Abstracts from the

Arctic Forum

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Foreword

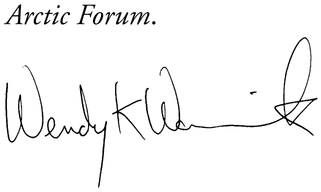
The abstracts presented in this volume proceed from presentations and posters given at the *Arctic Forum*, hosted by the Arctic Research Consortium of the U.S. (ARCUS) in Washington, DC. The *Arctic Forum* brings together principal investigators, National Science Foundation (NSF) and other agency officials, and student winners of the ARCUS Award for Arctic Research Excellence. ARCUS began hosting the *Arctic Forum,* in conjunction with its Annual Meeting, in October 1994, and this abstract series begins with the March 1998 *Arctic Forum*.

ARCUS represents arctic researchers through its membership of institutions organized and operated for educational, professional, or scientific purposes. ARCUS provides leadership in advancing knowledge and understanding of the Arctic by:

1. Serving as a forum for planning, facilitating, coordinating, and implementing arctic research,
2. Synthesizing and disseminating scientific information relevant to state, national, and international programs of arctic research, and
3. Encouraging and facilitating the education of scientists and the public in the needs and opportunities of research in the Arctic.

ARCUS also serves as a communication channel, providing information about current research activities and arctic issues to the scientific community as well as to agencies and the public. This work is done at many levels, including newsletters and other publications, electronic communications, workshops, and symposiums like the *Arctic Forum*.

As executive director of ARCUS, I thank the many researchers who share their results with the community through the *Arctic Forum* and the National Science Foundation for supporting this opportunity. Anne Sudkamp of ARCUS prepared the layout and design for this abstract volume; Diane Wallace, Milo Sharp, Alison York, and Alison Carter provided editorial and technical expertise throughout its development. We plan to publish the abstracts from the *Arctic Forum* annually. Please join us at the 1999 *Arctic Forum*.



Wendy K. Warnick
Executive Director
ARCUS
October 1998

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Arctic paleoenvironmental studies: a window to the past

Michael Retelle, chair

Accurate projections of environmental change in the Arctic will be gained through the understanding of the dynamics of the Earth system. This understanding is best obtained from studies of modern physical, chemical, and biological processes and from records of past environmental change. Past environments, reconstructed from various proxies such as glacier ice composition, tree ring and sediment core structure or fossil evidence, provide us with a context in which to gauge present changes in the arctic system against changes that have occurred in the past.

In this group of talks, presenters touched on many aspects of this picture. Robert Hoffmann examines changes in mammal populations as the Bering Land Bridge appeared and disappeared during the Pleistocene. Richard Alley discusses records from Greenland ice cores on paleoclimatic changes much larger and more abrupt than those that have affected human civilizations significantly during historical times. Konrad Hughen discusses the variability and dramatic warming shown in annual paleoclimate records from lake sediments, tree rings, ice cores, and marine sediments. Julie Brigham-Grette introduces us to the Paleoenvironmental Atlas for Beringia, a virtual atlas on the World Wide Web that will support our quest for understanding regional climatic and vegetational change.
Peter Johnson investigates paleoenvironmental data in sedimentary records from lakes in the Kluane Region of the southwest Yukon. Kurt Cuffey presents a heat- and ice-flow model, constrained by GISP2 measurements, that provides a history of climate measurements for the past 50,000 years in central Greenland.

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Pleistocene biogeography of mammals and Late Glacial climate change

Robert S. Hoffmann, National Museum of Natural History, Smithsonian Institution

Pleistocene biogeography was strongly affected by the appearance of the Bering Strait 3 million years ago, which disrupted what had been a persistent land connection between eastern Siberia and northern Alaska. Shortly thereafter, a series of major cold/warm climatic cycles began, culminating in the major glaciations of the Pleistocene. These produced alternation between land bridge and strait, either permitting or blocking intercontinental movement of terrestrial mammals. Northern hemisphere mammals were diverse, capable of surviving cold, arid steppe tundra, but also inhabiting wooded landscapes, grasslands, and deserts farther south. Community dominants were large herbivores such as mammoth, mastodon, bison, etc., and the large carnivores that preyed on them.

During Late Glacial time, most species of this megafauna became extinct, while most small and medium-size mammals survived. This extinction occurred between ~11,300 to 10,800 y BP, and has been widely attributed to the impact of human hunters entering the New World at this time. However, recent evidence shows that humans first arrived much earlier, before 25,000 y BP, probably following the southern margin of the land bridge along its ice-free coast and spreading south through an ice-free corridor to periglacial North America.

With the onset of end-Pleistocene warming about 12,000 y BP, a period of rapid climate change began, culminating in a period of violently fluctuating weather with extraordinarily steep temperature gradients and strong winds between about 11,500 to 9,500 y BP, subjecting the megafauna in particular to severe and abrupt climate changes throughout the late-glacial period (Levesque *et al.* 1997). It also caused unprecedented reorganization of plant communities, thus depriving species of habitats to which they had become adapted, allowing only the most adaptable forms to segregate into the newly forming communities, but causing the extinction of most of the megafauna.

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Arctic controls on global climate change—insights from Greenland ice cores

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Greenland ice cores and other indicators record paleoclimatic changes much larger and more abrupt than those that have affected human civilizations significantly during historical times. Changes of more than 20°C (*e.g.,* Cuffey *et al.* 1995), 4-5 fold in snow accumulation (*e.g.,* Cuffey and Clow, 1997), and more than an order of magnitude in wind-blown dust (*e.g.,* Mayewski *et al.* and Zielinski *et al.* 1997) have occurred in Greenland since the glacial maximum. Jumps of 1/3 to 1/2 this magnitude have occurred repeatedly, with some in years rather than decades (*e.g.,* Alley *et al.* 1993; Taylor *et al.* 1997; Severinghaus *et al.* 1998). Accumulation-rate changes larger than those expected based on the ability of warmer air to transport more moisture probably reflect storm-track changes (Kapsner *et al.* 1995). Synchronous changes in indicators of temperature and snowfall in Greenland, wind-blown materials from beyond Greenland, and methane probably reflecting global wetland area (*e.g.,* Severinghaus *et al.* 1998) indicate that large regions of the world experienced simultaneous changes, with typically cold, dry, and windy conditions occurring together. Within dating uncertainties, this pattern is confirmed by records from many other regions (*e.g.,* Hughen *et al.* 1996 and 1998).

