A Research Plan to Study Modes of Arctic Climatic Variability and Warmth

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Executive Summary

The Arctic is a critical region for studying global change because it impacts the entire Earth system through powerful feedback processes involving the atmosphere, cryosphere, land surface, and ocean. To identify most critical research directions for understanding past changes in the Arctic environment and how they relate to global change, community-wide meetings with broad representation of Arctic paleoenvironmental disciplines were held between 1997 and 2002. From these meetings, two integrative and urgent research topics emerged:

Modes of climatic variability within the Arctic. A key challenge is to develop the observational basis and theory to understand the full range of modes of environmental variability in the Arctic, their relation to climate states at lower latitudes, and the degree to which they are predictable. Researchers will recover and synthesize a network of high-resolution (annual to decadal) paleoenvironmental records that span at least 2,000 years and extend through the 20th century. This network will be used to address questions such as the periodicity and persistence of recognized climatic phenomena within the Arctic (e.g., the Arctic Oscillation) and their inter-relation with the global climate system. Longer records spanning the entire Holocene (last 10,000 years) at centennial resolution will also be investigated to assess whether the millennial-scale variability identified elsewhere in the Arctic is a widespread feature of Holocene climate.

Warm Arctic climates and their consequence. Many General Circulation Model (GCM) simulations with elevated atmospheric carbon dioxide (CO_2) show the Arctic will experience the effects of global warming first and will amplify its effects within the Earth system. Considering the apparent thinning of Arctic sea ice in recent decades and melting in Greenland, the need to understand the arctic warmth and its global impact is urgent. Researchers will describe the state of marine, terrestrial, and biological systems during periods when the Arctic shifted toward and experienced warmer conditions in the past. Studies will focus on three well-known periods of warmer-than-present conditions: (a) intervals during the last two millennia, (b) other warm intervals of the current interglacial period (Holocene), and (c) the last interglaciation.

The high-resolution paleoenvironmental records necessary to address these scientific areas will be based upon paleoclimatic proxies derived from lake and marine sediment cores, glacier ice, tree rings, and other paleoclimate archives. Interpreting the records will be accomplished through use of both multiple paleoclimatic proxies that are calibrated with various modern climatic variables, and by applying state-of-the-art geochronology. To accomplish a coordinated, multi-disciplinary effort and to insure data compatibility for the final synthesis of results, this research will encourage linked, multi-investigator collaborations to foster synergistic interaction among all interested investigators.

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* These meetings included the 1998 PARCS Science Planning meeting in Boulder, CO at which scientists representing arctic paleoclimatology, modern climatology and climate modeling communities gathered to identify critical research priorities in arctic paleoclimatology in relationship to global change questions. The workshop and widespread consultation resulted in publication of **PARCS,** 1999. *The Arctic Paleosciences in the Context of Global Change Research: PARCS Paleoenvironmental Arctic Sciences.* American Geophysical Union, Washington DC. 97 pp. Subsequent meetings among the arctic and paleoclimate communities included an open all-day meeting on PARCS at the 2000 Arctic Workshop at Univ. Mass., PARCS investigator meetings at the 2001 OAII and LAII Workshops at Salt Lake City, and PARCS investigator meetings at the ARCSS 2002 All Hands Workshop at Seattle.

Introduction

The Arctic region and ecosystem is an area of active research because it is particularly sensitive to climate change and because climatically-induced environmental changes can instigate further changes of global consequence. High-latitude process that affect vegetation cover, sea-ice extent, and water exchange between the North Atlantic and the Arctic Ocean, for example, have profound impacts on the global climate system. The Arctic system is not only an amplifier of variability in the global climate, but the effects of greenhouse forcing are likely to be amplified at high latitudes. Relatively little is known, however, about the extent, rapidity, and spatial pattern of climatic variability and its possible environmental impacts within and beyond the Arctic.

While the Arctic is one of the most sensitive regions to natural and human-induced environmental changes, the observational record of environmental change in the Arctic is short and geographically sparse. Few climate stations have records extending back beyond 50 years but those that do, indicate that the Arctic warmed by about 1°-2° C between 1910 and 1945. A number of stations show further warming over the past two decades. This observed increase in Arctic temperature is greater than that of the Northern Hemisphere as a whole and indicates an amplification of global climate change in the region. Existing instrumental and paleoclimatic records also show that the Arctic has experienced significant environmental variations at different temporal and spatial scales. Such variation, driven by natural and anthropogenic factors, is anticipated to occur in the future.

Although the instrumental record provides evidence of significant temporal and spatial variability associated with recent arctic environmental changes, the records are too short to identify the full potential range of variations that the Arctic has experienced in the past or may experience in the future. Paleoenvironmental records of past Arctic changes are the only means of extending the records back in time and increasing their spatial coverage in order to describe and understand the full range of temporal and spatial variability. For example, paleoenvironmental data collected from a network of lakes, wetlands, tree-ring sites, ice cores, and marine sources demonstrate that both the magnitude and spatial extent of 20th century Arctic warming may be unprecedented over the past 400 years. Understanding the causes of this warming and its feedback to the global climate system as a whole remains difficult. As a consequence, two areas of promising and widely pertinent research in global change in the Arctic are:

1. Modes of climatic variability within the Arctic

Researchers will recover and synthesize a network of high-resolution (annual to decadal) Holocene paleoevironmental records that span at least 2,000 years and extend through the 20th century. This network will be used to address questions such as the periodicity and persistence of climatic states within the Arctic and their inter-relation with the global climate system.

