-linear relationship between drainage area and channel cross-sectional area occurring between drainage areas of 300 and 600 km^2 on the Kuparuk River in northern Alaska. Beyond this shift, or hydraulic geometry transition zone, the channel is enlarged relative to its upper reaches. A hypothesis for this phenomenon is that different ice types, grounded ice in the small stream reaches and cap ice in the large ones, cause different erosional processes and thus different channel morphologies. This study seeks a correlation between ice type and channel morphology by collecting GPR data, and hence ice-type information at selected locations along the course of the Kuparuk River.

The two ice forms of interest as potential controls on channel morphology are cap and grounded ice. Cap ice occurs when the surface of a body of water freezes, but water remains beneath. Grounded ice occurs when the entire water column freezes down to the channel bottom. Grounded ice will potentially protect channel boundaries from erosion during snowmelt, typically the basin's highest flows. Cap ice will not protect the channel bottom and may even contribute to heightened erosion as it breaks up and scours the banks. GPR is a useful method for detecting these ice types because it responds to differences in media dielectric constants, which are large between water (81) and ice (3.5). Typically, GPR detects the ice-water boundary at similar depths along the entire river due to climatic controls on maximum ice thickness. Water, where occurring beneath the ice, is generally continuous from bank to bank where the channel is deep enough to resist solid freezing.

Initial GPR results show that there is indeed a transition from grounded ice to cap ice near the same drainage areas where the transition in channel morphology occurs. Future work must address the question of whether ice is controlling channel morphology or if channel morphology is controlling ice and whether other controls could be influencing this relationship. This study has significance concerning the hydrologic response of arctic watersheds to climate change. Likely consequences of a warmer climate include a change in the ice regime of arctic rivers, a dynamic readjustment of channel morphology, and consequent changes in hydrologic response.

Effects of Horizontal Resolution on GCM Simulations of Mid- and High-Latitude Circulation in the Northern Hemisphere

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Key features of the mid- and high-latitude atmospheric circulation are poorly simulated by current general circulation models (GCM) and are crucial to the coupled global atmosphere-land-ice-ocean system. These features include the mean annual cycles and variability of arctic atmospheric circulation. When such GCMs are coupled to dynamical sea-ice models, the resulting fields of sea-ice velocity and thickness are qualitatively unrealistic, with significant implications for climate feedbacks.

We have found that horizontal resolution has a significant effect on the wintertime arctic atmospheric circulation in simulations with the NCAR CCM3.6 using a spectral dynamical core with triangular truncation. Our analysis of simulations at T42, T85, and T170 indicates that the position and amplitude of the wintertime Beaufort high are improved with higher resolution. We find storms enter the northern North Atlantic and Barents Sea more frequently in the higher resolution models, in better agreement with observations. Kinetic energy and meridional heat transport are higher in the storm tracks in the higher resolution runs. In addition, the relative magnitude of the simulated Pacific and Atlantic storm tracks is more realistic, and there is evidence that more storms track across North America, where GCMs have typically failed to capture the observed path of storms. The influence of synoptic-scale eddies on the mean flow is both stronger and at smaller length scales at high resolution. These characteristics match well with observations, although the maxima in this influence are not necessarily well located.

Some areas show no improvement with increased resolution. For example, eddy kinetic energy and meridional heat transport at mid-tropospheric levels over Alaska increase with resolution, although they are higher than observed even at T42 resolution. Most midlatitude changes in the mean circulation are not clear improvements, such as the changes in position and amplitude of the Aleutian and Icelandic lows.

Predicting Carbon Storage in Tundra Soils of Arctic Alaska

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The distribution of soil organic carbon (SOC) was determined in 60 pedons from northern Alaska by horizon, within the seasonal thaw layer, and to a depth of 1 m. Concentration of SOC, bulk density, and SOC density were remarkably uniform for a given genetic horizon and had low standard errors. With increasing degree of decomposition, the bulk density increases, the percent SOC decreases, and the soil horizon C density increased in organic horizons. For mineral horizons, gleying is accompanied by an increase in C density, which is due to the effect of saturation on reduced decomposition of organic matter. Cryoturbation of organic minerals into the subsoil results in an increase in C density primarily from an increase in bulk density due to compaction from the overlying layers and more closely packed soil particles from frost stirring. Estimated SOC densities for individual horizons and for the seasonal thaw layer were highly correlated ($p<0.01$) with measured values from an independent data set for the same region published by other investigators. Variable quantities of segregated ice in the upper permafrost made it more difficult to estimate quantities of SOC to 1 m ($p=0.05$). The equations generated by this study will be useful for preparing a detailed soil C map of the arctic regions.

Factors Affecting the Distribution of *Populus balsamifera* on the North Slope of Alaska, USA

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Balsam poplar (*Populus balsamifera*) groves occur north of the Brooks Range and treeline in arctic Alaska in a region of continuous permafrost and tundra vegetation. A poplar grove near the Ivishak River (69°06' N, 147°53' W) was studied in detail and contains what appear to be eleven clones all within 350 m of the river. Individual clones ranged from 600 to 4,500 m^2 in size and 90 to 200 years in age. Poplar trees were significantly larger in diameter in clones within 100 m of the river and were less dense in clones away from the river. Unique soil thermal and moisture conditions appear to limit the expansion of poplar groves to only a few hundred meters from the river channel, including a "thaw bulb" or depression in the permafrost table and soil textural discontinuities that concentrate moisture in the rooting zone. We prepared a map showing the distribution of poplar groves on the North Slope from published reports, Landsat images, topographic maps, and observations of bush pilots. The groves occur within an area bounded by 68–69° N and 142–154° W. A preliminary model explaining the origin and distribution of balsam poplar groves was developed from the case study, unpublished data, and a review of the geologic, hydrologic, and ecologic literature. The groves preferentially occur in areas where there is a sharp change in relief from the Brooks Range to the Arctic Foothills, extensive river braiding accompanied by thermal springs, aufeis deposits, and a regional groundwater flow system that may be controlled by faulting and the accumulation of Ca-enriched precipitates.

A Comparison of Climate and Surface Energy Balance During Spring Melt at Three Arctic Sites (Spitsbergen, Siberia, Alaska)

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Since 1998, automatic weather and soil stations have been operated at sites close to Ny-Ålesund (Spitsbergen), the Lena River Delta (Siberia), and Ivotuk (Alaska). Continuous permafrost underlies all these sites. All stations are installed on patterned ground: frost boils on Spitsbergen, low-centered polygon in Siberia, and tussock tundra at Ivotuk. In addition to these differences in surface characteristics and soil material, the sites are characterized by climatic differences. The Lena Delta has the most continental climate (coldest winter air temperature and lowest precipitation), while Spitsbergen has a mild, maritime winter climate due to the influence of the Atlantic current.

By comparing surface energy balance components of these three sites, the control mechanism at the local scale (such as surface characteristics) are examined relative to the larger-scale factors (such as climate).

The surface energy balance was calculated during the snowmelt period for 1999 (Spitsbergen and Siberia) and for 2000 (Alaska). The calculated energy balance components include atmospheric fluxes (turbulent and rain) and ground sensible and latent heat, while net radiation was measured directly. Radiation provides the major energy input for snowmelt in Spitsbergen, while the snow ablation at Ivotuk is governed by sensible heat. At the Siberian site, about 5 cm of snow sublimate at subzero air temperatures after which the remaining snow is melted by net radiation.

The ground heat flux is an important component in the energy balance during snowmelt at the Spitsbergen site (between 30 and 50% of net radiation) due to the long duration of the snowcover.

Lake Sediment Paleoclimate Research in the Lofoten Islands, Arctic Norway

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The Lofoten Islands (at 67–69° N in the eastern Atlantic) are in a location that is sensitive to changes in ocean circulation within the Norwegian Sea, and they are strongly influenced by variations in the atmospheric circulation through the North Atlantic Oscillation (NAO). We therefore initiated a reconnaissance project in 2001 to recover lake sediments and peat deposits that might shed light on North Atlantic climate variability. Topography of the islands is mountainous, with deeply eroded, lake-filled cirques (tarns) and impressive moraines, reflecting the dynamic glacial environment that characterized the region in the past. The islands are replete with lakes, many of which are deep and close to sea level, and peat deposits are extensive.

Our initial goals—to recover high-resolution sedimentary records from the region—were not realized, as sedimentation rates are surprisingly low. Nevertheless, we have recovered Holocene-length records that document climate variability at the multi-decadal-to-century scale. Furthermore, we expect that the peat and lake sediments will shed light on several intriguing paleoenvironmental questions that we are now investigating. These include climate variability during the time of Viking settlement in the region; relative sea-level changes in the region during the Holocene, including the extent of the Tapes marine transgression; evidence for tsunami effects in coastal regions. In addition, we are examining the peat for tephras (that may have spread from Iceland) in order to provide a high-resolution chronology for the region.

Mass Balance and Area Changes of Four High Arctic Plateau Ice Caps, 1959–2001

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Small, stagnant ice caps without appreciable iceflow are particularly sensitive to climatic fluctuations, especially with regard to changes in ablation season temperature, and hence may provide an early warning of climate shifts. In a general sense, the areal extent of such ice caps is strongly related to their annual mass balance. We conducted mass balance measurements and GPS surveys on four high-arctic plateau ice caps from 1999–2001 and compared these measurements with topographic maps and aerial photography from 1959 and previously published data. Murray Ice Cap has experienced negative mass balance for at least the past three years (1999–2001), with net balance (bn) ranging from –0.19 to –0.7 m (1999), –0.12 to –0.87 m (2000), and –0.22 to –0.96 m water equivalent (2001). The mass balance of nearby Simmons Ice Cap was also negative in 2000 (bn = –0.15 to –0.72 m w.e.) and 2001 (bn = –0.37 to –0.7 m w.e.). All four ice caps showed considerable marginal recession and area reduction between 30 and 47% since 1959. Overall, the ice caps have experienced considerable mass loss since 1959, except for a period between the mid-1960s to mid-1970s. The regional ELA appears to have risen, on average, above the summits of the ice caps, indicating that the ice caps are remnants of former climatic conditions and out of equilibrium with modern climate.

The ARCSS/PARCS Connection at Lake El'gygytgyn, Northeast Siberia: Modern Process Studies Key to Interpreting a 3.6 Million-year Climate Record of the Arctic

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The El'gygytgyn depression in northeastern Siberia is a 3.6 million-year-old impact crater, partially filled by a large lake. Approximately fifty streams drain the crater watershed, carrying with them sediments and organic matter that contain proxy indicators of climate at the time of deposition. In 1998, we retrieved a 300,000-year-old sediment core from the center of the lake, creating the longest terrestrial climate record of the Arctic. This core reveals distinct transitions in most of the proxies, including sedimentation rate, laminations, diatoms, pollen, magnetic susceptibility, and other biogeochemical markers. These studies indicate that duration of lake ice cover—particularly whether it melts in summer—is the dominant control on lake biogeochemistry, making the study of lake ice dynamics an important part of our research.

Understanding the modern hydrological, limnological, and energy-balance processes is necessary to fully interpret the core record, because such observations provide our best opportunity to link climate and proxy dynamics. In addition to installing a number of local meteorological and limnological instruments towards this end, we have used a combination of SAR and Landsat to understand the modern lake-ice dynamics. Based on over 400 SAR scenes, we have determined the average dates of snowmelt onset, ice melt onset, and completion of both, as well as observed the dynamics of lake-ice break up. We have compared these data to modeled predictions of snow and lake ice dynamics with reasonable success. We can now use this model to hindcast the conditions necessary to keep the lake ice from melting during the summer.

We also observed an interesting distribution of bubble density within the lake ice that may have important implications in selection of the drilling location for the remaining 3 million years of record that may exist beneath the lake. The shallow shelves are very bright in the SAR scenes, indicating a high bubble density. These bubbles are formed through respiration and decomposition of life on the relatively warmer shelves. Two mechanisms may explain a central bright spot in the lake: gravity currents from the shelves and groundwater upwelling. Because the shelf water is about 4°C and the bulk of the lake is near 3°C, a density-driven current carries warm shelf water (and its inhabitants) to the bottom, causing increased respiration and decomposition there. Because the lake is surrounded by permafrost, but not underlain by it, the highly shattered bedrock is likely a conduit for groundwater upwelling. Seismic evidence suggests that piping structures exist within the sediments above the central peak. Long-term, consistent upwelling there has consolidated the sediments, correlating the deepest part of the lake basin with the central peak. The location of the central peak of the impact crater therefore may be correlated with the deepest part of the lake basin—this has important implications for future coring projects. The 1998 coring location is not within this central bright spot, possibly indicating it is in a different biogeochemical regime, particularly during glacial times when these gravity currents may have been established under the ice.

The future work we propose at Lake El'gygytgyn is an interdisciplinary field/laboratory and modeling research program focused on several objectives with two overarching themes:

1. Energy-balance modeling of the lake-ice cover, lake-circulation dynamics, and hydrology
2. Studies of the modern sedimentation, diatom ecology, isotopic geochemistry, and organic biogeochemistry as proxies of past changes in limnology

We propose that by integrating these two branches of study within ARCSS we can realistically fine-tune proxies of past change directly to a climatically driven energy-balance model of the lake system and effectively hindcast regional paleoenvironmental change. An evaluation of that change will lead to a better understanding of the systematic thresholds that lead to circumarctic and hemispheric teleconnections in the climate system. For example, by studying the transition from the winter thermal regime within the lake to the summer thermal regime, we hope to understand the processes that may have taken place when there was no true summer thermal regime during glacial conditions. That is, we will use the spring lake-ice moat formation under the current climate as an analog for the summer peak of lake-ice melt during glacial conditions, by studying lake mixing, stream runoff, diatom assemblages, water chemistry, and erosional processes, as well as use our models to conduct sensitivity analyses of the factors needed to maintain these conditions during the glacial times.

The linkage of proxies to energy-balance modeling, as we propose, will have applications to studies of lacustrine systems and sediments throughout the Arctic across high-resolution time scales. We believe our work is an excellent example of a project that fills an intellectual gap that has persisted in the past between modern process studies and paleostudies.

Multi-Proxy Evidence for Rapid and Pronounced Late-Glacial Climate Change in the Ahklun Mountains, Southwestern Alaska

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Determining the spatial and temporal pattern of abrupt climate events, such as the Younger Dryas event (YD; ~12.9 to 11.6 cal ka), is key to understanding interactions among the components of the climate system and for discerning regional climate teleconnections. Two independent records of late-glacial climate change in the Ahklun Mountains, southwestern Alaska, suggest that this region experienced rapid and pronounced climate oscillations coincident with the YD. First, an expansion of alpine glaciers during the Mt. Waskey advance produced an extraordinarily well-defined end moraine system. Eleven cosmogenic 10Be and 26Al exposure ages on moraine boulders, combined with radiocarbon ages from a lake core upvalley of one of the moraines, suggest that the advance culminated between 12.4 and 11.0 cal ka, sometime during, or shortly following, the YD. Reconstructed equilibrium line altitudes (ELAs) for the Mt. Waskey advance are 80 ± 30 m below modern values and are 25 to 40% of the full glacial lowering. Second, pollen assemblages, biogenic silica, and organic-carbon contents in a sediment core from Nimgun Lake (~100 km west of Mt. Waskey) indicate pronounced changes in terrestrial vegetation, aquatic productivity, and landscape stability coincident with the YD. For example, Betula shrub tundra abruptly reverted to herb tundra at the onset of the YD and became reestablished at the end of the YD.

The ecological changes recorded at Nimgun Lake likely reflect a climatic cooling and a decrease in effective moisture during the Younger Dryas. Using an empirical relationship between climate and the ELA of modern glaciers, and assuming that it was 30 to 50% drier during the Younger Dryas, then the ELA depression of 80 m for the Mt. Waskey advance could correspond to a temperature depression of ~1.5°C to 3.5 °C. These values are consistent with published modeling results for the North Pacific region during the YD. Thus, data from the Ahklun Mountains add to a growing body of evidence that the North Pacific region experienced pronounced climate oscillations coincident with the North Atlantic YD. Taken together, these results point toward a tightly coupled ocean-atmospheric system.

Beaufort Sea Coastal Erosion: the Elson Lagoon Key Site, Barrow, Alaska

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Coastal erosion over the past fifty years has been determined for sections of the coast at Barrow (Elson Lagoon) and near Kaktovik (Beaufort Lagoon) using photogrammetric analysis of aerial photographs starting in the late 1940s to the recent IKONOS imagery. During summer 2001, key sites for monitoring coastal dynamics were established at both locations as part of the Arctic Coastal Dynamics (ACD) program. The Elson Lagoon site is approximately 11 km long and is composed of four distinct segments. This lagoon coastline forms the eastern land boundary of the Barrow Environmental Observatory (BEO), a protected research area of 3,021 hectares. The Beaufort Lagoon site extends approximately 10 km along the shores of the Arctic National Wildlife Refuge. In addition to monitoring rates of circumarctic erosion and deposition, ACD seeks to estimate the amount and fate of eroded sediments and carbon derived from erosion of ice-rich permafrost. The initial ACD protocols were developed at a NSF-sponsored Russian-American Initiative on Shelf-Land Environments in the Arctic (RAISE) workshop in November 1999 in Woods Hole, Massachusetts.

This poster presents results from the Barrow site, including (1) establishment of historical rates of erosion based on a time series of aerial and satellite images, (2) establishment of permanent transects and benchmarks, and (3) bathymetric surveys offshore from selected benchmarks. Bluff elevations in the study area average 2.5 m and are dominated by polygonal ground consisting of ice-rich, fine-grained sediments, reworked peats, and ice wedges.

1. Erosion rates: A time series of coastline changes using sequential aerial and satellite imagery from 1948–1949, 1962–1964, 1979, 1997, and 2000 was established. Aerial photographs were rectified to a high-resolution (1 m) IKONOS summer 2000 satellite image base map. Rectification accuracy (relative to the 2000 image) ranged from 0.69 to 2.56 m RMS among periods. Photogrammetric analysis reveals high spatial variation in rates of coastal erosion. In a macroscale comparison of the four segments, erosion rates ranged from 0.7 m/yr to 3.0 m/yr for the period 1979–2000, with an overall erosion rate of 1.3 m/yr. For Segment A, mean annual erosion rates were remarkably similar among the earlier three periods for 1949–1964 (0.6 m/yr), 1964–1979 (0.6 m/yr), and 1979–1997 (0.7 m/yr), but were much higher for 1997–2000 (1.5 m/yr). The more recent period of 1979–2000 (0.9 m/yr) is 47% higher than the period of 1949–1979 (0.6 m/yr), and 23% higher than the fifty-one-year average (0.7 m/yr). Over the last fifty years, Section A of Elson Lagoon lost 8.6 ha of coast. Total lost for all sites between 1979 and 2000 was 28.2 ha. Field observations this past summer along Segment D revealed that this segment is composed of extensive areas of large, exposed ice wedges and blocks of calving, frozen, peat-rich tundra. This contributes to the greater rates of erosion as compared to Segments A, B, and C.
2. A total of fourteen transects were established at U.S. Geological Survey triangulation markers and several other sites along Segments A through D. Rebars with BEO numbered survey caps were installed at intervals from the benchmarks and perpendicular to the coast. GPS positions of stakes and measured distances from the top of the coastal bluff were recorded.
3. Seven offshore bottom profiles were measured on 9 and 10 August 2001. Four profile lines up to 10.7 km in length extended across Elson Lagoon to the shores

of the enclosing barrier islands. Three shorter lines of approximately 2 km length were measured at 500 m intervals parallel to the longer line off the most rapidly eroding Sector D. The hydrographic survey used a single-beam acoustic fathometer system with a 200 kHz narrow-beam transducer. GPS positions of soundings were logged with a horizontal accuracy of 5 to 10 meters. No broadcast of differential (DGPS) corrections was available in the area at the time of the survey. Lines off Sectors A and B reveal a submerged shoal about 1 m deep along its crest parallel to the coast, approximately 2 km offshore. The trough between the shoal crest and the mainland shore was approximately 2.5 m deep. The shoal corresponds to bathymetric trends that appear on the 1950s era topographic map, outwardly unchanged. Lines approaching Sector D are steeper nearshore than lines at corresponding offsets from adjacent Sectors A, B, and C, which is an indication of active submarine erosion. Deeper water nearshore furthermore allows more wave energy to reach further inshore. Fetches from north to northeast are longer than for Sectors A, B, and C in that directional sector.

The next step in the ACD science plan is to estimate the sediment and carbon lost due to erosion at the key sites, based on estimated ground-ice and organic carbon contents of the soils and near-surface permafrost. Additional details are available on the ACD web site: www.awi-potsdam.de/www-pot/geo/acd.html.

Establishment of the Elson Lagoon site was supported by the Barrow Arctic Science Consortium (BASC) through its cooperative agreement with the NSF Office of Polar Programs. Initial planning for the ACD and the Barrow photographic analysis were supported by OPP-9818294 and OPP-9818120. During summer 2001, Eric Hammerbacher and Craig Tweedie (Michigan State University) and David Ramey (BASC) assisted in site establishment and bathymetric survey, respectively. Matt Macander, ABR, assisted with the photogrammetric analyses.

Was Beringia a Glacial Refugium for Boreal Forest Species? New Perspectives from Mapped Pollen Data

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There has been a great deal of interest in the role of Beringia, northeastern Siberia to northwestern Canada, as a refugium for boreal tree and shrub taxa during the last glacial maximum (LGM). We asked the question: Do low percentages of shrub and tree pollen during the LGM indicate windblown pollen dispersal from distant source areas in temperate latitudes of Asia and North America, or do they document the existence of small refugial populations within Beringia? We utilized spatially distributed pollen records in the large PARCS database for Beringia to examine the history of seven boreal woody genera (*Salix*, *Betula*, *Alnus*, *Populus*, *Larix*, *Picea*, *Pinus*). The spatial patterns of pollen percentages in west and east Beringia were plotted from the LGM (21,000 cal yr BP) to 9,000 cal yr BP, when boreal taxa were widespread in both regions. Data were examined at 1,000-yr intervals to identify temporal and spatial patterns that indicate the presence or absence of refugia within Beringia. The maps for each taxon argue more strongly for survival within Beringia than for immigration from outside the region. Overall, the pollen maps indicate that all of the genera examined survived the LGM in small populations within Beringia; some occurred at scattered locations across broad areas while others were restricted to a few fairly discrete locations.

An Integrated Approach to Understanding Climate-Vegetation-Fire Interactions in Boreal Forest Responses to Climatic Change

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A major challenge in predicting boreal ecosystem responses to future climatic change is the extent to which shifts in *Picea glauca* forests will be driven solely by climate or by feedbacks among climate, vegetation, and fire. Paleoecological records from central Alaska provide a unique, natural experiment to explore this question. *P. glauca* expanded rapidly in central Alaska ca. 9–8.5 ka (C^{14} yrs), declined within 500–1,000 yrs across 9,000 km^2, and did not recolonize the area until ca. 2,000 yrs later. These dynamics could represent responses to (1) a regional climate oscillation or (2) interactions of fire and vegetation with a unidirectional climatic change. The goal of this new ARCSS SIMS project is to assess the causes and processes of the early-to-mid Holocene fluctuation in *P. glauca* in central Alaska, as a means to better understand factors controlling the past, present, and future distribution of boreal forest. Specific research tasks are to describe: (1) vegetation and fire histories through fine-resolution pollen, macrofossil, stomate, and charcoal records (10–100s yrs, 10s km); (2) climate changes through oxygen-isotope and trace-element content of sedimentary carbonates (ostracodes and abiotically precipitated carbonate); (3) ecological processes associated with treeline changes through ALFRESCO simulations of past vegetation dynamics. During the first field season of this project we surveyed water chemistry and morphology of nineteen lakes as potential coring sites. Sediment cores were also taken at several sites to define the overall sampling strategy, gain preliminary data on Picea dynamics, and confirm suitability of research techniques.

Land-Cover Change in the Western Arctic: Development of a Logistic Regression Model

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To develop the capability to predict future land-cover changes in the western Arctic, it is important to understand how patterns of land-cover change that have occurred in recent decades are associated with climate and fire history. We used logistic regression to develop an empirical model of land-cover change in Alaska and adjoining western Canada. The model predicts land cover based on elevation, aspect, slope, time since last wildfire, fire return interval, drainage class, growing-season air temperature, and precipitation. Land-cover prediction was limited to four main vegetation types: tundra (including shrubs), deciduous forest, black spruce forest, and white spruce forest. Preliminary results indicate that the vegetation predictions based on the logistic-regression model estimate land cover with 70% accuracy in the western Arctic.

Ectomycorrhizal Diversity of White Spruce (*Picea glauca*) at Three Treeline Sites along a Latitudinal Gradient in Alaska

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Factors limiting white spruce (*Picea glauca*) growth at treeline are poorly understood but are central in predicting future forest/tundra boundaries in response to global warming. Nutrient limitation and tissue loss are thought to reduce growth and reproductive success at treeline. Soil microbial communities may also have an effect on the establishment and success of trees growing at treeline. Mycorrhizae, the mutualistic symbioses between plants and fungi, are an essential component of ecosystem structure and function. However, research regarding the diversity and species composition of ectomycorrhizae at high latitudes or at treeline is very limited. Our goal is to determine ectomycorrhizae (ECM) diversity and species composition at treeline and contiguous intact forest. Ectomycorrhizae were sampled at three sites within each of three geographically distinct mountain ranges in Alaska from both forest and treeline sites. Soil cores were sampled from ten randomly selected trees at each location and site throughout the summer of 2001. White spruce roots were sorted from cores and ECMs were morphotyped and quantified for percent infection. Forty-seven morphotypes were found in the Chugach, forty in the White Mountains, and fifteen in the Brooks Range. Overall, there was no difference in the number of morphotypes found between forest and treeline sites.

Preliminary Runoff Modeling Results from Two Subarctic Watersheds, Kougarok, Alaska

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Preliminary runoff modeling results are presented for Mauze Gulch (4.9 km^2) and Niagara Creek (6.5 km^2). Mauze Gulch and Niagara Creek lie adjacent to each other on the Seward Peninsula near Kougarok, Alaska. These watersheds have been studied extensively as part of the Arctic Transitions in the Land-Atmosphere System (ATLAS) study. These watersheds are two of four that demonstrate a progression from a cold arctic to a warmer subarctic environment. Both watersheds are underlain by continuous, warm, thin permafrost (~15 m thick). A significant difference between the two watersheds is that Niagara Creek has been disturbed by a recent tundra fire. Models can be valuable tools when direct measurements are difficult to obtain, but they must be verified before they may be applied with confidence. The Swedish HBV model was chosen due to its simplicity and repeated success simulating stream discharge in arctic and subarctic Alaska. The model requires minimal input of meteorological data (temperature and precipitation) to simulate accurate hydrographs. Two consecutive years of data were used to calibrate the model, and a third year was used to independently test it. Data include snow-water equivalent, meteorological data, and stream discharge. By changing parameters in the model, such as field capacity of the soil, we would expect to quantify the physical differences between watersheds. On preliminary runs of the model we have reasonable agreement between measured and simulated hydrographs and feel that we are justified in proceeding with analysis. Future work will include modeling of four watersheds across a climatic gradient in order to better understand the impacts a warming climate may have on hydrological systems and see if model parameters relate to physical differences among watersheds.

Surface Temperature of the Arctic: Comparison of TOVS Satellite Retrievals with Surface Observations*

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Surface temperature is a fundamental parameter for climate research. Over the Arctic Ocean and neighboring seas conventional temperature observations are often of uncertain quality, however, owing to logistical obstacles in making measurements over sea ice in harsh environmental conditions. Satellites offer an attractive alternative, but standard methods encounter difficulty in detecting clouds in the frequent surface-based temperature inversion and when solar radiation is absent. The TIROS Operational Vertical Sounder Polar Pathfinder (TOVS Path-P) data set provides nearly twenty years (1979–1997) of satellite-derived, gridded surface skin temperatures for the Arctic region north of 60° N. Another data set based on surface observations has also recently become available. The International Arctic Buoy Program/Polar Exchange at the Sea Surface (IABP/POLES) project provides a gridded, near-surface air temperature data set based on optimally interpolated observations from Russian drifting ice stations, buoys, and land stations from 1979–1997.

In this study, we compare these two data sets and find areas with large differences (4 to 6 K) in both winter and summer. Over the ice-covered Arctic Ocean in both seasons, TOVS temperatures are substantially colder than POLES and over the Greenland-Iceland-Norwegian (GIN) Seas, TOVS is warmer. Using point measurements from manned ice stations and ships we find that POLES is too warm (~2 K on average) in January. The bias is larger (~4 K) in regions where the primary source of data is buoys, which contain warm biases in winter owing to the insulation effect of snow covering the sensors. The difference between skin and 2-meter temperatures accounts for approximately 1 K of the January discrepancy between POLES and TOVS. Over the GIN Seas in both seasons, POLES is too cold (~7 K) because values are based primarily on analyses from the National Centers for Environmental Prediction (NCEP). In July, the TOVS temperatures are approximately 6 K too cold over ice-covered regions owing to poor retrievals when cloud cover exceeds 95%. When overcast retrievals are removed, this difference is reduced to 2K. We therefore recommend that TOVS retrievals be rejected in summer when the retrieved cloud cover is over 95%.

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*This work has been published in *Journal of Climate* 15 (24): 3698–3708.

Evaluating Pollen Morphological Criteria to Separate Tree and Shrub Species of *Betula* (Birch) in North America

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Lake sediments from arctic and boreal regions commonly contain abundant pollen grains of *Betula* (e.g., >50% of total pollen spectra in some Holocene samples from Alaska). Because no reliable pollen morphological features have been identified to distinguish among various *Betula* species, the paleoenvironmental significance of *Betula* pollen profiles is often ambiguous.

The modern flora of Alaska and neighboring high-latitude regions of North America includes three species of *Betula*: *B. papyrifera*, *B. glandulosa*, and *B. nana*. These species differ greatly in their ecological and climatic affiliations. *B. papyrifera* is a common tree species of boreal forests, whereas *B. glandulosa* and *B. nana* are two dominant shrub species of tundra. The plants of these three species differ morphologically, but their pollen grains have very similar structures, making it difficult to use fossil pollen profiles of *Betula* for climatic and vegetational reconstructions.

Using an image analyzer with a semiautomated routine, we have measured 1710 pollen grains from fifty-seven plants of the three *Betula* species for four morphological characteristics as an attempt to identify criteria for separating these species. These characteristics are pore depth, pollen diameter, the ratio of pore depth to pollen diameter, and a shape factor. Our results show that pore depth is the most reliable criterion to separate these species. It groups the two shrub species (*B. glandulosa* and *B. nana*) together and clearly distinguishes them from the tree species (*B. papyrifera*). The mean pore-depth and standard deviation are 2.99 ± 0.43 μm, 2.35 ± 0.36 μm, and 2.22 ± 0.36 μm for *B. papyrifera*, *B. glandulosa*, and *B. nana*, respectively. There exists a pore-depth gray zone (~2.2–2.8 μm), in which pollen grains cannot be assigned to either group. The three remaining morphological characteristics overlap considerably among the three species, although they are statistically different between the shrub and tree species.

Because *Betula* pollen is a prominent component of interglacial pollen records from the arctic and boreal regions, the pore-depth criterion for distinguishing between tree and shrub *Betula* species promises to substantially improve our ability to reconstruct past ecological and climatic changes.

Using GIS to Assess Ice-Cover Impacts on a Productive Benthic System in the Northern Bering Sea

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During April 1999 and March–April 2001, late winter biological, sediment, and hydrographic measurements were made at twenty-eight stations in an area of historically high benthic biomass in the northern Bering Sea. Benthic macroinvertebrates are an important food source for diving seaducks (e.g., the threatened spectacled eider) and marine mammals in this region. This presentation will quantify the influence of seasonal ice cover on water column production and benthic processes during the two late winter cruises, using satellite ice-coverage data and GIS mapping tools within the context of a longer, decadal ecosystem study in the region. The years of 1999 and 2001 were very different in terms of ice extent and concentration. From mid-January to the end of April 1999, the ice concentration was at least nine-tenths for the entire study region. This uniformity of ice during the winter of 1999 may explain the lack of any correlation between ice coverage and any water column or benthic parameters during our subsequent April sampling. In contrast, the ice concentration and extent during 2001 was greatly reduced over the Bering Sea. A spatially and temporally integrated measure of ice concentration prior to late-winter sampling was significantly correlated with water column chlorophyll *a* measured during the cruise (Spearman's rho = -0.415, p = 0.35). Integrated chlorophyll *a* concentrations ranged from 3.1 to 52.2 (mg m^{-2}), low by comparison to maximum spring production events (e.g., during May 1994 integrated chlorophyll *a* ranged from 21.1 to over 2,000 mg m^{-2}). These data indicate a relationship between low winter ice coverage and temporal acceleration of water column production, which would be a likely scenario with global change. During 1999, benthic biomass (g C m^{-2}) was significantly correlated with late-winter measurements of sediment chlorophyll *a* (Spearman's rho = 0.504, p = 0.01). These data support the conclusion that late spring production events and subsequent advection of carbon within the study area are important for deposition and use of carbon in this region over an annual cycle.