The hypothesis of involvement of major changes in North Atlantic oceanic heat convergence has been tested in several modeling studies. That of Fawcett *et al.* (1997), for example, shows that a simulated reduction in the heat convergence in the GENESIS model produces Greenlandic anomalies similar to those observed in temperature, accumulation, storm track and strength, and even in seasonality of temperature and precipitation as interpreted from the ice-isotope/temperature calibration of Cuffey *et al.* (1995); the simulation also matches data from many other regions.

Large jumps have not been restricted to cold times (*e.g.,* Alley *et al.* 1997), but seem to have occurred when insolation and greenhouse gases were changing rapidly. These data are consistent with model results (Stocker and Schmittner, 1997) that rapid changes in forcing can produce even more-rapid climate changes.

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A compilation of annual paleoclimate records over the last 400 years

Konrad Hughen, Harvard University

A compilation of annual paleoclimate records from lake sediments, tree rings, ice cores, and marine sediments provides a view of circum-arctic environmental variability over the last 400 years. From 1840 to the mid-20th century, the Arctic as a whole experienced dramatic warming. This warming ended the Little Ice Age in the Arctic and has caused dramatic retreats of glaciers, melting of permafrost and sea ice, and alteration of terrestrial and lake ecosystems. Individual records show that average temperatures and interannual variability during the present century are significantly higher than those seen at any other time in the past 500 years and cannot be attributed to natural patterns of climate change. Some of the significant warming, particularly after 1920, was therefore likely due to anthropogenic increases in atmospheric trace gases. However, the initiation of warming in the mid-19th century and the magnitude of warming since that time suggest that increased solar irradiance, decreased volcanic activity, and feedbacks internal to the climate system also played roles.

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A Paleoenvironmental Atlas for Beringia and beyond

Julie Brigham-Grette, University of Massachusetts-Amherst

Paleoenvironmental data from sites in Alaska, northwestern Canada, and northeastern Russia are now of sufficient quality and quantity for regional syntheses of climatic and vegetational change. In an attempt to transmit such syntheses to the scientific community and the public, a "virtual atlas" on the World Wide Web has been developed as a departure from more traditional means of illustrating paleoenvironmental data. This atlas is a pilot project for the IGBP/PAGES Paleoenvironmental MultiProxy Analysis and Mapping Project (PMAP) that establishes a framework and a procedure for those wanting to do regional syntheses of paleoenvironmental data. What is unique about this atlas is that it combines primary paleo data (*e.g.,* raw counts) and modern environmental data and uses them to reconstruct paleoenvironmental and paleoclimate variables. The high quality interpreted data sets are provided with direct links to the primary data with full documentation of the interpretive process.

The Beringian Atlas is considered a "living document" that will evolve as new data becomes available. Moreover, the PALE (Paleoclimates from Arctic Lakes and Estuaries) science community expects to expand this atlas into a circum-arctic paleoenvironmental atlas through international collaborations, specifically with the Circumpolar Paleoenvironments (CAPE) Program. Even at this early stage, the Beringian Atlas has allowed us to ask new questions about past climates which will provide us with a better understanding of past environmental and climatic variability across the entire Arctic.

The URL for the Beringian Atlas is presently http://www.ngdc.noaa.gov/paleo/pale/atlas/beringia/. Comments about the Atlas can be directed to the designer, Matt Duvall (duvall@u.washington.edu).

This presentation also included a poster.

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Paleoclimate reconstruction in the southwest Yukon Territory, Canada

Peter G. Johnson, University of Ottawa and Association of Canadian Universities for Northern Studies (ACUNS); Konrad Gajewski; Terry Lacourse

In the Kluane Region of the southwest Yukon there are lakes with sedimentary records which range from organic accumulations to carbonate deposition to clastic deposition. These occur in open system basins with well developed surface inflow and outflow, in closed basins with groundwater control, and in lakes supplied from glacierized regions. Deglaciation of the area occurred, according to currently accepted ideas, about 12,500 y BP (Denton and Stuiver 1966). Bulk carbonates dates, which are problematic, suggest that the retreat of the ice may have been earlier. The sediment stratigraphic and pollen records indicate that there has been uninterrupted sedimentation through the Holocene. Within the stratigraphy the White River Volcanic Ash dated at 1147 y BP (Clague *et al.* 1995) provides an excellent recent marker horizon but no other stratigraphic correlations have been established between lakes. The paleoenvironmental data in the sediments is providing a detailed proxy record of change through the Holocene. The palynological record from Sulphur Lake conforms with the trends indicated from other studies in the region with an early grassland tundra being replaced with a *Betula* and *Pinus* community before the invasion of *Picea* about 8,500 y BP. Additional data from chironomids, ostracods, macrofossils, and charcoal is contained in the sediments. In the carbonate Jenny, Emerald and Keyhole lakes two species of pea clams are present through the record and the high degree of preservation will permit a detailed reconstruction of the lacustrine conditions. The population of the pea clams varies markedly through the sediment which is thought to indicate temperature fluctuations of the lake. The sediments also contain a detailed record of input of eolian sediment. The presence of small quantities of magnetite from the loess gives a definite magnetic susceptibility signal on the background of the carbonate sediments. The carbonates have a signal which is zero to slightly negative and experiments have shown that even a 5% by weight loess composition produces a recognisable magnetic susceptibility peak. Variations between cores probably represents variability during depositional events but there is evidence for loess contribution throughout the Holocene. Glacier fed lakes contain a proxy hydrological record in the clastic sediments which indicate considerable variability through time (Johnson 1997).

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Temperature, accumulation, and ice sheet elevation in central Greenland through the last deglacial transition

Kurt M. Cuffey, University of Washington (Winner of the ARCUS Award for Arctic Research Excellence); Gary Clow

We present a combined heat- and ice-flow model, constrained by measurements of temperature in the Greenland Ice Sheet Project 2 (GISP2) borehole and by the GISP2 $\partial^{18}O$ record and depth-age scale, which determines a history of temperature, accumulation rate, and ice sheet elevation for the past 50,000 years in central Greenland. Important results are: that the temperature increase from average glacial to Holocene conditions was large, approximately 15°C, with a 20°C warming from late glacial to Holocene; that the average accumulation rate during the last glacial maximum (between 15 and 30 kyr BP) was 5.5 to 7 cm yr-1, approximately 25% of the modern accumulation rate; that long-term (500-1,000 years) averaged accumulation rate and temperature have been inversely correlated during the most recent 7 millenia of the Holocene; and that the Greenland Ice Sheet probably thickened during the deglacial transition. The inverse correlation of accumulation rate and temperature in the mid and late Holocene suggests that the Greenland Ice Sheet is more prone to volume reduction in a warmed climate than previously thought and demonstrates that accumulation rate is not a reliable proxy for temperature. The elevation history of the ice sheet is poorly constrained by the model, and independent evidence is needed. We also present a simple estimate of the response time for thinning of the interior region of an ice sheet due to retreat of its margins. This was approximately 1,900 years for central Greenland during deglaciation.