2. Warm Arctic climates and their consequence

Researchers 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. Studies will focus on three well-known periods of warmer-than-present conditions: (a) intervals during the last two millennia, (b) other warm intervals of the current interglacial period (Holocene), and (c) the last interglaciation.

Statement of Research Objectives

The climatic variability of the last 400 years is superposed on longer-term changes that have occurred during the Holocene. Evidence from Greenland ice cores and from the North Atlantic Ocean suggest that the Arctic may have experienced a pattern of rapid climatic changes occurring with a periodicity of about 1,500 years. How such changes impacted different regions of the Arctic or whether they were instigated there is unknown. Most of the Arctic experienced summer temperatures significantly warmer (i.e., 1° to 2°C) than during recent centuries and the early to middle Holocene (i.e., 10,000 to 5,000 years ago). This is partly due to greater summer insolation at high northern latitudes caused by changes in the orbital geometry of the Earth. The time and duration of the greatest warming differed geographically. These differences result from multiple oceanic, atmospheric, and terrestrial processes that work in concert with physiography to modulate the effects of broader-scale forcing and can be examined in light of synoptic-scale atmospheric circulation features and surface-climate responses.

The primary goal of this research is to reconstruct the spatial and temporal patterns of climatic change on time scales ranging from annual to millennial, and to compare these with known patterns of historically and paleoclimatologically documented oscillations (e.g., Arctic Oscillation, North Atlantic Oscillation, Bond Cycles) to elucidate possible driving mechanisms and longer-term behavior of the Arctic climate system. The available instrumental records indicate the presence of distinct modes of variability, often separated by abrupt climate transitions. Using the paleoclimate record, a much larger number of climate modes become apparent as longer time periods are examined. The many abrupt shifts in climate state during the last glacial period are well known from Arctic paleoclimate research. It now appears that the climate during the present interglaciation was also characterized by multiple, distinct modes of variability. A key challenge to the Arctic research community is to develop the detailed observational basis and theory to understand the full range of modes of environmental variability in the Arctic, their relation to climate states at lower latitudes, and the degree to which these modes are predictable. The data sets will be from the highest-resolution multi-proxy paleoclimate records possible (including ice cores, tree rings, and lake and marine sediment cores) with temporal resolution ranging from annual to decadal. These records will span at least 2,000 years and will extend through the 20th century. The development of longer records that extend through the Holocene with centennial resolution will also be encouraged in an effort to gauge the persistence and strength of longer-term climatic oscillations.

The research is expected to contribute to an understanding of a warmer Arctic and its impact on the global climate system by describing the state of marine, terrestrial, and biological systems during periods when the Arctic shifted toward, and experienced, warmer conditions in the past. In light of the results of many GCM simulations with elevated atmospheric CO_2 that show the Arctic will experience the effects of global warming first and will amplify its effects within the Earth system, and considering the apparent thinning of Arctic sea ice in recent decades and melting in Greenland, the need to understand the Arctic warmth and its global impact is critical. Research 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. Research 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 (i.e., the Medieval anomaly); (2) other warm intervals of the current interglacial period (generally during the early to middle Holocene; ca. 10,000-5,000 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.

These two areas of research will help answer critical questions about climate change in the Arctic and how it inter-relates with the global system, for example:

- Is the 20th century warming of the Arctic unprecedented in the last 1,000 to 10,000 years?

- What are the spatial-temporal modes of climatic variability on times scales ranging from inter-annual to millennia? How persistent are the recognized climate phenomena of the Arctic Oscillation and longer-term cycles?

- How do the hypothesized climatic events of the historical record (i.e., Little Ice Age and Medieval anomaly) relate to the longer-term modes of Arctic variability? What is their spatial and temporal pattern? What role did the Arctic play in driving these events?

- What are the environmental consequences of extreme warming in the Arctic and how do these changes feedback to the global climate system?

Research Strategy

To assure compatibility and to facilitate integration between paleoclimate records from the Arctic with similar records from other regions, the research strategy for this initiative will closely follow that of the ESH study of Holocene Climate Variability. In the Arctic, sensitive indicators of past climate changes are stored in ice, biological materials, and lake and ocean sediments that span the last 10,000 years or more. These records will be sampled at the centennial scale to document the millennial-scale variability, and a subset of these records will focus on the finest possible temporal resolution to provide decadal- to annual-scale resolution. The network of high-resolution paleoenvironmental records will be derived from lake and marine sediment cores, glacier ice, tree rings, and other sources. Interpretations will be based on a multi-proxy approach that includes varves, stable isotopes, geochemstiry, diatoms, moss spores, pollen, lake levels, and snowline elevations. Those studies designed to provide quantitative estimates of climate (i.e., temperature, effective precipitation) and those that link records between marine and terrestrial systems will receive highest priority. Unraveling the paleo-records will be accomplished through use of both multiple proxies and the study of modern processes that calibrate the various proxies, and by applying state-of-the-art geochronology. New records will be encouraged from geographic areas where data are sparse or where a denser network of sites is needed to capture sub-regional-scale heterogeneity of climate variability. To accomplish the coordinated, multi-disciplinary effort and to insure data compatibility for the final synthesis of results, this initiative will encourage linked, multi-investigator collaborations among marine, lacustrine, glacial, tree-ring, and paleoecological specialists working with climate dynamicists and modelers.