Growth of Sphagnum under Extended Growing Season at Toolik Lake, Alaska

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Climate models predict that climate warming will be greatest at high latitudes. Along with temperature, the length of the growing season is anticipated to increase with climate change in the Arctic. While considerable effort has been dedicated to studying the effects of altered season length on vascular plants, little attention has been paid to the responses of mosses, including the tundra dominant sphagnum. Because sphagnum has previously been shown to be photoinhibited in arctic tundra, we hypothesized that sphagnum would decrease growth in response to early season snowmelt. Alternatively, sphagnum may increase growth due to additional seasonal light and/or season duration. During two arctic summers, 2000 and 2001, we examined the vertical growth response of sphagnum species in situ using the cranked-wire method under an artificially extended growing season. Summer season was extended by careful snow removal early in the season. In 2000, the growth rate of sphagnum under the extended season was considerably lower than that of controls in the beginning of the season, but after six weeks growth rates were similar. In 2001, growth of sphagnum under the extended season remained below that of the controls throughout the entire season. These results indicate that earlier snowmelt has a negative effect on the growth rate of sphagnum, possibly due to photoinhibition. However, the response of sphagnum may be the result of earlier snowmelt affecting factors other than light, such as early season temperature, water table, depth of the active layer, and sphagnum water content. During the summer of 2002, we plan to investigate how light and these other important factors affect sphagnum growth and physiology in response to an extended growing season.

Radiation in the Arctic

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The main parameters affecting the characteristics of the radiation regime of the underlying surface are cloudiness, surface albedo, and transparency of atmosphere. The variations of transparency of different temporal scale are determined by the variations of total atmospheric water content and aerosol. The maximal changes of albedo in the Arctic relates with formation or melting of snowcover. The cloudiness determines the incoming short- and long-wave radiation near the surface. The variety of cloud forms, water content, phase state, and spatial structure cause the obvious restrictions in the modeling of incoming radiation in cloudy conditions. The tremendous amount of data about polar atmosphere, including cloudiness and radiation, were collected during the field phase of SHEBA. But for climate investigations these data have limited value due to temporal and possibly spatial variability of the above mentioned characteristics of atmosphere.

The large number of radiation measurements and cloudiness observations (4 to 8 times per day) had been collected on coastal and island polar stations beginning in the 1930s and drifting stations "North Pole" from 1950 to 1991. The monthly mean values of radiation characteristics were published by Marshunova and Mishin (1994) and in the *Arctic Meteorology and Climate Atlas* (Arctic Climatology Project, 2000). These data were used to analyze the relation of monthly mean values of radiation parameters with monthly mean cloudiness, as well as for investigating its interannual variability (e.g., Makshtas et al. 1999). Evidently, the monthly mean data have the restricted value for developing the adequate optical, radiation, cloudiness, and atmospheric boundary layer models, as well as for adequate climate estimations of radiation and turbulent heat fluxes due to averaging. The analysis of simultaneous nonaveraging radiation, meteorological, radio sounding, and snow data are needed. The other problem related with climate investigations is the comparison of data obtained with different instruments under the same weather conditions.

Our proposal is to create the new comprehensive data set on CD, combining the improved data of meteorological and snow measurements on the drifting stations, previously published on CD in 1994; the improved data set of "North Pole" stations radio-sounding data (first version published by Kahl et al. in 1993); the new data set of all available radiation measurements executed on drifting stations together with supplemented observations of cloudiness; and estimations of main parameters of energy exchange between atmosphere and sea ice in the Arctic Basin. Later, we think it would be very useful to create a similar data set for coastal and island polar stations.

In support of this proposal, IARC has now executed three projects funded by IARC-Frontier and NSF: Intercalibration of the Russian and U.S. sensors used for radiation measurements in the Polar Regions (under logistical support of ARM); the investigation of long-term variability of the free atmosphere in the Arctic; and a new archive of radio-sounding data to develop and to validate atmospheric boundary layer parameterization. In addition, together with AARI we made preliminary research into the possibility of using the Sechi disk of historical data for investigations of radiation regimes of the arctic shelf seas.

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An Arctic Environmental Observatory in Bering Strait

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The Arctic Environmental Observatory in Bering Strait is a research effort designed to improve data collection capabilities at the juncture of the Bering and Chukchi Seas, where nutrient-rich Pacific water flows predominantly into the Arctic Ocean. The observatory currently includes three distinct tasks. One is the development of a water intake system to sample Bering Strait water on a year-round basis using shore-based instrumentation. A second component is a marine mammal sampling and survey program that takes advantage of the high degree of dependence on subsistence hunting by residents of Little Diomede Island. Finally, a ship-based sampling program is annually sampling water column and benthic parameters at specific long-term stations located from south of St. Lawrence Island and north into the Chukchi Sea. The overall goal remains to improve capabilities to detect and monitor environmental change in the Bering Strait region.

The marine mammal sampling program at Diomede and the annual shipboard sampling effort are well underway. For example, results of the ship-based benthic sampling are being combined with previous studies of benthic biomass, sediment metabolism, and other sediment parameters to continue documenting a decadal pattern of declining trends in biomass and other changes in benthic species composition. The objective of a continuous, year-round water sampling system for Bering Strait waters remains under development. In two successive field seasons—2000 and 2001—we deployed an interim water intake and continuously measured salinity, temperature, chlorophyll *a*, nitrate, and phosphate over month-long time increments on a demonstration basis. Water has been pumped into a shed under the Diomede Village School using a jet well pump and then through automated instrumentation to measure the aforementioned parameters, at minutes-to-hour frequencies. Discrete daily water samples have also been collected for determination of stable oxygen-hydrogen isotope ratios, silicate, nitrite, and ammonium, and to assure data quality acquisition by the automated nutrient instruments. A radiometer has also been continuously recording UV radiation and PAR on the school roof. Future work includes a geophysical survey during 2002 that will determine the best orientation and location for drilling an underground/undersea pipeline that can serve as the basis for a more permanent water inlet system that will be less vulnerable to ice and storm damage.

The Role of Plant Functional Types in Land Surface Exchange in High-Latitude Ecosystems: Measurements and Models

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Climate change has the potential to influence vegetation dynamics in high-latitude ecosystems, which may in turn feed back to the climate system through alterations in carbon storage and surface energy balance. Our component of the Arctic Transitions in the Land-Atmosphere System (ATLAS) project focuses on improving understanding of the role of species, or groupings of species (plant functional types) in the land-surface exchange of arctic ecosystems in response to warming. We hypothesize that changes in the distribution of plant functional types will exert control on land-surface exchange in the arctic system through changes in surface parameters such as albedo, roughness length, and canopy resistance. We address our hypothesis through a combination of fieldwork and modeling experiments.

Fieldwork for this project occurred at ATLAS sites in Alaska (Ivotuk and Council) and in Russia (Cherskii). In conjunction with tower-based measurements of CO_2, water, and energy exchange, we measured vegetation characteristics, including biomass and leaf area index. The vegetation types at the study sites span a gradient from tundra through tall-shrub tundra to forest. At Council, differences in albedo among vegetation types controlled summer season net radiation. These differences were attributed to increased canopy complexity and variation in the distribution of plant functional types along the sequence from tundra to forest. Canopy complexity, as indicated by measurements of leaf area-index, ranged from 0.52 in the tundra to 2.70 in the forest. The significantly different distribution of functional types with the development of a complex canopy was reflected in an eight-fold difference in total biomass along the sequence from tundra to forest.

Extrapolation of the field measurements to broader spatial scales is a major component of the synthetic activities of our project. We have developed a dynamic version of the Terrestrial Ecosystem Model (TEM-DVM) that tracks carbon and nitrogen pools and fluxes through plant functional types and are in the process of testing and validating that model. We have used the field data from the ATLAS sites to update parameterizations for the arctic and subarctic plant functional types in the Land Surface Model (LSM). In an asynchronous model coupling experiment, TEM-DVM will be used with LSM-CCM3 to evaluate the influence of vegetation dynamics in the arctic and subarctic, north of 50° N, on surface energy balance and boundary layer structure.

Utilizing IFSAR Data for Mapping North Slope Hydrology and Landforms

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Intermap Technologies, Inc. is a provider of high-resolution elevation data. Intermap's mission is to facilitate better decision making in government and industry by becoming the primary global supplier of high-quality, low-cost digital elevation products. The key component of Intermap's mapping capability is its STAR-3i system. STAR-3i is an InterFerometric Synthetic Aperture Radar (IFSAR) system, which generates digital elevation models (DEMs) and orthorectified images (ORRIs) simultaneously. Intermap's products are used by a wide variety of private and public sector GIS/mapping customers for applications including national mapping, hydrology/flood management, petroleum exploration, resource management, and telecommunication planning.

The Influence of Anomalous Atmospheric Circulation on the Annual Cycle of Precipitation in High Northern Latitudes

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To a large extent, the transport of water vapor and the patterns of moisture sources and sinks are determined via the large-scale atmospheric circulation. In previous studies the precipitation distributions over the arctic basin have been used to demonstrate the impact of decadal-scale circulation anomalies associated with wintertime teleconnection patterns. The mean annual cycle of precipitation over the north polar cap, however, has been shown to have the largest values in the summertime; in addition, the character of the average annual cycle has a strong regional sensitivity. For example, the annual cycle of precipitation over Greenland varies radically over short distances, from a wintertime maxima in the southeast to a summertime maxima in the north. This suggests that the distribution of surface moisture fluxes may be used to diagnose the significant summertime circulation features and their anomalies over the Arctic Basin and surrounding terrestrial watersheds. In this paper we use available reanalysis data as validated against in situ observations to characterize the annual cycle of precipitation over high northern latitudes and its relation to the atmospheric circulation. An analysis is then performed to identify the years of anomalous precipitation and characterize the atmospheric circulation patterns leading to these regional precipitation events.

Bioavailability and Chemical Characteristics of Soil: Organic Matter in Arctic Soils

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The purpose of this study was to evaluate bioavailability and chemical characteristics of soil organic matter (SOM) in arctic tundra soils. Laboratory incubation technique was used to determine CO_2 respired from the samples during the incubation period that was used as an index of bioavailability of the SOM. Cross polarization magic angle spinning (CPMAS) ^{13}C NMR and liquid-state ^{13}C NMR, pyrolysis-gas chromatography/mass spectrometry (Py-GC/MS) techniques were applied to evaluate the chemical characteristics of the SOM. Amino sugar contents in these soils were measured to indicate the microbial contribution to SOM.

The study of the bioavailability and chemical composition of SOM in soils of arctic tundra suggests that, with global warming, these soils may have a greater potential to contribute to greenhouse gas emissions than soils from other regions, since the decomposition processes of organic matter in arctic tundra soils respond to temperature increase more than soils in other regions. The major components in these tundra soils contributing to CO_2 evolution are polysaccharides and low-molecular-weight compounds such as neutrals and organic acids. The accumulation of organic matter in these soils is believed to be due to selective preservation, although some inert humic substances are formed by condensation processes.

Carbon Stocks in an Age-Series of Drained Thaw Lakes in Arctic Alaska

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Replicate cores were taken to an average depth of 124 cm from twelve drained thaw-lake basins representing four age classes (young, medium, old, and ancient) near Barrow, Alaska. Based on radiocarbon dating, the basins range from <100 to >4,000 yr BP. The cores were sectioned into decimeter intervals, and the bulk density and field moisture content were determined. Soil organic carbon (SOC) was measured on a Dohrmann DC-190 carbon analyzer and SOC stocks were estimated for the surface organic layer, the seasonal thaw layer (ca. 0–35 cm), the near-surface permafrost (35–100 cm), and the upper 1 m. The thickness of the surface organic layer, the degree of decomposition of SOC, and the organic C pool in the surface organic layer all increase with basin age. However, the organic C pools in the seasonal thaw layer, the near-surface permafrost, and the upper 1 m layer are unrelated to basin age because of high within-basin variability in C pools.

Dendroclimatic Investigations at the Circumpolar Arctic Treeline

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Recent dendroclimatic field collections and analyses have yielded millennial- and near-millennial-scale tree-ring chronologies from climatically sensitive sites in: (1) the Wrangell-St. Elias Mountains of Alaska, (2) the Yukon Territory of Canada, and (3) the Taymyr Peninsula of Siberia. These records are contributing to our understanding of arctic climate over the past 1,000 years.

1. At Wrangell-St. Elias (Davi et al. in review), a network of fourteen chronologies of white spruce (*Picea glauca*) ring width and density have been produced, dating as far back as 1415. The density network was used to reconstruct warm-season temperatures for the region, dating back to 1513, and accounts for 53% of the local temperature variance. The ring width network shows good agreement with reconstructed and recorded arctic and Northern Hemisphere temperatures (Jacoby and D'Arrigo 1989; D'Arrigo et al. 1993; Mann et al. 1999) and is in phase with well-dated glacier fluctuations in the Wrangell Mountains (Wiles et al. in review).
2. In the Yukon, a white spruce chronology, TTHH, has been completed for an elevational treeline site near 65° N that dates back to AD 1099. This series generally shows similar trends to those seen in the reconstructions of arctic and Northern Hemisphere temperatures.
3. At Taymyr, four Siberian larch (*Larix gmelini*) chronologies have been developed, the oldest dating back to AD 1130 (Jacoby et al. 2000). These were used to reconstruct May through September temperatures back to AD 1580, and account for over 46% of the variance in temperature. The reconstruction shows unusual warming in the first half of the twentieth century and also shows similarities to the Arctic and hemispheric paleorecords.

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Studies of Seismic Stratigraphy in Arctic Lakes

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The aim of this poster is to give a broad overview showing examples of how seismic surveys can be coupled with core studies to provide a three-dimensional view of a lake basin's sedimentary architecture. We will focus on two case studies where seismic and core studies were combined. First, we analyzed Birch Lake, where sub-bottom data and core transect studies were used to identify and date lake-level changes associated with fluctuations in effective moisture. Second, we analyzed Coghill Lake, where acoustic data and core studies were used to document and date a paleo-earthquake event. We used an ORE-Geopulse seismic system (3–7 KHz) towed by boat to collect an array of seismic reflection profiles from five Alaskan lakes. Navigation was logged by GPS, and the seismic data was digitally recorded with a DAT recorder for further processing. Future work, beginning this summer, will use a Triton Elics * Edgetech full spectrum (4–24 KHz) sub-bottom profiler with Delph Seismic Office and SGIS post-processing software that includes georeferencing of the data for analyses and interpretation.

Birch Lake, located in central Alaska in the corridor between the Alaska and Brooks Ranges, remained unglaciated during the late Quaternary. Results from seismic profiles and core transects (sedimentology, geochemistry, magnetic susceptibility, and pollen) reveal significant lake-level changes during the late Pleistocene and Holocene. We analyzed a network of twenty-two seismic profiles (18 km) and compared them with data from eight sediment cores collected on a transect from the margin of the lake to its depocenter at 13.5 m to derive a lake-level history. Twenty-five AMS radiocarbon dates on discrete macrofossils provide a high-resolution chronology of water-level fluctuations. The seismic profiles from Birch Lake illustrate the use of acoustic data as a potentially powerful tool to identify onlap sedimentary structures and erosion surfaces associated with lake-level changes even in difficult shallow settings. Although Birch Lake is currently overflowing, the results indicate that prior to 8.9 ka B.P. the lake was a closed-basin system.

Coghill Lake is an important sockeye nursery lake in the Coghill District of the Prince William Sound commercial fishing management area. Sockeye returns to the lake have declined in recent years, but long-term data on Sockeye variability is lacking. In a project designed to investigate the long-term history of Sockeye populations in Coghill Lake, a seismic survey was done to identify suitable coring sites and a series of cores were collected. A recent and very large delta failure was noted during the sub-bottom survey at the inlet at the north end of the lake. The debris flow from this failure covered approximately a third of the lake bottom. Lead-210 and cesium-137 data indicate that this event occurred in 1964 during the magnitude 8.4 earthquake that caused extensive damage in Anchorage and Valdez. The epicenter of the quake was within 15 miles of Coghill Lake.

The Impact of Subgrid-Scale Snowcover on the Hydrological Cycle of an Alaskan Watershed

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Given their ubiquitous presence during most of the year on the North Slope of Alaska, snow and ice processes are critical components of the hydrological cycle that demand special consideration. In this work, therefore, we present hydrological simulations that focus on the evolution of the snowcover in the Kuparuk River Basin (KRB). These simulations are conducted using NASA's Seasonal-to-Interannual Prediction Project (NSIPP) Catchment-based Land Surface Model (CLSM). Emphasis is given to subgrid-scale variations in the snowpack and their effects on the simulated water and energy budgets of the KRB. It is shown that partitioning of the snowpack into shallow and deep areas, rather than treating it as a horizontally uniform surface, leads to a significant improvement on the timing and intensity of the modeled spring melt. It is also demonstrated that the consideration of subgrid-scale variations in snow enhance the evaporative fluxes throughout the post-transition period. This implies that the presence of deep snowdrifts on the arctic landscape may act as a delayed source of groundwater that alters the warm-season surface energy and water budgets. To determine the area covered by a deep and a shallow snowpack in the KRB, a blowing snow model is then applied along several transects in the basin. Variations in wind speeds induced by changes in topography along the low-level flow yield snow deposition and accumulation areas. These results allow us to relate the end-of-winter snowcover distribution in the KRB with its climate and its topography. As such, we are able to develop a parameterization for subgrid-scale variations in snowcover that is applicable to any watershed.

The Arctic System Science Data Coordination Center

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The ARCSS Data Coordination Center (ADCC) at the National Snow and Ice Data Center (NSIDC), University of Colorado at Boulder, is the permanent data archive for all components of the ARCSS Program. Funded by the National Science Foundation's Office of Polar Programs, our focus is to archive and provide access to ARCSS-funded data and information. The concept of system science depends on the accessibility and exchange of data and information within the scientific community. The ADCC strives to be a catalyst to facilitate that accessibility and cooperation.

A major concern of the research community is the availability of reliable data for research. Working with ARCSS investigators, the ARCSS Committee, and NSF, the ADCC is continually acquiring data and developing data products appropriate and useful for the research community. Integration of the data and information from ARCSS projects described on this poster is a high priority at the ADCC. We also work with other national and international data centers to provide optimum accessibility to data and information from the ARCSS archive.

The ADCC strives to provide the most contemporary means of data accessibility to the scientific community. We have developed ingest procedures to help ARCSS researchers submit data and information to the long-term archive. The ADCC home page (http://arcss.colorado.edu/) has become an important tool for data accessibility and integration within ARCSS. Data and information are also distributed on other media (CD-ROMs, disks, data catalogs, etc.) when appropriate. The ADCC maintains a complete backup of the ARCSS archive to ensure data and information collected from the program are available on a long-term basis.

Tracking Climate Change in the Canadian High Arctic Using Paleoenvironmental Techniques

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Research by our two labs—PAL (Paleoenvironmental Assessment Laboratory) at the University of Toronto and PEARL (Paleoecological Environmental Assessment and Research Laboratory) at Queen's University—has focused on tracking environmental and paleoenvironmental change in the Canadian Arctic islands. We use mainly freshwater diatoms as biomonitors, since they exhibit a rapid response to shifts in the environment and they preserve well in lake and pond sediments. Our early work on shallow ponds on east-central Ellesmere Island revealed unprecedented environmental shifts that occurred ca. 1850 AD; these have been linked to shifts in climate, namely a longer growing season, i.e., warmer conditions. One main goal of our research is to complete a spatial and temporal map of freshwater diatoms in the Canadian Arctic islands, a region thought to be extremely sensitive to environmental change. In our regional calibrations, we collect physical, biological, and chemical data from water bodies and use these data to construct transfer functions that can be used to interpret and quantify the paleoenvironmental data gathered from sedimentary cores in each region. Having baseline ecological data allows for long-term monitoring. In addition to working with diatoms, we also examine other indicators such as chrysophyte cysts, chironomid head capsules, testate amoebae, and sponge spicules. These can be used to track nutrient input levels, river inflows, microhabitats, duration of growing season (climate), extent of ice and snowcover and other information such as pH and salinity. This research is largely funded by Canadian sources (e.g., NSERC); however, we work closely with our American colleagues who are working on similar aspects of high-latitude research.

Benthic Faunal Biomass in the Western Arctic: Linkage to Overlying Water Column Processes

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The ultimate goal of our research is to link patterns of benthic community structure and biomass in the Chukchi and Beaufort Seas to associated physical and biological processes that can be identified as key determinants of global change. Benthic organisms integrate elements in the adjacent water column and therefore can be used as indicators of long-term change. We used Geographical Information Systems (GIS) software as a tool to map the biomass and distribution of benthic organisms for comparison to other features (e.g., ocean depth, seasonal ice extent, currents, water column chlorophyll, etc.). Benthic data were assembled in an ACCESS relational database and analyzed with the GIS programs ArcView and Arc/Info. A Geostatistical Analyst extension to ArcMap was used to interpolate the data with kriging techniques to produce probability estimates of benthic biomass across the study area. Plotted benthic data reveal areas of high biomass (>250 g/m^2) north of the Bering Strait in the Chukchi Sea and south of the Bering Strait in Gulf of Anadyr waters. In contrast, benthic biomass along the nearshore Alaskan Beaufort Sea shelf is less than 30 g/m^2, except along the regions of the western Beaufort and east of the Mackenzie River delta. The high benthic biomass in the Bering-Chukchi parallels the abundance of benthic-feeding marine mammals in this region compared to the Beaufort Sea. We are conducting further studies to examine the linkages between chlorophyll standing stocks and the productivity of overlying shelf waters with the physical forcing processes that regulate the advection of carbon to these benthic communities.

Data Coordination for Paleoenvironmental Arctic Sciences

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The Paleoenvironmental Arctic Sciences (PARCS; formerly PALE) component of the ARCSS Program manages its own data. This fact grew out of need to maximize the resources available to us by teaming our data management efforts with those of the NOAA Paleoclimatology Program. Long-term archiving of PARCS data is assured through our cooperation with the NOAA and its World Data Center A for Paleoclimatology. The PARCS data manager (Mathieu Duvall) develops and maintains the databases and web sites (www.ngdc.noaa.gov/paleo/parcs). The data manager also serves as the primary contact with PARCS researchers.

From the early stages of our data management effort, we realized the need to engage the principal investigators in the data management process. We also have a great need to synthesize the data generated from PARCS' spatial network of sites. A simple but effective way to meet these goals is to combine the archiving of basic data with the generation of value-added data sets. The emergence of the World Wide Web offered us an opportunity to try this model by creating an electronic (web-based) paleoenvironmental "atlas." Here we gather modern environmental and paleoenvironmental data and make them available in a variety of formats from their primary (raw) form to more interpreted or value-added forms. We also provide detailed descriptions of the methods used to generate the value-added data. The other benefit of this approach is that the atlas is a "living document" in that it can be expanded and revised with relatively little effort as the science progresses.

The success of this integrated approach to data management has led us to adopt it across the board. PARCS will create integrated, data-centered web sites based on the atlas model for both of its near-term science goals. As each working group proceeds through the steps of its research plan, PARCS data management will be compiling data for each and working with the members of the working groups to synthesize and visualize the data. As progress is made, these data sites will be expanded and their data will be instantaneously added to the permanent archives at NOAA.

Verification of the Thaw-Lake Cycle Using Radiocarbon Dating, North Slope, Alaska

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We conducted a program of basin age verification, soil sampling, and vegetation description of drained thaw-lake basins between Barrow and Atqasuk. This is part of our effort to determine the amount of carbon sequestered in drained basins, changes in carbon accumulation rates over time, and to understand the influence of climate on the geomorphological evolution of lake basins on the Arctic coastal plain. We have recently radiocarbon dated more than thirty basins in order to determine the timing of basin drainage. Results verify the original vegetation-based classification scheme.

Our findings confirm that organic C and ground ice on the Arctic coastal plain of Alaska increase with time in the drained thaw lake basins.

There is a reasonably strong ($r^2 = 0.69$) positive correlation between thickness of the organic layer and ^{14}C age.

Preliminary results show age class boundaries at 750 ^{14}C yr BP (medium-old basin) and 2,000 ^{14}C yr BP (old-ancient basin). No basin was found to be older than 5,000 ^{14}C yr BP.

The thickness of the surface organic layer increases from <5 cm in the youngest basins to >50 cm in the oldest basins.

STAR-Light: Enabling a New Vision for Land Surface Hydrology in the Arctic

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STAR-Light, a 1.4 GHz radiometer for use on light aircraft, is an enabling instrument for monitoring thickness and water content of the active layer throughout the circumpolar Arctic. Our underlying vision is that the active layer can be modeled with a Soil-Vegetation-Atmosphere Transfer (SVAT) model that is forced by available data on weather and downwelling radiation. Through near-daily assimilation of satellite observations of microwave brightness at a frequency that is sensitive to liquid water in the upper few centimeters of soil, these SVAT models will maintain reliable spatial estimates of the thickness and water content of the active layer.

Key for this vision are accurate SVAT models for arctic terrains, an airborne radiometer for the extensive field observations necessary to calibrate these models, and a satellite radiometer to provide near-daily observations. SVAT/Radiobrightness models for arctic tundra are in the early stages of development. The hydrology community has converged upon 1.4 GHz brightness as the most effective observation for sensing soil moisture, and the European Space Agency is completing a preliminary study of a 1.4 GHz Soil Moisture Ocean Salinity (SMOS) satellite mission for later this decade. STAR-Light is an NSF-funded, airborne instrument for SVAT model calibration in the Arctic beginning in 2004.

We will describe our progress with the STAR-Light development and describe how others can participate in this research.

Modeling Regional Evaporation: Significance of Landscape Heterogeneity in Arctic Coastal Plain Ecosystems Using BIOME-BGC

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Evaporation (E) is a major component of the hydrologic cycle, coupling directly to the energy and carbon cycles. Because the evaporation process is acutely nonlinear, changes in scale of observation along with model grain and extent can have significant affects on model estimates. BIOME-BGC is a widely used ecophysiological process model, which incorporates the water, carbon, and nitrogen cycles while providing a link to the MODIS products. Estimates of evaporation will be made at both landscape (1 km^2) and regional (100 km^2) scales using BIOME-BGC. Given the scale at which the model will be used, it implies that a course grained (>=1 km^2) grid cell will be necessary. However, BIOME-BGC assumes spatial homogeneity within a grid cell while the Arctic coastal plain is a mosaic of land-cover types at these scales. Therefore, the effects of subgrid heterogeneity on model E estimates need to be addressed. For the Arctic coastal plain, evaporation models may need to account for two classes of heterogeneity: (1) different sources of E (i.e., water, vascular vegetation, and nonvascular vegetation) and (2) spatial variations of moisture availability for E (i.e., soil moisture and active-layer depth). Both classes of heterogeneity vary over time. At regional scales, the dominant sources of E are shallow thaw lakes and vegetation, which have significantly different controls over the E process. At the landscape scale, differences in the controls over the E process between the two major sources, vascular and nonvascular vegetation, can be significant and may affect E estimates. Furthermore, soil moisture controls E rates from the surface and spatial variations can significantly influence E estimates. Therefore, this poster presents a strategy for investigating and determining how critical the representation of this heterogeneity is on model estimates of E using BIOME-BGC.

Detecting Changes in Arctic Tundra Plant Communities in Response to Warming Over Decadal Time Scales

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Detecting the response of vegetation to climate forcing as distinct from spatial and temporal variability may be difficult, if not impossible, over the typical duration of most field studies. We analyzed the spatial and interannual variability of plant functional type biomass from field studies in low arctic tussock tundra and compared these to climate-change simulations of plant community composition using a dynamic tundra vegetation model (ArcVeg). There was substantial spatial heterogeneity of peak season live aboveground biomass in low arctic tundra at Ivotuk, Alaska (68.5° N, 155.7° W) in 1999, when samples were collected from 0.1 m^2 plots. Coefficients of variation for live aboveground biomass ranged from 41% for deciduous shrubs, 80% for graminoids and 84% for mosses to over 200% for lichens and forbs. Spatial heterogeneity in the ArcVeg dynamic vegetation model, generated as a result of grazing, soil disturbances, and demographic stochasticity, compared favorably to the field data. Field studies also indicate a high degree of interannual variability with possible trends associated with warmer climates, such as increasing shrub biomass and declining moss biomass. These field data coupled with ArcVeg simulations suggest that some changes in plant community composition might be detectable within one or two decades following the onset of warming, and shrubs and mosses might be key indicators of community change. Model simulations also project increasing landscape-scale spatial heterogeneity (particularly of shrubs) with increasing temperatures.

Tundra Carbon Loss During Winter: Temporal, Landscape, and Geographic Variability

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For the past six winters we have documented patterns of carbon (C) loss during the long non-growing season in various arctic and subarctic plant communities and under various experimental treatments. These studies, along with those of other arctic research scientists, have shown that there is significant loss of carbon from tundra ecosystems during winter and that these effluxes can represent a considerable percentage of the annual carbon budget in some systems, even changing some ecosystems from net annual carbon sinks to sources. These studies have also shown that there is considerable variation in efflux patterns during the winter period and from one year to the next. We have also found that both wintertime and summertime conditions, experimental or otherwise, can dramatically change the magnitude of C efflux during the non-growing season. We present a review of published and unpublished data from wintertime carbon efflux studies and show temporal, landscape, and geographic patterns of variability. Variation in C efflux at a site is often as great as or even greater than variation across large geographic areas.

The Challenges of Modernity for Reindeer Management: Integration and Sustainable Development in Europe's Subarctic and Boreal Regions

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Reindeer Management is a research project funded by the European Commission during 2001–2004. Reindeer Management aims to address fundamental questions regarding the sustainable use of reindeer (*Rangifer tarandus*) in northernmost Europe in order to enhance the quality of life of local reindeer-herding communities and the appropriate management of living resources. Reindeer management is among the most important competing uses of natural resources and the environment in the Barents Euro-Arctic region. It is also one of the oldest, most resilient forms of livelihood within the region. As competition has increased and the effects have become visible, in particular over the past twenty-five years, there have been widespread reports of overgrazing and calls for significant reductions in the number of animals. The combined effect of these trends is that political discussion about reindeer management policy and its relationship with other uses of the environment (such as tourism, forestry, hydropower, and mining) is intensifying. Until recently, research has been primarily biological, with an emphasis on meat production. In the process, socio-cultural imperatives and traditional knowledge are undervalued. Indigenous herders are reluctant to recognize the validity of regulations derived from state-funded research adhering strictly to agricultural norms.

A Dedicated Canadian Research Icebreaker: A Proposal Submitted to the International Joint Ventures Fund of the Canada Foundation for Innovation

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The assessment of potential impacts of present and future variability and change in the Arctic Ocean (anthropogenic or natural) requires a significant increase in oceanographic research efforts. Because of its arctic responsibilities and as one of the first countries that will be impacted, Canada should play a leading role in the present international effort to study the changing Arctic Ocean. Unfortunately, it does not. Canadian experts in arctic oceanography from universities and federal departments form the core of an effective international research network that has recently completed the highly successful International North Water Polynya Study (NOW). They have designed a coordinated science plan for the international study of the Canadian sector of the Arctic Ocean over the next ten years and beyond. A dedicated research icebreaker is the one obstacle preventing Canada from assuming leadership in the international study of its own Arctic regions and from becoming a major player in the building international effort to study the changing Arctic Ocean. The infrastructure requested consists of the Canadian icebreaker *Sir John Franklin*, her refit and transformation into a state-of-the-art research icebreaker, the specialised scientific equipment necessary to complete her scientific mission, and partial operating funds. This infrastructure is the key to jump-start an urgently needed Canadian-led international program to study the changing Arctic Ocean over the next twenty years.

The Canadian Arctic Shelf Exchange Study

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The extent and thickness of arctic sea ice vary considerably from year to year and over decadal time scales. Assessing the effects of present variability in sea-ice cover on arctic marine ecosystems and regional climate requires a substantial improvement in our understanding of the links between freshwater and sea ice, sea ice and climate, and sea ice and biogeochemical fluxes. The need for data is particularly strong for the shallow coastal shelf regions (30% of the Arctic basin) where variability in the extent, thickness, and duration of sea ice is most pronounced and where arctic marine food webs are most vulnerable to change. Given its arctic responsibilities and as one of the first countries to be affected, Canada should play a leading role in the increasing international effort to study the Arctic Ocean.

Toward that goal, the CASES Research Network was conditionally funded in March 2001 by the Natural Sciences and Engineering Research Council of Canada (NSERC) to conduct the Canadian Arctic Shelf Exchange Study (CASES), an international effort under Canadian leadership to understand the biogeochemical and ecological consequences of sea-ice variability and change on the Mackenzie Shelf.

High-Resolution Lake Sediment Studies from Sawtooth Lake, Nunavut

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South Sawtooth Lake, Ellesmere Island (79° 20' N, 83° 51' W), contains a 4.60 meter-long, annually laminated (varved) sequence that spans the last 2,550 years.

Varves are studied in detail using image analysis of thin sections, which allows the retrieval of the grain size of single sedimentary events. From a calibration data set with instrumental data, we linked the median grain size of the spring-deposited layer with the intensity of snowmelt. The poster presents the reconstruction of snowmelt intensity for the last 400 years. We discuss the correlation with other records of annual climate in the area.