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Terrestrial research in the Arctic

John Hobbie, chair

Arctic research has progressed from observations of natural history, its biological, physical, and anthropological features, to synthesizing knowledge of these features into the larger arctic natural system. One important finding in recent years is a warming over both arctic continents beginning in the 1970s. Mark Serreze presents the evidence for this change, one causing the 20th century Arctic to be the warmest of the past 400 years. This change raises the question of how the alterations of climate affect the exchange of greenhouse gases such as carbon dioxide and methane with the atmosphere. This cycle of warmer temperatures causing more gas release and even warmer temperatures is a possible feedback from the Arctic to the entire global atmosphere. George Kling describes the current carbon balance in the Kuparuk River Basin, the site of the ARCSS-Flux study, and lays out research needs to extrapolate our understanding to the pan-arctic scale. Sadredin (Dean) Moosavi's research takes up the controls of methane oxidation, a process that occurs in tundra soils and reduces the amount of this gas reaching the atmosphere. Change was also the theme of Jack Kruse's talk in which he describes the flagship program, NSF's Arctic System Science, whose goal is a predictive understanding of interactions of global change with the arctic system. He points out that terrestrial research in particular must include the larger animals and human interactions if we seek a complete system understanding. One way this is possible is to use the tool of comparative research. Lawrence Hamilton discusses how fishing communities in first-world societies respond to large-scale environmental change. Black brant geese, another animal species important to the inhabitants of the Arctic, are the subject of another presentation in which Brian Person describes how they actually improve the quality of their food by forming heavily grazed "lawns."

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Opportunities for integrative research in the NSF ARCSS Program

Jack Kruse, University of Alaska Anchorage and University of Massachusetts-Amherst

Our goal in ARCSS is to understand the arctic system and, based on that understanding, to predict the interactions of global changes with the arctic system. Our initiatives deal with important components of the arctic system, but we need to think about the likely gaps in our knowledge of the arctic system and the likely impediments to linking the science generated under the separate ARCSS projects.

ARCSS Program research is moving forward well:

- SHEBA is producing a wealth of science,
- The implementation plan for LAII's new ATLAS initiative is out,
- OAII published its Announcement of Opportunity for the SBI initiative,
- The RAISE initiative, based on its draft science plan, is moving forward,
- The PALE community is preparing a new science plan,
- A HARC Announcement of Opportunity is taking shape, and
- We just distributed the new ARCSS science plan.

The research initiated thus far, however good, presents an incomplete implementation of the ARCSS science plan. There are important gaps in our knowledge and lack of integrative connections between many aspects of the research.

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Such gaps include:

- We need a common set of climate models to integrate terrestrial and marine processes. We also need to develop data sets suitable for climate predictions on a regional scale.
- We need to get humans and higher trophic-level species into the arctic system picture. The ATLAS implementation plan notes the absence of a HARC component.
- Along the same lines, the SBI initiative is in a region of high human/marine mammal interest; it is also focused on deep shelf-basin interactions more than on the land-marine interface. We need SBI researchers to work with Native experts and other researchers to identify linkages that won't "dilute" the science.
- RAISE will introduce a macro-scale hydrologic component to ARCSS. ATLAS notes the need for a hydrologic component in its focus on small-scale processes. Freshwater inputs to the marine system are important to OAII's goal of predicting interactions between the arctic and world ocean system. Freshwater inputs are also important to predicting changes in sea ice, coastal marine productivity, and contaminant transport. We need people to think through how these initiatives can complement each other and what additional work needs to be done to develop an arctic system hydrologic component.

Observational evidence of recent change in the northern high-latitude environment

Mark Serreze, University of Colorado; John E. Walsh; F. Stuart (Terry) Chapin, III; Thomas E. Osterkamp; Mark Dyurgerov; Vladimir E. Romanovsky; Walter C. Oechel; James H. Morison; Tingjun Zhang

Studies from a variety of disciplines document recent change in the northern high-latitude environment. Prompted by predictions of an amplified response of the Arctic to enhanced greenhouse forcing, we present a synthesis of these observations. Pronounced winter and spring warming over both continents since about 1970 is partly compensated by cooling over the northern North Atlantic. Warming is also evident over the central Arctic Ocean. There is a downward tendency in sea ice extent, dominated by reductions along the Eurasian coast, attended by warming and increased areal extent of the Arctic Ocean's Atlantic layer. Negative snow cover anomalies have dominated over both continents since the late 1980s and terrestrial precipitation has increased since 1900. Small arctic glaciers have exhibited generally negative mass balances. While permafrost has warmed in Alaska and Russia, it has cooled in eastern Canada. Increased plant growth has been attended by greater

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shrub abundance and northward migration of the tree line. Evidence also suggests that the tundra has changed from a net sink to a net source of atmospheric carbon dioxide.

Taken together, these results paint a reasonably coherent picture of change, but their interpretation as "fingerprints" of greenhouse warming is open to debate. Roughly half of the pronounced recent rise in Northern Hemisphere temperatures reflects changes in atmospheric circulation. These include generally positive phases of the North Atlantic and Arctic Oscillations and extratropical responses to the El-Niño Southern Oscillation. The recent warming is also no larger than the interdecadal temperature range during this century. On the other hand, not all of the recent warming is explained by circulation and the general patterns of change broadly agree with model predictions. An anthropogenic effect is also suggested from interpretation of the paleoclimate record, which indicates that the 20th century Arctic may be the warmest of the past 400 years.

Pending revision, this article has been accepted for publication in *Climatic Change*:

Serreze, M.C., J.E. Walsh, F.S. Chapin III, T. Osterkamp, M. Dyurgerov, V. Romanovsky, W.C. Oechel, J. Morison, T. Zhang, and R.G. Barry. 1998. Observational evidence of recent change in the northern high-latitude environment. *Climatic Change*. Under revision.