Deliverables/Products

Among the specific science products to be produced are:

- An online georeferenced database of paleoclimatic time-series of high frequency (annual to decadal resolution) Arctic climate variability over the past 2,000 years.

- An online database of Geographic Information System (GIS) based maps of regional high frequency variability in Arctic climate based on summer temperature estimates – and other climatic variables where possible - over the past 500 to 2,000 years at annual resolution.

- An online georeferenced database of newly acquired and existing paleoclimatic observations and time-series documenting past warm arctic conditions during the Holocene and last interglaciation (LIG).

- An online database of GIS based maps of Arctic summer temperature – and other climatic variables where possible – and cryosphere-land surface conditions for the Holocene at 500-year resolution.

- An online GIS based map of summer temperatures – and other climatic variables where possible – and crysophere-land surface conditions during the thermal maximum of the LIG.

During the course of the study, open annual meetings will be held for researchers and other interested investigators to share results and to develop new and productive research plans for the analysis of Arctic climate variability and warmth.

Implementation Plan and Time Line

This research effort, in order to be successful, will more forward in a phased and overlapping approach that includes synthesizing existing data, generating new high-resolution records, modeling, and iterative data-model comparisons.

Phase I. Synthesize existing information

This initiative will begin with a major effort to synthesize data already available from the Arctic to finalize high profile, state-of-the-knowledge research papers that will be disseminated to the broadest scientific community.

Published and unpublished paleoclimatic records with annual-scale resolution are presently being compiled for the Holocene with a focus on the past 2,000 years. These paleoclimatic proxy records will be synthesized and the resulting time series analyzed statistically to assess inter-annual modes of variability. Available information on the spatial-temporal pattern of Holocene warmth in the Arctic is also presently being compiled. The goal is to understand the spatial and temporal properties of general climatic variability and warmer-than-present conditions in the Arctic. This effort will also help to identify the most important geographic gaps and the most fruitful paleoclimate proxies for future research.

To place the 20th century and the interval of maximum Holocene warmth into the context of even higher but realistic future temperatures, a new effort is underway to better understand the LIG. Research on the LIG is important because it will lead to an improved understanding of role that high-latitude processes (e.g., those involving the cryosphere) play within the global climate system. The goal is to determine how close modern and early Holocene conditions are or were to reaching threshold conditions that might instigate further warming similar to that experienced during the LIG. Recent research utilizing marine and lake sedimentary archives and ice cores provide new evidence of exceptional warmth in the Arctic during the LIG, the last time the Earth was substantially warmer than present (up to 5° C warmer in places). In addition, new GCM simulations of the LIG provide model evidence of the Arctic's sensitivity to naturally forced climate variability. Given the high interest in Arctic warmth and the new quantitative data emerging from paleo-archives, the international community will meet in open scientific meetings to evaluate the evidence for Arctic warmth during the LIG.

Phase II: Recover new records

Following efforts to review and update the state of the knowledge, additional research will focus on developing new records of climate variability from around the Arctic in order to fill the climatic, spatial, and temporal gaps identified by our preceding synthetic efforts. Studies that address variably on time scales of annual to centennial will move forward simultaneously with studies to address the nature of longer Holocene and LIG warm periods. Modeling studies aimed at understanding the forcing mechanisms for inter-annual to millennial scale climate variability within the Arctic and to identify thresholds with the Arctic system and their feedbacks to the global climate system will also be encouraged.

Phase III: Integration of data and models

During this phase of this research effort, new and previously published data will be synthesized into Arctic-wide compilations that illustrate the spatial and temporal variably of climatic change. This will be an iterative and on-going effort. The data set will be compared with simulations of regional and global models of the Earth system. The goal of the data-model comparisons is to investigate the processes that link various elements of the Arctic system and the feedbacks between the arctic and global climate systems. The spatial reconstructions will take advantage of the PARCS Paleoenvironmental Atlas as a vehicle for uniform data syntheses (see: http://www.ngdc.noaa.gov/ paleo/parcs/ datasearch.html). Maps will be constructed to illustrate the spatial pattern of climatic changes during various time slices and associated with various climatic modes. Time series will be generated to further elucidate the modes of variability. A final set of high-profile syntheses concerning the various modes of climatic variability resolved, including their temporal and spatial properties in the Arctic and the context of recent Arctic warming relative to past major warm intervals, will be produced at the conclusion of this research effort.