The poster also presents the most recent data obtained from the 4.60 meter-long sequence. We produced a reconstruction of the intensity of anoxia for the entire sequence using observation of sedimentary structures in thin sections. We produced a reconstruction of the summer rain intensity based on the occurrence of sand layers as well: more frequent rainy summers occurred between 650 AD and 1450 AD and may be related to a medieval warm period. Diatoms are present in the record only in the last ~100 years. Organic matter content is mainly driven by terrestrial input. We performed environmental magnetic measurements, namely anhysteretic remanent magnetization (ARM), isothermal remanent magnetization (IRM), and magnetic susceptibility. The sediment is characterized by regular and strong oscillations between two different magnetic mineral assemblages, the first being rich in fine-grained magnetite, the latter characterized by a lower concentration of magnetite but a coarser magnetite grain size. Spectral analysis indicates a significant frequency of ~128 years. We discuss the fluctuations of those proxies throughout the entire sequence and their climatic significance, and we compare them to other records in the Arctic.

An Investigation of Water Loss Mechanisms in Shrinking Thermokarst Ponds near Council, Alaska

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In an attempt to better understand the hydrological dynamics of thermokarst ponds, energy and water balances will be performed for a unique study site near Council, Alaska. Preliminary analyses have revealed that the vast majority of ponds in this area have a smaller surface area compared with aerial photographs taken over the last fifty years. It is important to investigate the cause of this change to determine if this could be a broad-scale result of a changing climate.

The study site encompasses two thermokarst ponds and a network of channels and marshy areas connecting the two ponds. From DC electrical sounding and permafrost boring data, the discontinuous permafrost in the area is typically 20 to 60 meters thick. The first field season yielded data indicating a significant downward hydraulic gradient beneath one of the two ponds, thus indicating an open talik through which water is draining to the subpermafrost aquifer. The magnitude of this water loss component relative to losses through the marshy channels, evaporation at the pond surface, and evapotranspiration from the encroaching floating mat is being quantified.

The downward migration of water through open taliks is suspected to play a significant role in thermokarst pond dynamics by creating an additional water loss mechanism and thereby contributing to the total loss rate. This extra loss mechanism is unique because it is functional throughout the year, whereas the other loss mechanisms are only active seasonally. Ultimately, this contribution will increase water level fluctuations in the pond between recharge periods and continually lower the pond water level throughout the winter. Consistently lower water levels will allow for changes in vegetation and other surface conditions and imply a slow succession from pond to marsh. This is contrary to conceptual models describing thermokarst lakes in higher arctic regions wherein drainage is described as “catastrophic”; therefore, the cyclic nature of thermokarst ponds in areas of thin, discontinuous permafrost, where open taliks are common, is questionable. To help provide clues about the succession from thermokarst pond to marshy depression, a qualitative survey of ponds in the area will be done this 2002 field season.

Heat Budget and Decay of Clean and Sediment-laden Sea Ice off the Northern Coast of Alaska

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Sea ice in arctic coastal regions is often characterized by significant sediment loads that are entrained into the ice during frazil ice formation or through anchor ice rafting over shallow coastal shelves. Sediments in the top layers of sea ice alter the energy balance by reducing the albedo and hence increasing the amount of absorbed shortwave radiation. This process is expected to have an influence on the energy and mass balance of the ice, especially during the melting season when shortwave irradiative fluxes are highest and the snow on the ice has melted away, uncovering the bare sea ice. In contrast, higher extinction coefficients of sediment-laden ice are expected to significantly reduce the amount of internal solar heating. It is presently not clear how these contrasting effects combine in either enhancing or reducing the amount of ice melt and timing of ice decay in arctic coastal areas.

In this study, we will compare the heat budget and decay of clean and sediment-rich sea ice off the coast of Barrow, Alaska. Two sites will be considered in detail: clean coastal fast ice from the Chukchi Sea (CS) as well as sediment-laden ice from Elson Lagoon (EL), with a sediment concentration of a few hundreds of mg/L in the upper 0.2–0.3 m. Thickness and snowcover of the ice were roughly comparable (CS: 1.54 m max. ice thickness, 0.37 m max. snow depth, EL: 1.49 m max. ice thickness, 0.48 m max. snow depth). The onset of melt occurred on approximately 25 May at both sites. After this date, the snowcover melted away in approximately 2.5 weeks. With the subsequent melting of the ice sediment, accumulation at the surface was observed on the EL ice. At both sites, melt ponds were forming and growing in size and depth during the course of the melt season.

We present data of the temperature distribution in the ice, mass balance (i.e., snow and ice thickness, top and bottom ablation), salinity profiles, and measurements of spectral albedo both for clean and sediment-laden ice, together with some model results. Temperature records show that seasonal warming of the EL ice is delayed significantly by absorption of radiation in the uppermost, sediment-laden layers. As compared to the CS ice, the EL ice at 10 cm depth stays at temperatures below –2°C for over seven days longer. However, our observations show that ablation at the top of the sediment-laden ice is faster than for the clean ice, although the initial snow depth was thicker and hence disappeared later.

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*Deceased

Surface Water Biogeochemistry of West Siberian Peatlands and Linkages to Carbon Accumulation and Export

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The West Siberian Plain (WSP) of arctic Russia stores a major fraction of global soil carbon in the form of peat, with annual accumulation rates thought to be on the order of 10^{12} g C/year. Determining locations of present carbon accumulation in this region is essential for understanding future possible carbon-cycle dynamics and globally significant greenhouse gas exchange. Despite their importance, however, locations and amounts of carbon accumulation within the WSP are poorly constrained. The relative amount of carbon sequestered in these peatlands compared with that exported through the adjacent rivers ultimately entering the Arctic Ocean is also of great interest. Biogeochemistry of rivers draining nearby peatlands is important both for understanding the hydrologic exchange between these systems and for determining ultimate sources and sinks of organic carbon. Peatlands export more organic carbon per unit area to the oceans than any other biogeographical land type in the world. Thus, the oceans are an important sink for terrestrial organic carbon as well as nutrients, which are crucial for the high biologic productivity seen in both coastal and interior areas of the Arctic Ocean.

Field campaigns in 1999, 2000, and 2001 were conducted in the WSP. A total of 201 locations distributed throughout the WSP have been sampled, including ninety-eight river, forty-nine peatland lake, forty peat surface, twelve peat pore, and two groundwater samples. Measurements of pH, specific conductivity, and temperature were taken in the field. Filtered water samples were taken both for cation analysis (Ag, As, Al, B, Ba, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Li, Mg, Mo, Mn, Na, Ni, P, Pb, S, Sb, Se, Si, Sn, Sr, Ti, Tl, V, and Zn) and anion/nutrient analysis (NO_3N, NH_4N, total nitrogen, dissolved organic nitrogen, dissolved organic carbon, total phosphorus, Cl, and SO_4). Peatland type and potential for peat accumulation have been quantified through surface water chemistry, particularly the four base cations (Ca, Mg, Na, and K), conductivity, and pH. Preliminary results show relatively small variation in peatland surface water chemistry. Most peatlands are nutrient poor and classify as either bog or poor fen. More variability is seen in the inorganic constituents of river water samples. The relatively low concentrations of Ca and Mg found in rivers underlain by permafrost exponentially increase as sampling sites move into nonpermafrost areas. Regional variability is also seen in the nutrient and organic carbon content of river water.

Implications of Thermobaricity on Buoyancy, Mixing, and Ice Thermodynamics for the Arctic System

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The nonlinear property of thermobaricity in the equation of state for seawater has potentially profound implications for the buoyancy budget of the Arctic Ocean and its shelf waters. The buoyancy budget of seawater is controlled by the budgets for water, salt, and heat. The nonlinear dependence of the thermal expansion upon temperature and pressure, which is termed "thermobaricity," causes seawater buoyancy to be nonconservative. This property may cause static and dynamic instabilities for enhanced vertical mixing and deep-water formation. On the other hand, this phenomenon also has the potential of enhancing stability and "one-sided" cross-frontal transport of physical properties and tracers onto the shelf whenever temperature and salinity gradients tend to be buoyancy-neutral or "spicey."

There are significant implications for the formation and melting of sea ice, as well. A critical analysis of the coupled thermodynamics between polar mixed layer, ice, and atmosphere shows that whereas wind-stirring entrainment of deep warm water can melt ice and form polynyas above a shallow mixed layer, thermobarically-enhanced free convection under net surface cooling conditions can maintain an ice-free surface, provided the mixed layer is deeper than a critical depth, which is dependent upon the relative strengths of haline and thermal stratification below the mixed layer.

To be realistic, physical models and budgets for mixing, transport, and air-sea-ice interaction in the arctic system must account for these phenomena.

How Warm Was the Early Holocene?

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Due to its geographic position, Iceland is sensitive to subtle variations in the intensity of the North Atlantic Drift and deep convection in the Nordic seas. Available evidence already indicates that ice caps expanded in the late Holocene. However, the history of the large ice caps on Iceland remains debated: did they appear only after 5,000 yr BP when most North Atlantic land masses experienced the onset of Neoglaciation, or are they remnants of the glacial ice sheet that covered Iceland at the last glacial maximum, and simply expanded modestly in the late Holocene? Furthermore, there are no continuous records of environmental change from the terrestrial realm for the full Holocene, and little is known about the magnitude of environmental change during deglaciation. We propose to reconstruct environmental change for the past 15 ka, with a primary focus on the status of Iceland's large ice caps through the Holocene and conditions during the early deglacial interval, and a secondary focus on changes in summer temperature in the terrestrial environment since 10 ka. The most reliable archives of terrestrial environmental change are lake sediments in strategically situated basins containing continuous time-series of key proxies.

Lake Hvítárvatn is a glacier-dominated lake located at 420 m on the eastern margin of Langjökull Ice Cap in central western Iceland. The sediment record preserved in Hvítárvatn will allow us to reconstruct the status of Langjökull since regional deglaciation (10 ka). We expect the primary sediment characteristics to reflect the glacial setting in the Hvítárvatn catchment. Deglaciation occurred ca. 10 ka, when the main ice sheet retreated toward the east (Kaldal and Víkingsson, 1991). As ice recession proceeded, capture of this sediment would have occurred suddenly once the Hvítá drainage became ice-free, shortly after 10 ka. If at this time Langjökull had already disappeared, then we would expect a nonglacial depositional environment, dominated by diatoms and fine-grained minerals, with relatively low sedimentation rates. Neoglacial summer cooling began sometime after 5 ka. If Langjökull disappeared in the early Holocene, it would have reformed at some time during Neoglaciation. Even before the Langjökull outlet glaciers reached the lake, products of their erosion would be delivered to Hvítárvatn by fluvial systems draining these glaciers, as well as from Fulakvisl, a stream draining the northeast sector of Langjökull. Sediments in Hvítárvatn would be dominated by glacial silt and fine sand (most clays stay in suspension and are evacuated out the Hvítá drainage), with low organic-matter content, and much higher sedimentation rates than under nonglacial conditions.

Reference

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Understanding Arctic Ecosystem Response to Climate Change: The Role of Individual Species

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In arctic terrestrial ecosystems where plant species richness is inherently quite low, individual species with particular growth characteristics may be crucial in determining community and ecosystem response to climate change. We are investigating two moist tussock tundra sites in northern Alaska that differ in glacial history and have distinctly different plant species composition. The older, acidic site is located on a surface deglaciated 66,000 ya (pH 3–4), while the younger, nonacidic site was deglaciated 10,000 ya (pH 6–7). The older surface supports a relatively species-poor plant community dominated by evergreen and deciduous shrubs (including *Betula nana*), sedges, and mosses (with abundant *Sphagnum* spp.). The more diverse plant community on the younger site is dominated by sedges, minerotrophic mosses, and dwarf shrubs, although shrubs are less abundant than at the older site, and *Betula nana* is rare. Forbs are more abundant and diverse at the younger, nonacidic site.

The addition of N+P caused an increase in deciduous shrub biomass and production at the older site after four years because of the increased abundance of *Betula nana*. However, on the younger site, biomass and production of sedges and forbs increased with added nutrients, and deciduous shrub biomass did not change. Although *Betula nana* can reproduce clonally as well as sexually, to become more abundant at the younger site *Betula* must be able to recruit new individuals via seed dispersal, since there are currently only a few individuals established at the site. In a laboratory experiment, *Betula* germinated at a range of pH levels from 3 to 7, but had the greatest germination success at pH 4. Both seedlings and adults of *Betula* transplanted from the older site survived on the younger surface after one and two years, respectively, with seedling survivorship greater than adult. Preliminary results of a seed sowing experiment suggest *Betula* seeds can successfully germinate at the younger site when other vegetation is removed, although again, success rates may be low. *Betula* seedlings are rare at the older site, but most often found on the edges of frost boils, a landscape feature absent from the younger site. Thus, *Betula* may be restricted from the nonacidic community by lack of safe sites for germination and possibly too few seeds being produced, but could likely establish if disturbed sites and local seed sources were available. Should this occur, the younger site response to increased soil nutrients may converge with that of the older site, with similar repercussions for ecosystem carbon cycling.

Hiukitak River Camps: Integrating Western Science and Traditional Inuit Knowledge in Arctic Field Ecology

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I had a dream last night that Lena was saying to put away the little notebook and not write—to put away the cameras and not take pictures. Instead we were supposed to listen, listen. She was very agitated. We put away our cameras and notebooks but it was difficult (from Victoria Moses' journal, Hiukitak River, 2000).

The University of Minnesota summer class Arctic Field Ecology met with Inuit elders at remote camps during the summers of 1999 and 2000. The activities took place near the mouth of the Hiukitak River, on the eastern shore of Bathurst Inlet, between Umingmaktuuq and Qingaok, Nunavut. Students from the United States and Canada met with Inuit elders and family members for the final week of a four-week ecology course. Students listened, asked questions, hiked, and heard stories about Inuit life on the land, Nuna, as they added to their science-based learning with knowledge from the Inuit inhabitants of Nunavut.

The combined Inuit and Western educational program serves to: (1) open students to the wealth of traditional knowledge, (2) ease research access to Native-owned lands, (3) inform Native people as to the potential role of modern science in land and resource management, (4) provide employment and new skills to Native people, and (5) educate a new generation of Natives and scientists who can work together to solve land-management problems of the future.

Ultimately, the learning experience is profoundly influenced by the personalities of the teachers and students. We present the people involved, the knowledge that was shared by the elders as an attempt to preserve Inuit ecological knowledge of the Bathurst Inlet area, and we summarize the points that best integrated the content from the Arctic Field Ecology course with the knowledge provided by the elder Inuit. Much of the material we present comes from staff and student photos, journal entries, and recollections of the experience. It documents some of the things we learned from our Inuit instructors, Lena Kamoayok and Sandra Eyegetok.

We are developing a framework to integrate similar material into the current study: Biocomplexity of arctic frost-boil ecosystems, an investigation of climatic and biotic controls and feedbacks associated with ecosystem patterns and processes in frost-boil ecosystems.

Energy and Mass Balance Observations in the Land-Ice-Ocean-Atmosphere Environment of Barrow, Alaska

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There is substantial recent evidence that the Arctic climate is warming. The sea ice cover also shows signs of diminished extent and thickness. Changes and variability in the state of coastal ice covers, including tundra lakes, which account for up to 50% of the coastal zone in Siberian and North American arctic lowlands, are of particular importance in this context. Studies of ice anomalies and variability in the onset of ice melt and freeze-up show that the individual components of the system may interact strongly with one another due to the differences in surface albedo between the prevailing surfaces (e.g., sea ice, tundra, lake ice) and the resulting contrasts in the input of solar energy. The co-evolution and interaction of the mass and energy balance of these different coastal surface types is largely unexplored.

To investigate these issues, we are carrying out a cooperative research program along the Arctic coast near Barrow, Alaska, that is concentrating on the measurement of a comprehensive suite of sea ice properties, including the heat and mass fluxes at the lower and upper ice surfaces. Such information is critical to understanding the role of the ice cover in the climate system and its importance as indicator and modulator of climate variability and change. Corresponding measurements of the heat balance associated with the tundra and coastal lakes have also been obtained.

On-site measurements have been made from November 1999 through late June 2001 at five locations, including a freshwater lake, a seawater lagoon, shorefast sea ice in both the Chukchi and Beaufort sides of Point Barrow and a tundra site about 1 km inland. These sites were selected to encompass the range of surface conditions found in the Barrow area. Automated monitoring stations have been deployed each year on the ice during late fall, as soon as it was stable enough to work on. Intensive field sessions have been carried out during April and from late May through the end of June in order to characterize the development of the spring/early summer melt season when conditions are highly variable and nonuniform, and the interactions between the ice, ocean, and atmosphere are greatly accelerated. Among the measured and derived quantities are the seasonal evolution and variability of ice thickness, snow depth, melt pond areal coverage and depth, temperature gradients and conductive heat transfer in the ice, ice salinity and salt flux, surface albedo, and ice transmissivity. In addition, several photographic survey flights have been flown during the onset of melt. These flights provide photographic links among the surface sites and allowed us to extrapolate the surface-based observations to a 10 km size scale. The dates for the establishment and decay of the ice cover were obtained from autonomous web camera observations that provided year-round images of the near-shore sea ice. We present an overview of our program with illustrations of the changes in surface conditions together with representative results of the observations.

The Glacial and Sea Level History of Wrangel Island, Northeast Siberia

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Detailed fieldwork on Wrangel Island provides the first field evidence to adequately test the hypothesis of the existence of an East Siberian Ice Sheet during the Last Glacial Maximum (LGM). Field evidence indicates that the extent of ice on Wrangel Island during the LGM and possibly older glaciations was limited to a few north-facing cirques in the highest mountains. Cosmogenic isotope ages (10Be and 26Al) on bedrock indicate that the central mountains of Wrangel Island have been ice-free for at least the last 35 ka and possibly longer. Tors, commonly forming columns 10 m high, are ubiquitous throughout the mountains and appear to never have been overrun by ice. Eighteen forthcoming cosmogenic isotope ages will provide more insight as to the exposure age of the tors. The lack of glacial landforms and deposits in any major river valleys further supports a limited ice extent.

Marine shorelines, ancient beach ridges, and barrier islands on the northern plain are recognized on the ground as well as on air photos and satellite images. Associated with these landforms is lagoon and marine sediment (up to 40 m above sea level and 20 km inland). D/L aspartic amino acid ratios on mollusks, infinite radiocarbon ages on wood and normally magnetized sediment indicate a mid-Pleistocene age for the deposits. The shorelines are interpreted to be eustatic, not isostatic, in origin.

Radiocarbon dates on mammoth bones, teeth and tusks, and other animals (rhinoceros and bison) yield ages that range continuously through time from >38 ka to 3,700 years, indicating the local presence of large mammals during the LGM and most of the Holocene (Vartanyan et al. 1993). These data preclude the presence of an East Siberian Ice Sheet during the LGM and probably over the past half million years.

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Local Dimensions of Climatic Change: West Greenland's Cod-to-Shrimp Transition

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The rise and fall of West Greenland's cod fishery, ca. 1920–1990, reflects interactions between climate, ecosystem, and society. The fishery arose when the Irminger Current brought in cod and allowed spawning off West Greenland. Cod became a mainstay of the economy, but this fishery declined steeply in the 1960s, then vanished a few decades later. Overfishing together with climatic change drove down the cod stocks. Social factors filtered the consequences for Greenlanders.

As cod declined, shrimp fishing expanded steadily and became the export pillar of Greenland's economy. Some communities benefitted, while others were set back. In the cod-to-shrimp transition, we see two patterns that characterize the human dimensions of climatic change:

- complex interactions between physical, ecological, and social systems; and
- a prominent role played by social capital.

Our analyses tell this story in steps, linking climatic variation to ocean conditions, ecological interactions, economic activities, and ultimately to human communities.

Ocean-Atmosphere-Ice Interactions

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Ocean-Atmosphere-Ice Interactions (OAII), a component of the Arctic System Science (ARCSS) Program, was established in 1991. Since its inception, the thrust of OAII has been to investigate the arctic marine environment in the context of global change and the overall goals of ARCSS.

That the Arctic is highly sensitive to, and has an impact on, global climate out of proportion to the relatively small portion of global area that it occupies is a proposition that is easy to justify. Obtaining appropriate data from the arctic marine environment, however, can be costly and difficult. These factors plus the interdisciplinary thrust of the ARCSS Program require a significant degree of planning, consensus building, and project development. The OAII Science Steering Committee (SSC) and Science Management Office (SMO) exist in order to assist with these activities.

So far, the OAII component of ARCSS has involved more than one hundred principal investigators and several major research projects including the ongoing Surface Heat Budget of the Arctic Ocean (SHEBA) and the Western Arctic Shelf-Basin Interactions (SBI) projects. The OAII SSC and SMO have also been instrumental in nurturing the trans-ARCSS Study of Environmental Change (SEARCH) initiative.

Out-of-Phase Glaciation in Central Beringia during Marine Isotope Substages 5e/d or 5a/4?

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The rapid expansion of glacial ice across parts of the Arctic while eustatic sea level remains high, or the out-of-phase glaciation hypothesis, is a compelling new theme to emerge from Quaternary research in the last ten years. Huston et al. (1990), Roof (1995), and Brigham-Grette et al. (2001), demonstrate that the mountains of Beringia have been rapidly glaciated (having undergone glacierization) during several of the marine-oxygen-isotope interglaciations in the mid to latter part of the Quaternary. The advance of late Wisconsinan ice was restricted to mountainous areas across Beringia during the LGM (e.g. Kaufman et al. 2001; Gualtieri et al. 2000), thus preserving an extensive record of older glacial deposits that date sometime during the last interglacial, isotope stage 5.

Deposits of substage 5e are represented on the Alaska coast by marine deposits of the Pelukian transgression (Brigham-Grette and Hopkins, 1995) and a later high sea-level event within stage 5 represented by the Flaxman formation. Extensive stage 5 deposits can also be found on Chukotka Peninsula, northeastern Siberia. An analysis of the stratigraphy and alloisoleucine/isoleucine ratios obtained from fossil mollusk shells by Brigham-Grette et al. (2001) have indicated post-substage 5e high sea-level stands within these sequences, preceded by a rapid and intense glaciation in northeast Russia and St. Lawrence Island. However, the epimerization reaction of L-isoleucine to D-alloisoleucine occurs at an insufficient rate to separate out intra-stage 5 events.

Gas chromatographic (GC) analysis has the ability to separate D/L ratios of all common amino acids found in mollusk shells. Goodfriend et al. (1996) analyzed amino acid ratios in bivalves of arctic marine deposits and determined that the higher racemization rate of aspartic acid provided significantly higher temporal resolution. This method, not widely applied to the Arctic, has been used to reanalyze shells from high sea-level stands of substage 5e and post 5e collected from the Flaxman formation, Alaska, the Val'katlen and Nunyamo sections, northeast Russia, and marine deposits of St. Lawrence Island. To support our results, electron spin resonance (ESR) geochronology was also used to serve as an independent proxy to test the reliability of the GC ratios. Our results indicate that local valley glaciers across the Chukotka Peninsula advanced during the transition between substage 5a and stage 4. Chukotkan valley glaciers were most extensive between about 80–70 kyr., corresponding with the collapse of a Barents/Kara sea-ice sheet proposed by Siegert et al. (2001) and Mangerud et al. (2001). The alternate timing of these two events strongly suggests a link between ice-sheet collapse in central Russia and valley glacierization to the east in Beringia.

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The Summer Air Temperature Field near Barrow, Alaska: Preliminary Results

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The human impact on local climate is most dramatically evidenced as the "urban heat island." Warmer temperatures are of particular concern in regions underlain by ice-rich permafrost, since enhanced ground heat flux can cause permafrost degradation, ground subsidence, and damage to infrastructure and buildings. Beginning in mid-June 2001, fifty-four temperature data loggers were installed in the vicinity of Barrow, Alaska (71.3° N, 156.5° W), a village of ~4,500 people on the Arctic coastal plain of Alaska. About half of the instruments are in the "urban" area and located near sites of high winter energy use such as schools, power plants, and shopping centers. The remainder are distributed across the ~150 km^2 study area to measure the background temperature field. Each instrument mast consists of a two-channel data logger, which measures and records temperature on an hourly basis. One high-resolution thermistor is installed in a radiation shield mounted 1.8 m above the base and measures air temperature; the other is inserted 5 cm into the organic mat and measures near-surface ground temperature. In addition, a meter stick is installed on some masts to measure snowcover thickness in winter.

This preliminary study examines the summer (mid-June to mid-August) air temperature field only. During this period, the mean daily temperature across the study area was 2.5°C, with an average daily temperature range of 5.6°C. Our preliminary conclusions are: (1) The summer air temperature field is strongly influenced by local meteorological conditions such as cloud cover and wind direction. Large differences in mean daily temperature and daily temperature range are observed across the study area on clear days. (2) A highly localized temperature gradient can develop along the coast of Elson Lagoon or the Chukchi Sea. This maritime effect is determined by wind direction and appears to develop primarily during the day. (3) As expected, there is no strong urban heat island effect in summer. (4) The summer of 2001 was significantly cooler than normal, especially late in July and in August.

Effects of Anthropogenic Nutrient Enrichment on Chlorinated Fatty Acids in Aleutian Amphipods and Implications to Steller's Eiders

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Development activities related to economic diversification are increasing in the Arctic. The U.S. breeding population of Steller's eider (STEI) is a threatened species of sea duck that winters and feeds on the Alaska Peninsula and eastern Aleutian Islands. It is commonly found in close proximity to developed areas, specifically in correlation to seafood processing outfall lines that discharge into the nearshore ecosystem. The increased nutrient levels and organohalogens associated with seafood processing waste may have significant effects on the fatty acid composition of marine invertebrates, the main prey items of the STEI. In particular, chlorinated fatty acids (CFAs), identified in fish both from Alaskan and Scandinavian waters, are major contributors of extractable, organically bound chlorine in animal lipids and may have toxic effects at higher trophic levels through bioaccumulation. While CFAs may occur naturally, anthropogenic sources may raise their concentration in living tissue. In toxicological studies of CFAs, the most pronounced effects have been found in reproductive processes, particularly in the male reproductive tract.

Currently, no data exist on the levels of CFAs in amphipod populations within the winter feeding grounds of the STEI. This project has the following goals:

1. To determine and compare the distribution and profiles of nonchlorinated fatty acids and CFAs in marine invertebrates found in developed (impacted) versus nondeveloped (nonimpacted) areas of the eastern Aleutian Islands.
2. To determine the rate of turnover of CFAs versus nonchlorinated analogs in invertebrate populations using radio-labeled fatty acids.
3. To determine the fate and diversity of CFAs at higher trophic levels using radio-labeled fatty acids.
4. To determine if CFAs are targeting the male and female reproductive system in a model organism and if so, what cell population(s).

If CFAs are assimilated like nonchlorinated fatty acids, are incorporated into membrane lipids, and are recalcitrant to catabolism, they may give rise to ecotoxicological effects when released to the environment and accumulated in biota. Currently, these effects are unknown.

Towards Improving the Representation of Ocean Mixing Associated with Summertime Leads: Results from a SHEBA Case Study

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The effects of leads or openings within sea ice are crudely represented in climate models. In particular, there are sub-gridscale processess associated with leads that affect ocean stability, vertical mixing, and ultimately the sea-ice mass budget. Ocean general circulation models do not usually differentiate between ice- and lead-covered regions. In this study, we attempt to isolate the most important features associated with the sub-gridscale effects of summertime leads. Ice/ocean mixed-layer model simulations are performed for a case study from 28 June–18 July 1998 from the SHEBA field project. The model used for these simulations is a single-column version of the NCAR Community Climate System Model. During the time of the case study, SHEBA observations indicate that calm winds occurred and coincided with a warming and freshening of a lead in the vicinity of the SHEBA camp. A subsequent storm caused the warm, fresh lead water to be mixed under the sea ice.

In control integrations of this event, we use a traditional method in which a single-ocean, mixed-layer calculation is forced with fluxes that are aggregated over the ice and open water portions of the domain. This is compared to simulations in which separate mixed-layer calculations are done for the lead and under-ice regions. We find that it is particularly important for the surface of the lead to be realistically embedded within the ice cover and thus isolated from the under-ice system. With the multiple mixed-layer calculation method, better simulations of the lead and under-ice vertical temperature and salinity profiles result. This feeds back to the ice-mass budgets, resulting in considerably different lateral melt rates and open-water formation.

Pronounced Climatic and Ecological Changes in Alaska during the Past 2,000 Years

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High-resolution geochemical, pollen, and charcoal analyses of lake-sediment cores from two Alaska lakes provide new evidence for marked environmental variations during the past two millennia. Paired oxygen-isotopic analyses of abiotic carbonate and benthic-ostracode shells from the sediments of Farewell Lake (62° 33' N, 153° 38' W, 320 m a.s.l.) reveal three time intervals of comparable warmth: AD 0–300, 850–1200, and post-1800, the latter two of which correspond to the Medieval Climatic Anomaly and climatic amelioration following the end of the Little Ice Age (LIA). A marked climatic cooling occurred around AD 600, coinciding with extensive glacial advances in Alaska. Comparisons of this temperature record with ostracode trace-element ratios (Mg/Ca, Sr/Ca) suggest that colder periods were wetter and warmer periods drier. Pollen data from this site, which is well below the altitudinal limits of any tree species in that region, do not show clear signals of vegetational change related to the LIA or the twentieth-century warmth. In contrast, a high-resolution pollen record from Grizzly Lake (62° 43' N, 144° 12' W, 720 m a.s.l.), located near the altitudinal limits of *Picea mariana* (black spruce) and *Betula papyrifera* (paper birch), suggests abrupt vegetation shifts in the past 1,000 years. At the onset of the LIA, these tree species declined markedly in favor of species characteristic of alpine tundra and disturbed sites. Vegetation recovered abruptly in response to climatic warming at the end of the LIA. Charcoal analysis of the same sediment core suggests that the LIA climatic cooling caused vegetation dieback, leading to increases in fuel availability and fire occurrence. Overall variations in this paleoecological record are similar to those in the average annual temperature of the Northern Hemisphere.

Spatial and Temporal Variability of Arctic Surface Temperature over the Last 400 Years

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Spatial networks of high-resolution (annual–decadal) paleoclimate records from throughout the Arctic can be used to distinguish different modes of variability and trace their behavior back in time. A compilation of primarily annual-resolution records from varved lake sediments, tree rings, ice cores, and marine sediments provided a view of circumarctic environmental variability over the last 400 years. Average arctic summer temperature documents dramatic twentieth-century warming that ended the Little Ice Age in the Arctic and caused dramatic retreats of glaciers, melting of permafrost and sea ice, and alteration of terrestrial and lake ecosystems. Unfortunately, combining records into a single arctic average results in the loss of valuable spatial information. Empirical orthogonal function (EOF) analysis of the original time series confirms that the dominant signal is a circumarctic temperature trend with twentieth-century warming common to all study locations. Other modes of variability are also apparent, including one with spatial and temporal patterns similar to the Arctic Oscillation (AO). Currently, PARCS researchers are coordinating existing data sets for new EOF analysis in order to increase confidence in these reconstructions of natural variability, as well as discriminate between internally and externally forced arctic climate variability. Additional records are critically needed in order to maximize the length and spatial density of these networks, so that we may achieve full precision in identifying natural modes and accurately measure their range of variability.

A 2,500-Year Long Temperature-Sensitive Tree-ring Record in Far Northeastern Eurasia

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We have developed a more than 2,500-year long temperature-sensitive tree-ring record in far northeastern Eurasia, at the center of the largest longitudinal sector of the Arctic lacking such a record. This record is based on material from a network of tree-ring sites in the Indigurka coastal region, and is well replicated through almost all of its length. During the course of collecting material for this chronology, the oldest known tree in the Russian Federation was found (1,104 years). A number of the trees we used have more than 700 rings, improving the chances of capturing multidecadal to century-scale variability. The widths of annual rings of larch trees from this region contain a remarkably clear and strong summer temperature signal. Sixty-six percent of the variance of early summer (6 June through 7 July) temperature is accounted for by the tree-ring width index series, 60% in cross-validation (Hughes et al. 1999). There are also strong correlations between the tree-ring chronologies and temperature from June through August. The record is characterized by variability on several time scales, including a twentieth century that is significantly warmer than any other period of similar length, a clear indication of the effect of large explosive volcanic eruptions on summer conditions in the Arctic, and a sharp cooling after 1976. While many of the twenty coolest early summers in the reconstruction since AD 1400 occur within a few years after major explosive eruptions from low-latitude volcanoes, several of the twenty warmest early summers followed major explosive eruptions from high-latitude volcanoes. We found no evidence to support the suggestion that these reconstructed warm summers represented a rebound in tree growth from volcano-induced cold conditions. Useful information on the climate effects of volcanic eruptions may not be limited to years with unusually cool summers, but may also be extracted from reconstructed unusually warm summers. One of the most notable features of the record is a series of very small or missing rings implying a period of several very cold summers commencing in AD 536. This is also seen approximately 2,000 km to the west on the Taymyr Peninsula (Nuarzbaev and Vaganov 1999) and much further south, in Mongolia. It also coincides with a number of other meteorological events, sometimes collectively called "the AD 536 dust veil event" (Baillie 1994). In the case of our material, growth was so disrupted that several of the trees sampled lack clear ring structure for several years. Our results confirm that this was a very unusual event whose human consequences would be severe were it to recur in modern conditions. It is, therefore, worthy of further study.