Forage variation in brood-rearing areas used by Pacific black brant geese on the Yukon-Kuskokwim Delta, Alaska

Brian T. Person, University of Alaska Fairbanks (Winner of the ARCUS Award for Arctic Research Excellence); Christopher A. Babcock; Roger W. Ruess

1. We investigated the effects of grazing by black brant geese on *Carex subspathacea* lawns on the Yukon-Kuskokwim Delta, Alaska.

2. We compared variation in growth and forage quality in both grazed and temporarily exclosed sites to determine responses of *C. subspathacea* to grazing at landscape scales within two nesting colonies that had experienced different population dynamics over recent decades.

3. Landscapes differed in forage quality, grazing patterns, and in the effect grazing had on *C. subspathacea* forage characteristics. We found no effect of grazing on net above-ground primary productivity (NAPP) over a wide range of natural grazing intensities at the landscape scale.

4. No differences in forage quality, NAPP, or response of *C. subspathacea* growth rates to grazing pressures could be detected between colonies. This suggests that goose grazing does not have deleterious effects on *C. subspathacea* in this ecosystem.

5. It has been suggested that gosling growth rates are sensitive to seasonal declines in forage availability and quality. Spatial variation in forage quality and availability per sampled area exceeded seasonal variation in these characteristics and is likely to have dramatic effects on gosling growth and recruitment rates.

This article has been accepted for publication:

Person, Brian T., Christopher A. Babcock, and Roger W. Ruess. 1998. Forage variation in brood-rearing areas used by Pacific black brant geese on the Yukon-Kuskokwim Delta, Alaska. *Journal of Ecology* 86: 243–260. In press.

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Human adaptation to large-scale environmental change in the North Atlantic Arc (NAARC)

Lawrence Hamilton, University of New Hampshire

Over the past half-century, fisheries-dependent communities across the northern Atlantic have experienced large changes in their natural-resource base. Fishing pressure, interacting with climate variation, led to the decline or collapse of some economically crucial fish populations. Fishing communities and regions adapted to these changes in part by pursuing other species, typically invertebrates or forage fish. Governments have also supported efforts at economic diversification, in hopes of building up non-fishing livelihoods. Individual-level adaptations include outmigration. The most fisheries-dependent places now have negative population growth, and its timing in several instances corresponds to specific ecological changes. The human resources and social organization of fishing communities, as well as their natural resources, constrain the available paths for adaptation.

Atlantic Arc fishing communities provide an opportunity for comparative research on how contemporary first-world societies respond to large-scale environmental change. The NAARC project is conducting such research by gathering both quantitative and qualitative data-time series databases at the community or regional level for Norway, Iceland, the Faroe Islands, Greenland and Newfoundland/Labrador; and also in-depth case studies of selected fishing communities in Norway, Iceland, and Newfoundland. These data allow us to explore relationships between environmental (climate) variation, fisheries outcomes, and social/demographic change. Preliminary analyses have uncovered a number of common patterns in these relationships across different societies. In their efforts to adapt, contemporary fishing communities could be viewed as empirical models for likely human responses to global change.

This project is supported by a grant from the Arctic System Science (ARCSS) Program of the National Science Foundation. More information about NAARC can be found at: http://pubpages.unh.edu/~lch/naarchom.htm.

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Carbon cycling in the Arctic—some results from the ARCSS-LAII Flux Study

George W. Kling, University of Michigan

The ARCSS-Flux study estimated the current carbon balance in the Kuparuk River Basin (9200 km^2) of the Alaskan Arctic. Using a biogeochemical model (MBL-GEM) driven by data on soils, vegetation, hydrology, and climate provided by Flux Study investigators, a best estimate of the net ecosystem productivity (NEP or mean C storage) over the basin ranged from -10 to +10 g C m^{-2} yr^{-1}. Temperature and soil moisture were most important in determining the magnitude of net carbon storage. Measurements of carbon exported from land to surface waters and eventually lost from the basin were of the same order of magnitude as NEP; on average 3.7 g C m^{-2} of basin per year were lost to surface waters, and 32% of this amount was lost directly to the atmosphere by evasion of CO_2 from lakes and streams. The evasion of methane from water to the atmosphere was larger per unit area compared to terrestrial methane fluxes. In addition, CO_2 produced by terrestrial decomposition during winter months is also lost to the atmosphere; this loss is estimated to range from the same magnitude as NEP to as much as 25% of the summertime soil respiration. Because the aquatic and winter fluxes are not included in biogeochemical models at present, model estimates of NEP are likely to be too high.

Data currently available for other parts of the Arctic indicate that spatial extrapolations of these results to pan-arctic scales may be in error by 20-40%. However, much larger errors are probably associated with temporal extrapolations of these results. This is because our understanding of carbon cycling is limited to only one of the two major land surfaces (acidic and non-acidic) that dominate the Arctic. There is evidence that these two surfaces responded differently in terms of carbon storage during the last 6,000 years, during which time temperatures warmed by similar amounts to predictions of future arctic warming. In addition, changes in vegetation (from grasses to shrubs) associated with the response of these different surfaces to climate change will affect carbon storage as well as the characteristics of energy exchange with the atmosphere.

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CH_4 oxidation by tundra wetlands as measured by a selective inhibitor

Sadredin C. Moosavi, University of New Hampshire (Winner of the ARCUS Award for Arctic Research Excellence); Patrick M. Crill

Rates of methane (CH_4) oxidation were measured in three wet sedge communities on Alaska's North Slope in 1993 and 1995 using the selective inhibitor methyl flouride (CH_3F). Comparison of CH_4 flux prior to inhibition (net flux) with flux after inhibition (gross flux) enables one to infer CH_4 oxidation rates by difference. Oxidation rates from Franklin Bluffs, Sagavanirktok River floodplain, Toolik Lake Inlet, and Toolik Lake Outlet averaged 24.9, 14.7 (1.6), (17.6), and 25.2 (49.8) mg CH_4/m2/d in 1995 (1993), respectively. Plot level data suggest that oxidation rates vary greatly spatially and temporally down to the meter scale. As a percentage of flux, however, mean CH_4 oxidation rates of 13.4, 21.7 (2.0), (16.5), and 19.4 (38.0)% at Franklin Bluffs, Sagavanirktok, Toolik Lake Inlet, and Toolik Lake Outlet in 1995 (1993), respectively, were seen to be rather uniform over the region. The effects of temperature on CH_4 production appear to be the dominant control on CH_4 oxidation rates in wet sedge environments as opposed to soil moisture dependency in upland soils. Nutrient fertilization was not found to influence the fraction of CH_4 lost to oxidation. This suggests that CH_4 oxidation, while significant in tundra wetlands, may consume a near constant fraction of available CH_4.

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Focus on the Arctic Ocean

Vera Alexander, chair

It is not a great exaggeration to say that this session is a landmark occasion in the history of arctic oceanography. The Arctic Ocean is arguably the least understood portion of the world seas; most of the research that has been conducted in the past has been motivated by military concerns. This is not all bad, and a significant amount of information has been acquired in this way, partly by academic scientists through programs such as AIDJEX (Arctic Ice Joint Deformation Experiment). Nevertheless, access for academic scientists has been limited by the absence of suitable platforms as well as by the perceived expense of supporting such work in the absence of a dedicated arctic logistics support budget.

All this is changing now. An offshoot of the military interest is the dedication of a polar nuclear submarine for arctic research, the SCICEX Program. At the same time, data previously classified is becoming available. So the military still plays a role which is now supportive of basic ocean research for its own sake and for gaining an understanding of the changes which the arctic seas are experiencing. Cooperation with Canada has allowed the joint transect to the North Pole of Canadian and United States icebreakers, and currently a Canadian icebreaker is frozen into the arctic ice to study heat exchange and heat budgets of the Arctic Ocean-the SHEBA (Surface Heat Budget of the Arctic Ocean) program of NSF and ONR (Office of Naval Research).

The new U.S. Coast Guard vessel *Healy* will guarantee improved research access to the Arctic Ocean, and now the burden is on us to design the programs and on the agencies to provide financial support for them. The papers in this session already reflect the new vigor and improved access, and document the significant scientific understanding that has resulted.

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Distribution and variability of freshwater sources within the Arctic Ocean surface and halocline waters

Brenda Ekwurzel, Lamont-Doherty Earth Observatory (Winner of the ARCUS Award for Arctic Research Excellence)

Recent evidence indicates erosion of the highly stratified Arctic Ocean halocline in the Eurasian Basin. To understand the evolution of the halocline observed in the 1990s, we must identify the freshwater source component distribution within the halocline and quantify any changes. Three icebreaker cruises during summer and fall provide tracer data between Fram Strait and Bering Strait: ARK IV/3 (*FS Polarstern* in 1987); ARCTIC91 (*Oden*); and AOS94 (*CCGS Louis S. St-Laurent*). Salinity, nutrients, oxygen, tritium, helium, and $\partial^{18}O$ data were used to evaluate the freshwater sources with salinity less than the Atlantic Water inflow through Fram Strait: Pacific Water, river runoff, and sea-ice meltwater.

Similar tracer ages were found across the entire basin along halocline isopycnal surfaces. Halocline mean 3H/3He apparent age measured within 33.1 ± 0.3 psu is 4.3 ± 1.7 years and for 34.2 ± 0.2 psu is 9.6 ± 4.6 years. Isopycnal mixing is dominant within the halocline. However, there are lateral variations in the relative age structure suggesting, for example, slower flow over the Nansen-Gakkel Ridge. Sea-ice meltwater is the only freshwater component in the southern Nansen Basin (between Svalbard and the Nansen-Gakkel Ridge), consistent with Atlantic Water melting of sea-ice as an important process for local halocline formation. The river-runoff fraction results suggest the majority of Pechora, Ob, Yenisey, Kotuy, and Lena river waters do not flow off the shelf closest to their river deltas, but stay on the shelf and travel in a cyclonic circulation into the East Siberian Sea where most of the river-runoff flows off the shelf at the Mendeleyev Ridge.

Where 1994 measurements overlap with 1991 data, we evaluate changes that occurred during this interval. At almost the identical station location (*ca*. 89°N, 145.5°E) over the Lomonosov Ridge, the 1994 surface Pacific Water Mass fraction dropped to 4% from over 18% measured in 1991. The river-runoff and sea-ice meltwater fractions seem to be in steady-state, at least at this central arctic location and between 1991 and 1994. Variability in Pacific Water mass distribution over these three years is also evident when compared to the past several decades. ARCTIC91 and AOS94 Pacific Water fraction results document a decrease in extent of Upper Halocline Water, the traditionally defined core of the Pacific Water mass, compared to historical data. This decrease in an important source of fresher water has the potential to influence the salinity of Arctic Ocean water outflow through Fram Strait, which may influence deep water formation areas downstream.

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Ventilation of intermediate water in the central Canadian Basin observed on the SCICEX 96 cruise

William M. Smethie, Lamont-Doherty Earth Observatory; Peter Schlosser; Tom Sawyer Hopkins; Gerhard Boenisch

During the SCICEX 96 cruise of the U.S. Navy submarine, *Pogy*, a line of 8 stations was occupied through the central Canadian Basin extending from the Lomonosov Ridge to 78°N. *Pogy* surfaced at each station and hydrocasts were performed using a CTD to measure temperature and salinity and 10-liter Niskin bottles to collect water samples. Aliquots of water were taken for tritium, ^{3}He, and CFCs and returned to Lamont for analysis. The distribution of these tracers and of temperature and salinity reveal that the water in the center of the Canadian Basin beneath the halocline is derived from Atlantic water that flows through the Barents Sea, entering the Arctic Ocean in the vicinity of the Kara and Laptev seas. About 10 years is required for the water to be transported from the slope region of the Laptev Sea to the central Canadian Basin. It had been previously thought that water beneath the halocline in the central Canadian Basin was ventilated on a much longer time scale, which is the case for the northern Canadian Basin.

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Enhanced geophysical instrumentation for SCICEX; the Seafloor Characterization and Mapping Pods (SCAMP)

*Dale Chayes, Lamont-Doherty Earth Observatory; *Bernard Coakley; Robert Anderson; Margo Edwards*

Since 1993 the U.S. Navy has made a Sturgeon-class, nuclear-powered attack submarine available for annual unclassified science cruises to the Arctic Ocean.