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Seward Peninsula Radio Telemetry Project

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A radio telemetry system has been installed on the Seward Peninsula as part of the Arctic Transitions in the Land-Atmospheric System (ATLAS) project. Currently the Water and Environmental Research Center maintains eight meteorological stations on the Seward Peninsula, three located near Council, three near Kougarok, and two midway between Council and Nome. The radio telemetry installation allows for real-time access to four of these stations and will be expanded to include all eight during the spring of 2002. The advantages of this radio system are that it allows two-way access to data logger sites, is easily expandable, can handle large amounts of data, and is inexpensive to operate once installed. In addition to the radio network installation, software has been developed that posts the current meteorological conditions on the Internet for other researchers and the general public to view. These sites are also being utilized by the local pilots and the National Weather Service to improve weather forecasts for the Seward Peninsula. This has helped to further improve our relations with the local community. The first winter of operation has allowed us to learn more about the system installation and work through some of the problems associated with operating remote radio sites in Alaska. The current conditions for our Seward Peninsula meteorological stations may be viewed at www.uaf.edu/water/projects/atlas/metdata/atlasmetsitemap.htm.

Near-real-time telemetry of meteorological data has improved our capability to monitor weather processes, better enabling us to respond to extreme events and allowing more efficient planning of field excursions. Utilizing all of these field data, we will refine our coupled model of thermal and hydrologic processes to address questions related to physical differences among watersheds existing in slightly different climatic regimes of the Arctic.

East Greenland Shelf Records of Natural Climate Variability on Millennial-to-Decadal Time Scales

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Sediment cores from the East Greenland shelf in the vicinity of Denmark Strait are being studied to extract records of natural variability in sea-ice conditions, sea-surface and sea-floor temperatures, and glacier fluctuations from the last deglaciation through the Holocene. AMS radiocarbon dates on foraminifers and molluscs and the occurrence of the Vedde Ash (11,980 ± cal yr BP) and Saksunarvatn tephra (10,180 ± cal yr BP) provide the chronologies for the cores. Sedimentation rates at the sites allow decade-to-century reconstructions throughout the last 16 cal. ka, although not in a single core. Stable O and C isotopes in planktic and benthic foraminifers, foraminiferal assemblages, sediment analyses, and ice-rafted detritus (IRD) are the environmental proxies used to reconstruct the paleoceanographic and glacial histories of the area. This poster shows the reconstruction of the Greenland Ice Sheet margin during deglaciation, evidence for glacial meltwater spikes and Atlantic Intermediate Water influx during GS-2, GI-1 (Bølling-Allerød), evidence supporting continued Atlantic Intermediate Water influx and a large meltwater spike during GS-1 (Younger Dryas), and evidence for the southward advance and fluctuations of the arctic sea-ice margin in the Holocene.

Spatial Heterogeneity of Decadal Tundra Vegetation Changes in Northern Alaska

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Normalized Difference Vegetation Index (NDVI) has been shown to be one of the major indicators of vegetation features such as LAI and biomass in various regions. The features of daily repeating and large spatial coverage makes the NDVI derived from NOAA-AVHRR sensors a useful source for monitoring spatial gradients and temporal changes in vegetation for large and remote regions like the circumpolar Arctic.

In this study, we examined the trends and intensity of interannual changes of AVHRR-derived NDVI along latitudinal gradients, and across vegetation types and bioclimate subzones, on the North Slope of Alaska over the last decade, from 1991–1999. There are several approaches in this study:

1. Processing AVHRR-NDVI data and extracting sample sites: based on the USGS AVHRR biweekly composites, we further corrected the NDVI data using BISE cloud filter and temporal co-registration, then we calculated annual peak NDVI (Peak-NDVI) and Time-Integrated NDVI (TI-NDVI) for the study areas from 1991–1999. To provide more detail on decadal NDVI dynamics and trends in vegetated areas for various categories, we carefully located and defined forty-one homogenous tundra sample sites based on CIR and MSS images, averaging 9 km^2 for each sample site.
2. Latitudinal gradients: We summarized 10-year Peak-NDVI, TI-NDVI, and their temporal variation (standard deviation) with 0.1º latitude interval along two Alaskan transects. The analysis suggested similar latitudinal patterns for both indices: a relatively low and flat NDVI between 71.2º and 70.40º N, constant increase of Peak-NDVI and TI-NDVI from 70.4 to 69.40º N, high and flat NDVI from 69.4 to 69.10º N, and a slight drop from 69.4 to 68.40º N along the gradient. Higher variations in Peak-NDVI can be found near the coast and along the Oumalik-Sagwon transitional zone, while higher variances in TI-NDVI were mainly located in the southern part of the transects.
3. Vegetation types: We categorized the sample sites based on four major tundra types in the region, namely shrub tundra, moist acidic tundra (MAT), moist nonacidic tundra (MNT), and sandy tundra. It is shown that higher variance in Peak-NDVI occurred in sandy tundra and MNT, while lowest for MAT and shrub tundra; in contrast, highest variance in TI-NDVI was found for shrub tundra, followed by MAT, MNT, and sandy tundra. These patterns indicate that changes of NDVI for graminoid-dominated tundra mainly occurred during peak growing season, while the changes for shrub-dominated tundra mainly occurred as earlier onset and possibly later senescence.
4. Bioclimate subzones: We summarized both Peak-NDVI and TI-NDVI according to three bioclimate subzones, namely prostrate dwarf shrub zone (Subzone C), erect dwarf shrub zone (Subzone D), and low shrub zone (Subzone E) in the region. The highest temporal variance in Peak-NDVI occurred in Subzone C, followed by Subzone D and Subzone E; in contrast, highest temporal variance in TI-NDVI was found in Subzone E, which is much higher than Subzone C and Subzone D. The results indicate that changes of NDVI in higher arctic mainly occurred during peak growing season, while the changes in lower arctic mainly occurred as a lengthening of the growing season.

Radiative Transfer in Atmosphere-Sea Ice System: Significant Enhancement of the Solar Irradiance Across the Air-Sea Ice Interface

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The change in the index of refraction across the interface between the atmosphere and the underlying ocean (or ice) affects the transport of radiation throughout this coupled system. This study shows that the downward irradiance can be significantly enhanced across this interface. A quantitative theoretical examination of this effect shows that the enhanced downward irradiance (EDI) depends primarily on the change in the index of refraction across the interface, the single scattering albedo and the phase function of the underlying ice, the solar zenith angle (SZA), as well as cloudiness. Radiative transfer simulations indicate that for multiyear sea ice, the increase in downward irradiance across the air-ice interface can be as large as $EDI^{clear} = 0.38\ W \cdot m^{-2} \bullet nm^{-1}$ in the visible region under clear-sky conditions when the SZA is 65°. For cloudy conditions the enhancement is somewhat smaller ($EDI^{cloudy} = 0.26\ W \bullet m^{-2} \bullet nm^{-1}$). Integrated over the spectral range for photosynthetically active radiation (PAR, 400–700 nm) the EDI effect through the air-ice interface may become as large as $EDI_{PAR}^{clear} = 90\ W \bullet m^{-2}$ for clear and $EDI_{PAR}^{cloudy} = 63\ W \bullet m^{-2}$ for cloudy-sky conditions. When the SZA is 25°, these values increase significantly and may become as large as $EDI_{PAR}^{clear} = 238\ W \bullet m^{-2}$ and $EDI_{PAR}^{cloudy} = 190\ W \bullet m^{-2}$. This EDI effect has strong influence on radiative energy transfer throughout the atmosphere-sea ice-ocean system.

Species Migration and Ecosystem Response to Changing Climate: Issues for Alaskan Boreal Forest

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A major challenge in ecology is to understand the causes, mechanisms, and ecosystem consequences of species migration in response to global environmental change. In this study, we examine the dynamics and potential ecosystem effects of range expansion of lodgepole pine (*Pinus contorta* var. *latifolia*) along its northern distribution limits. We document large increases in post-fire pine populations along the distribution edge. These data provide evidence for current migration activity and illustrate the potential for rapid range extension to occur through the growth of outlier populations. Continued migration of pine into Alaska is likely to have strong ecosystem effects. Using a landscape model of fire and succession, we illustrate that changes in pine distribution may alter fire disturbance regime in Alaska under current and warming climate scenarios.

Plant Communities, Soil Properties and Frost Heave in Cryoturbated Arctic Tundra

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Vegetation and soils of the arctic tundra are strongly influenced by cryoturbation, or soil disturbance caused by ice formation in seasonally frozen soils (Washburn 1980). Frost boils, which are circular ground features as a result of frost heave, display tight linkages among vegetation, soil, and frost heave. They represent a natural disturbance regime with major soil movement occurring twice a year. Cryoturbation inhibits or leads to only very slow plant succession on frost boils (Svoboda and Henry 1987). So far, many different plant successional stages have not been described or linked to soil characteristics. Vegetation and soil data will be analyzed along different environmental gradients to give insight as to how plant and soil attributes change with different temperature and moisture regimes.

Frost heave, a major component in the frost-boil ecosystem, is strongly influenced by ground surface temperature. Changes in soil-surface temperature caused by insulation or exposure of the ground should alter the heat flux between soil and air and lead to changes in the cryoturbation regime and other ecosystem characteristics. The amount of frost heave and thaw depth should reflect changes in heat flux, initiated by alteration of the soil-surface temperature. However, these manipulations remain to be performed to gain a better understanding of the relationships among soil-surface temperature, frost heave, vegetation, and soil properties. These hypotheses will be tested by manipulating soil-surface temperatures on, and in between, frost boils during different seasons.

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A Record of Holocene Glacial Activity from Proglacial Waskey Lake, Southwestern Alaska

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Mountain glaciers are sensitive indicators of climate change, fluctuating in response to the integrated effects of changing temperature (mainly melt season) and precipitation (mainly snowfall) over time scales of decades or longer. Sediment deposited in glacier-fed lakes affords a continuous record of up-valley glacier fluctuations. The sediment also records paleoenvironmental conditions prior to the Neoglacial period when glaciers were less extensive than present, and climate akin to that of anticipated greenhouse warmth. Although sediment cores from glacier-fed lakes have been used successfully to reconstruct Holocene glacier activity throughout the Arctic, this approach has not been used previously in Alaska. In this study, we combined an analysis of a sediment core with moraine mapping to reconstruct the history of glacier fluctuations in the Waskey Lake drainage, southwest Alaska.

Waskey Lake (informal name) occupies a steep glacial trough near the north flank of Mt. Waskey, the highest summit in the Ahklun Mountains. The lake is fed by six active glaciers that together cover 20% of the 23.5 km^2 drainage basin. The lake is 0.2 km^2 at an elevation of 500 m asl. Two cores were taken from near the deepest part of the lake at 8 m water depth. We focused on WL-1, a 6.5 m-long core extending to 11.0 cal ka. Seven AMS ^{14}C ages on vegetation macrofossils and a prominent tephra that we correlate with the eruption of Aniakchak Volcano provide secure chronological control. We interpret downcore changes in lithology, clay mineralogy, magnetic susceptibility (MS), organic carbon (OC), and grain size (GS) as changes in extent of glacier ice cover up-valley.

The most significant trends include: (1) relatively high MS, low OC, low kaolinite: quartz, and sand-rich sediment indicate ice-proximal sedimentation from 11.0 cal ka to ~9.2 cal ka; (2) between ~9.2 and 3.3 cal ka, low MS, high OC, clay- and fine-silt-rich GS, high kaolinite:quartz, and low sedimentation rate indicate an absence of glaciers in the drainage and an increase in biologic productivity; (3) at ~3.3 cal ka, MS increases along with the sedimentation rate and the proportion of coarse silt, and OC decreases, as glaciers expand in the drainage basin. This trend culminated ~500 years ago when snowline lowered ~35 m below today's, glaciers expanded to nearly twice their present size, and moraines were deposited several hundred meters beyond the modern glacier fronts.

Rangifer vs. *Rangifer*: Ecological and Socioeconomic Consequences of Caribou Expansion onto Reindeer Ranges in Western Alaska

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Over the last century, reindeer herding has provided a major economic base in villages of western Alaska in addition to representing an important component of their cultural identity. Concomitant with the explosion of the Western Arctic Caribou Herd, now numbering almost 500,000 animals, there has been an unprecedented westward shift in the herd's migratory patterns onto reindeer ranges on the Seward Peninsula. As a result of the caribou expansion there are large areas of reindeer range where lichens have been largely eliminated and where approximately half of the reindeer have been lost due to out-migration with caribou. Our interdisciplinary study is driven by this natural experiment in an effort to examine and model these substantive ecological and socio-economic impacts on local communities. The project examines reindeer herding as a basic industry in a region where few alternatives to locally based industries exist. We examine traditional knowledge regarding reindeer herding through oral history interviews, in an attempt to examine ecological constraints over herding during the past century and to understand how socio-ecological processes have shaped the current state of reindeer husbandry in Alaska. Our ecological studies focus on field experiments and monitoring programs that examine the environmental conditions controlling reindeer and caribou distributions throughout the annual cycle. Finally, we combine ecological and economic information to design herd management strategies to mitigate the impacts of caribou on the viability of reindeer herding.

Circumpolar Soils Map and Supporting Database

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An international group has been working on a circumpolar database. The latest draft of this map will be presented and discussed as needed, as will the supporting data that goes with the map. One of the recent objectives has been to improve the Alaska part of this by tying into the data collected by Dr. Ping and others on the North Slope.

Affect of Three Seasons of Elevated Soil Temperature and Water Table Manipulation on the Coastal Arctic Tundra Ecosystem Near Barrow, Alaska

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Northern arctic ecosystems comprise 14% of the earth's landmass but make up 25–33% of the terrestrial soil carbon pool. Under conditions of changing climate, these ecosystems have the potential to affect local and global carbon budgets. In order to understand how northern ecosystems will respond and adapt to predicted climate changes and to improve climate and ecosystem models, an elevated soil temperature and water-table manipulation was installed in the arctic coastal tundra ecosystem at Barrow, Alaska at the beginning of the 1999 summer growing season and maintained until the end of the 2001 summer season. The experiment is a complete factorial design of six treatments: a control, elevated soil temperature, elevated water table, lowered water table, elevated temperature and elevated water table, and elevated temperature and lowered water table. There are three replicates of each treatment in three blocks for a total of eighteen experimental plots. The water-table manipulation and soil temperatures of treatments were determined based on predicted changes in temperature and water table for 2050 from GCM predictions. Temperatures are expected to increase while an increase as well as a decrease in water table has been forecast. Measurements taken during the 1999 to 2001 seasons include CO_2 fluxes, active-layer depth, and water-table depths.

Changes in the soil carbon balance were detected after one full season of manipulation and these changes continued for the next two seasons, even though the local weather varied significantly from year to year. Ecosystem respiration was most affected by elevated soil temperatures, showing significantly higher CO_2 efflux compared to the controls and water-table manipulations for the duration of the experiment. Gross ecosystem exchange was also affected, with a significant increase in GEE with the presence of an elevated water table. Not all treatments had large effects, as lowering the water table alone did not appreciably affect CO_2 fluxes compared to the controls. With a decreased water table and elevated temperatures, the increased CO_2 efflux may be an indication of increased microbial activity due to soil aeration, while the elevated water table plots may suppress decomposition and encourage additional plant growth. These results give an indication of ecosystem response to changes in precipitation and elevated temperatures. Depending on future conditions, there is the possibility of large changes in the soil carbon pool of this region.

An N-Factor-Based Map of Active-Layer Thickness in the Kuparuk River Basin, Alaska

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The n-factor, or ratio of temperature at the ground surface to that in the air, has been used extensively in cold-regions engineering problems. Although this parameter has considerable potential for mapping geocryological phenomena, lack of data on surface temperature under natural land covers has impeded its widespread use. Recent advances in data-logger technology permit measurement of soil-surface temperature at high temporal and spatial intervals. Arrays of temperature loggers were installed at the surface in a series of sites in north-central Alaska with representative soil and vegetation characteristics. N-factors were calculated from air and surface temperature data and used with observations of soil thermal and moisture properties to construct high-resolution maps of active-layer thickness over a 26,278 km^2 area. Comparative analysis indicates that the n-factor-based maps produce spatial patterns and volumetric estimates of thawed soil similar to other methods, but at significant savings of time and labor in the field. The maps should be of considerable interest to a wide audience, including ecologists, geographers, geologists, and hydrologists.

Synthesis of the Effects of Climate Gradient and Associated Factors on Vegetation in the Alaskan Arctic at the ATLAS Sites: 1998–2001

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The Arctic Transitions in the Land-Atmosphere System (ATLAS) project was developed to determine the effect of changes in climate on key parameters of arctic ecosystems. The focus of our group has been to determine the effect that climate change may have on arctic vegetation and closely associated factors. Specifically, we have examined the effects of summer warmth on leaf area index (LAI), total aboveground phytomass, and normalized difference vegetation index (NDVI) across the three arctic bioclimate subzones (Subzones 3–5) in northern Alaska and into the subarctic at Council. We have also investigated the relationship of these factors to differences in geologic substrate. We conducted our field research at ATLAS sites within these subzones during the summer months of 1998–2001, from the coastal acidic tundra of Barrow on the Arctic Slope (71° N) to the moist acidic low shrub of the Seward Peninsula at Council (64° N).

Summer warmth, defined as the sum of mean monthly temperatures greater than 0°C, was used as a key index (SWI) for comparisons between the sites. The SWI varies from 9°C at Barrow to 34°C at Council. From Barrow to Quartz Creek (65° N, SWI = 32°C), a 5° increase in the SWI correlates with about a 115 g m^{-2} increase in the aboveground phytomass for zonal vegetation on acidic sites and about 60 g m^{-2} on nonacidic sites.

Between all sites, shrubs account for most of the aboveground phytomass increase on acidic substrates, whereas mosses account for most of the increase on nonacidic soils. LAI is positively correlated with SWI on acidic sites, but on the nonacidic sites the relationship is unclear, since the field instrumentation was unable to capture differences other than that of the erect vascular plant component of the plant canopy. The NDVI is positively correlated with SWI on both acidic and nonacidic soils, but on nonacidic parent material the NDVI is consistently lower than that of the acidic substrates. One of the most interesting observations was the large increase in mosses at warmer temperatures in nonacidic environments. The increase in mosses on nonacidic sites could affect the soil surface temperatures and decrease the activity of frost boils, which play an important role in nutrient availability and a variety of other ecosystem properties that maintain the nonacidic ecosystems. The sandy substrates at Atqasuk had the lowest productivity and NDVI of all the mesic sites, despite relatively warm temperatures compared to the coastal sites. Low nutrient availability accounted for low productivity, and relatively high lichen cover, which has low spectral reflectance in the near-infrared channels, accounted for the low NDVI values.

The Quartz Creek site on the Seward Peninsula had SWI of 32°C and demonstrates how a system much like that of the Arctic Foothills in northern Alaska might respond to warming. Shrub biomass in the water tracks is much higher, and the tussock tundra systems display greater tussock height and more sedge biomass. The maritime climate of the southern Seward Peninsula near treeline, represented by Council, supports abundant shrub-tundra plant communities with high biomass, and suggests that a special maritime variant of Subzone 5 is justified. It appears that climate warming will likely result in increased phytomass, LAI, and NDVI on zonal sites. Acidic areas supporting abundant shrub phytomass will likely demonstrate the greatest changes.

High Wind Events for Barrow, Alaska

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Surface wind observations from Barrow, Alaska, are used to construct a climatology of high wind events from 1945 to the present. High wind events appear to be increasing over the past twenty years, after a lapse in the late 1960s to the early 1980s. Two of these events are chosen for further study. One of these is a storm that occurred on 10 August 2000 and was reported by the National Weather Service as having record wind gusts of over 33 ms^{-1}. The storm eroded the beach to within 100 meters of a main location of Barrow's underground utilities, sank the dredge barge, washed out a boat ramp, and removed roofs from forty buildings. The second case study is a storm that occurred 3–5 October 1963 that also caused high winds, possibly record flooding and considerable damage. Unconfirmed reports suggest a maximum wind speed of 33 ms^{-1} was observed. Though a large number of high wind events occur in the winter, summer and autumn events can cause greater damage, due to the sea ice edge being situated far from the coast, increasing likelihood of large waves and storm surges.

Problems of Soil Erosion on Terskij Coast (Kolskij Peninsula, Northwest of Russia) and Ways to the Sustainability

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Introduction

The territory of the middle part of Terskij coast is located in the zone of thin northern taiga woods and borders upon the forest-tundra. It belongs to the objects least converted by a man in the entire European northeast. Remoteness from the large inhabited settlements and roads and extremely low occupancy are suitable for conservation of old-age landscapes in the practically undisturbed state. Wood felling, the main threat for landscapes of such a type, has never taken place in this territory. The small native population is engaged in the traditional fields of activity: hunting, fishing, and deer raising.

Research has been carried out within the framework of the project "Terskij Coast" with the help of British funds. The BP Conservation Programme (BP Amoco p.l.c., FFI, BirdLife International), and Whitley Award Foundation in the neighborhoods of the village Chavańga in the southeast region of Murmansk (northwest of European Russia). Coordinates for this research are 66° 08' N, 37° 45' E. Our tasks include carrying out the complex zoological-botanical investigations, exposure to the actual territory environmental problems, and searching for the ways to their solutions and the estimation of expediency of refuge creation.

Raising and substantiation of the ecological problem

The sharpest environmental problems include soil erosion. The low power of the sod in conditions of relatively high latitudes aggravates the situation. Mechanical influences easily destroy the sod. Around settlements, mechanical influences include mainly the motion of the Caterpillar machinery (the basic technique of the native population) and pasturing of small horned cattle, and in particular sheep. So, in the region of a mouth of the river Varzuga, an area about 30 km^2 is completely covered with free sand and constantly mixed by wind.

However, due to absence of a road system in this territory and the small amount of settlements, these difficulties, extremely strongly expressed in the neighborhoods of the settlements, essentially do not threaten the landscape as a whole. Sheep quantity decrease (approximately in 2.5–3 times) within the last several years has been a positive influence.

We have found soil damage far from inhabited settlements (50–80 km). The damage represents the centers of erosion from several meters up to 300–400 m in diameter. We have not found any other indications of anthropogenic influence in those places.

Through analysis of archival materials and interviews with members of the native population, we have established that the cause of these damages is increasing due to pasturing of reindeer. In the eastern region of Murmansk, nomadic deer raising is widespread. During the season, people drive large deer herds (sometimes hundreds of head) from south of the area to the north, to the coast of the Northern ice ocean and back, using natural wood, wood tundra, and tundra landscapes as pastures. Such a way of deer raising leads to periodical separation from the herds and loss of groups in several scores of deer.

The separated deer exist in free conditions, join in herds, and reproduce. It is not possible to estimate their general quantity, but from the analysis of the materials about deer-raising complexes one can conclude, that the quantity of the wild deer in some cases exceeds the quantity of the home deer. The wild deer destroy the sod, contribute to erosion processes in the natural landscapes, and also strongly reduce their pasturable value, competing with the home deer.

The number of wild deer in the present time is bound only by productivity of the pastures, that is from the lower part of the trophic pyramid. Regulation from above does not take place, as there are no predators capable of being deer feeders.

In other parts of the Murmansk region where reindeer are abundant, wolves regulate their quantity. On the Terskij coast, there are no wolves. Analysis of archival data of hunting organizations and interviews with members of the native population helps to establish that wolves in the east of the Murmansk region have been annihilated by a well-directed campaign to combat agricultural and hunting pests over sixty to seventy years. Wolves coming to Terskij coast from the west are rare, people continue to shoot wolves, and wolf populations cannot be restored. There is only one kind of big predator, a bear, which is not a deer feeder.

Consequently, global erosive damage of the soil cover in the natural landscapes of middle Terskij coast follows from multiple excess above the norm of the reindeer quantity, which has become possible due to absence of predators.

Possible solutions to the problem

It is obviously not realistic to change the system of nomadic deer raising, excluding the possibility of the domestic deer becoming wild. We believe that officials ought to restrict the deer quantity. An advisable variant is the cancellation of obligatory licensing for shooting of deer, at least for native population. The corresponding recommendations are given for consideration by the local authorities.

Restoring the natural pressure of wolves can be a way to solve this problem. For this purpose it is necessary to have wolves in a quantity sufficient for creation and maintenance of the population. The last is defined mainly by the presence of a sufficient forage reserve (aside from deer, there should be hares, lemmings, and mouse-type rodents). According to our data, in the last two years at Terskij coast extremely low quantity of mouse-type rodents has been observed, and lemmings are practically absent, which would exclude the opportunity of restoring the wolf population. The question about the causes of such a decrease of the rodents' quantity and if it is a temporary fluctuation or not is still unresolved. Accordingly, the perspective of restoring of wolf quantity is not clear now. This problem needs further research by various profile zoologists, ecologists, zoo technicians, and masters of hunting.

Acknowledgments

We are grateful to all participants of the project, especially to the botanists Dr. D. Sokoloff, N. Liksakova and zoologists N. Chist'akova, N. Grechanaia, A. Khrushchova, P. Kvartal'nov, A.Tupikin.

VECO Polar Resources—Arctic Logistics Support Services

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Changes in Carbon Dioxide Exchange of Wet-Coastal Tundra Ecosystem for Three Growing Seasons

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Eddy covariance was used to measure the inter- and intra-seasonal carbon dioxide exchange of a wet coastal-tundra ecosystem at Barrow, Alaska (71°19' N, 156°36' W) during the 1999–2001 growing seasons (June–August). Net CO_2 influx generally peaked during the midday period when photosynthetically active radiation (PAR) was at a diurnal maximum, while peak net efflux occurred between 23:00 and 2:00 when PAR was at a diurnal minimum. The amplitude of the diurnal trend in CO_2 flux varied markedly both within and between the growing season. The wet coastal tundra ecosystem was a net source of 0 to 2.0 gC m^{-2} d^{-1} during the early season snowmelt period. During the midseason peak in productivity, this ecosystem was a net sink of CO_2 varying from –0.1 gC m^{-2} d^{-1} to –5.6 gC m^{-2} d^{-1}. Sink strength decreased considerably after the midseason peak in productivity, presumably because of reductions in PAR, relatively high temperatures, and a decline in leaf area. On a daily basis, the average magnitude of the daily net uptake of CO_2 by the wet coastal-tundra was –0.99 gC m^{-2} d^{-1} in 1999, –0.59 gC m^{-2} d^{-1} in 2000, and –0.71 gC m^{-2} d^{-1} in 2001, exhibiting a small seasonality associated with the change in environmental and biological variables. Over the course of the 1999–2001 growing seasons, the wet coastal-tundra ecosystem was a net sink of carbon dioxide, showing the magnitude of carbon sink between –76.8 gC m^{-2} and –58.4 gC m^{-2}.

Assessing Hydrologic Impacts of Ice Sheet Extent in Northern Eurasia

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Dramatic changes in the hydrology of Eurasia occurred during the last glaciation. Discharge of many rivers was probably reduced, reflecting colder and drier climates of the Siberian lowlands. Potentially, some large drainages were dammed by advancing ice sheets, diverting discharge from the Arctic Ocean to the Black Sea. Uncertainty persists on the eastern and northern margin of the Eurasian ice sheet, where small changes in extent (10s to 100s km) would progressively impound more northerly river flow. Ice-sheet configurations are based on modifications of the Peltier ice sheet reconstruction with data defensible margins. Minimum, intermediate, and maximum configurations are represented by an eastern ice sheet limit in the Kara Sea, Taymyr Peninsula coast, and western North Siberian Lowland, respectively. Topographic grid is provided by a contemporary 5-minute resolution global data set, which is regridded to 30-minute resolution. The river network configuration was derived from automated network delineation methods working off the digital terrain data.

The minimum ice sheet forms a proglacial lake that fills the Kara Sea with drainage to the north. This proglacial lake and concentrated runoff at the easternmost margin may have limited expansion of the ice sheet. The intermediate ice-sheet configuration forms a large proglacial lake equal in volume to the present-day Caspian Sea. The Ob and Yenisey Rivers are indirectly blocked with the presence of a contiguous ice sheet between Franz Josef Land, Svernaya Zemlya, and the Taymyr Peninsula. Most drainage is routed to the east into the Laptev Sea. The maximum ice-sheet extent directly blocks the Ob and Yenisey Rivers, forming a massive proglacial lake, equivalent in volume to two Caspian Seas. Drainage is shifted to the south, resulting in expansion of the Aral, Caspian, and Black Seas. These simulations show the importance of the eastern and northern ice-sheet margins between Franz Josef Land, Svernaya Zemlya, and the Taymyr Peninsula in diverting freshwater flow from the Arctic Ocean.

ArcticRIMS: A Rapid Integrated Monitoring System for Analysis of the Pan-Arctic Hydrologic Cycle

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In order to accommodate the growing need for timely estimates of the arctic terrestrial hydrological cycle we present the Rapid, Integrated Hydrological Monitoring System (ArcticRIMS). This system couples EOS-era satellites, numerical weather prediction (NWP) models, and near-real-time observations of river discharge data with an atmosphere-land water budgeting scheme to compile operational fields (at one to three month time lags) of key hydrological cycle variables. The present research focuses on the land surface runoff and river discharge component of ArcticRIMS. A dual approach to the problem of estimating these values is taken through real-time monitoring of river discharge and via near-real-time modeling of the water balance driven by modified NWP products.

The land-surface water budget model is a daily model that contains a simple snowmelt routine, a two-layer soil component for root zone and deep soil, and active-layer thaw based on a degree-day approach. Fields of daily precipitation and air temperature, modified from NCEP reanalysis products, are used to drive the model from 1999 to the present. Local runoff surfaces and other spatial fields are estimated over the entire pan-arctic domain. The runoff is then routed downstream to the monitoring gauges and to the Arctic Ocean and is compared to the observed river discharge record. Time lags of one to two months between the last date simulated and the present day are determined by lags in the availability of the NCEP data.

The observational ArcticRIMS sites (the observed river discharge gauges) obtained in real time currently number fifty-seven stations (sixteen in Russia, ten in Canada, nineteen in the U.S., and twelve in Norway). In total they cover a drainage area of 13.2 million km^2, which is equivalent to 63% of total non-ice-covered land area of the pan-arctic or 79% of total Arctic Ocean drainage (not including Hudson Bay drainage and Greenland). The data for these gauges are supplied as provisional data, which means that normal adjustments to the data by the respective national agencies has not been implemented. Data is collected daily from the USGS and Environment Canada and weekly from Russia. This effort builds upon an existing pan-arctic river-discharge database, R-ArcticNET available over the Internet (www.R-ArcticNET.sr.unh.edu/), or on CD via the National Snow and Ice Data Center, Boulder, Colorado, USA.

Modeling a Sequence of Biogeochemical Interactions along an Arctic Hill Slope

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A process-based, plot-scale model of ecosystem carbon (C) and nitrogen (N) dynamics in terrestrial ecosystems (MBL-GEM III) was used in the past to study effects of global climate change on C-N interactions and consequent change in tussock tundra C storage at the regional scale. In this paper, we have used the same model to analyze how down-slope movement of water and N affect responses of tussock tundra to changes in atmospheric CO_2 and climate near Toolik Lake, Alaska. The model was applied to twenty 1 m x 1 m plots spaced 5 m apart on a 100 m transect on a theoretical hill slope comprised of only moist tussock tundra. Both water and inorganic N were transported from plot to plot and increased down slope. Our analysis was based on the premise that the spatial and temporal patterns of changes in C storage strongly interact with changes in the N cycle. We also examined the effect of soil moisture on the rate of decomposition as represented by two available soil-moisture response curves that differ in the degree of inhibition of decomposition as soils become more waterlogged. Simulations were run from 1920 to 2100, using historical and projected CO_2 and climate data. In both moisture response simulations, the model predicted a long-term increase in C sequestration in all plots in response to higher CO_2 concentrations and temperature, mostly as a result of an increase in vegetation C:N ratio and a redistribution of N from soil to vegetation. However, in the simulation with the stronger inhibition of decomposition by waterlogging, downhill plots accumulated more C than uphill plots. Surprisingly, most of this C accumulation was in plants, not soils. The simulation with the weaker inhibition of decomposition by waterlogging also had a gradient with downhill plots gaining more C in plants than uphill plots, but this spatial pattern in C gain was offset by a greater loss of C from soils at the bottom of the hill associated with larger losses of ecosystem N downhill. Thus, the net gain in C was about the same for all plots along the hill slope in this simulation. Results clearly indicate the importance of hill-slope processes in controlling the response of tundra to changes in CO_2 and climate. They also emphasize the need to better understand factors controlling soil processes, particularly decomposition. This work is a first step toward a broader extrapolation of spatial interactions to more complex landscapes incorporating other tundra types.

Interpolation and Visualization of CTD Data near a Nival Tributary at Lake Tuborg, Ellesmere Island

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CTD casts were performed in a 4x4 grid near a nival tributary at Lake Tuborg, Ellesmere Island, Canada. Fluvial input from this delta enters a deep (155 m) meromictic subbasin. The delta face is steeply dipping, so high-energy flows interact with chemocline close to shore. The CTD used in this study is a SeaCat SBE19, with a SeaTech 25 cm path-length, transmissometer (660 nm wavelength). Grid cells were 105 m on each side. The CTD recorded water temperature, conductivity, transmissivity, and depth every 0.5 s, and data were "binned" at 0.5 m intervals. Grids were completed on 16, 19, 23, and 28 June 2001: the period of peak nival melt. CTD data have recently been interpolated, visualized, and analyzed using an open source program called OpenDX (www.opendx.org). OpenDX allows visualization of 3-D data "clouds," 2-D "slabs," and isosurfaces. Most important, it allows data analysis and export at all stages.

A sharp transmissivity decline is present between about 55 and 65 m, the cause of which is uncertain, but corresponds to the position of the chemocline. Overflows were first seen on 16 June, when two areas of high attenuation were visible close to shore. These areas matched the position of two tributary arms. Overflows and interflows progressively spread offshore, and increased in intensity through time. Water below the chemocline remained relatively fresh throughout the study period, implying suspended sediment concentrations (SSC) were insufficient to penetrate the chemocline. Water below the chemocline was continuously near 2.5°C. Water above the chemocline was cooler, but progressively warmed. No erosion of the chemocline is visible through time. Surface plots of histograms, and inter-comparison of concurrently recorded variables have been completed. Future research will focus on a field calibration of the transmissometer to SSC, allowing calculation of the mass of sediment within visualizations.

Light Transmission through Ponded Sea Ice: A Two-Dimensional View

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Analysis of data collected during summer 1998 at the Surface Heat Budget of the Arctic Ocean (SHEBA) field station in the central Arctic Ocean revealed significant diurnal variations in ocean heat content near the bottom of the sea-ice cover (M. McPhee, personal communication). The source of this heat is almost certainly solar radiation entering the ocean through leads, melt ponds, and bare ice. The amount of transmitted energy, however, appears to be about twice as much as can be explained from the estimated optical properties and observed areal coverage of these three surface types. A possible explanation is that melt ponds transmit substantially more shortwave energy to the ocean than previous measurements would indicate.

To investigate this possibility, a two-dimensional Monte Carlo radiative transfer model was used to calculate spatial variations in spectral irradiance beneath melt ponds as a function of pond diameter, pond depth, and ice thickness. Results indicate that both pond size and measurement location can contribute to an overestimate of light attenuation in the ice beneath the pond. On thick first-year ice, for example, measured transmissivities will always be lower than the true value unless pond diameter exceeds about 6 m. The minimum pond size necessary for accurate values increases with ice thickness. Similar errors can occur even beneath very large ponds unless measurements are made at least 3 m from the edge of the pond. The significance of such errors is likely to increase throughout the summer melt season as the ponds deepen, ice beneath the ponds thins, and optical properties change. It is not clear to what extent historical data on the optical properties of ponded ice may have been compromised by such measurement problems, but a critical reexamination of these properties seems warranted.

Theoretical Archetypes for Understanding Interactions between Sea-Ice and Large-Scale Atmospheric Dynamics

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The development of sea-ice parameterizations for use in general circulation models (GCMs) has historically been characterized by a focus on increasing the complexity of the parameterization by adding previously unrepresented or under-represented physics, such as melt ponds, ice ridging, etc. (e.g. Arbetter et al. 1999; Holland and Curry 1999).

Increased physical complexity, however, is not the core issue in the GCM parameterization problem. As Arakawa (1993) points out in the case of parameterizing moist convection, parameterization is the link between that which provides a control upon the physical process being parameterized and the feedback the physical process provides. In what way does the large scale affect the physical process being parameterized, and how does the physical process in turn influence the large scale? With sea-ice parameterizations, there does not currently appear to be an adequate understanding of how the large and small scales interact.

This poster describes recent work begun in developing theoretical archetypes relating sub-grid-scale sea ice and large-scale atmospheric dynamics, using theory developed for parameterizing tropical moist convective processes as a starting point.

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Numerical Simulation of the Impact of Shallow Thaw Lakes on the Thermal Regime of Permafrost in the Alaskan Arctic

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Thaw lakes are one of the dominating landscape features in the Alaskan arctic. The extent of their role in climatic and hydrologic systems has not fully been quantitatively analyzed. This study assesses numerically the long-term impacts of shallow thaw lakes on the thermal regime of permafrost. Using a two-dimensional, physically based, finite element model of heat transfer with phase change under a cylindrical coordinate system, we investigated the influence of shallow thaw lakes on the thermal regime of permafrost and talik formation. We also studied the thermal consequences to permafrost and talik after drainage of thaw lakes and the effects of changes in mean permafrost surface temperature on the thermal regime of ground under drained thaw lakes.

The simulated results indicate that the existence of thaw lakes is a significant heat source to permafrost. For a lake with a long-term lake bottom temperature greater than 0.0°C, a talik forms under the lake. The maximum talik thickness (distance from lake bottom to permafrost surface) ranges from 27 m, 43 m, 61 m, to 77 m with long-term lake bottom temperatures of 1.0°C, 2.0°C, 3.0°C, and 4.0°C, respectively, after 4,000 years of a shallow thaw lake over permafrost. For a lake with a long-term mean annual temperature less than 0.0°C, no talik forms under the lake; however, permafrost temperature increases significantly. Changes in lake bottom temperature, which is a product of changes in air temperature, snow thickness and properties, lake ice thickness, and lake water depth, have a significant influence on permafrost thermal regime, talik thickness, and talik formation rate under thaw lakes. The change in lake-water depth, however, has very limited impact on the thermal regime of permafrost if the mean lake-bottom temperature does not change.

The potential long-term response of permafrost thermal regime and talik freeze-up after lake drainage are also investigated. The simulated results indicate that talik of 27 m, 43 m, and 61 m in thickness under a thaw lake could freeze up in 95, 246, and 355 years, respectively, after drainage of a thaw lake. Changes in mean annual permafrost surface temperature would have significant impact on the time of talik freeze-up. We concluded that talik freeze-up and permafrost aggradation are very fast processes under the drained lakes in northern Alaska.

Spatial Variability of Frost Heave and Thaw Settlement in Tundra Environments: Application of Differential GPS Technology

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Although the timing, magnitude, and processes involved in frost heave and thaw settlement are traditional areas of research in periglacial geomorphology and cold-regions engineering, little is known about their spatial variability. Recent concerns about the effects of global warming in polar regions have brought the issue of permafrost degradation and thaw settlement into the public consciousness (e.g., Linden 2000; Nelson et al. 2001). Recent technological advances provide a means for assessing the spatial variability of heave and subsidence, over a range of scale.

This preliminary study is designed to: (a) determine the feasibility of using differential GPS technology to measure frost heave and thaw settlement in different tundra environments; and (b) determine the scale of maximum variability of heave and settlement within instrumented areas of limited dimensions. During summer 2001, two 1 ha sites in northern Alaska, one in the Brooks Range foothills and one on the Coastal Plain, were instrumented with small cylindrical platforms designed to support a differential GPS antenna, and to move freely with the active layer while minimizing disturbance to surrounding vegetation. Thirty-two platforms were installed at each site, and distributed according to a nested hierarchical sampling strategy (Webster and Oliver 1990; Nelson et al. 1999). Each sample point was probed to determine active-layer thickness at several intervals throughout the summer. Under ideal conditions the differential GPS unit is capable of measuring vertical movement on the order of 1 cm. In June and August 2002, the vertical displacement of each platform will be measured using differential GPS. This information will provide a basis for the design and installation of a more extensive instrumental network in a variety of landcover types.

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Marine Climate and Relative Sea Level Across Central Beringia

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During the last glacial maximum (LGM) sea level was lowered by ~125 m. The size of Beringia increased dramatically, and the flow of fresher, nutrient-rich Pacific water into the Chukchi Sea was cut off due to the resulting emergence of the Bering Strait. These conditions affected the Beringian climate, the freshwater budget of the Arctic Ocean, and ocean circulation as they changed through time, but exactly how is not understood. Controversies exist as to whether the Bering Land Bridge was dominated by moist or dry tundra as large mammals and man migrated between continents. This lack of understanding is partly due to the fact that relative sea level in Beringia is likely to have differed from eustatic sea level as a result of tectonic and possible glacio-eustatic effects. In addition, very little high-resolution proxy data exists for sea surface conditions in the Bering and Chukchi Seas.

In order to address these problems and begin defining the link between marine and terrestrial environments, a research program of gravity, piston, and vibracoring will be conducted in the Bering and Chukchi Seas during the summer of 2002. The cores will be used to develop high-resolution records of intermediate ocean ventilation in the Bering Sea; surface ocean temperature, salinity, sea-ice extent, and iceberg discharge in the Bering and Chukchi Seas; and relative sea level in the Bering Strait region since the LGM.

Relative sea level is to be established by collecting a series of vibracores up the thalwag of ancient river/estuary systems on the Chukchi shelf. This should provide cores with relatively high deposition rates from which a transgressive history can be constructed from peats, fossils, C/N ratios, and organic C and N isotopes. The research is to be carried out on the USCG icebreaker *Healy* in June and July 2002 (Bering Sea) and September 2002 (Chukchi Sea).

An Integrated Assessment of the Impacts of Climate Variability on the Alaskan North Slope Coastal Region: Project Overview

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Warming of the arctic climate is having substantial impact on Alaska's North Slope coastal region. Increasing amounts of open water in the arctic seas, combined with rising sea level, thawing permafrost, and changing human geography, are predicted to contribute to increased impacts of meteorological events with their attendant storm surge, flooding, and erosion. This poster describes a project that is underway to understand, support, and enhance the local decision-making process on the North Slope of Alaska in the face of increasing sea-ice variability and extreme weather events.

Land-Atmosphere Interactions in Beringia over the Last 21 ka: An Investigation of Climate Feedbacks Using the Arctic Regional Climate System Model

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The geographical distribution of different vegetation types, lakes, and coastal zones represent significant controls of energy, water, and CO_2 exchanges between land surfaces and the atmosphere. The goal of this research is to improve our understanding of the characteristics, mechanisms, and feedback processes associated with changes in vegetation, sea level, and standing surface water in Beringia during the last 21,000 years, and to use this understanding to aid in the development of predictive tools for future pan-arctic climate change. Our specific research objectives and tasks include compiling detailed data, including topographic and vegetation changes, and simulating paleoclimatic conditions using a GCM (CCM3) and a regional climate model (ARCSyM) to study the effects of paleoclimate boundary conditions.

Revisiting the Fast-ice Regimes of the Chukchi and Beaufort Seas 25 Years On

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Interest in the fast-ice regime of the Alaska coast was prompted by the needs of coastal oil development, coincident with an increasing interest in the ice cover of the polar regions as a component of the climate system. While the latter led to the foundation of the NSIDC, Barry et al. (1979) focused on the former in a key study of fast-ice climatology and implications for offshore development. Twenty-five years later, offshore development has forged ahead with an increased economic commitment, while concerns are rising both locally and globally about the response of the coastal ice to recent climate trends.

Of particular interest from the perspective of coastal processes are the duration of the fast-ice season and the occurances of ivus or ice-push events. Here we combine an analysis of AVHRR and ground-truth data for the years 1998–2001 in the vicinity of Barrow, Alaska. Generally, the behaviour of the fast ice in these three ice seasons agree with the broad descriptions given by Barry et al., in terms of freezing and break-up times and mean ice thickness and extent. However, it is the less general, episodic events that may be more telling of regime changes and are certainly of greater impact at a local scale for economic and subsistence activities in the Arctic.

The ice season of 2000–2001 was characterised by midwinter ice breakouts opening a lead at the beach near Barrow. In June 2001, the ice was pushed onshore over a length of at least 20 km during an ivu event. Based on aerial photography, ground observations, and side-looking radar, we examine the extent and variability of the shove as well as large-scale forcing. This study highlights the importance of small-scale processes impacting local communities, but forced by regional or hemispheric atmosphere-ice-ocean dynamics.

Reference

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The Investigation of Long-Term Variability of the Free Atmosphere in the Arctic

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Starting in 2000, the International Arctic Research Center executes the project "Climate variability of the polar atmosphere revealed with historical radio soundings information."

This project is an international effort to create, with unified modern technique, a new data set of the radio soundings executed north of 65° N on the Russian coastal (island) polar stations. The data of sixty-seven polar stations, eight of which had begun observations in the mid-1930s, will be prepared next summer. Together with existent archives of soundings from U.S., Canada, Norway, and Denmark, and some Russian polar stations collected in the Comprehensive Aerological Reference Data Set (CARDS), and improved archive of the drifting stations "North Pole," the new data set will make it possibile to reveal the seasonal and interannual variability as well as the trends of main parameters of the troposphere, stratosphere, atmospheric boundary layer, and cloudiness and to obtain the new estimates of energy and moisture fluxes across 70° N. In addition, the data of rocket soundings executed on the Franz Josef Land archipelago will allow investigation of climate variability of the upper atmosphere from 1969 to 1993.

Also, within the framework of the project, the long-term variation of the free atmosphere temperature in the North Polar Region (60–90° N) is investigated, with the original database, containing the results of observations on 116 meteorological stations, ships' observations, and observations on the drifting stations "North Pole." The special procedure had been developed for accounting data from moving platforms (ships, drifting stations) in the monthly averaged data set. The analysis of temperature trends was made for the period 1959–2000. In mean, the air temperature in the North Polar Region increased in the main part of the troposphere (850–400 mb) and decreased in the upper troposphere and in the stratosphere. It was found that the total energy of polar atmosphere attributed to so-called mean energetic level does not show any trends, but undergoes long-term variation.

Preliminary estimates of spatial-temporal variability of water vapor on 850, 700, 500, 400, and 300 hPa, executed with the mentioned database, show the decrease of specific humidity in the free atmosphere (300–850 hPa) from 1959 to 1987, the year of the largest negative anomalies, close to 2s. Later the quantity of water vapor increased, especially in the layer 850–700 hPa.

Future plans:

- Creation of final version of historical data set of the radio soundings, including data of soundings, executed in 1930s.
- Comprehensive statistical analysis of spatial-temporal variability of the main characteristics of free atmosphere, including Wavelet and EOF analysis.
- Estimate of energy and water vapor exchange with middle latitudes under different peculiarities of atmospheric circulation.
- Comparison with NCEP-NCAR and ECMWF reanalysis.

Socio-Ecological Approach to Water Management in Taz-Ob Area (Siberia, Russia)

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This poster presents a socio-ecological approach to natural fish resources and water management in the circumpolar northern regions of the Russian Federation with a focus on the Taz-Ob area. The long-term data (monitoring) on fish community diversity and abundance, fish feeding resources, and geographical, biological, hydrological, and other conditions have been used for decision-making.

The two main features considered are restricting the well-being for the largest breeding stocks of marketable fish species in Siberia. They are: (a) abiotic—a very specific ice situation that leads to annual oxygen deficit in the lower Ob and (b) anthropogenic—the oil exploration industry in Ob-Taz Aria, modern and planned.

Marketable fish-farming accompanied by sustainable stock enhancement is proposed to solve a problem.

The approach submitted consists not only of industrial compensation of the catches, but also of:

1. using the unique Taz Bay as a growing waterbody for valuable fish stocks, according to the unlimited feeding resources;
2. habitat protection, i.e., the foundation of protected areas, especially for spawning, in the Taz-Ob drainage region;
3. working out special measures to preserve traditional lifestyle for indigenous peoples from Yamalo-Nenets Autonomous Okrug (Ob drainage-basin) and Taymyr Autonomus Okrug (Enisey basin) as well as involving them in decision making.

Climate Impacts at Barrow, Alaska: Quantifying Coastal Erosion and Flooding

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A variety of empirical and modeling approaches are being taken to assess the history and risk of erosion and flooding along the Chukchi Sea coast near Barrow, Alaska. Part of a broad assessment of climate impacts for the North Slope, www.colorado.edu/Research/HARC/, this study uses field measurements, digital imagery, GIS, and numerical modeling to quantify past processes and rates, as well as possible future scenarios of variable conditions and changing environment.

An initial requirement for analysis is the development of spatial data sets. A few products are currently available or are being processed for on-line release. These include a 100 m Digital Elevation Model (DEM) for the entire North Slope; an initial, low-precision DEM of the Barrow triangle; and a database of ground control points (GCP's) measured by differential GPS, at http://instaar.Colorado.EDU/QGISL/barrow_gcp. High-precision GPS was also used during the summer of 2001 to collect closely spaced points for baseline topography of bluff geometry and shoreface profiles. Other data sets and imagery being developed are a high-precision DEM of the Barrow triangle (based on the 1964 CRREL 1:5,000 topographic maps); nearshore and shelf bathymetry (based on a local navigational chart); and time-series ortho-rectified aerial photography for years 1948, 1964, 1979, 1984, and 1997.

Time-series image analysis will document spatially variable rates of shoreline erosion for the last half century. Shoreline positions will be delineated from the coregistered orthophotos for at least five time slices. Spatial GIS algorithms will be scripted to measure rates of coastal retreat or aggradation and to identify environmental controls on erosion. An empirical model will be applied through multiple regression and principle component analysis to predict shoreline positions for future scenarios and for specific risk to community infrastructure and interests. Similarly, the high-resolution DEM will provide input for an empirical analysis of flood risk associated with wave setup and summer or early fall storm surges.

In addition, we will use a three-dimensional simulation of nearshore oceanographic and sedimentologic dynamics, the Delft3D model, www.wldelft.nl/soft/d3d. This module-based package incorporates the effects of wind, waves, tides, currents, sediment transport, and other nearshore processes. Time scales will be daily to decadal, and spatial scales will be 5–20 km, with grid cell spacing on the order of 5 m or less. The Delft3D model will be used to evaluate the effectiveness and consequences of future policy and climate scenarios. Specifically, the model will be used to test for coastal impacts under various storm conditions and long-term forcings, as modulated by possible beach "nourishment" and other mitigation efforts.

At this early stage in our project, we have begun to incorporate feedback from the Barrow and North Slope communities—as well as from collaborative research programs in the area—to fine-tune our research objectives and results. Funded through the Human Dimensions of the Arctic System (HARC) program, our research addresses societally relevant impacts of unprecedented warming, diminished sea ice, and climate variability on the land-sea interface of a low coastal plain.

Spatial Analysis of Glaciers and Climate Sensitivity: A Feasibility Study from Southwestern Alaska

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Recent advances in geographic information systems (GIS) make it possible to assemble large, empirical, multiparameter data sets that bear on environmental variation, process, and change. For example, GIS permits analysis of the extent, area-altitude relations, microclimatic, and major climatic relationships of all glaciers within a region. Complementary to laser-altimetry and field measurements of mass balance, this approach takes advantage of spatial, rather than temporal, variation to better understand glacier-climate relationships.

A case study for the Ahklun Mountains, southwestern Alaska, demonstrates the feasibility, resolution, and glacier-climate significance of the new approach. Data sources include high-resolution DEM's (grid-cell spacing of 62 m), gridded PRISM climate estimates, and digitized glacier outlines from 1:63,360 topographic maps (based on aerial photography from 1972–1973). Using raster GIS, thirty-two parameters were calculated for each of the 106 cirque and small valley glaciers in the Ahklun Mountains, including area, elevation, slope angle, aspect, curvature, potential insolation, backwall height, hypsometric equilibrium line altitude (ELA; based on an accumulation area ratio of 0.6), summer temperature, winter precipitation, and sensitivity to climate-induced changes in ELA. The 106 cirque and small valley glaciers have a median size of 0.26 km^2, a total area of 59.6 km^2, and a statistically preferred aspect of 334°. Hypsometric ELA averages 929 m ± 127 m.

Ten percent of the ELA variation is explained by a trend surface dipping 5 m/km southwestward toward the Bering Sea as a moisture source. Inclusion of aspect, a basin coefficient, backwall height, distance from lakes, and upslope area in stepwise multiple regression brings explanation to a level of 52% and highlights the importance of microclimatic/topographic controls on ELA and mass balance. Furthermore, 73% of ELA variation is explained by winter precipitation, summer temperature, aspect, and other microclimatic variables.

Sensitivity to a rise in ELA is estimated from area-altitude relationships. With an increase in ELA of only 50 m, accumulation areas would shift from ca. 60% of each glacier surface to only 28% on average, and total glacier area would, with time, decrease 40% to about 36 km^2.

Errors for the parameters are insignificant in comparison with high local variability. Results include not only data sets, but the ability to draw meaningful relationships from spatial trends. The Ahklun glaciers will be strongly affected by climate-induced changes in accumulation or ablation.

An NSF-funded project was recently initiated to ascertain glacier-climate relationships across Alaska using GIS. This project will measure numerous parameters for all Alaska glaciers across strong climatic and glacio-dynamic gradients, will clarify climatic controls on mass balance, and will identify which glaciers are most sensitive to twenty-first-century climate change. This study will clarify the dynamics of the arctic cryosphere under unprecedented warming.

Natural Gas Hydrate Stability in the Arctic

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Global warming may affect the rate of release of methane from gas-hydrate deposits in both the ocean and terrestrial permafrost. In turn, this release could accelerate global warming trends beyond the current predictions of the Intergovernmental Panel of Climate Change (IPCC). Since methane-hydrate deposits are large and responsive to changes in temperature and pressure, the potential for methane-hydrate to force climate change is significant. At present, no accurate, comprehensive model exists for evaluating the effect of climate change on methane hydrate stability. We seek to develop a state-of-the-art model to answer the following fundamental questions:

- Is oceanic gas hydrate less stable than nearby terrestrial permafrost gas hydrate?
- Will arctic hydrates respond more rapidly than hydrates in lower latitudes because of more rapid warming in this cold region?
- Will rising sea level significantly counteract the effect of warming seas?

Advanced Ocean and Sea-Ice Modeling of the Pan-Arctic Region in Support of the NSF/ARCSS Program

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The main objectives of the Naval Postgraduate School Arctic Modeling Effort are to:

1. Employ coupled, pan-arctic, ice-ocean models at increasingly high resolution for regional studies of sea ice and ocean conditions and their variability
2. Contribute towards understanding of the role of the arctic system in global climate.
3. Provide feedback to global ocean and climate models on physical and numerical requirements for realistic modeling of the Arctic Ocean.
4. Allow integration of spatially and temporally sparse data into a coherent large-scale picture.
5. Provide background physical conditions for biochemical models.

A 1/12° and 45-level, coupled ice-ocean model of the pan-arctic region has been developed in an effort to improve model representation of sea ice and ocean conditions in the Northern Hemisphere. The domain extends from ~30° N in the North Pacific, through the Bering Sea, Arctic Ocean, and Nordic seas to ~45° N in the North Atlantic. This regional model adapts the Los Alamos National Laboratory (LANL) global Parallel Ocean Program (POP) model with a free surface. The original sea-ice model with the viscous-plastic rheology and the zero-layer thermodynamics is being replaced with the LANL CICE 3.0 sea-ice model, which includes a multicategory ice thickness distribution, nonlinear profiles of temperature and salinity, and the elastic-viscous-plastic rheology formulation for computational efficiency. The bathymetry data consists of the ETOPO5 database and other historical charts for latitudes south of 64° N. To the north of 64° N, the new 2.5 km resolution International Bathymetric Chart of the Arctic Ocean (IBCAO) database has been implemented. Additional improvements of this regional model include a realistic transport through Bering Strait, better representation of eddies and narrow boundary currents, exchanges through the Canadian arctic archipelago and Nordic seas, and shelf and slope bathymetry. The model has been integrated in a spinup mode for thirty-three years forced with the climatological atmospheric forcing derived from the ECMWF 1979–1993 reanalyzed data. An additional twenty-year integration has been completed so far using the realistic 1979–1981 ECMWF daily-averaged atmospheric data. Results from this recent integration are shown focusing on the western Arctic Ocean. Insights into the dynamics of this region might prove especially useful for the planned Phase II of the Shelf Basin Interaction (SBI) field program, beginning in 2003.

www.oc.nps.navy.mil/~pips3 and www.oc.nps.navy.mil/sbi.

A Circumpolar Perspective on Fluvial Sediment Flux Toward the Arctic Ocean

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Quantification of sediment fluxes from rivers is fundamental to understanding land-ocean linkages in the arctic system. Numerous publications have focused on this subject over the past century, yet assessments of temporal trends are scarce, and consensus on contemporary fluxes is lacking. Published estimates vary widely, but often provide little accessory information needed to interpret the differences. We present a pan-arctic synthesis of sediment flux from nineteen arctic rivers, primarily focusing on contributions from the eight largest. For this synthesis, historical records and recent unpublished data were compiled from Russian, Canadian, and American sources. Evaluation of these data revealed no long-term trends in sediment flux, but did show stepwise changes in the historical records of two of the rivers. In some cases old values that do not reflect contemporary fluxes are still being reported, while in other cases typographical errors have been propagated into the recent literature. Most of the discrepancy among published estimates, however, can be explained by differences in years of record examined and gauging stations used. Variations in sediment flux from year to year in arctic rivers are large, so estimates based on relatively few years can differ substantially. To determine the best contemporary estimates of sediment flux for the eight largest arctic rivers, we used a combination of newly available data, historical records, and literature values. These estimates contribute to our understanding of carbon, nutrient, and contaminant transport to the Arctic Ocean and provide a baseline for detecting future anthropogenic or natural change in the Arctic.

Environmental Variation, Vegetation Distribution, and Carbon Dynamics in High Latitudes

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In this study, we evaluated how vegetation distribution and carbon dynamics are related to environmental variation spanned by the network of the International Geosphere Biosphere Program (IGBP) high-latitude transects. While the most notable feature of the high-latitude transects is that they generally span temperature gradients from southern to northern latitudes, there are substantial differences in temperature among the transects. Also, along each transect temperature co-varies with precipitation and photosynthetically active radiation, which are also variable among the transects. Although there are similar sequences of vegetation transitions along these gradients, there is variance in climatic associations with vegetation transitions among the transects. Both climate and disturbance interact to influence latitudinal patterns of vegetation and soil carbon storage among the transects. The analyses in this study have taken an important step toward coordination of global-change studies among the high-latitude transects. Coordinated studies have the potential to substantially improve understanding of controls over vegetation dynamics and carbon dynamics in high latitudes in ways that will further clarify the role of high-latitude ecosystems in the earth system.

Does Nitrogen Partitioning Promote Species Diversity in Arctic Tussock Tundra?

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Attempts to identify “assembly rules” for plant communities have been frustrated by difficulties in studying how plants compete for belowground resources. We used ^{15}N soil-labeling techniques in a N-limited, tussock tundra plant community at Toolik Lake, Alaska, to examine how co-occurring species partition available soil N, and how such partitioning may influence species diversity and composition. The five most productive species were well differentiated with respect to the chemical form (ammonium, nitrate, and glycine), season (June and August), and depth (3 and 8 cm) of N uptake. Species dominance (productivity) was positively correlated with the similarity between the uptake and availability of native forms of N, suggesting that resource competition has strongly influenced the organization of this community. We are further investigating this hypothesis by examining the degree of spatial overlap among species that are similar or dissimilar in their use of N. Uptake of ^{15}N injected at different distances from individual plants showed significant interspecific differences in lateral rooting areas and a high potential for overlap of rooting areas among species. We illustrate how the “total” overlap among species can be calculated from the lateral overlap of rooting areas and the degree of ecological overlap measured by ^{15}N partitioning, and how this new measure of overlap can be used to test whether resource competition has contributed to the spatial organization of this community.

Arctic Ocean Warming: Submarine and Acoustic Measurements

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In 1993, the USS *Pargo* made the first Submarine Science Expedition (SCICEX) to the Arctic Ocean. In April 1994, the first Transarctic Acoustic Propagation (TAP) experiment, designed to measure Arctic Ocean temperature, was conducted. SCICEX cruises to the Arctic followed annually from 1995 to 2000. Expendable CTDs and on some cruises standard CTDs were deployed along or close to the TAP acoustic section. In October of 1998, as part of the Arctic Climate Observations using Underwater Sound (ACOUS) program, a source was deployed in the Franz Victoria Strait and a receive array was deployed in the Lincoln Sea. In April 1999, a second acoustic section was made across the Arctic when recordings of the ACOUS source were made at the APLIS Ice Camp in the Chukchi Sea as part of the support to SCICEX '99. The acoustic sections compared with the SCICEX sections have shown that measurement of the average temperature in the Atlantic Layer is easily and very reliably accomplished with the acoustic thermometry measurements. Furthermore, all of these measurements have documented the steady rise in the temperature of the Atlantic Layer, starting in the early 1990s.

The SCICEX 2000 cruise was the last scheduled SCICEX cruise to the Arctic. Future scientific measurements in the Arctic by submarine will be accomplished intermittently on a not-to-interfere basis in conjunction with naval operations. Analysis of the first acoustic thermometry time series record from October 1998 through December 1999 is underway after the successful recovery of the ACOUS Lincoln Sea receive array in March 2001. Acoustic thermometry can provide a long-term reliable capability for monitoring Arctic Ocean temperature and other variables, including the thermocline depth. This can be accomplished by including acoustic receivers and sources on moorings that are currently under consideration for deployment in the Arctic under the proposed Study of Environmental Arctic Change (SEARCH) program and possibly as part of NSF's Ocean Observations Initiative (OOI).

CAPE: Circum-Arctic PaleoEnvironments

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CAPE (Circum-Arctic PaleoEnvironments) is an umbrella organization within IGBP-PAGES (Focus 4: Polar Programs: Paleoclimate and Environmental Variability in Polar Regions) through which international and national arctic paleo programs can be linked. The primary emphasis of CAPE is to facilitate scientific integration of paleoenvironmental research on terrestrial environments and adjacent margins covering the last 250,000 years of earth history, particularly those tasks that cannot easily be achieved by individual investigators or even regionally focused research teams. Circumpolar syntheses of environmental reconstructions for specific time slices or key time series will be accomplished through focused international meetings that are intended to bring together the primary data and modeling communities. The first CAPE meeting, held in April 1997 in Lammi, Finland, addressed the topic of Holocene spatial and temporal patterns of environmental change in the Arctic. The second CAPE meeting, held in June 2000 in Kirkjubaejarklaustur, Iceland, addressed the topic of Sea Ice in the Climate System: Lessons from the North Atlantic Arctic. A third CAPE meeting is tentatively planned for fall 2002 in New England to address the topic: How warm was the Arctic in the last interglacial.

ARCSS Field Project Data Management at JOSS

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Integration of multidisciplinary data from a variety of field projects is particularly critical to the timely and accurate understanding of the rapid changes that are now underway in the Arctic. The University Corporation for Atmospheric Research (UCAR) Joint Office for Science Support (JOSS) is involved in the data management support for a number of ARCSS field projects, both domestic and international, including SHEBA (Surface Heat Budget of the Arctic Ocean), ATLAS (Arctic Transitions in the Land-Atmosphere System), ITEX (International Tundra Experiment), SBI (Shelf-Basin Interactions), and ARCMIP (Arctic Regional Climate Model Intercomparison Project). In addition, work is underway at JOSS on committees and programs to further improve the collection, archiving, display, and dissemination of arctic data.

JOSS has worked with science management offices, project offices, and investigators to support their ongoing project efforts while fostering a consistent data management strategy that makes sense for the project science objectives. This includes the specification of a data policy, consideration of data format, and documentation guidelines that maximize the ease of data exchange and archival.

Data access and archival are handled through a data management system that offers scientists a means to submit their data, identify and download other data sets of interest, display selected data sets on-line, and update data sets and documentation as necessary during the life of the project. During intensive field collection periods, an on-line field catalog is supported by JOSS to provide interactive access to common data sets of interest and allow sharing of preliminary data and analyses among project scientists.

Finally, JOSS provides support where appropriate for project scientists with the integration of their data sets for education and outreach through the compilation of special CD-ROMs. An example of this is the Ivotuk CD-ROM currently being compiled by investigators in the ATLAS project. JOSS works with the project scientists to define the scope and requirements and produce the CD-ROM.

Patterns of Cetacean Relative Abundance in the Alaskan Arctic Relative to the Arctic Oscillation: A GIS Perspective

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Eighteen years of sighting data from line-transect aerial surveys offshore northern Alaska were analyzed using GIS to investigate spatial differences in beluga and bowhead whale distribution and relative abundance during alternate phases of the Arctic Oscillation (AO). The AO represents the major atmospheric forcing feature in the Arctic, with shifts from one regime to another forced by changes in the location and intensity of the Icelandic Low and Siberian High pressure cells. Circulation and ice drift in the Beaufort Gyre is anticyclonic (clockwise) when the AO is in the positive phase and cyclonic (counter-clockwise) when in the negative phase. These shifts in basin-scale circulation affect sea-ice extent, vertical water stratification, and transport (in-flow) through Bering Strait, which in turn alter cetacean habitat characteristics. Although the distribution of beluga and bowhead whales was not clearly segregated in alternate AO phases, patterns of meso-scale relative abundance were distinctly different. These patterns were manifested by significant differences in depth at sightings. Mean depth at bowhead sightings was 87 m in cyclonic conditions and 51 m in anticylonic conditions ($t=3.3$, $p<0.001$); for beluga, mean depth at sightings shifted from 788 m to 318 m ($t=4.4$, $p<0.0005$), respectively. Whale movements in alternating AO states may reflect responses to shifts in prey availability, although this suggestion remains speculative for lack of concomitant hydrographic and forage data. To fully understand the influence of atmospheric forcing on cetacean habitats will require the integration of data sets across a suite of disciplines as well as temporal and spatial scales. The requirement of cetaceans to forage in zones of high prey density suggest that the spatial patterns expressed by relative abundance indices may provide a key to underlying bottom-up ecosystem structure.