These cruises, known collectively as the SCICEX program, have collected water samples and CTD casts from surface stations as well as underway oceanographic and geophysical data across the entire deep Arctic Ocean. Approximately 66,000 km of underway gravity anomaly and narrow beam bottom sounder data collected during 130 science days in the SCICEX operational area have substantially expanded the unclassified data base for the Arctic Ocean. Two more cruises in 1998 and 1999 will complete the planned SCICEX program.

It has been widely recognized that the stability, silence, range, and independence from surface conditions render a Sturgeon-class submarine a nearly ideal platform for geophysical measurements. The submarine's independence from surface ice is a particular advantage in the Arctic, permitting the first ever systematic bathymetric surveys in the basin.

In recognition of this unique opportunity, NSF's Office of Polar Programs has funded the fabrication, testing, and installation of a SeaMARC™-type sidescan swath bathymetric sonar and a data acquisition and quality control system. In support of NSF's commitment, a private organization, the Palisades Geophysical Institute, has funded acquisition of a chirp, swept-frequency, sub-bottom profiler. The transducers for these sonars will be mounted in two pods attached to the keel of the submarine.

The sub-bottom profiler was accepted and delivered in January 1998. Acceptance tests of the sidescan swath bathymetric system will be conducted at Raytheon in Mukilteo, Washington, during February 1998. Bench tests of system components will be followed by a tow test in Puget Sound. The transducer pods are under construction at the Applied Physics Lab and Twin Manufacturing. Delivery is expected in mid March. The data acquisition system was tested during the 1997

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SCICEX cruise on the *USS Archerfish*. It performed well, logging the non-sonar data (sail-mounted CTDs, gravimeter, and ship's information) continuously during thirty days in the operational area.

The installation process is well underway. To take advantage of a dry-docking period scheduled for the *USS Hawkbill*, the ship selected for SCICEX 1998 and 1999, we separated the installation into two phases. The first phase of the installation was restricted to attachment of the hard mounting points for the pods, which must take place in dry-dock, fitting the pod foundations and installation of an external cable. With support from the Applied Physics Lab at Johns Hopkins and Electric Boat in Groton, Connecticut, the first phase of SCAMP installation was completed on time in late June.

With help from the Applied Physics Lab, Electric Boat, and the Arctic Submarine Lab, the required engineering documentation (TEMPALT) for the second phase of the installation was submitted to the Navy for evaluation at NAVOCEANO on January 20th. Evaluation of the TEMPALT to date has advanced smoothly. The final installation of the transducer arrays is planned for April 1998 during a scheduled Pre-Overseas Movement maintenance period for the *USS Hawkbill*. To complete this phase of the installation, divers, with crane support, using purpose-built handling gear will attach the transducer pods to the underside of the submarine dockside in Pearl Harbor.

If all goes according to plan, the *USS Hawkbill* will collect co-registered backscatter, bathymetry, chirp sub-bottom profiler and gravity anomaly data during the remaining unclassified arctic cruises. If previous cruises are an indication of what we can expect in the future, the next three cruises in this program will collect approximately 40,000 km of additional underway data and approximately 670,000 km^2 of swath imagery by the end of the 1999 trip.

Study of Arctic change

Jamie Morison, University of Washington

Participants at a November 1997 workshop on the Study of Arctic Change presented research results corroborating earlier observations that the Arctic Ocean and atmosphere are in the midst of a significant physical change. More than 70 oceanographers, sea-ice experts, and atmospheric scientists reported on manifestations of the change, discussed key questions, and deliberated how to further study the change.

By mid-1997, data from arctic expeditions and atmospheric studies suggested that the influence of Atlantic Water in the Arctic Ocean has become more widespread and intense in this decade than had previously been documented.

New observations include:

- There is a correlation between an increase in the temperature of Atlantic Water in the Arctic and the North Atlantic Oscillation index.
- Since 1990, there has been a marked decrease in heat and salinity input to the Arctic from the Pacific Ocean through Bering Strait.
- The cold halocline, which insulates the sea-ice cover from heat stored in Atlantic Water, has thinned and, in some areas, disappeared in the 1990s.
- There has been a trend in the 1990s toward decreasing ice extent, especially in the Siberian shelf seas.
- Spring and early summer air temperatures have increased. The melt season in the Arctic has gotten longer. In at least one Alaska location, permafrost temperatures have been increasing since approximately 1991.
- In atmospheric circulation within the North Pacific region in the 1990s, a Polar Pattern is increasingly important relative to the Pacific North American and North Pacific circulation patterns.
- Beaufort Sea mixed-layer salinities measured in late 1997 during the SHEBA experiment are substantially lower than they were in the 1970s. This finding suggests that there has been increased melting of ice during summer. Heat (solar radiation) stored in the mixed layer is also greater.

Together, these and earlier observations suggest that the arctic change is at least a decadal-scale phenomenon that has broad implications and a relation to changes at lower latitudes. Workshop participants proposed that an international Study of Arctic Change should include:

- regular measurements of atmosphere, ocean, ice, and some terrestrial parameters for at least the next decade;

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- examination of historical records for evidence of such change in the past; and
- a modeling effort to try to understand the causes of the change. Fortunately, many of the required observations are being carried out now as part of other programs. Prompt attention can close critical gaps.

The Arctic Change workshop was funded by ARCSS. A draft Workshop Report is available for review (http://psc.apl.washington.edu/publication/Arctic_Change/arctic.pdf).

This presentation also included a poster.

The Surface Heat Budget of the Arctic Ocean (SHEBA) field experiment

Don Perovich, Cold Regions Research and Engineering Laboratory

SHEBA is a research program studying the surface heat budget of the Arctic Ocean, that is cosponsored by the National Science Foundation and the Office of Naval Research. The program is motivated by the importance of the arctic sea-ice cover in global climate and by the uncertainties in the treatment of arctic pack ice in general circulation models. The principal goals of SHEBA are to:

- Determine the ice-ocean-atmosphere processes that control the ice-albedo feedback mechanism and the cloud radiation feedback mechanism, and
- Develop models that improve simulations of present day arctic climate and the simulation of arctic climate using GCMs.

Recognizing the complex and interconnected nature of the ice-albedo and cloud-radiation feedbacks, SHEBA was designed as an interdisciplinary program. It focuses on the processes governing the interactions between the atmosphere, ice, and ocean through a combination of a field experiment, data assimilation, and modeling.