Reconstruction of Past Surface Temperatures of Eurasian Arctic Ice Caps

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Due to high air temperatures during summer, the Eurasian arctic glaciers are subjected to melting. Meltwater percolates into the snow-firn sequences. As a result of heat and mass exchange with meltwater, the active-layer temperature is significantly higher than the mean air temperature. Melting intensity during summer months is proportional to the third power of the mean air temperature. Hence, small changes of summer air temperatures induce big changes of the active-layer temperatures. A new regularization method for solution of the inverse problems was developed and applied here to reconstruct the glacier surface temperatures in the past. This mathematical technique allows for finding the unique solution of the problem.

Borehole temperatures have been measured in the biggest ice caps in the Eurasian Arctic: Austfonna (Svalbard), Windy Dome (Franz Josef Land), and Akademia Nauk (Severnay Zemlya). These ice caps are located in western, central, and eastern parts of the Eurasian Arctic. The calculated surface temperatures of the glaciers exhibit weak dependence on the variations of the accumulation rate at the surface and the geothermal flow in the last 200 years. The bottom parts of the Akademiya Nauk Ice Cap and Windy Dome are in a steady state, while Austfonna Ice Cap is in a nonsteady state as a result of the bottom melting. The estimated rate of melting of the Austfonna bottom ice is in the range of 2 to 7 mm/y.

The lowest surface temperatures of the Austfonna Ice Cap occurred during the Little Ice Age, started 500 years ago. Drastic warming recorded in the borehole temperatures started approximately 150 years ago. One hundred and fifty years ago the ice temperatures here were colder by 10–11°C than those that were 600 years ago. Present ice temperatures are the highest for the last 2,000 years.

The lowest surface temperatures at the Windy Dome were 300–320 years ago in the middle of the Little Ice Age. They were 13°C colder than the warmest temperatures of approximately thirty to forty years ago. The most interesting feature of the recent climate change here is almost 3°C cooling that has taken place for the last thirty to forty years. With the exception of recent warming, the most eastward Akademia Nauk Ice Cap had temperature changes similar to the Windy Dome. The Medieval Warming is noticeable only in the western Arctic. Interpretation of the temperature data is based on comprehensive analysis of various data obtained from the ice cores.

The Circumpolar Active Layer Monitoring (CALM) Program: Research Designs and Intial Results

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The Circumpolar Active Layer Monitoring (CALM) program, designed to observe the response of the active layer and near-surface permafrost to climate change, currently incorporates more than 100 sites involving fifteen investigating countries in both hemispheres. In general, the active layer responds consistently to forcing by air temperature on an interannual basis. The relatively few long-term data sets available from the northern high-latitude sites demonstrate substantial interannual and interdecadal fluctuations. Increased thaw penetration, thaw subsidence, and development of thermokarst are observed at some sites, indicating degradation of warmer permafrost. During the mid-to-late 1990s, sites in Alaska and northwestern Canada experienced maximum thaw depth in 1998 and a minimum in 2000; these values are consistent with the warmest and coolest summers. The CALM network is part of the World Meteorological Organization's (WMO) Global Terrestrial Network for Permafrost (GTN-P). GTN-P observations consist of both the active layer measurements and the permafrost thermal state measured in boreholes. The CALM program requires additional multi-decadal observations. Sites in the Antarctic and elsewhere in the Southern Hemisphere are presently being added to the bipolar network.

Harmonic Approximation of Climatic Time Series

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Tree rings, the ratio of oxygen isotopes in Antarctic ice, and instrumental records of temperature are examples of information sources for climate change studies. It is well known that time series obtained from the aforementioned sources are stochastic processes. In general, these processes can be described by a sum of two components, a function and a noise. In numerous cases the functions have a form of almost periodical signals. Functions of this specific type are the major subject of our investigations, since they play the most important role in prediction of system behavior. For instance, by using harmonic waves approximation, it is possible to make predictions about the air temperature variations, even if the original measured data include some noise. Extrapolations can be made both in the past and into the future. Particularly, to perform simulation of permafrost dynamics we used prolonged time temperature series as upper boundary conditions.

Calculations of harmonic components are based on the best mean-square approximation of a signal, which was sampled at limited uniform time points. The most appropriate number of harmonics, corresponding frequencies, amplitudes, and phases are to be determined. During this research work, several numerical methods were used in order to reconstruct frequencies from a signal. All of them use Gramm matrix of different shifts of the corresponding signal. This matrix is an analog of autocovariance function in the theory of stochastic processes. The reconstruction of frequencies is equivalent to a general eigenvalue problem for ill-conditioned quasi-Toeplitz matrix.

The harmonic analysis was performed for several different time-scale series:

1. Historical isotopic temperature records from Vostok ice core (400,000 years).
2. Northern hemisphere temperature reconstruction for the past millennium (1,000 years).
3. Two-stage average of Northern Hemisphere maximum latewood density tree-ring chronologies (600 years).
4. Instrumental measurements of air temperature in Yakutsk, Russia (120 years).

Suppression of Bedload Transport by Bottom Ice

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In arctic rivers, the dominant hydrologic event of the year often occurs due to spring snowmelt. During this period, smaller streams and the headwater reaches of the larger rivers are frozen to the bottom, with the runoff occurring over the ice. This condition affects sediment transport processes in three ways: (1) by limiting the amount of bedload material available during competent flows, (2) by rafting bedload material as the ice breaks free from the bed surface, and (3) by exposing bedload material to high flow velocities as the ice initially melts out in localized areas. The protection offered by the bottom ice during these competent flow periods is believed to be the dominant effect, resulting in a significant reduction in bedload transport.

Ongoing research of sedimentation and channel morphology of the Upper Kuparuk River, in the Alaska Arctic, is being performed to quantify these processes and determine the potential effects of a decrease in bottom ice presence due to global climate change. The methods employed to study these processes include channel cross-section surveys, passive and active tracers, and sediment traps.

The study presented in this poster will focus on the comparison between the flows required to generate bedload transport, as determined analytically, with the recorded flow history for the study site (1993–2001) to determine what percentage of competent flows occurred during the presence of bottom ice and how much bedload transport may have been reduced by this condition.

Tundra Carbon Fluxes in Response to Experimental Warming along Moisture and Latitudinal Gradients

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The standard International Tundra Experiment (ITEX) experiment originally focused on the phenology and growth of individual plants and later, communities, in response to experimental warming. However, the standardized ITEX experiments also represent a tremendous opportunity to examine ecosystem function in response to warming across latitudinal and moisture gradients. One integrative measure of ecosystem function is net ecosystem exchange (NEE) of carbon, which has relevance to biogeochemical cycling at larger scales. As part of the North American ITEX (NATEX) project, we initiated measurement of carbon fluxes of the ITEX warming experiments across the latitudinal and moisture gradients represented by our sites (Alexandra Fiord, Barrow, Atqasuk, and Toolik). Fluxes were assessed using static chamber techniques conducted over twenty-four-hour periods sampled regularly throughout the summer for at least two years for each site. At Toolik, warming increased carbon losses at both moist and dry sites. In contrast, at both Atqasuk and Barrow, warming increased carbon uptake at wet sites and increased carbon losses from dry sites. At Alexandra Fiord, warming increased uptake at moist sites, but for both wet and dry sites the response depended on the sample year. At both wet and dry sites in Alaska, warming increased gross photosynthetic uptake, even in sites that had greater net carbon losses with warming. The results indicate that the respiration response to warming determines whether the carbon balance of a site becomes more positive or negative with warming.

Carbon Exchange in a High-Arctic Oasis

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Plant and ecosystem CO_2 exchange patterns were measured over two growing seasons in three high-arctic tundra sites exposed to ambient environmental conditions and to experimentally warmed (2–3°C) temperatures. The study sites spanned extreme hydrologic variation (wet to dry) and were located at the Alexandra Fiord lowland, a high-arctic oasis located on the east coast of Ellesmere Island (78°54' N, 75°55' W, ~50 m elevation). Plant and ecosystem growing season carbon exchange, including net CO_2 exchange, photosynthesis, and respiration, were measured with an infrared gas analyzer connected to a sampling chamber. Under ambient conditions, the wet and dry ecosystems were net C sinks during the course of this study, while the mesic site was a net annual source. Warming did not substantially change the net carbon exchange patterns of any of the ecosystems when summed over the entire growing season, but there were some significant effects of warming at certain times during the growing season. Warming did significantly increase photosynthetic C uptake at the dry and mesic sites and increased respiratory C losses at the dry site (less so at the mesic and wet sites). Species-level carbon and nitrogen dynamics showed much higher variability among the three sites than between the ambient and warmed treatment. There were significant differences in C and N dynamics among species and, in several cases, within a species at the three different sites.

Modeling of Soil Seasonal Freeze/Thaw Over the Arctic Drainage Area

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Within the ArcticRIMS project (Rapid Integrated Hydrological Monitoring System for the Pan-Arctic Land Mass), we apply a finite-element one-dimensional heat-transfer model to simulate soil freeze/thaw processes for the arctic drainage area. Reanalyzed NCEP surface temperature with a topography correction and SSM/I-derived snow thickness are the main forcing parameters. We use soil bulk density and composition (sand, gravel, silt, and clay) from the SoilData System of IGBP, and an annual snow density cycle for different snow classes from the CRYSYS data set. Soil moisture content is from a climatology of a permafrost/water balance model at the University of New Hampshire. Here we show first results of active layer depth (ALD), thaw depth, and frozen ground depth (FGD) for the period September 1998 through December 2000 and compare them to measurements of thaw depth at Circumpolar Active Layer Monitoring Network (CALM) field sites.

Effects of Sample Mass and Type on Radiocarbon Dating of Beringian Lake Sediments

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Accelerator mass spectrometry (AMS) radiocarbon-dated lake sediment cores from Siberia and Alaska often have age reversals, dates that are anomalously old or young compared to the majority of dates from the record. We hypothesized that unreliable dates result from small sample size (higher susceptibility to contamination) or from the type of material dated (differential taphonomy or decomposition). To explore the consequences of sample mass and type, we conducted several dating experiments on plant macrofossils from Grizzly Lake (interior Alaska), Upper Capsule Lake (northern Alaska), and several other sites in Alaska and Siberia. In one set of experiments, radiocarbon dates were obtained for very small (<0.05 mg), small (0.05–0.1 mg), medium (0.1–0.3 mg), and large (>0.3 mg) pieces of the same woody macrofossil. In a second set of experiments, several types of plant material were dated from the same depth in a core. In the sample-mass experiments, reliable ages were obtained for samples as small as 0.05 mg. For samples <0.05 mg, the dates had very large standard errors and were often significantly younger or older than dates for larger pieces. In the sample-type experiments, charcoal and wood were generally older than the other types of material (e.g., moss, seeds, leaves) from the same depth. These results suggest that for arctic and subarctic lake sediments the selection of samples for AMS radiocarbon analysis and the interpretation of radiocarbon dates should consider the possibility that plant macrofossils differ in terms of their terrestrial residence time, taphonomy, or susceptibility to contamination.

Climatic and Geomorphic Controls on Holocene Vegetation Change in the Arctic Foothills, Alaska

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Pollen records from lakes on contrasting glacial surfaces in the Arctic Foothills of northern Alaska help us understand Holocene vegetational changes in relation to climate change and geomorphic variability. Analyses of records from the Itkillik II (<11,500 years BP) and Sagavanirktok (>125,000 years BP) glacial surfaces show how substrate influenced the response of plant communities to the regional onset of cooler and wetter climatic conditions ca. 7,500 cal years BP. Stratigraphic patterns of key taxa and comparisons of fossil and modern pollen assemblages using the Canberra metric of dissimilarity allow us to interpret past changes in vegetation across these landscapes. The frequent occurrence of *Equisetum*, Polypodiaceae, *Selaginella rupestris*, and Rosaceae in the Red Green Lake record indicates that the vegetation of the Itkillik II surface resembled moist graminoid prostrate-shrub tundra (GPS) both during the warm, dry early Holocene and after the climate cooled in the middle Holocene. Sagavanirktok surfaces were also dominated by GPS tundra during the early Holocene, as indicated by relatively high abundance of Bryidae, Polypodiaceae, *Equisetum*, and Rosaceae in Upper Capsule Lake pollen samples from this interval. However, these taxa declined after 7,500 cal years BP, and *Rubus chamaemorus* and *Bistorta plumosa* became more common, suggesting that GPS communities were replaced by moist dwarf-shrub tussock-graminoid tundra (DST) when conditions became cooler and wetter. Under these climatic conditions, the fine-textured soils of the Sagavanirktok surface held enough moisture that DST tundra and overall vegetation cover increased, leading to permafrost aggradation, anoxic, acidic soil conditions, slower decomposition, and a thick organic layer that further insulated the substrate. In contrast, coarse-textured substrates maintained low soil moisture and GPS tundra on Itkillik II landscapes even under cool and moist climatic conditions.

Physical Properties of the Freezing Active Layer on Alaska's North Slope

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The presence of unfrozen water content in frozen soils facilitates soil microbiological activity, even at cryotic temperatures. The winter contribution of tundra soils to net annual gas fluxes is thought to be significant, despite the frozen or near frozen state of the active layer during most of this period. The concept of the active layer corresponding to the thawed layer may require modification, justifying an interest in the physical state of the soil during the cold seasons. The low liquid water content levels associated with frozen soils require a precise and calibrated technique for measurement that is often complicated by freezing. Time domain reflectometry probes installed at four locations in the foothills of the Brooks Range on Alaska's North Slope, in a range of soil types, supply bulk soil dielectric data through the fall and winter. These data are combined with temperature and soil physical data to characterize the physical state of these freezing and frozen soils. Freezing characteristic curves and differences in moisture content between vegetated and nonvegetated soils are presented.

Quantifying Arctic Change: The Unaami Data Collection

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The Unaami Data Collection is a set of eighty-five multidisciplinary time series that represent pan-arctic changes over the last twenty-five years. It includes fisheries, biological, terrestrial, oceanic, sea ice, atmospheric, and climate index data. The name Unaami derives from the Yup'ik word for "tomorrow," as used in the science plan for Study of Environmental Arctic Change (SEARCH).

The Unaami Data Collection is available through a web site offering interactive access to graphics, metadata, simple correlation matrix calculations, and data download, at www.unaami.noaa.gov.

Relating Seasonal Patterns of CO_2 Flux to Spatial Representations of NDVI in Arctic Alaska

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Seasonal changes in ecosystem CO_2 flux result from the combined patterns of leaf phenology of the individual species components, but ascribing flux patterns to individual species or functional groups is problematic. Climate changes will differentially affect leaf phenology of component species, resulting in changing patterns of ecosystem CO_2 flux. As part of the ITEX program, we have been measuring CO_2 flux and the normalized difference vegetation index (NDVI) on season manipulation treatments to investigate the relationship between gross primary productivity (GPP) and NDVI. CO_2 flux has been measured using static chambers and NDVI has been measured using an agricultural digital camera (ADC), which provides a spatial representation of NDVI on the study plots. Preliminary oblique images from this study have been analyzed with promising results. Further data will be analyzed using images photographed from nadir for more specific area evaluations of NDVI and CO_2 flux and to compare these evaluations with point-frame functional-group data for chamber-flux areas. It is hoped that these comparisons will indicate which groups are responsible for the major seasonal changes in NDVI/CO_2 flux within treatments. The final product should present usable correlations from NDVI values derived from ADC images, resulting in quick evaluations of CO_2 flux for a specified area as well as recognition of the functional groups responsible for major flux changes. The widely used spectral bands of NDVI also create the potential for introducing usable model parameters for scaling from plots to larger spatial areas.

An Analysis of Varved Sediments from Murray Lake, Ellesmere Island, Nunavut, Canada

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Sediment cores recovered from high-arctic Murray Lake are used to reconstruct the sediment history of the basin since approximately 6.5 ka years BP when there was significant glacier activity in the watershed area. In addition, well-preserved varves from the upper 55 cm of the record are used to reconstruct climatic and environmental changes for the past 1,000 years.

Murray Lake (81° 20' N, 69° 30' W) lies on the eastern edge of the Hazen Plateau and approximately 5 km from Archer Fjord on Ellesmere Island, Nunavut, Canada. The watershed area for the lake is approximately 284 km^2 with 7% of it glaciated by the Murray and Simmons ice caps. Murray Lake is the southern lake of a southward draining pair. The lakes are each approximately 6 km^2 and lie at 107 and 106 m above sea level at the bottom of a U-shaped valley. Murray Lake's northern basin (the deepest basin in the pair) is 47 m deep and is slightly stratified, although not anoxic. Runoff into the lake is dominated by nival melt from the west, and a combination of nival and glacial melt from the Simmons and Murray ice caps to the east.

Two short (55 cm) cores and two vibracores, measuring 5.2 and 3.6 m long, were recovered from the northern basin in 47 m of water. Analyses of the cores shows a sequence of sediments that is undisturbed, finely laminated, and clastic. The analysis of thin sections from the short cores reveals 1,000 sub-millimeter laminae-couplets that appear annual. The sediment sequence from the long cores overlaps with the short cores and shows a sedimentation that has a uniformly microlaminated structure for the upper 2.2 m. Below 2.2 m, the sedimentation abruptly changes to much larger (0.5–1 cm) couplets consisting primarily of course-grained silts with clay caps. The laminae continue unbroken until 4.5 m where the laminae are interrupted by pulses of sand 1–10 cm thick.

Digital images of the thin sections are used to count and measure varves to develop a reproducible chronology. In addition, image-analysis techniques enable a reconstruction of grain size and a measure of horizontality on an annual basis for the past 1,000 years. The chronology is constrained with four radiocarbon dates from macrofossils at separate intervals. Detailed paleomagnetic data is also used to match the record to four other records in the region.

The Seasonal Evolution of Albedo in a Snow-Ice-Land-Ocean Environment

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As part of a program studying arctic coastal processes, we investigated the ice-albedo feedback in a land-ice-ocean regime near Barrow, Alaska. For the past two years, from April through June, spectral and wavelength-integrated albedos were measured along 200 m survey lines. These lines were installed at four sites and included sea ice, lagoon ice, fresh ice, and tundra. Initially all sites were completely snow-covered and the albedo was high (0.8–0.9) and spatially uniform. As the melt season progressed, albedos decreased at all sites. The decrease was greatest and most rapid at the tundra site, where the albedo dropped from 0.8 to 0.15 in only two weeks. The spectral signature also changed as the wavelength of maximum albedo at the tundra site shifted from 500 nm for snow to 1,100 nm for tundra. As the snowcover melted on undeformed first-year ice, there was rapid and extensive ponding, resulting in a decrease of the spatially averaged, wavelength-integrated albedo from 0.6 to 0.2 in only five days. Extensive pond drainage and below-freezing temperatures caused the albedo to rebound briefly to 0.55 before resuming a steady decrease. Comparison of these results to data collected in the central Arctic indicated that albedos of fast ice in the coastal regime decreased more rapidly than pack-ice albedos.

Increasing Arctic River Discharge Threatens Atlantic Thermohaline Circulation

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Discharge of freshwater from Eurasian rivers to the Arctic Ocean has increased significantly over the past sixty-five years. Should this trend continue, the quantity of extra water delivered to the Arctic Ocean would be on the order of that predicted by global circulation models to significantly impact Atlantic thermohaline circulation. By linear extrapolation, increasing river discharge reaches critical forcing values on a millennial time scale. Coupled to future changes in temperature as estimated by IPCC 2001, increasing river discharge reaches critical forcing values within the next 200 years. As part of a pan-arctic response to global warming, contributions from North American rivers, Greenland, and net precipitation on the ocean could provide additional freshwater forcing. Correspondence between the Eurasian river discharge anomaly and the North Atlantic Oscillation index suggests that increases in river discharge are coupled to hemispheric climate patterns. Increases in air temperature over Eurasia and North America provide evidence of arctic-wide change. Past changes in thermohaline circulation, recorded in ice-core and ocean sediments over the last 100,000 years and more, have led to large and rapid changes in the climate of the North Atlantic region. Such changes may occur again in the near future if freshwater inputs to the Arctic Ocean continue to increase.

Organic Carbon in Soils of Arctic Alaska: Advances in Our Understanding of the Arctic Ecosystem

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Soils descriptive physical and chemical data are now available for the first time for sites across arctic Alaska. These data are being used in integrated C-Flux, ATLAS, CALM, and the USDA Global Change Initiative projects examining arctic terrestrial systems. These field investigations have been key in the field testing of the newly adapted Gelisol order in Soil Taxonomy and to supporting development of the Circumpolar Soils Map and the North American Soil Carbon Map. The soils data set has contributed to climatic modeling efforts.

Detailed and specific studies of soil organic carbon (SOC) stocks under the ARCSS-LAII program indicate that arctic soils contain twice as much of the terrestrial C pool as previously reported. This newly accounted-for SOC is of significance not only in magnitude, but also in its quality as it relates to the arctic and global C cycles under changing climate. Organic matter characterization study indicates that soil active layers contain relatively large amounts of their C in fractions that are in an intermediate state of decomposition and are susceptible to further decomposition under warmer temperatures and changing moisture levels. Large amounts of SOC stocks are found in both the active layer and upper permafrost due to cryoturbation. This portion of SOC is not highly decomposed and thus is susceptible to increased decomposition with warming winter and shoulder-season conditions such as those that are now being observed in arctic Alaska.

This research provides a basis for future work to link terrestrial C-flux to soil C stocks and quality for the circumpolar Arctic. ATLAS research thus far has laid the soils groundwork for such a link while providing important data to all facets of the project. The recognition of winter soil processes as key to understanding whole season C-fluxes in the Arctic enforces the necessity of future research. Research is needed to understand soil processes and soil C cycles and their controls within the context of soil-landscape evolutionary processes as they occur in the arctic system.

Making a New Step: Zhokhov 2000 Project, Expedition of 2001

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This project was started in 2000 with support from the Rock Foundation. The main focus is to continue the excavations of an Early Holocene archaeological site found in a remote area of the Arctic Ocean. The first excavations of the Zhokhov site were done in 1989 and 1990 (Pitulko 1993, 1998). Ten years later we have a chance to continue this work. However, the objectives of the project are much wider than simple archaeological excavations. The purpose of the project is to reveal and understand a sequence and scale of environmental changes that took place in this part of the world in the Late Pleistocene and Early Holocene, and evaluate their importance for human habitation in this area, cultural changes, and adaptations. That involves Quaternary research, paleontology, and permafrost studies as well as searching for new sites in the New Siberian island chain. When doing our field program this summer, we conducted field research in Zhokhov and New Siberia Island as well. In Zhokhov we concentrated mainly on excavations of the site that yielded a great number of the artifacts, including new categories of those. This includes decorated tools, shovels made of mammoth ivory, barbed and side-bladed harpoons, fragments of baskets or mats, etc. The program in New Siberia was focused on the permafrost, paleontology, and Quaternary studies, and all directions of this research were successful. This also includes possible evidence of human habitation (worked mammoth tusk) found in the southeastern part of the island. However, the most important evidence of that had been received during a short-term excursion into the lower area of the Yana River valley. Approximately 140 km from the river mouth we discovered a cultural layer that had been dated to 25–27,000 years ago. That date is confirmed by four C^{14} dates run by the isotope lab of the Institute of Geology in Moscow. The AMS date by Beta, which had been run from one of the organic artifacts (the foreshaft), coincides with the others. The assemblage includes broken bones of Pleistocene animals (mammoth, horse, reindeer, and bird bones). The lithic technology of the site could be characterized as so-called pebble industry, with a number of chopper and chopping tools, scrapers, and uncompleted bifacial tools. Except that we have a single bone artifact that belongs to the cultural layer (most probably a fragment of an awl). Another artifact found by chance a few years ago at the site is made of very unusual material. This is a foreshaft of approximately 40 cm in length manufactured of a wooly rhinoceros horn. By its shape it resembles the foreshafts found in some of the Clovis sites in North America. Because of this unique artifact, the name for the site is suggested to be Yana/RHS (Rhinoceros Horn Site).

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Reproductive and Vegetative Growth Responses of *Cassiope tetragona* to Experimental Warming from 1986–1998 at Alexandra Fiord, Ellesmere Island, Canada

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General circulation models (GCMs) of the Earth's atmosphere predict significant climate change in the high latitudes within the first half of the twenty-first century, due to the effects of anthropogenically enhanced greenhouse gases in the atmosphere (Maxwell 1992; Houghton et al. 1996). By employing a common temperature manipulation, the International Tundra Experiment (ITEX) seeks to understand variability in arctic and alpine species' response to increased warmth across climatic and geographic gradients of tundra ecosystems (Henry and Molau 1997; Arft et al. 1999). This study investigates the vegetative and reproductive response of one of the core ITEX species, the circumpolar evergreen dwarf shrub *Cassiope tetragona* to seven years (1992–1998) of experimental warming at Alexandra Fiord, Ellesmere Island, Canada. Plant stems from *Cassiope tetragona* plants were harvested at the end of the 1998 growing season from four plot pairs in a mesic tundra community. Using retrospective analysis, annual growth increments were determined from leaf internode distance measurements. The annual production of leaves, flower buds, and flower peduncles were counted as well. Multiple analysis of variance and multiple analysis of covariance showed no significant differences in annual growth increments or in the annual production of leaves between the pretreatment (1986–1991) and treatment (1992–1998) periods. However, reproductive effort was significantly greater during the treatment period. These results support some short-term experimental warming studies of *Cassiope tetragona*, confirming an absence of a significant vegetative response (Johnstone 1995; Molau 1997), but a significant increase in reproductive effort due to increased growing season temperatures (Nams 1982; Johnstone 1995). Recent work has explored the relationship between climatic conditions and the two growth and reproductive variables during the pretreatment and treatment periods.

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Second Draft of the Circumpolar Arctic Vegetation Map

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The maps presented here are preliminary products of the Circumpolar Arctic Vegetation Map (CAVM), a project to map the vegetation and associated characteristics of the circumpolar tundra region. The maps show spatial variation in characteristics important to understanding and modeling ecosystem functions and their response to climatic change. These maps can be viewed at the following website: www.geobotany.uaf.edu / cavm.

The CAVM project was initiated in 1993 as an outcome of the First Arctic Vegetation Classification workshop in Boulder. It was funded through supplements to the FLUX studies, and through a major award as part of Arctic Transitions in the Land-Atmosphere System (ATLAS). The CAVM is an international project with participants from the U.S., Canada, Germany, Denmark, Iceland, Norway, and Russia, who have collaborated at four international workshops in St. Petersburg, Russia (1994); Arendal, Norway (1996); Anchorage, Alaska (1997, 1998); and Moscow (2001). The proceedings have been published as U.S. Open File Reports and INSTAAR Occasional Papers. The CAVM project has also resulted in several publications in the *Journal of Vegetation Science*, *Arctic and Alpine Research*, and *International Journal of Remote Sensing*.

The first draft of the CAVM was presented in November 2001 at the ARCSS meeting in Salt Lake City. The version presented here (February 2002) is being reviewed by all the contributors. Publication of the revised map, funded through the committeee for Conservation of Arctic Flora and Fauna (CAFF) and the U.S. Fish and Wildlife Service, is expected in 2003. CAVM participants will meet again at the Second International Arctic Vegetation Classification Conference, planned for 2004 in Greenland. The goal of that meeting will be to publish the more detailed CAVM vegetation community map and produce regional papers that describe the vegetation communities.

The CAVM mapping method integrates information on soils, bedrock and surficial geology, hydrology, remotely sensed vegetation classifications, normalized difference of vegetation index (NDVI), previous vegetation studies, and regional expertise of the mapping scientists (Walker 1999). The information was used to define polygons drawn by photo-interpretation of a 1:4,000,000 scale AVHRR image base map. The base map is a composite AVHRR false color infrared image of the maximum reflectance of each 1 km^2 pixel of 1993 and 1995 data. Hand-drawn polygons reflect the following characteristics: (1) they are greater than a minimum polygon size of 3.5 mm (14 km on the ground) for circular polygons and 2 mm (8 km on the ground) for linear polygons, (2) they consist of a relatively homogeneous landscape unit (either plains, hills, mountains, valleys, lakes, or glaciers) with boundaries visible on AVHRR imagery, and (3) they consist of relatively homogeneous substrate chemistry (nonacidic, acidic, or saline substrates).

The maps presented here include nine maps of characteristics that influence or reflect vegetation patterns (approximately 1:20 million scale), and one larger scale map (1:10 million) of the vegetation of the circumpolar arctic. We include four maps showing some of the data used to create the vegetation map: the AVHRR base map, a map of NDVI derived from the AVHRR, a map of phytomass density derived from the NDVI data and ground studies, and a map of elevation based on the GTOPO 30 digital elevation model. We also include five maps derived from the CAVM: a map of bioclimate subzones of the arctic zone, a map of longitudinal floristic regions, a map of percent lake cover, a map of basic landscape units, and a map of parent material chemistry. The large-scale map shows the dominant vegetation, described in terms of the dominant plant growth forms in each mapped polygon.

We must emphasize that this product is a draft and will likely be extensively revised before publication. The plant physiognomy legend has already been reviewed and revised since the version presented at Salt Lake City in November 2001. Individual mapping teams will be closely reviewing the vegetation physiognomy map. Several hundred plant communities were grouped into the twenty legend categories, so the mappers will be looking at specific local community descriptions, verifying that they have been assigned to the correct category in the legend. They will also be reviewing the landscape and parent material chemistry maps.

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Acknowledgments

This project was funded by the National Science Foundation Arctic Transitions in the Land-Atmosphere System (ATLAS) project (OPP-9732076).

International Arctic Buoy Programme

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Dramatic changes in Arctic climate have been noted during the past two decades. Observations from the International Arctic Buoy Programme (IABP) have played a significant role in the detection of this change over the Arctic Ocean. For example, using IABP data, Walsh et al. (1996) showed that atmospheric pressure has decreased, Rigor et al. (2000) showed that air temperatures have warmed, and in concert, the circulation of sea ice and the ocean have changed so as to flow less clockwise (Steele and Boyd 1998; Kwok 2000; and Rigor et al. 2002). In addition to studies of Arctic climate and climate change, observations from the IABP are also used to validate satellites; for forcing, validation and assimilation into numerical climate models; and for forecasting weather and ice conditions. The data and more information on the IABP can be obtained from http://iabp.apl.washington.edu/.

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The Effects of ITEX Climate Manipulations on Nitrogen Cycling in the Canadian High Arctic

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Climate warming in high latitudes is expected to increase plant productivity and absorption of CO_2 from the atmosphere. This negative feedback to CO_2-induced climate warming may be constrained by the availability of nitrogen in tundra ecosystems. The focus of this research was to examine the changes in soil nitrogen availability and plant nutrient acquisition under simulated conditions of climate warming in the Canadian High Arctic. The research site is located at Alexandra Fiord, Ellesmere Island, Canada (78° 53' N, 75° 55' W). Experimental plots are passively warmed by 1–3°C during the growing season using open top chambers (OTCs), which were established in 1992. These studies are part of the International Tundra Experiment (ITEX).

During the 2001 growing season, the nitrogen economy was examined at five plant communities along a soil moisture gradient. The ITEX sites are located in a wet sedge meadow, two mesic dwarf shrub-cushion plant communities, a dry deciduous dwarf shrub-graminoid community, and an upland polar semidesert. Ion exchange membranes (IEMs) were used to obtain a relative index of nitrogen availability between the control plots and the OTCs, and between the five sites. The flux of NO_3 and NH_4 to the IEMs was measured following snowmelt, during peak growth, and at senescence. Soil nitrogen mineralization, microbial nitrogen immobilization, and dissolved organic nitrogen transformations were examined using the buried bag method over the growing season. Preliminary findings indicate that warmer temperatures have increased plant growth and nutrient use efficiency, leading to higher C:N ratios. Analyses of vegetation and soil C:N ratios will be used to determine if the quality of plant litter has affected soil nutrient availability over the course of the warming experiments.

A Permafrost Observatory at Barrow, Alaska

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The most convenient way to assess recent changes in permafrost temperatures is to reoccupy sites where high-quality permafrost temperature records were obtained for some period of time in the past. One such ideal location is Barrow, Alaska, where the U.S. Geological Survey (USGS) had an extensive measuring program during the 1950s to early 1960s under the direction of one of the co-authors (Brewer).

During summer 2000, the initial phase of establishing a Permafrost Observatory at Barrow was undertaken. The overall goal of establishing the observatory is to compare present permafrost temperatures with relevant previous, very high-quality measurements (precision generally at 0.01°C), and continue measurements into the future. In late July, new thermistor cables were inserted in three of the original USGS holes to depths of 9.3, 14.2 (“Special #2” site), and 23.8 meters, and in a new hand-held, augered hole to the depth of 8.2 meters and located within several meters of the 14.2 m hole. The hot-water jetting and augering were performed by Austin Kovacs, Kovacs Enterprise. Two Campbell data loggers were installed to read the cables at hourly intervals. By the end of August, the temperature field in the 14.2 m hole had reached the equilibrium.

Comparison between permafrost temperature profiles obtained at the same location (“Special #2” site) by Max Brewer on 9 October 1950 and on 9 October 2001, shows that at the 15 m depth, permafrost temperature is warmer at present by more than 1°C. This noticeable, but still moderate, increase for such a long period of time can be explained using results of our previous analysis of long-term permafrost temperature variations at Barrow. This analysis shows that the thermal conditions at the permafrost surface were quite similar during the 1940s and 1990s (except for unprecedented extremes of 1998 and 1999). Much colder permafrost temperatures (up to 2 to 3°C colder) were typical for Barrow during the 1970s.

The historical permafrost data provided a unique opportunity to independently test our model and modeling results. To compare calculated temperatures with measured data, we used the time interval between September 1951 and October 1952. The results of this comparison were much better than expected. For the entire period, in the depth interval between two and eighteen meters the differences between calculated and measured permafrost temperatures were typically smaller than 0.3°C. They practically never exceeded 1°C in the upper two meters of soil.

The next phase of the project is to install cables in several proposed deeper holes (30 to 50 meters) in the vicinity of North Meadow Lake, which is located within the northern border of the Barrow Environmental Observatory (BEO). These deeper boreholes will provide data from the depth of zero amplitude at approximately 20 m and deeper thermal profiles to reconstruct recent changes in surface temperatures of permafrost. Shallow thermistor cables will be installed for temperature measurements in the active layer and uppermost permafrost as an additional site for the Circumpolar Active Layer Monitoring (CALM) program. This BEO site is being developed as a future long-term, interdisciplinary research area. The current permafrost temperature project is funded by the International Arctic Research Center (IARC) under the auspices of the National Science Foundation.

Long-term Responses of Wet Sedge Tundra to Changes in Nutrients, Temperature, and Light

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We examined the long-term responses of wet sedge tundra to changes in nutrient availability, temperature, and light. Measurements of biomass, species composition, ecosystem CO_2 flux, and plant N pools were conducted in 1994 after six to nine years of treatment and in 2001 after 13–16 years of treatment, allowing a comparison of the short-term vs. longer-term vegetative responses to treatment. Unlike tussock tundra, after thirteen to sixteen years of treatment wet sedge biomass has leveled off or declined in fertilized plots, while species composition continues to change. Changes in species composition appear to have a limited impact on aboveground N concentrations, biomass N, and ecosystem CO_2 flux. Ecosystem CO_2 flux was greater in 2001 than 1994 despite lower biomass in 2001. CO_2 flux per-unit biomass and per-unit biomass N were also greater in 2001 than 1994. Graminoid blade percent N was consistently greater in 2001 compared to 1994, which could explain the higher CO_2 flux rates in 2001. Fertilization increased belowground biomass and decreased the ratio of below- to aboveground biomass.

Circumpolar *Rangifer* Monitoring

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Caribou/reindeer (*Rangifer tarandus*) is a keystone subsistence resource of the arctic system. Following a directive from the Arctic Council to the committee for Conservation of Arctic Flora and Fauna (CAFF), a circumpolar monitoring initiative focusing on human-*Rangifer* systems has been established. The monitoring program includes five areas of activity:

1. Remote sensing of normalized difference vegetative index (NDVI) analysis and its relationship to herd reproductive success
2. Climate, biological and socio-economic indictors of change
3. Local and traditional knowledge perspectives on conditions and system processes
4. Assessment of trends and implications of change using simulation modeling
5. Communications tools that disseminate findings and promote discussion among parties about the overall health of the system

Details on the circumpolar *Rangifer* monitoring network are found at www.rangifer.net, the site of the Human Role in Reindeer/Caribou Systems initiative of the International Arctic Science Committee.

Active Layer Thickness and Permafrost Temperature Regime (Past, Present, and Future) within the East-Siberian Transect: Modeling Approach using GIS

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Understanding land-atmosphere interactions in arctic ecosystems requires information on the potential response of the thermal regime of permafrost and the active layer to seasonal, interannual, and long-term climatic variability and change. The contents of free and bounded water and temperature regime within the active layer are primary factors that quantify the magnitudes of summer and winter respiration and carbon fluxes, which are the results of microbial and other biological activities. Any changes in the active layer have a direct impact on the temperature regime and consequently on dynamics of permafrost and permafrost stability. In turn, the active-layer thickness and temperature regime depend mostly on the combination of climatic parameters, such as mean annual air temperature and annual air temperatures amplitude, let alone the mean annual snowcover thickness, soils thermal properties, and moisture content.

Our study area encompasses the Tiksi-Yakutsk East Siberian transect, designated as the Far East Siberian transect in the IGBP Northern Eurasia Study project (IGBP-NES) (IGBP, 1996), is centered on the 135° meridian, and is a collaborative effort of IGBP-NES with the GAME project of the WCRP. The ecosystem and the permafrost within the transect are especially vulnerable to the positive changes in active-layer thickness and temperature. Permafrost in east Siberia contains a significant amount of ice in the form of segregated ice, ice wedges, and buried layers of ice. If summer thawing will reach the ice horizon, or if the temperature in the permafrost rises so that the process of permafrost thawing starts, then major changes in the ecosystem may occur; for example, wetlands or grasslands may gradually replace the boreal forest.

The purpose of this work is to show the spatial extent and dynamics of the active-layer thickness and its influence on permafrost stability for different scenarios of climate change, using ArcView software. In order to calculate active-layer thickness and permafrost temperature, we chose Kudryavtsev's equations. The major parameters in these equations are mean annual air temperature and seasonal air amplitudes. Also, mean annual snow thickness, thermophysical properties of snow and soils (heat capacity and thermal conductivity), and soil moisture are taken into account.

Chemical Characteristics of Nearshore Waters in the Laptev, East-Siberian, and Chukchi Seas: Preliminary Results of POI Trans-Arctic Expedition-2000

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Any attempt to understand the effects of the Arctic Ocean on global change or the effects of global change on the Arctic Ocean requires thorough knowledge of the nearshore processes as a linkage between land and ocean processes in the Arctic. The Arctic Ocean has the broadest shelf in the world ocean: the continental shelves occupy about 36% of the Arctic Oceanic area. Moreover, greater than 90% of all organic carbon burial occurs in sediments depositing on deltas, continental shelves, and upper continental slopes, and the significant portion of organic carbon withdraw has occurred over the Siberian shelf that was explored poorly.

An expedition of the Pacific Oceanological Institute onboard the hydrographic vessel *Nikolay Kolomeitsev* along the Northern Sea Route was the first expedition where modern hydrological and hydrochemical data were obtained during one season (summer-fall of 2000) in all Russian arctic seas. This is the first time the oceanographic cruise was focused on the nearshore biogeochemical processes. Hydrochemical anomalies obtained over the shallow Siberian shelves demonstrate the significant role of coastal erosion and consecutive destruction of the land-derived organic matter in formation of the biogeochemical regime in the Arctic Siberian seas that agrees with our data obtained in the nearshore expeditions (Semiletov 1999a, b). Transport of particulate organic carbon forced by the coastal erosion might be similar in value to the dissolved organic carbon transport by the rivers, whereas the total transport of terrestrial particulate eroded material is more significant than solid transports by rivers. The nearshore zone of the Siberian seas is mainly a source of atmospheric CO_2 emission, though the Arctic continental margin in whole may serve as a net CO_2 sink (Semiletov 2001; Pipko et al. 2002).

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Comparative Analysis of Thermal and Moisture Trends in the Active Layer of Permafrost (North Slope, Alaska)

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During the period from 1986 to the present, an intensive system of temperature and moisture (since 1999) measurements in the active layer and in near-surface permafrost operates. It includes nine observation places in northern Alaska (to the north and northwest of the Brooks Range). At each of these sites we measure hourly air and ground surface temperatures, soil temperatures down to one (or 1.5) meter depth with about 10 cm increments and volumetric soil moisture at three or four different depths within the active layer. At the new Happy Valley site, we also automatically measure snow thickness. Every year since 1996, we measured maximum end-of-summer active-layer thickness and maximum end-of-winter snowcover thickness at the sites along the Dalton Highway. The longest, fifteen years of uninterrupted measurements at the northernmost three sites (West Dock, Deadhorse, and Franklin Bluffs), provide unique information on the active layer and upper permafrost temperature dynamics. It should be stressed also that the recent warming brought soil temperatures at the North Slope sites to a surprisingly high level. Mean annual ground surface temperature at West Dock reached –5.7°C in 1999, –3.7°C at Deadhorse in 1998, –3.2°C at Franklin Bluffs in 1998, and probably unprecedented –0.95°C at Happy Valley in 1998. However, the last three years show a definite decrease in temperatures at these four sites. The cooling amounted to less then one to 1.5°C in the mean annual permafrost surface temperatures and to 1.5 to 2.5°C in the mean annual ground surface temperatures. In contrast with the Dalton highway sites, the Ivotuk sites do not show any distinguishable cooling during 1999–2001, though mean annual air temperature was 2°C colder in 2000 compared with 1999. Also, mean annual temperatures of the ground and permafrost surfaces here are unexpectedly high.

Local Variability of Temperature and Soil Moisture in the Active Layer of Permafrost (Ivotuk and Council, 1998–2001)

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The upper part of permafrost is extremely sensitive to changes in climate. Modifications in the hydrological and temperature regimes in the permafrost active layer produce important transitions in ecosystems. However, the active-layer characteristics are very variable on different types of landscapes. We continue to replenish the time series of ground-temperature and ground-moisture data obtained at the Ivotuk and Council sites. The Ivotuk study site is located within the northwestern foothills of the Brooks Range, Alaska. Here we survey moist acidic and nonacidic tundra plots, shrub plot, and moss plot. The Council study area is located on the outskirts of a settlement with the same name in the southern Seward Peninsula. Here we survey a forest site, a woodland site, a shrub site, and a tundra site. Three years of investigations in Ivotuk (two years in Council) demonstrate significant temporal and spatial variability of the hydro-temperature patterns of the permafrost active layer. Mean annual temperature in Ivotuk at 0.5 m depth varies from –4 to –2.6°C. This value in Council varies from –1.3 to +0.5°C. Mean annual temperatures of the ground and permafrost surfaces at Ivotuk are unexpectedly high. While mean annual air temperatures at these sites are just slightly warmer than at the Prudhoe Bay sites (typically less than 1°C), mean annual ground surface temperatures were between –1.5 and –2.5°C and mean annual permafrost surface temperatures were typically between –2 and –3°C during 1999–2001. They are 2 to 3°C warmer than at the Deadhorse and Franklin Bluffs sites. The most reasonable explanation could be the differences in the snow thicknesses and its thermal properties. The differences in temperature and moisture regime between two years of measurements at the Council sites were very significant, especially during the winter. The 1999–2000 winter was much warmer than the previous one. For example, at the tundra site the complete freeze-up of the active layer occurred in March 2001. In the previous winter this happened in November. At the shrub site, temperature in the upper one meter of soils has never dropped below –1°C for the entire winter. The obtained results help to estimate correctly the integral large-scale permafrost characteristics of the region.

Long-Term Variability of the Pan-Arctic Hydrological Budget and the Decline in Hydrological Monitoring Networks

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Russia, Canada, and the United States possess 92% of the non-ice covered pan-arctic land area and contain the overwhelming majority of its monitoring stations. To estimate the current status of river discharge gauges across the pan-arctic, data from the University of New Hampshire, the U.S. Geological Survey, the Water Survey of Canada, Environment Canada, and the Russian Hydrometeorological Service (Roshydromet) were used. The Arctic Ocean drainage basin is the best monitored in terms of freshwater flow to the coastal zone. During the 1980s, when the number of stations reached its maximum, about 74% of the total nonglacierized pan-arctic basin area was monitored. Even under such favorable conditions, no measurements were taken in large regions of the basin, ranging from 40% in North America to 15% in Russia. The total area monitored decreased to 67% from 1986 through 1999 at a rate of 79% in Russia and 51% in North America because some important downstream gauges located mainly on medium- and small-sized rivers were closed. The total number of gauges is also an important index of our capacity to develop high-resolution mapping of contemporary runoff. This constitutes an essential tool for monitoring progress of climate change and for studying the overall hydrological response throughout the region. Over the last fifteen years, the number of hydrologic gauges serving the pan-arctic reverted to that of the early 1960s. There is a significant difference in the decline of discharge networks of various sub-regions across the pan-arctic drainage. The network cutbacks were especially severe in the Far East of Siberia and the province of Ontario, where 73% and 67% of river gauges were closed between 1986 and 1999, respectively.

An analysis of long-term variations of river discharge based on data sets up to the year 2000 shows a sustainable increasing trend for all regions of the pan-arctic basin except the Hudson Bay watershed. The average rate of increase in discharge to the Arctic Ocean was 3.6 km^3/year (1.9 km^3/year in Eurasia and 1.7 km^3/year in North America) for 1936–2000. The rate is significantly higher (10 km^3/year) for the period when global air temperature had a fast rise since 1976. Especially high values of river inflow to the ocean are observed since 1986. The mean annual discharge for 1986–2000 was about 200 km^3/year greater than for 1936–1985. Thus additional freshwater discharge for this period was 2800 km^3. This volume approximately equals the total annual inflow from Eurasia. An integrated analysis of air temperature, precipitation, and runoff was carried out for the ten largest river basins representing a wide variation in geography. All these river basins show the air temperature increasing during the last ten to twenty years. The greatest runoff increase is observed for the large European rivers (Northern Dvina, Pechora) where it results from a significant precipitation increase. The largest Siberian river basins, which have wide permafrost extent, demonstrate the increase in runoff despite no trend or a decreasing trend in precipitation. It is likely the result of several components such as permafrost melting, a shorter winter period, an increase in groundwater storage, and faster spring snowmelt.

Climatic Variability in the Kuparuk Region, North-Central Alaska: Optimizing Spatial and Temporal Interpolation in a Sparse Observation Network

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Air temperature fields are required as input to spatial models in ecology, geocryology, and biogeochemistry. Air-temperature data from a sparse, irregular meteorological network in the Kuparuk region of north-central Alaska were interpolated spatially and temporally to provide a thirteen-year (1987–1999) series of thawing degree-day fields at 1 km^2 resolution. Procedures involved standardizing diverse temperature records, followed by application of topographically and climatologically aided interpolation using station data and digital-elevation models to incorporate the effects of local topography. The accuracy of the interpolation procedures was assessed using cross-validation. Considering the number of data points used for interpolation, their distribution, and the size of the area, the combination of climatologically assisted and topographically informed spatial interpolation procedures provides adequate representation of the annual degree-day fields for the Kuparuk region. Spatially integrated mean absolute error does not exceed 3% in any year. To investigate the spatial distribution of interpolation uncertainties, the cross-validation errors obtained at each station for each year were interpolated spatially to a regular 1 « 1 km grid consistent with the degree-day fields.

Age, Carbon Content, and Climatic Stability of West Siberian Peatlands

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The West Siberian Lowland (WSL) is the world's largest high-latitude wetland, with a 1.8 x 106 km^2 forest-palustrine zone covering nearly two-thirds of western Siberia. Over half of this area consists of peatlands, which since the early Holocene have sequestered atmospheric carbon in the form of undecomposed plant matter. The total carbon pool of the former Soviet Union (FSU) has been roughly estimated at ~215 Pg C, suggesting that nearly one-tenth of the world's soil carbon pool lies stored in Siberian peatlands. The region has recently attracted attention from the global change community, owing to recent studies elsewhere that suggest CO_2 and methane exchange from peatlands may change dramatically under a warming climate. Since 1999, an international team of scientists from UCLA, the Russian Academy of Sciences, Tomsk State University, and the University of Utah has conducted a major field and satellite remote-sensing study of the role of WSL peatlands in the global carbon cycle. Central to the study is the extraction of peat cores throughout the region, from which peatland age and carbon content are determined from thermal analysis and radiocarbon dating. After successful summer field campaigns in 1999, 2000, and 2001, we have collected nearly 100 cores, as well as thousands of other measurements and samples of peat depth, surface moisture, botany, water geochemistry, river sediment load, and land surface cover. The scope and scale of these data are unprecedented in the region. Numerous satellite images of the area have also been compiled, including 150 m MSU-SK visible/near-infrared imagery from the Russian RESURS-01 platform since 1994, ERS synthetic aperture radar and scatterometer products since 1991, DMSP SSM/I passive microwave data since 1987, and fifty-two Landsat MSS scenes acquired in 1973. These satellite data sets are now being combined with point field observations and GIS analyses of existing Russian peat maps to determine the Holocene evolution, total carbon content, desiccation susceptibility, and contemporary wetness variability of the world's largest peatland. Numerous peat basal dates of 9,000–10,000 radiocarbon years BP indicate that WSL peatlands formed rapidly throughout the region in the early Holocene. Low humification suggests few or no major decomposition events in the past 10,000 years.

Gap in the ARCSS Program: The Role of Light in the Arctic Environment

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It is well recognized that light plays a major role in our environment, including the high-latitude regions. This is so because light "drives" photobiology and photochemistry in the natural environment, including the Arctic. Light is also the driver of the dynamics of the atmosphere-sea ice-ocean system. Therefore, an understanding of the disposition of light energy in the arctic system (atmosphere-land or atmosphere-sea ice-ocean system) is a prerequisite for understanding climate evolution. Finally, we rely on light reflected from the atmosphere-surface system to give us information about atmospheric and surface properties (remote sensing). Yet our knowledge of the light field in the Arctic and how it changes with atmospheric and surface conditions is less than satisfactory. This is especially the case in the ultraviolet spectral range, where measurements are largely lacking. This poster is meant to provoke discussion about how our knowledge of this basic parameter, the light field, in ARCSS can be improved. What can we do to close this gap in the ARCCS Program?

Sediment Inclusions in Alaskan Coastal Sea Ice: Spatial Distribution, Interannual Variability, and Entrainment

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We investigated the spatial characteristics of sedimentary inclusions and elucidated processes controlling their spatial and temporal variability in the fast ice cover of the shallow-marine environment of Elson Lagoon near Barrow, Alaska. This was accomplished by examining the frazil ice layer of sea-ice cores representing the 1998, 1999, and 2000 fall freeze-up periods and comparing the results with a sediment resuspension model. Sediments occur exclusively as aggregates of clay to fine-silt sized particles that were confined to brine inclusions in the frazil ice. The average cross-sectional area of these aggregates is positively correlated with sediment concentration of the frazil ice ($R2 = 0.82$, $P<0.01$). The minimum distance between neighboring aggregates (nearest-neighbor distance) is negatively correlated with sediment concentration ($R2 = 0.78$, $P<0.01$). However, little correlation exists between the number of aggregates and sediment concentration. Sediment concentrations ranged from 24 mg/L to 1470 mg/L and sediment loads ranged from 2 g/m^2 to 384 g/m^2, with 1998 and 2000 sediment loads being one to two orders of magnitude smaller than 1999 sediment loads. Similarly, the potential for bottom-sediment resuspension was greater in 1999 than in 1998 and 2000 by more than a factor of two. Resuspension potential is controlled spatially by the local bathymetry and interannually by wind velocity and fetch. At sub-meter scales, increases in bottom sediment resuspension result in greater sea-ice sediment concentrations, larger aggregates, and smaller nearest-neighbor distances.

Evidence of a Temperature-albedo Feedback in Northern Alaska Related to Earlier Spring Snowmelt

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An important process that occurs every spring over continental regions of the Arctic is the melting of the snowpack. Variability in the date when the tundra becomes snow free can affect the net annual energy budget on a global scale through complicated feedbacks. If the global mean temperature increases, the Arctic is predicted to experience enhanced warming because of a positive radiative feedback caused by decreasing surface albedo as ice and snowmelt. Using observational evidence we evaluate this "temperature-albedo feedback" for the North Slope of Alaska. The timing of snowmelt depends on many factors other than air temperature, especially changes in winter snowfall. Beginning in 1985 an objective method, based on radiometric data, has been used at the CMDL Barrow Observatory (BRW) to determine the date of snowmelt there. Using proxy data, the record of melt has been extended back to 1966. An analysis of this longer time series, in conjunction with ancillary data, reveal the primary factors that influence the annual snow cycle in northern Alaska. A common feature of all records is that complete melt-out occurs each year over a short period of time. This fact makes monitoring the melt relatively straightforward and provides a record useful for evaluating regional climate change. An examination of the combined radiometric and proxy record of melt dates for BRW indicates that the melt has advanced by about eight days since 1965. The most pronounced change occurred during the last decade. Analyses of other station records tend to support this conclusion. Year-to-year variability in the date of snowmelt is largely explained by (natural?) circulation-driven fluctuations in winter snowfall, springtime temperatures, and cloudiness. As predicted by model studies, an earlier snowmelt increases the net surface radiation budget and, in turn, air temperatures tend to rise. It is not conclusive, however, that the trend towards an earlier melt will continue and warming will accelerate. The occurrence of relatively late melt seasons for the past three years indicate a return to earlier climatic conditions. It appears that another shift in synoptic patterns may be in progress. To what extent this shift may be due to the changing mode of the Arctic Oscillation has yet to be evaluated. It will be essential to monitor the annual snow cycle over the entire Northern Hemisphere land areas in conjunction with evaluations of planetary modes of circulation to fully understand the processes that underlie changes in temperature as a result of albedo feedbacks.

ATLAS Project: Ivotuk Site CD

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The overall goal of the LAII ATLAS program is to understand the role of the arctic terrestrial system in global climate change by studying the interactions and feedbacks in the land-atmosphere system that govern ecologically and socially important impacts. The more immediate research objective is to determine the geographical patterns and controls over climate-land surface exchange (mass and energy) and to develop reasonable scenarios of future change in the arctic system.

The ATLAS field deployment included data from seven sites covering more than four years (1998–2001). Data collection was phased in and out at each site to meet science objectives and other collaborations. The participating investigators decided that the compilation of data and information for key ATLAS sites was an important next step in documenting the results of this work. This CD is a compilation of information and measurements made at the Ivotuk site on the North Slope of Alaska by more than thirty scientists and technicians. It contains data, photos, and descriptions encompassing a 2.5 year period from 1998 through June 2000. The main purpose of the CD is to provide a single archive source for the multidisciplinary data collected at this site. Additional photos and data set descriptions help the user understand the data that is accessible on this CD.

SnowSTAR-2002: An Over-Snow Traverse from Nome to Barrow, Alaska, in 2002

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An over-snow traverse that will follow a 750 km route from Nome to Barrow, Alaska, in March and April 2002 is planned. The purpose of the traverse is to measure the snow-depth distribution and the snow characteristics north and south of the Brooks Range, testing whether there is a gradual or abrupt transition at this mountain barrier. South of the range we will sample the snow along the tree line, comparing adjacent tundra and forest snowcovers. North of the Brooks Range we will repeat a set of measurements made on a similar traverse between Ivotuk and Barrow in 2000. In addition to snow distribution measurements, we will also measure the light attenuation in the snow; this is an important parameter for assessing the degree to which photochemistry can occur. We will also sample for trace metals and other elements that can tell us about the source of the winter precipitation, as well as shedding some light on whether arctic haze tends to be confined north of the Brooks Range, as is generally thought. An eighth-grade teacher will accompany us on the traverse and will assist us in outreach at the five villages along the route. The traverse is called SnowSTAR-2002 (Snow Science Transect, Alaska Region-2002).

Snow and Shrub Albedo Measurements during the Snowmelt at Council, Alaska, 2001

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The albedo of snow and vegetation was measured every few days at five sites near Council, Alaska, between April and June 2001. The five sites ranged from tundra without shrubs, through shrubby tundra, to shrubland and forest. At each site a 50 m-long cable was suspended above the ground and shrub canopy. Swedges on the cable at 1 m intervals allowed us to move a suspended instrument cart along the cable, stopping every meter to measure the albedo and to photograph the snow and vegetation that was vertically beneath the cable. A 30 x 30 cm area of the snow was sampled for the surface debris load each time that albedo was measured at a site. Pre-snowmelt albedos (approximately 0.8) were highest (and nearly equal) at the tundra, shrubby tundra, and shrubland sites, the latter because the shrubs were buried in snow. As the melt proceeded, shrubs were rapidly exposed at the snow surface, lowering the albedo and accelerating the melt. As a result, the shrubland site melted out to completion first, even though conspicuous melt began first at the forest and tall shrub sites. The tundra site maintained high albedo values (>0.7) the longest, but nevertheless melted out shortly after the shrubland site due to very high rates of melt late in the melt season. Shading from tall shrubs and forest canopies resulted in the melt taking the longest at those sites. Our results suggest that the presence of shrubs can accelerate snowmelt when the shrub height is about the same as the snow depth, but that if the shrubs are either significantly taller or shorter than the snow depth, the rate of melt falls off. There appears to be a critical transition in albedo and melt behavior when shrubs and snow are similar in size. Shrubs smaller than the snow depth have relatively little effect, while shrubs larger than the snow depth behave like a forest canopy. These results have important ramifications for the transition of tundra to forest or shrub.

Aboveground and Belowground Production Patterns in Alaskan Tussock Tundra: Plasticity in Response to Climate Change

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Understanding system nutrient and water balance under current and future climate regimes requires a thorough knowledge of plant resource allocation. With recent improvements in optic and electronic technology, minirhizotron camera systems have become a useful tool for measuring root production dynamics in some natural systems. This study examined the patterns of shoot growth relative to root production and the influence of warming, fertilization, and increased winter snow on differential resource allocation. Shoot growth measures and minirhizotron images were taken on a mean interval of 7.7 days during the 2001 growing season, with an additional fall sampling date to capture late-season root production.

Results from our control plots suggest an inverse relationship between aboveground growth rate and belowground production rate in the moist tussock system. During periods of peak aboveground growth rate, belowground production rate was at a relative minimum. Conversely, during periods of peak belowground production rate, aboveground growth rate was at a relative minimum. In contrast to control plots, warming and fertilization treatments produced periods of high concurrent above- and belowground production early in the growing season, but resumed the pattern of mutual exclusivity by mid-July. Allocation patterns in plots treated with increased winter snow displayed a magnified case of mutual exclusivity in aboveground growth and belowground production. Upon emergence from the snow, nearly all growth was concentrated above ground. With progression of the growing season, belowground production rate increased steadily, while aboveground growth rate decreased steadily, such that the aboveground minimum and the belowground maximum were coincidental in late August.

These patterns, derived from treatment and control plots, suggest a trade-off in resource allocation, where environmental constraints necessitate partitioning of carbon and nutrient acquisition. We hypothesize that, in addition to nutrient limitation, conditions specific to the respective microclimates of roots and shoots are important determinants of the observed patterns. Patterns in aboveground growth may closely correspond with variables such as photosynthetically active radiation and ambient air temperature, while patterns in belowground production, in addition to the indirect influence of aboveground variables, may correspond closely with soil temperature, depth of thaw, and microbial biomass. Based on these differences, we hypothesize that the apparent mutual exclusivity in aboveground growth and belowground production is a consequence of the buffered soil environment, which delays the onset and extends the terminus of the growing season, and the balance between cumulative microbial metabolism and plant available nutrients. These hypotheses will be tested in a path-analysis framework.

Photochemical Ozonolysis of Alkenes to Acids in Surface Snow

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Over the past decade research at Summit, Greenland, has focused on the understanding of atmosphere-to-snow transfer and postdepositional processes of the chemical species used as proxies in the ice-core records. A more complete understanding of these processes is needed to be able to reconstruct paleoatmospheric concentrations of trace gases from ice cores, which at Summit include the GRIP and GISP2 ice cores that represent the longest (~250 kbyr) high-resolution data set available for paleochemical ice-core records within the Northern Hemisphere. Over the past several years, new data have emerged indicating that surface snow may be one of the most photochemically oxidizing regions of the lower atmosphere. Photolysis drives fast nitrogen cycling, revolatilizing nitrate ion from the surface snow in the form of NO, NO_2, and HONO (Honrath et al. 1999; Dibb et al. 2002; Jones et al. 2000) and organic chromophores to alkenes, aldehydes, and other important trace gases (Sumner and Shepson 1999; Couch et al. 2000; Swanson et al. 2002). Rapid loss of ozone has also been recorded within the snow (Peterson and Honrath 2001) and appears to create a vertical gradient in ozone in the surface boundary layer (Helmig et al. 2002). Measurements within the surface snow (1 m depth) have recorded a peak 0.25 ppbv alkene production (Swanson et al. 2002), rapid ozone destruction of 0.78 ppbv hr-1 (Peterson and Honrath 2001), and high organic acid concentrations (2–10 ppbv) (Dibb et al. 2002). Combining these measurements, we put forth a set of possible mechanisms that could explain the high concentration of organic acids (C1–C2) through the ozonolysis of the photochemically produced alkenes. Also, we hope to use results from SF_6 tracer experiments to model flow dynamics within the surface snow and thereby calculate average diurnal sinks for ozone and production estimates for the alkenes and organic acids. Implications for ice-core records and tropospheric chemistry will then be presented.

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Trans-Basin Sections: An Ideal Tool for Understanding Arctic Change

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The water masses of the Arctic Ocean and Nordic Seas are sensitive to changes in the characteristics and supply of the source waters, many of which are internal to the overall region. Hence, at interannual and longer time scales, changes in the source regions become imprinted on the system, reflections of its ocean climate state.

Reference-quality sections of CTD, hydrographic, and tracer data obtained from the Nordic Seas and Arctic Ocean during the 1980s and 1990s have become our primary window to the structure and circulation of the subsurface water masses there, and have played a formative role in the transformation of oceanographic thinking about the region and its relationship to the global thermohaline circulation. Where reference-quality Arctic Ocean profile data from the mid-1980s and late-1990s overlap, there are clear signals of change: not only the well-known 'warming' signal is seen but there is also a signature of a late-1980s Arctic Ocean ventilation event, while over this time oxygen concentrations in the dense waters of the Greenland Gyre dropped sharply.

A review of the reference-quality sections that have been done—with a note on what remains to be done—suggests that decadal reoccupation of a trans-arctic CTD/hydrographic section across the Chukchi Borderland, Makarov Basin, Lomonosov Ridge, Amundsen Basin, and western Nansen Basin, together with a decadal survey across the key basins of the Nordic seas, if carried out to reference quality, could provide a window to observe and understand the response of Arctic Ocean and Nordic sea waters to decadal changes in forcing and to understanding changes in the contributions of these waters to the dense waters of the World Ocean.

Long-Term Fertilization Alters Aboveground Production and Species Composition in Alaska Wet Sedge Tundra

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Global warming will likely impact plant communities in the Arctic significantly. One model suggests that a warming climate will stimulate microbial activity and increase nutrient availability in tundra ecosystems. We investigated how eleven years of experimental nutrient enrichment (N plus P fertilization) of wet sedge plots at the Toolik Lake LTER site on the North Slope of Alaska is influencing species composition and seasonal biomass accumulation. We estimated aboveground biomass of dominant species, using regressions that predict species biomass from frequencies of point frame hits across the growing season. The N plus P fertilization increased aboveground biomass by a factor of 3.6 and dramatically altered species composition. Most notably, *Carex chordorrhiza* was six times more abundant in the fertilized plots compared with controls. The total biomass and relative abundances of *C. rotundata* and *Eriophorum scheuzeri* were greatly reduced by fertilization. N plus P additions also increased the amount of standing litter, lowered soil temperature, and reduced thaw depth. Long-term fertilization, therefore, impacts wet sedge tundra communities both directly and indirectly.

Global Warming will Likely Impact Plant Co-Simulation of Soil Freezing and Thawing: Impact of Snowcover and Unfrozen Water Contents

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We developed a numerical simulation model based on a finite difference method in order to clarify the combined effect of snowcover and unfrozen water in soils on the ground thermal regime. A two-dimensional computer model was carried out for the West Dock site in the Prudhoe Bay region of Alaska, where we have a complete set of input data for 1998–1999 and where the active layer and upper permafrost temperatures were measured continuously since 1986. These calculations were made to evaluate the new model performance and to study the spatial and temporal variability of temperatures and unfrozen water contents in the active layer and permafrost for this particular site. The modeling results also show that there is a significant lateral variability in soil temperatures on a one-meter spacial scale. This variability is caused mostly by the spatial changes in the snow thickness and microtopography. However, this lateral inhomogeneity in the permafrost temperatures rapidly decreases with depth.

In the present study we propose methods for reconstruction of the snowcover thermal properties and the unfrozen water content curves based on precise high-frequency temperature measurements in shallow boreholes. These methods are based on a solution of improperly posed problems for the one-dimensional quasilinear heat equation. The temperature data measured at several depths in the active-layer and near-surface permafrost from the Alaska sites (Barrow, Franklin Bluffs) and from Yakutsk, Russia (Chabody) were used to reconstruct snowcover properties and/or unfrozen water contents for these sites.

System Interaction: The Linking of Small-scale Tourism with Traditional Renewable Resources Usage in South Greenland

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The linking of small-scale tourism with traditional renewable resources usage is central for the understanding of the interaction between the local land-use and social systems and elements of the global system involvement in the Arctic and sub-Arctic. The project includes an analysis of environmental changes, induced by changes in land-use patterns as well as changes due to increased external influence.

Land Cover Classification and Modeling of Ecosystem Carbon Flux in the Barrow Environmental Observatory (BEO) Using IKONOS Satellite Imagery

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This poster describes a land-cover classification the Webber group has developed for the BEO area in consultation with Pacific Meridian Resources / Space Imaging (PMR) and a spatially explicit model of carbon flux (Gross Ecosystem Exchange—GEE), which has been developed through collaboration of the Webber (MSU), Gamon and Huemmrich (CSULA), Oechel (SDSU) and Oberbauer (FIU) groups working in Barrow.

Until now, no high-resolution land-cover classification existed for the Barrow area. This is largely due to the limited capability by which remote-sensing techniques and automated-classification techniques have been able to accurately describe the heterogeneous land cover of the coastal tundra of northern Alaska. Panchromatic and multispectral imagery from the new high-resolution (1 m panchromatic, 4 m multispectral) Space Imaging IKONOS satellite was acquired for the BEO in mid-July and mid-August 2000. Using pan-sharpened multispectral imagery, classification decision rules (fourteen classes) based on recent vegetation sampling undertaken by the Webber group, and 225 GPS-located training sites of known land-cover type, a supervised classification was performed in ERDAS Imagine 8.4. The classification appears to represent the area well, although an accuracy assessment is yet to be completed during summer 2002.