The SHEBA field experiment began in October 1997 when the Canadian Coast Guard Icebreaker *CCGC Des Groseilleirs* was frozen into the ice in the Beaufort Sea and will continue until October 1998. The observational focus is on obtaining a data set of simultaneous and contiguous observations from the top of the atmosphere, through the sea ice and into the upper ocean over an entire annual cycle. The measurements include profiles of atmospheric temperature, humidity, and wind speed; cloud coverage and properties; longwave and shortwave radiation fluxes; snow depth and properties; ice mass balance; the reflection and absorption of the incident sunlight; the thermohaline structure of the upper ocean; and the flux of heat from the ocean to the ice. Measurements will be made on the local scale, that of the floe and its neighbors; as well as on the aggregate scale, over tens of kilometers. This integrated data set will be used to understand the processes governing the surface heat budget, to develop and test parameterizations suitable for climate models, and to evaluate single column models.

This presentation also included a poster.

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Poster presentations

Each year ARCUS puts out a call for posters for the *Arctic Forum*, inviting participation from the Arctic research community. In 1998 posters illustrated Julie Brigham-Grette's talk, *A Paleoenvironmental Atlas for Beringia and beyond* (see page 8) and Don Perovich's talk, *The Surface Heat Budget of the Arctic Ocean (SHEBA) field experiment* (see page 28).

Three posters also displayed on their own, and their abstracts are presented here. *Circum-Arctic Map of Permafrost and Ground Ice Conditions* is a full-color map prepared by the International Permafrost Association, in cooperation with the Circum-Pacific Council for Energy and Mineral Resources. It shows permafrost and ground ice over the Arctic and surrounding continental land masses.

Site fidelity and movements of brood-rearing brant in the oil fields of northern Alaska by Philip D. Martin, U.S. Fish and Wildlife Service, and others discusses results from this multi-year brant-banding project.

Contemporary water and constituent balances for the Pan-Arctic Drainage System: continent to coastal ocean fluxes by Bruce J. Peterson, The Ecosystems Center, Marine Biological Laboratory, and others describes the Pan-Arctic Drainage project and its results to date.

Circum-Arctic Map of Permafrost and Ground Ice Conditions

Jerry Brown, International Permafrost Association; Oscar J. Ferrians, Jr.; J.A. Heginbottom; E.S. Melnikov

This full-color map showing permafrost and ground ice over the Arctic and surrounding continental land masses has been released by the U.S. Geological Survey (USGS) and was displayed at the American Geophysical Union meeting in San Francisco in December 1997. The map gives a birds-eye view from a polar projection and includes most of the northern hemisphere including the Tibet Plateau and mountain permafrost in the European mountains. It was compiled by an international team led by the USGS, the Geological Survey of Canada, and the Committee of Geology of the Russian Federation.

This compilation will help researchers document the effect of global environmental change. This is the first time that data on the entire North Polar region and adjacent lands has been compiled into a single map. It provides consistent and current information on the location, abundance, and extent of permafrost and ground ice in the northern hemisphere.

The map, USGS Circum-Pacific Map Series CP-45, at a scale of 1:10,000,000, was prepared by the International Permafrost Association (IPA), in cooperation with the Circum-Pacific Council for Energy and Mineral Resources. The IPA is an affiliated organization of the International Union of Geological Sciences. Its eight working groups provide information products related to permafrost, seasonal frost, artificial ground freezing, and periglacial phenomena.

The map measures 40" by 58" and can be ordered for $4.00 plus $3.50 handling from the USGS. Telephone 1-800-USA-MAPS for more information on ordering.

A modified, digital version is now available on the CD Circumpolar Active-layer Permafrost System (CAPS) prepared by the National Snow and Ice Data Center, Boulder, Colorado, and accessible on the Internet (contact User Services at nsidc@kryos.colorado.edu). The CD was demonstrated at the Seventh International Conference of Permafrost, held at Yellowknife, Canada, June 23–27, 1998.

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Site fidelity and movements of brood-rearing brant in the oil fields of northern Alaska

Philip D. Martin, U.S. Fish and Wildlife Service; Tim Obritschkewitsch; Betty A. Anderson; Alice A. Stickney

Up to 2,000 brant (adults and goslings) are present in the Prudhoe Bay and Kuparuk oil fields during the brood-rearing period. Brant were captured and banded at brood-rearing locations from 1991-1997, goslings were web-tagged at colonies in 1995-1996, and eight females were tracked via radiotelemetry in 1996. Recapture of adult females among Kuparuk brood-rearing areas was non-random (p=0.021); females tended to return to the same location in successive years, although there was considerable interchange among Kuparuk brood-rearing areas up to 20 km apart. Interchange between Prudhoe Bay and Kuparuk (35 km distant) was rare, with only 4 of 193 recaptures representing cross-over. Most of the brood groups (estimated >90% in 1996) in the Kuparuk area originated from the Colville River delta colonies to the west, traveling the 20 km along the coast to Oliktok Point in as little as 2 days. Many of these birds continued eastward to brood-rearing areas near Milne Point. Four of six radio-equipped birds from colonies within the oil field remained on inland lakes to rear their broods, while two females traveled to the coast. Brant at Oliktok frequently crossed a pipeline/road corridor, and 29-57% of radioed broods (n=7) crossed oil field roads.

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Contemporary water and constituent balances for the Pan-Arctic Drainage System: continent to coastal ocean fluxes

Bruce J. Peterson, The Ecosystems Center, Marine Biological Laboratory; Charles Vorosmarty; Cort J. Willmott; Mark C. Serreze; Richard B. Lammers; Alexander I. Shiklomanov; Michael A. Rawlins; Steven Frolking; Jonathan B. Holden; Igor A. Shiklomanov; Viatcheslav V. Gordeev; Michel Meybeck; Vitaly A. Kimstach

One of the expected effects of global climate change on the Arctic is a dramatic change in the freshwater balance. Changes in freshwater input to the Arctic Ocean will affect sea ice formation, wetland and ocean productivity, and thermohaline circulation in the world's ocean. In spite of the importance of freshwater runoff to the Arctic and global climate, a contemporary data set for the entire Arctic has never been compiled.

The Pan-Arctic Drainage project seeks to estimate contemporary water and constituent balances for the entire land area of the Pan-Arctic drainage system, including the drainage region of Hudson and James bays as well as the Yukon and Anadyr rivers entering the Bering Sea.