A spatially explicit light-use efficiency model was developed for daily gross ecosystem exchange (GEE) on 16 August 2000 (second date of acquisition of IKONOS imagery). Empirical plot-based light-use efficiency models of daily GEE were developed from diurnal CO_2 flux measurements and hyperspectral reflectances. Ground-based tramline hyperspectral reflectances were used to atmospherically and mechanistically correct IKONOS multispectral imagery bands 3 and 4. These were used to spatially extrapolate light-use efficiency models developed at the plot scale to the landscape level. The model displays extreme detail and a large range in daily GEE at the northern section of the BEO from 0 to 2.75 gC m^{-2} d^{-1}. Accuracy of the model will be tested in summer 2002 in a broad range of land-cover types.

Facilitating Scientific and Technical Research With the Former Soviet Union

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The U.S. Civilian Research and Development Foundation (CRDF) for the Independent States of the former Soviet Union (FSU) is a private, nonprofit, grant-making organization created in 1995 by the U.S. government (National Science Foundation).

The CRDF promotes scientific and technical collaboration between the United States and the countries of the former Soviet Union. The foundation's goals are to support scientific cooperation in basic and applied research; advance the transition of former weapons' scientists to civilian activities; and encourage research and development cooperation between U.S. industry and FSU science.

CRDF programs provide grants in all areas of civilian basic and applied science and technical research. Grants average between $3,600 to larger, institutional grants of $1 million. Grant duration varies from short-term, three-month support to long-term support of up to three years. The CRDF also assists other organizations in conducting research and development activities in the FSU through payment transfer, equipment and supplies delivery, and other project management services. The CRDF-National Science Foundation Cooperative Programs/Science Liaison Office supports the Office of Polar Programs and Directorate for Geosciences Arctic and geosciences activities in Russia.

ARCTIC CHAMP: An Analysis of the Hydrologic Cycle and its Role in Arctic and Global Environmental Change

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There is accumulating evidence that the hydrologic cycle of the Arctic is changing. The productivity, carbon balance, energy balance, and runoff of arctic terrestrial ecosystems will be affected by the combined changes in temperature and precipitation. Over decadal time scales the stature and relative abundance of plants may be changing, producing new patterns of feedback to regional and global energy and carbon balances. Increases in freshwater transport to the Arctic Ocean may at some point reduce the formation of North Atlantic Deep Water, resulting in a cooling in the North Atlantic region. Because of these changes, we need to have a better understanding of arctic hydrology and the natural linkages of related atmospheric, terrestrial, and oceanic processes and cycles.

In September 2000, scientists met for a National Science Foundation-sponsored workshop to determine research priorities for arctic hydrology and how it can contribute to the goals of the National Science Foundation (NSF) Arctic System Science Program. There are several notable gaps in our current level of understanding of arctic hydrological systems. At the same time, rapidly emerging data sets, technologies, and modeling resources provide us with an unprecedented opportunity to move substantially forward. Workshop participants defined the following important unresolved questions:

- What are the major features (i.e., stocks and fluxes) of the pan-arctic water balance and how do they vary over time and space?
- How will the arctic hydrologic cycle respond to global change?
- What are the direct impacts of arctic hydrology changes on nutrient biogeochemistry, and ecosystem structure and function?
- What are the hydrologic-cycle feedbacks to the oceans and atmosphere in the face of global change? How will these feedbacks influence human systems?

Key challenges were associated with (a) a sparse and declining observational network, (b) lack of understanding of the basic hydrological processes operating across the pan-arctic, and (c) absences of cross-disciplinary synthesis. These gaps demonstrate an urgent need to reformulate the manner in which arctic hydrological research is funded and executed. Implementation of the recommended actions requires a dedicated research program to support arctic hydrological synthesis studies. To support this new science, members of the scientific community recommended that NSF invest in the development of a pan-Arctic Community-wide Hydrological Analysis and Monitoring Program (Arctic-CHAMP) to provide a framework for integration studies of the pan-arctic water cycle and to articulate the role of freshwater in terrestrial ecosystem, biogeochemical, biogeophysical, ocean, climate, and human dynamics. The primary aim of Arctic-CHAMP is to catalyze and coordinate interdisciplinary research with the goal of constructing a holistic understanding of arctic hydrology through integration of routine observations, process-based field studies, and integrative modeling. The contributions of an Arctic-CHAMP toward articulating the diverse physical, biological, and human vulnerabilities to a changing climate provide an important impetus for international cooperation in wisely managing this critical part of the earth system.

Stratification of Thermokarst Lakes in Northeast Siberia Based on Diffusive CH_4 Emissions

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Lakes occupy up to 30% of the land surface in noertheast Siberia and are important contributors to atmospheric methane year round. Our objective is to determine whether processes of methane production and emission differ among lakes located on the floodplain of the Kolyma River and on upland, "yedoma" soils. The term "yedoma" refers to ice-rich Pleistocene soils with a high labile carbon content. Climate warming in the Holocene facilitated thaw of these soils to form thermokarst lakes. The labile carbon in yedoma soils is thought to be an important energy source for methanogenic bacteria in anaerobic lake sediments of upland lakes. Floodplain lakes, also located on permafrost soils, formed both by permafrost thaw as well as the influence of meandering river channels. Floodplain lakes do not have the same inputs of yedoma soils, and thus may not produce as much methane as upland lakes.

Measurements of methane production in lakes sediment, both in situ and in laboratory incubation flasks, during summer 2001 suggest that sediments from upland, yedoma lakes produce more methane than sediments from floodplain lakes. Using pyrolysis-gas chromatography/mass spectrometry (GC/MS), we found that methane production potentials were positively correlated to organic carbon content and the relative amount of polysaccharides in lake sediments. Methane production was negatively correlated to lipid and phenolic contents of sediments. Whereas production of CH_4 was higher in yedoma lakes, methane emission via molecular diffusion was greater in floodplain lakes and other shallow ponds not subject to thermal stratification. Convective mixing in shallow floodplain lakes transports methane-rich water to the surface, where it diffuses along a concentration gradient into the atmosphere. Bottom water of deeper, stratified yedoma lakes, which is supersaturated in methane, did not circulate to the surface during our summertime measurements. These results suggest that if seasonal turnover occurs in upland lakes (spring or fall), there may be periods of exceptionally high CH_4 release via molecular diffusion.

The Arctic Research Consortium of the United States

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The Arctic Research Consortium of the United States (ARCUS) is a nonprofit membership organization, composed of universities and institutions that have a substantial commitment to research in the Arctic. ARCUS promotes arctic research by improving communication among the arctic research community, by organizing workshops, and by publishing scientific research plans. ARCUS was formed in 1988 to serve as a forum for planning, facilitating, coordinating, and implementing interdisciplinary studies of the Arctic; to act as a synthesizer and disseminator of scientific information on arctic research; and to educate scientists and the general public about the needs and opportunities for research in the Arctic.

In Search of a Model Arctic: Towards Improving the Simulation of Arctic Climate in GCMs

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Simulations of the arctic climate produced by general circulation models (GCMs) exhibit a number of significant problems that affect their usefulness for understanding climate and predicting climate change. These include biases in the mean sea-level pressure pattern and its temporal variability, biases in the mean cloud cover, and the seasonal transitions of arctic clouds. The biases result in further problems in coupled atmosphere-ice-ocean models, such as driving sea-ice drift, ice thickness, and ocean currents that are counter to observations.

Current efforts are focused on diagnosing the problems of arctic climate in the current generation of climate models, such as the CCSM, CCC CGCM, GISS GCM, GENESIS, and others. Simulations with the CCM, with higher spatial resolution and with the Lin-Rood dynamics, have shown improvements in the circulation patterns over the Arctic Ocean. Simulations with CCSM, with reduced radiative cloud liquid water path for polar clouds, show an improvement in surface shortwave radiation.

Improving the arctic climate simulations in GCMs requires a collaborative effort between GCM groups and the arctic climate community, such as within the CCSM Polar Climate Working Group. First, new model parameterizations can be developed based on existing arctic climate studies. Second, simulations with new parameterizations can be planned and executed that require sufficient computing resources. Third, model improvements can be validated and incorporated into the community models, while ensuring that enhancements in the arctic climate simulation are compatible with the model solution outside of polar regions.

Contrasting Responses of Nitrogen Fixation in Arctic Lichens to Experimental and Observed Nitrogen and Phosphorus Availability

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Here we investigate the influence of nitrogen (N) and phosphorus (P) on N fixation and abundance of two N-fixing arctic lichens, *Peltigera apthosa* and *Peltigera polydacyla* in mesic tundra at Toolik Lake, Alaska. We estimated N fixation using the acetylene reduction assay (ARA) method among research plots treated with either control (no fertilization), N, or P, and between two different moist tundra types, acidic and non-acidic tundra. We also measured the abundance of the lichens in all treatments and on the two different tundra types. Acidic and nonacidic tundra differ in N and P availability, as well as in pH and plant biomass, all factors known to potentially influence lichen N fixation and/or abundance. Specifically, the acidic site has higher N availability while the nonacidic site has higher P availability. Therefore, we compared the rates of N fixation and lichen abundance measured among the fertilization treatments with measurements made in lichens from the two tundra types to assess the influence of nutrient availability on N fixation.

We found highest rates of N fixation in treatment plots fertilized with P, intermediate rates in control plots, and the lowest rates in plots fertilized with N. We also found that on acidic tundra, lichen abundance was much lower in plots fertilized with N than in either control or P-fertilized plots. Finally, although we did not find significant differences in rates of N fixation between acidic and nonacidic tundra, we found that the two N-fixing lichens are more abundant on acidic tundra than on nonacidic tundra. Our results suggest that despite demonstrable P limitation of N fixation, variation in P availability among moist tundra types is not an important factor influencing either N fixation or abundance of N-fixing lichens, since lichens had similar rates of fixation and lower abundance at the more P-rich nonacidic site. Similarly, despite a reduction in N fixation and abundance of lichens in response to N fertilization, lichens were more abundant at the more N-rich site, suggesting that N availability per se is not the primary control of the abundance and activity of N-fixing lichens in moist tundra.

Ecophysiological Characteristics ($\delta^{13}C$ and $\delta^{15}N$) of *Carex* Plants and Populations along the Eurasian Coastal Arctic

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Understanding the physiological performance of arctic plants and populations that may be experiencing changing climates is an important part of global change research in northern latitudes. Leaf gas exchange and mineral nutrition are the basis of the carbon and nitrogen cycles of arctic ecosystems and may be altered by warmer temperatures, changes in precipitation, alterations of irradiance, or shifts in atmospheric N deposition. Most studies of leaf gas exchange and mineral nutrition in arctic plants have been conducted in Alaska, Greenland, northern Sweden, and on Svalbard with few studies from the Eurasian coastal Arctic, even though this region represents between one-third to one-half of the circumpolar arctic landscape.

Studies of the physiological performance of widely distributed *Carex* plant populations along the Eurasian coastal Arctic were conducted as part of a joint Swedish-Russian expedition with vegetation collections at seventeen different sites across 160° of longitude. Surrogate in situ physiological measures were made possible at these sites by quantifying the isotopic ($\delta^{13}C$ & $\delta^{15}N$) characteristics of leaves from these plants and populations, providing an integrative measure of gas exchange and mineral nutrition. The leaf carbon isotope discrimination (LCID) of *Carex* plants exhibited significant ($F = 2.11$, $P<0.022$) population differences even when considering the significant ($F = 6.2$, $P<0.018$) covariant. *Carex* plants at northeast Taymyr Peninsula, Chelyuskin, Taymyr Peninsula, northwest Taymyr Peninsula, Faddeyevsky Island, and Indigirka Delta all had LCID values that were generally higher than those of plants from the other populations, especially populations at the Yana Delta. The leaf $\delta^{15}N$-values of *Carex* plants exhibited significant ($F = 8.2$, $P<0.001$) differences between populations without differences among ramet age classes or any significant interaction, even when considering the significant ($F = 4.7$, $P<0.039$) covariant affect. The leaf $\delta^{15}N$-values of plants at the Yana Delta, Faddeyevsky, and Indigirka Delta were significantly higher than those of plants from other populations. The leaf $\delta^{15}N$-values were most depleted in the populations from Kanin Peninsula, Chelyuskin, and Ayon Island sites.

Carex LCID was inversely ($P<0.01$) correlated with mean annual temperature and stomatal density and to a lesser extent with the depth of thaw. Leaf carbon isotope discrimination was typically enriched in *Carex* leaves of plants from colder sites and was depleted at sites where temperatures were warmer and possibly drier. We also found that LCID was significantly ($P<0.05$) correlated with shoot height suggesting that under conditions of higher rates of gas exchange, plant growth is greater. Correspondingly, *Carex* leaf $\delta^{15}N$-values were inversely ($P<0.05$) correlated with mean annual precipitation. Under wetter conditions, leaf $\delta^{15}N$-values were depleted compared to plants that were found under lower rainfall conditions across the Eurasian coastal Arctic. In addition, lower leaf $\delta^{15}N$-values were found in *Carex* leaves of plants growing where soil organic matter content was higher. Plant N content was inversely correlated with mean July temperature ($P<0.05$), inversely with stomatal density, and positively with stomatal size.

In summary, *Carex* populations across the Eurasian coastal Arctic are not performing the same physiologically and may exhibit differential sensitivity to changes in climate.

Within individual clones of *Carex*, the ecophysiological performance of ramet age classes are not consistent, with juvenile ramets exhibiting strong sensitivity to the environment, especially in surrogate leaf gas exchange characteristics. We found that LCID is inversely related to air temperature (especially in juvenile ramets), suggesting that as climates warm, mesic tundra dominated by *Carex* may become a weaker C sink and possibly even a carbon source if ecosystem respiration increases, as has been observed in other experimentally warmed tundra systems. The inverse relationship between precipitation and leaf $\delta^{15}N$-values indicates that the fundamental mineral nutrition of *Carex* systems will be altered with changes in climate, and these new plant mineral nutrition traits will likely be associated with shifts in the characteristics of soil N pools and with the proportions of ammonium, nitrate, and organic N sources acquired by *Carex* plants.

Bias Correction of Gauge-Measured Precipitation Data: Methods and Results

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Systematic errors caused by wind-induced undercatch, wetting, and evaporation losses in precipitation measurement have long been recognized as affecting all types of precipitation gauges. The need to correct these biases, especially for solid precipitation measurement, has now been more widely acknowledged as the magnitude of the errors and their variation among gauges became known and their potential effects on regional, national, and global climatological, hydrological, and climate change studies were recognized. To assess the national methods of measuring solid precipitation, the World Meteorological Organization (WMO) initiated the Solid Precipitation Measurement Intercomparison Project in 1985. Thirteen countries participated in this project and the experiments were conducted at twenty selected sites in these countries from 1986–1987 to 1992–1993.

This poster will review the bias-correction methods for many national gauges commonly used in the Northern Hemisphere. The results of the WMO Solid Precipitation Measurement Intercomparison Project will be presented, with the emphases on comparison among the national gauges and applicability of the WMO methods in the high latitudes. Ongoing efforts and preliminary results of the bias corrections in Alaska, Northwest Territories/Yukon, Siberia, Greenland, and the Arctic Ocean (drifting stations) will be summarized to demonstrate the magnitude of the biases in these northern regions and to show the potential impact of the bias corrections on large-scale climatological and hydrological studies (such as GEWEX and ACSYS/CliC). Recommendations for future work will also be provided.

Hydrologic Response of Major Siberian Rivers to Climate Change and Variation

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The long-term temperature, precipitation, and river streamflow records have been analyzed in this study to examine the hydrologic regime of large Siberian rivers (Lena, Yenesei, and Ob Rivers) and their response to climate change and variation. This study found significant changes in hydrologic characteristics over Siberia. The Ob River winter runoff has increased by 30 to 40% and the summer runoff has risen in July by 10%. There is a clear tendency, particularly during the 1980s and 1990s, toward peak streamflow of the Ob River in July, August, and even in September. This shift of the Ob River's maximum monthly discharge toward late summer may be a response of the river system to the intensified summer rainfall over western Siberia. Yenesei River summer runoff has decreased by 20 to 30% and winter discharge has gone up by 35 to 110%. Lena River snowmelt starts early due to strong warming in spring season. This results in an increase of discharge in May and a decrease of run-off in June. Mid-summer runoff has not changed significantly in the Lena River, but the winter runoff has increased by 25 to 80% mainly due to changes in river ice and permafrost condition. These changes identified in this study are very likely the consequence of recent climate warming over the Siberian regions and also closely related to change in permafrost. Warming in Siberia results in higher permafrost temperatures and a deeper active layer. The thicker active layer, having a greater groundwater storage capacity, in fact, has more groundwater storage amount due to melt of ground ice and increased precipitation input. This increased groundwater storage in turn results in greater contribution of subsurface water to the river systems and hence increases the winter season runoff. Future research will focus on identifying the changes in hydrologic regimes in different sub-basins of the watersheds and on examining the interannual variation of monthly discharge/river ice and their responses to climate and atmospheric circulation. Development of a coupled regional climatic-hydrologic model is also necessary in order to better understand and quantify the complex land-atmosphere interaction and feedback.

The Dynamics of Spruce Regeneration and Thermokarst Processes near Council, Alaska

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Collaborative research among paleoecologists, geophysicists, and hydrologists have revealed some interesting patterns among permafrost dynamics and spruce invasion and may relay information regarding the physical controls on spruce regeneration and periglacial processes as influenced by a changing climate. Further, these studies may provide evidence of interdependence among biotic and abiotic responses to a changing climate. Research in tundra ponds near Council, Alaska, has documented a general decrease in pond size, presumably related to widespread degradation of permafrost in the area. Although white spruce commonly occupy the upland hills and well-drained banks along larger stream channels, they are largely absent from level tundra areas away from stream channels. However, spruce are common on the well-drained banks of thaw ponds, and their age structure and spatial distribution within and around these ponds provide many clues to the dynamic and perhaps cyclic nature of pond development and decay.

Field data on spruce distribution suggest a spatial association between spruce and thermokarst features, and moisture and thaw-depth data indicate that the restriction of spruce to banks (and, perhaps, to other thermokarst features) is probably driven more by moisture than by temperature. Spruce are apparently tolerant of frozen soils, but in level areas where permafrost can significantly impede drainage it is the very wet soils that prevent spruce establishment. Spruce invasion of level tundra areas like those around Council will therefore be dependent not just on soil warming, but on sufficient melting of permafrost to allow some soils to actually drain and dry out. Strongly nonlinear temporal dynamics of spruce expansion in these areas are thus likely. Thermokarst development, which accompanies degradation of ice-rich permafrost, not only enables establishment of tundra ponds, but also creates the complex mosaic of saturated soils near the ponds and the well-drained pond banks suitable for establishment of white spruce. As the thermokarst expands and pond banks collapse into the saturated pond perimeter, however, spruce populations may succumb to the wet soils, thus providing a time signature of the expanding pond. Although the spatial association of spruce and thermokarst features suggests that spruce may be strongly influenced by changes in permafrost conditions, it is also possible that the establishment of spruce forests on the banks of tundra ponds may, in turn, influence the cycle of pond development and decay. The nature of possible feedbacks between spruce establishment and the dynamics of thaw-pond formation remain largely unknown.

Climate Change: Evidence from Historical Soil Temperature Measurements in the Former Soviet Union

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Preliminary analyses of the historical near-surface soil temperature measurements from 250 stations in the former Soviet Union indicate that mean annual soil temperature at 40 cm depth has increased by about 0.9°C from 1930 to 1990. The increase is more pronounced from 1970–1990. Further analyses show that the increase during winter months (December/January/February) is largest, about 1.8°C over the period of the record; followed by spring (March/April/May), about 1.0°C. Corresponding changes in summer (June/July/August) and autumn (September/October/November) are slightly less than 0.4°C. On an annual basis, changes in soil temperature followed the pattern of changes in air temperature, with some modification due to precipitation. In winter months, changes in soil temperature correlated positively with changes in air temperature and winter precipitation (presumably snowfall). Variations in snowcover thickness overall have a positive impact on soil temperature due to snow insulation effects. In summer, changes in soil temperature are probably mainly controlled by precipitation (presumably rainfall) since air temperature exhibits little variability. There is an anti-correlation between soil temperature and summer precipitation (rainfall). This is because of the so-called soil-moisture feedback mechanism, assuming that an increase in rainfall will increase the near-surface soil moisture. Although soil temperature increased about 1.0°C during spring months over the period of record, there are no clear relationships between soil temperature, air temperature, and precipitation. Other factors such as the timing of snowmelt and near-surface soil moisture may play roles in affecting soil temperature. Further analyses are needed to understand fully the response of soil temperature to changes in climate variables.

Determining Regional-Scale Net Ecosystem CO_2 and H_2O Vapor Fluxes by Aircraft-Based Eddy Covariance Measurements

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Year-round landscape-scale fluxes from eddy covariance towers have been conducted on the North Slope of Alaska beginning in 1997. Three towers located in Prudhoe Bay, Barrow, and Atqasuk, Alaska, represent validation points for ecosystem production and flux models for arctic ecosystems. Towers provide excellent temporal measurements. However, due to the limited footprint of stationary towers, large spatial extrapolation of fluxes are problematic, especially if the region is heterogeneous or patchy. Aircraft-based eddy covariance allows for not only regional-scale flux measurements, but also a means for assessing tower footprint representativeness and extrapolation of tower data.

Airplane-based eddy covariance measurements of regional-scale net ecosystem CO_2 and H_2O fluxes were taken on the North Slope of Alaska. The San Diego State University Sky Arrow environmental research aircraft was used during the 1999–2001 summer growing seasons (June–September). Three flightline transects were repeatedly flown throughout the summer between the Arctic Ocean and the foothills of the Brooks Range. A hierarchical approach is used to determine regional-scale fluxes, providing a means to scale from towers to aircraft to satellites.

Preliminary results include products of large-scale fluxes, spectral imagery, and reflectances of surface conditions and features. Calibration of airplane instrumentation shows promising results in the proper elimination of aircraft motion, facilitating accurate assessment of the turbulent winds and fluxes. Along with the aircraft-based flux measurements, low-level remote sensing products such as surface temperature, NDVI, PRI, as well as digital spectral imagery have been taken. The purpose of these products is to provide a linkage between towers and satellites and an accurate means of assessing regional-scale fluxes of CO_2 and H_2O vapor.

Workshop Agenda

ARCSS All-Hands Workshop
February 20-22, 2002
Bell Harbor International Conference Center
Seattle, WA

Tuesday, February 19, 2002
Evening (Sound Conference Room and Lobby outside Harbor Dining Room)

7:00 p.m. Pre-conference icebreaker reception and registration

Day 1— Wednesday, February 20, 2002
Morning

7:30 a.m. Continental breakfast (kiosks)
Registration (Entry Lobby)

Plenary (Bay Auditorium)

8:30 a.m. Welcome and introduction to the meeting
Jack Kruse, Chair, ARCSS Committee
University of Massachusetts & University of Alaska Anchorage

The workshop aims to identify the central scientific themes and approaches that will allow the ARCSS Program to build on work to date and develop new research focused on environmental impacts and biocomplexity as well as global change.

8:50 a.m. The Evolution of the ARCSS Program: Past, Present, and Future
Mike Ledbetter, Director, ARCSS Program
Office of Polar Programs, National Science Foundation

9:20 a.m. Current ARCSS Research: Introduction to Component Talks
Amanda Lynch, *University of Colorado*

Component talks will focus on major discoveries, key uncertainties and their readiness for research, and priorities for integrative research. The presentation time will include time for questions and discussion.

9:30 a.m. Paleoenvironmental Arctic Sciences (PARCS)
Glen MacDonald, *University of California, Los Angeles*

10:00 a.m. Ocean-Atmosphere-Ice Interactions (OAII)
Lou Codispoti, *University of Maryland*
Richard Moritz, *University of Washington*
Jackie Grebmeier, *University of Tennessee*

10:45 a.m. BREAK

11:00 a.m. Land-Atmosphere-Ice Interactions (LAII)
Terry Chapin, *University of Alaska Fairbanks*

11:30 a.m. The Russian–American Initiative on Shelf-land Environments in the Arctic (RAISE)
Lee Cooper, *University of Tennessee*

11:50 a.m. Human Dimensions of the Arctic System (HARC)
Henry Huntington, *Huntington Consulting*

12:10 p.m. LUNCH

Afternoon

Plenary (Bay Auditorium)

New Research Initiatives

1:30 p.m. The Hydrologic Cycle and its role in Arctic and Global Environmental Change (Arctic-CHAMP)
Charles Vörösmarty, *University of New Hampshire*

2:00 p.m. Study of Environmental Arctic Change (SEARCH)
James Morison, *University of Washington*
Lou Codispoti, *University of Maryland*

2:30 p.m. Nearshore and Coastal Processes Initiative
Ken Dunton, *University of Texas*

2:45 p.m. Biophysical Feedbacks and Transitions in the Arctic Regional System: Life Webs
Matthew Sturm, *Cold Regions Research & Engineering Laboratory*

3:00 BREAK

Plenary (Bay Auditorium)

3:15 p.m. Current ARCSS Research: Key Uncertainties and Next Steps
Moderator:
Craig Nicolson, *University of Massachusetts*

Each panelist will make a five-minute presentation focused on one ARCSS question, addressing the key uncertainties and priorities for research from their disciplinary or programmatic perspective. Each pair of five-minute presentations will be followed by approximately ten minutes of comments, questions, and discussion from workshop participants and panelists on that question, allowing a few minutes for the moderator to summarize before moving on to the next question and pair of panelists. Thus each of the four questions will have approximately 20 minutes for presentation, discussion, and summarization.

How will the arctic climate change over the next 10-100 years?
Amanda Lynch, *University of Colorado*
Konrad Hughen, *Woods Hole Oceanographic Institution*

How will human activities interact with future global change to affect the sustainability of natural ecosystems and human societies?
Bruce Forbes, *University of Lapland*
Matthew Berman, *University of Alaska Anchorage*

How will changes in arctic biogeochemical and hydrologic cycles and feedbacks affect arctic and global systems?
Glen MacDonald, *University of California, Los Angeles*
Kelly Falkner, *Oregon State University*

Are predicted changes in the arctic system detectable?
Marilyn Walker, *University of Alaska Fairbanks*
Wieslaw Maslowski, *Naval Postgraduate School*

Plenary (Bay Auditorium)

4:45 p.m. Introduce thematic working groups, working group co-facilitators, working group instructions, and assign working group locations.
Jack Kruse, Chair, ARCSS Committee
University of Massachusetts & University of Alaska Anchorage

a. **Nearshore and coastal processes**
Ken Dunton, *University of Texas*
Lee Cooper, *University of Tennessee*

b. **Biophysical feedbacks and transitions in the arctic regional system: Life webs**
Matthew Sturm, *Cold Regions Research & Engineering Laboratory*
Terry Chapin, *University of Alaska Fairbanks*

c. **The pan-Arctic community-wide hydrological analysis and monitoring program (Arctic-CHAMP)**
Charles Vörösmarty, *University of New Hampshire*
Larry Hinzman, *University of Alaska Fairbanks*

d. **Modes of variability in the arctic system**
James Morison, *University of Washington*
Larry Hamilton, *University of New Hampshire*

Working Groups Meet (Sound, Cove, Marina, Pacific Board Rooms)

5:00 p.m. Working groups begin discussions

Each working group will designate a rapporteur(s) to present the group's summary in plenary session and a recorder to track and summarize discussions.

Evening

6:15 p.m. DINNER

Dinner buffet in the International Promenade for $20
Or on your own (but hurry back).

7:30 p.m. Poster Session (Harbor Dining Room
No-host bar and dessert.

Day 2—Thursday, February 21, 2002

Morning

7:30 a.m. Continental breakfast (kiosks)

Plenary (Bay Auditorium)

8:30 a.m. Brief review of working groups, questions

Identify smaller breakouts that have developed within each working group.
Jack Kruse, Chair, ARCSS Committee
University of Massachusetts & University of Alaska Anchorage

Working groups (Sound, Cove, Marina, Pacific Board Rooms)

9:00 a.m. Working groups; groups may break into smaller groups as needed

The smaller rooms (Coastal, Channel, Port, Seaway, Waterway) will be available "on-demand" so that 5-15 people may break out to work on a specific sub-topic.

12:00 p.m. LUNCH (International Promenade)

Afternoon

Working groups (Sound, Cove, Marina, Pacific Board Rooms)

1:00 p.m. Working groups continue

3:15 p.m. BREAK

Plenary (Bay Auditorium)
Reports from Working Groups

Reports include presentation by rapporteur and discussion.

3:30 p.m. Nearshore and coastal processes
Rapporteur:
Steve Zeeman, *University of New England*

3:50 p.m. Biophysical feedbacks and transitions in the arctic regional system
Rapporteur:
Matthew Sturm, *Cold Regions Research & Engineering Laboratory*

4:10 p.m. The pan-Arctic community-wide hydrological analysis and monitoring program (Arctic-CHAMP)
Rapporteurs:
Katey Walter, *University of Alaska Fairbanks*
Paul Overduin, *University of Alaska Fairbanks*

4:30 p.m. Modes of variability in the arctic system
Rapporteur:
Larry Hamilton, *University of New Hampshire*

4:50 p.m. Summary discussion

5:00 p.m. BREAK

5:30 p.m. Student Poster Session
No-host bar and appetizers.

Evening

7:30 p.m. BANQUET

Special Multimedia Presentation
Gift of the Whale: The Iñupiat Bowhead Hunt, A Sacred Tradition
By Bill Hess, Running Dog Publications

Day 3—Friday, February 22, 2002
Morning

7:30 a.m. Continental breakfast (kiosks)

Plenary (Bay Auditorium)

8:30 a.m. Discuss burning questions, clarify working group process, progress, and products expected from the groups.
Jack Kruse, Chair, ARCSS Committee

Working groups (Sound, Cove, Marina, Pacific Board Rooms)

9:00 a.m. Working groups continue discussions, review progress, and prepare summary presentations.

12:30 p.m. LUNCH (International Promenade)

Afternoon
Plenary (Bay Auditorium)

1:30 p.m. Working Group Summaries

The designated rapporteur for each working group will present the group's summary. During the summaries, a small panel will participate in the process of clarifying, questioning, and synthesizing the presentations. The rapporteur for each group will have 20 min. to present a summary, the panel members will have 15 min. to respond, and the panel moderator will have 5 min. to synthesize and summarize. The members and process of this ad hoc panel may change as the workshop develops.

Moderator:
Mary Edwards, *Norwegian University of Science and Technology*

Ad Hoc Panel:
Linda Brubaker, *University of Washington*
Henry Huntington, *Huntington Consulting*
Mark Serreze, *University of Colorado*
Don Perovich, *Cold Regions Research and Engineering Laboratory*
John Hobbie, *The Ecosystems Center, Marine Biological Laboratory*
Carin Ashjian, *Woods Hole Oceanographic Institution*

1:45 p.m. Summary: Student forum

Rapporteurs:
Lesleigh Anderson, *University of Massachusetts*
Jennifer Benning, *University of Alaska Fairbanks*
Zach Lundeen, *University of Massachusetts*
Katey Walter, *University of Alaska Fairbanks*
Jason Vogel, *University of Colorado*
Andy Mahoney, *University of Alaska Fairbanks*
Jill Johnstone, *University of Alaska Fairbanks*

2:15 p.m. Summary: Near shore and coastal processes working group

Rapporteur:
Julie Brigham-Grette, *University of Massachusetts*

3:00 p.m. Summary: Biophysical feedbacks and transitions working group

Rapporteur:
Josh Schimel, *University of California Santa Barbara*

3:45 p.m. BREAK

4:00 p.m. Summary: Hydrologic cycle working group

Rapporteur:
Larry Hinzman, *University of Alaska Fairbanks*

4:45 p.m. Summary: Modes of variability working group

Rapporteurs:
Lou Codispoti, *University of Maryland*
James Overland, *National Oceanic and Atmospheric Administration*
Larry Hamilton, *University of New Hampshire*

5:30 p.m. What's Next?

A word from the incoming ARCSS Committee chair
Jonathan Overpeck, *University of Arizona* (Presented by Jack Kruse)

5:45 p.m. Closing comments
Mike Ledbetter, Director, ARCSS Program
Office of Polar Programs, National Science Foundation

Day 4—Saturday, February 23, 2002
Plenary (Sound Room)

9:00 a.m.	The ARCSS Committee, Science Management Office directors, and Science Steering Committee chairs will spend the morning developing and packaging the conference results so that they are available via the Internet soon after the workshop ends to promote community discussion and follow-up.
10:20 a.m.	BREAK
10:40 a.m.	ARCSS Committee, SMO directors, SSC chairs meeting continues
12:00 p.m.	LUNCH—on your own

Afternoon (Sound Room)

1:00 p.m.	ARCSS Committee meeting
4:00 p.m.	AC meeting adjourns

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PROCEEDINGS OF THE
ARCTIC SYSTEM SCIENCE PROGRAM
ALL-HANDS WORKSHOP

FEBRUARY 20–23, 2002
SEATTLE, WASHINGTON