At the beginning of the project, river discharge gauges which originated from the UNESCO RivDis

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data set for drainage basins greater than 15,000 km^2 numbered approximately 90 gauges. The current set of gauges from large drainage basins include some 650 gauges. The total number of gauges collected so far of all sizes is over 3,500.

Under the Global Hydrological Archive and Analysis System, new data have been collected from the United States Geological Survey, Environment Canada, and the State Hydrological Institute in St. Petersburg, Russia. A long-term discharge field for the Pan-Arctic region was created using the observed data for large basins from all three sources.

The study also delineates seas within the Arctic Ocean and their drainage systems, which will allow estimates of regional freshwater fluxes to the Arctic Ocean.

Aerological estimates of mean annual precipitation minus evaporation (P-E) were calculated for the Ob, Yenesei, Lena, and Mackenzie basins covering the period 1975-1995. Long-term mean monthly values for the four basins were also estimated.

Large temporal variability in the P-E estimates relative to the annual observed river runoff suggested a limitation to this method. However, specific catchments, the Mackenzie Basin, show promise for future analysis.

Preliminary simulations using the Permafrost Water Balance Model (P/WBM) were run for the major basins in the Pan-Arctic. Annual 30-year time series (1960-1990) for the Ob River show a close correspondence between observed and simulated runoff.

The poster is available on the Internet at the following URL: http://www.csrc.sr.unh.edu/csrc/hydro/arctic/Poster/.

Special guest speaker

Dennis Stanford, National Museum of Natural History, Smithsonian Institution

The peopling of the New World: an alternative view

Clovis technology has been long held by scholars to represent the first people who came into North America via Siberia, but after decades of research there is little archaeological evidence to support this position. Consequently I've been convinced that Clovis is a New World invention, developed by a population of people who were already in North America. The recent discoveries of human remains from the Early Holocene period and dated ca 9,000 years BP underscore the complexity of the peopling of the Americas, because their physical traits appear to resemble more closely an early population that spread across Europe and Asia prior to the development of physical features associated with North Asians and American Indians. From looking at the artifactual evidence we now have from North America and Northeast Asia, as well as the physical remains, it's clear that multiple migrations through a very long time period of many different people of many different genetic origins came into the Americas at different times. Some of these early migrants probably survived and flourished in the New World, while others did not. Those who survived no doubt intermixed with subsequent newcomers.

The argument proposed in this paper is that some of the Clovis predecessors may have originated in Europe rather than Asia. This argument is supported by genetic research—mitochondrial lineage X found so far only in North America and Western Europe and North Africa—as well as by a robust series of technological traits shared by Clovis and late Solutrean technology found on the Iberian Peninsula. These ideas are quite provocative and merit serious research.

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Program

8:30 a.m. **Welcome and Introductions** .... ***William Fitzhugh, Director, Arctic Studies Center, National Museum of Natural History, Smithsonian Institution, and ARCUS board member***

8:40 a.m. **Arctic paleoenvironmental studies: a window to the past** .... ***Chair, Mike Retelle***

8:45 a.m. Pleistocene biogeography of mammals and Late Glacial climate change ..... *Robert Hoffmann, Emeritus Curator, National Museum of Natural History, Smithsonian Institution*

9:10 a.m. Arctic controls on global climate change—insights from Greenland ice cores .... *Richard Alley, The Pennsylvania State University*

9:35 a.m. A compilation of annual paleoclimate records over the last 400 years .... *Konrad Hughen, Harvard University*

10:00 a.m. A Paleoenvironmental Atlas for Beringia and beyond .... *Julie Brigham-Grette, University of Massachusetts-Amherst*

10:25 a.m. BREAK

10:45 a.m. Paleoclimate reconstruction in the southwest Yukon Territory, Canada .... *Peter Johnson, University of Ottawa and Association of Canadian Universities for Northern Studies (ACUNS)*

11:10 a.m. **Terrestrial research in the Arctic** .... ***Chair, John Hobbie***

11:15 a.m. Opportunities for integrative research in the NSF ARCSS Program .... *Jack Kruse, University of Alaska Anchorage and University of Massachusetts-Amherst*

11:40 a.m. Observational evidence of recent change in the northern high-latitude environment .... *Mark Serreze, University of Colorado*

12:05 a.m. Forage variation in brood-rearing areas used by Pacific Black Brant Geese on the Yukon-Kuskokwim Delta, Alaska .... *Brian Person, University of Alaska Fairbanks*

12:30 p.m. LUNCH

1:30 p.m. Human adaptation to large-scale environmental change in the North Atlantic Arc (NAARC) .... *Larry Hamilton, University of New Hampshire*

1:55 p.m. Carbon cycling in the arctic regions—some results from the ARCSS-LAII Flux Study .... *George Kling, University of Michigan*

2:20 p.m. Ch_4 oxidation by tundra wetlands as measured by a selective inhibitor .... *Sadredin Moosavi, University of New Hampshire*

2:45 p.m. **Focus on the Arctic Ocean** .... ***Chair, Vera Alexander***

2:50 p.m. Distribution and variability of freshwater sources within the Arctic Ocean surface and halocline waters ... *Brenda Ekwurzel, Lamont-Doherty Earth Observatory, Columbia University*

3:15 p.m. Ventilation of intermediate water in the central Canadian Basin observed on the SCICEX 96 cruise .... *Bill Smethie, Lamont-Doherty Earth Observatory, Columbia University*

3:40 p.m. BREAK

4:00 p.m. Enhanced geophysical instrumentation for SCICEX: Seafloor Characterization and Mapping Pod (SCAMP) .... *Bernard Coakley, Lamont-Doherty Earth Observatory, Columbia University*

4:25 p.m. Study of Arctic change .... *Jamie Morison, Polar Science Center, University of Washington*

4:50 p.m. The Surface Heat Budget of the Arctic Ocean (SHEBA) field experiment .... *Don Perovich, Cold Regions Research and Engineering Lab*

5:15 p.m. Close of Meeting

ARCUS Annual Reception and Banquet, Arlington Hilton Hotel—Gallery Ballroom Foyer

Reception: 6:00 p.m. .... Special Screening: “The Changing Arctic: Science in the Far North”

Banquet: 7:00 p.m., Gallery I

Awards Ceremony.. ARCUS Award for Arctic Research Excellence

Special Guest Speaker .... *Dr. Dennis Stanford, National Museum of Natural History, Smithsonian Institution*
“The peopling of the New World: an alternative view”

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